Abstract Book

4th International Geologica Belgica Meeting

11-14 September 2012 – Brussels, Belgium

MOVING PLATES AND MELTING ICECAPS

Processes and Forcing Factors in Geology

GB 2012

GEOLOGICA BELGICA CONGRESS

Guest editors

X. Devleeschouwer	O.D. Earth and History of Life, Royal Belgian Institute of Natural Sciences
V.M.A. Heyvaert	O.D. Earth and History of Life, Royal Belgian Institute of Natural Sciences
S. Louwye	Research Unit Palaeontology, Ghent University
K. Piessens	O.D. Earth and History of Life, Royal Belgian Institute of Natural Sciences
T. Smith	O.D. Earth and History of Life, Royal Belgian Institute of Natural Sciences

Publication address

Geologica Belgica, Jenner street 13, 1000 Brussels, Belgium

Responsible editor

J.-C. Duchesne, Jenner street 13, 1000 Brussels, Belgium

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Dear participants of GB2012,

It was a pleasure one year ago to organise the 4th International Geologica Belgica conference, and it is with the same pleasure that we now present the official proceedings of this conference. We hope this may be a lasting memory to, as well as the scientific valorisation of your work presented at this international event.

Some of the abstracts in these proceedings are only the teasers for the several **full papers that appeared in the Geologica Belgica** journal during the past year. We know that several other papers are still under review or under preparation, but for those that have been published, we have added a reference next to the abstracts. However, make certain to keep an eye open for follow-up papers of abstracts and authors that attracted your attention during GB2012, as well as consult the recently appeared volumes, which include the **special volume 16(4) – "Dispersal of continental vertebrates during the Paleogene"**. For those that are not member of Geologica Belgica (only excusable if you were an international participant), you may notice that the updates on the Geologica Belgica website (www.geologicabelgica.be) allow free access all the articles published in the Geologica Belgica journal (**Impact Factor currently standing at 1.041**).

Let the record show that the 4th International Geologica Belgica conference attracted **241 participants** from **26 different countries**, who presented a total of **137 oral** and **99 posters** during three days, in up to three parallel sessions. The program was animated by a field trip in Brussels, a visit to the museum and its collections, and the unique occasion to enjoy the conference dinner in the main dinosaur gallery of the museum.

As usual, special attention went out to the young researchers with a **competition for best oral and best poster presentation**. The abstracts of the top three laureates are highlighted in this volume. If you want to refresh your memory, we invite you to pages 121, 122, 139, 146, 236 and 261 to read about the work of these upcoming talents. **Trond Torsvik was awarded the André Dumont Medal 2012** for his outstanding career. His publication "From Wegener until now: the development of our understanding of Earth's Phanerozoic evolution", which most perfectly addressed the conference theme, appeared in volume 15(3) of Geologica Belgica that each participant received as part of the welcome package.

A special **thank you to all who chose to participate to GB2012**, and especially to the five key-note speakers, the chairs of the sessions, the scientific committee, the enthusiastic team of young geologists and palaeontologists, the event personnel of the RBINS, and of course our sponsors.

You are no doubt already looking forward to the **5th International Geologica Conference in 2015** that will be hosted and organised by the University of Mons.

Looking forward to meeting all of you again,

Kris Stephen Thierry Vanessa Xavier

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Chairmen: Mike Bentley & Frank Pattyn
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Session 05 **Paleocene-Eocene Thermal Maximum: sedimentology, geochemistry and the biotic response**
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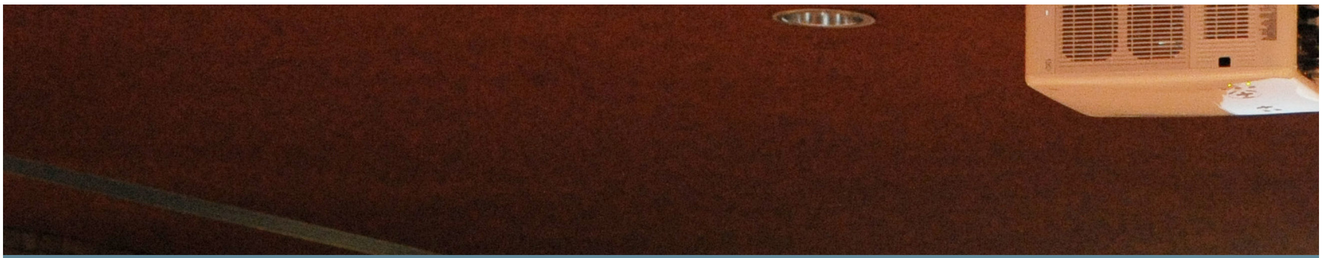
➲ Large auditorium



Session 01

Antarctica’s contribution to past and future sea-level change

Chairmen: Mike Bentley & Frank Pattyn
Key-note peaker: Glen Milne

Evidence of important basal sliding under an East Antarctic outlet glacier

Callens D.[1], Matsuoka K.[2], Steinhage D.[3], Smith B.[4], Pattyn F.[1]

→ dcallens@ulb.ac.be

1 Laboratoire de Glaciologie, Université Libre de Bruxelles, Brussels, Belgium

2 Norwegian Polar institute, Tromsø,Norway

3 Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

4 Polar Science Center, University of Washington, Seattle, USA

We present results of an Airborne Radar profiling of 2 majors outlet glaciers of East Dronning Maud Land (Antarctica), revealing the presence of a very deep subglacial valley beneath one of the glaciers. We also detected an important contrast of roughness between upstream and downstream region. Furthermore, surface velocity of these glaciers was inferred from interferometry, from which basal conditions were retrieved using a higher-order ice sheet model. By combining radio echo sounding, interferometry and ice sheet modelling, we are able to demonstrate that high surface velocity of one of the glacier is due to ice deformation in midstream region (>70 km from the grounding line) and due to dominant basal sliding downstream of this area. We associated this basal sliding with the very low roughness area in the downstream part of the glacier. This result shows that marine sediments also play a dominant role in the dynamics of outlet glaciers in East Antarctica.

Grounding line migration on unstable bedrock slopes: The example of Thwaites Glacier, Antarctica

GB 2012 Contestant for Best Oral Presentation

Docquier D., Pattyn F.

→ david.docquier@ulb.ac.be

Laboratoire de Glaciologie, Université Libre de Bruxelles, Belgium

Recent satellite observations of the Antarctic and Greenland ice sheets show accelerated ice flow and associated ice sheet thinning along coastal outlet glaciers in contact with the ocean. However, many uncertainties exist with respect to the behaviour of these ice sheets, especially the marine ice sheets, which rest on bedrock below sea level. This could imply significant errors in estimating sea level rise due to ice sheet melting. Marine ice sheet stability is mostly controlled by the dynamics of the grounding line, i.e. the junction between the grounded ice sheet and the floating ice shelf. While the grounded ice is dominated by vertical shear and basal friction, the ice shelf is dominated by longitudinal stretching and lateral shearing. Stress coupling is then essential at the grounding line.

Here we report on the state-of-the art of grounding line migration in marine ice sheets and address different ways in which grounding line migration can be attributed and represented in ice sheet models. Using flowline and three-dimensional ice sheet models we performed a number of sensitivity experiments (i.e. changes in sea level, sub-ice shelf melt rate, and buttressing effect) with different spatial resolutions and stress approximations. The models are tested using simple geometries (linearly downward-sloping and overdeepened bedrocks) on one hand and they are applied to Thwaites Glacier on the other hand. This last glacier is one of the fastest and largest ice streams in Antarctica and is a major contributor to the current sea level rise. A discussion is given on the stability of marine ice sheets on upward-sloping bedrocks, as well as on the robustness of numerical schemes to capture grounding line migration within short (centennial) time scales.

This research forms part of the FP7 'ice2sea' project (www.ice2sea.eu).

Ice rises: The double role of imprinting and archiving ice-dynamics at the sheet-shelf boundary of Antarctica

Drews R.[1], Eisen O.[2], Martìn C.[3], Steinhage D.[2], Pattyn F.[1]

→ reinhard.drews@ulb.ac.be

1 Laboratoire de Glaciologie, Université Libre de Bruxelles, Belgium

2 Alfred-Wegener-Institute, Bremerhaven, Germany

3 British Antarctic Survey, Cambridge, UK

Almost three-quarters of the Antarctic ice-sheet boundary is in contact with the ocean. Floating ice shelves extend the continental ice seawards and provide an interface for the interaction of ice and ocean. Ice rises are grounded features embedded within ice shelves. They typically develop a local ice-flow regime which on the one hand buttresses the large-scale ice flow from the Antarctic continent, and on the other hand may stabilize the grounding-line position on a inland facing bedrock slope. As a consequence of the nonlinear ice rheology, the stratigraphy of ice rises is often arched-upwards beneath the divides (referred to as the "Raymond effect"). Using radar and ice-flow models, this feature can be visualized and interpreted as a proxy for the ice-flow history in the surrounding. Additionally ice rises are of particular interest for upcoming ice-core arrays.

This study presents the results of airborne and ground-based radar surveys on ice rises situated along the Dronning Maud Land coast. The dataset is complemented with satellite remote-sensing (SAR and InSAR) and serves as input for different ice-flow models. We synthesize the data in order to check the suitability of a proposed ice-core site, to investigate the role of anisotropic ice flow, and to derive characteristic time scales for the temporal (non-)stability of the divide position. Eventually we also aim to clarify the role of ice rises in defining the grounding-line location. The various parameters that can be derived from ice rises help to constrain the extent and volume of the Antarctic ice sheet in the past, and also contribute to an enhanced forecast for the future contribution of Antarctica to sea level rise.

The evolution of the Greenland ice sheet on millennial to century times scales

Milne, G.

→ gamilne@uottawa.ca

University of Ottawa, Department of Earth Sciences, Canada

This presentation will focus on the use of different types of observations in developing a model reconstruction of the Greenland ice sheet (GrIS) from the time of the last glacial maximum to the present day. A range of proxy records will be discussed, including geomorphological information on ice extent, the inference of past ice surface elevation from ice core records, and sea-level changes reconstructed from the geological record. Results of this model calibration exercise will be described for three periods: (1) the late glacial and early Holocene, (2) the early to mid Holocene and, (3) the past millennium. The first period is of interest as this is when the ice sheet retreated from the continental shelf to become predominantly land-based. Delineating the forcings responsible for this early phase of retreat is crucial to test both our understanding of the relevant processes and the ability of models to simulate them. The second period is of interest due to the relatively high temperatures that the ice sheet was exposed to during the Holocene Thermal Optimum. It is expected that these temperatures will be returned to in the 21st century and so the early Holocene can be used as a part analogue for how the GrIS might evolve on millennial time scales as our planet continues to warm. The third and final period considered examines the response of the ice sheet on century time scales and, in particular, how the south west sector (considered to be the most sensitive to climate change) responded to the Medieval Warm Period and the Little Ice Age. The response of the ice sheet on these shorter time scales is most relevant to making estimates of its contribution to global mean sea level rise in the next century. The presentation will also include a discussion of the application of the GrIS model reconstruction to interpret geodetic observations (e.g. GPS, satellite gravity) with an aim to infer ice mass changes over the past decade or so.

Deglaciation & relative sea-level change on the Antarctic Peninsula in the last 10 000 years

Roberts S.J.[1], Hodgson D.A.[1], Sterken M.[2], Verleyen E.[2], Vyverman W.[2], Sabbe K.[2], Bentley M. J.[3], Watcham E.[3], Whitehouse P.L.[3], Balbo A.[1,4], Moreton S.[5]

→ sjro@bas.ac.uk

1 British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge, CB3 0ET, UK

2 Laboratory of Protistology and Aquatic Ecology, Ghent University, B-9000 Gent, Belgium

3 Dept of Geography, University of Durham, South Road, Durham, DH1 3LE, UK

4 Institución Milá y Fontanals, C/Egipcíaques, 15. Barcelona. Barcelona E-08001, Spain

5 NERC Radiocarbon Laboratory, Rankine Avenue, East Kilbride, UK

The recent disintegration of Antarctic Peninsula ice-shelves and the associated accelerated discharge and retreat of continental glaciers has highlighted the need to provide a longer-term perspective for present ice mass losses from Antarctica and individual ice sheets' contribution to future sea-level rise.

Observations of present-day ice mass change need to be corrected for ongoing glacial isostatic adjustment, a process which can only be constrained by field data.

Since relatively little terrestrial geological data constraining the geometry, volume and melt history of the former Antarctic Peninsula Ice Sheet from the Last Glacial Maximum-Holocene exists, the glacial isostatic correction needed to better assess present day satellite measurements of ice loss remains poorly constrained.

Focussing on recently published evidence from the north-eastern Antarctic Peninsula and the South Shetland Islands, we summarise new geological field constraints on the timing and rate of Antarctic Peninsula deglaciation and changes in relative sea-level (RSL) and compare field data with existing ice sheet models.

Holocene-age sedimentary records with clear and well-dated marine-terrestrial transitions were extracted from three isolation basins at different altitudes on Beak Island, providing quantified rates of Holocene RSL change for the north-eastern Antarctic Peninsula region.

Relative sea level on the north-eastern Antarctic Peninsula fell from a maximum of c. 15 m above present at c. 8000 cal yr BP, at a rate of 3.91 mm yr-1 declining to c. 2.11 mm yr-1 between c. 6900-2900 cal yr BP, 1.63 mm yr-1 between c. 2900-1800 cal yr BP, and finally to 0.29 mm yr-1 during the last c. 1800 years.

The new Beak Island and South Shetland Islands RSL curves presented improve the spatial coverage of RSL data for Antarctica, and imply significant thinning of the former Antarctic Peninsula Ice Sheet by the early-Holocene.

They are in broad agreement with some, but not all, glacio-isostatic adjustment models for each locality, and with work undertaken elsewhere on the Antarctic Peninsula.

Moreover, they provide key field-based data for the glacial-isostatic correction required by satellite-derived gravity measurements of contemporary ice mass loss, which can be used to better assess the future contribution of the continental ice derived from the Antarctic Peninsula to rising sea-levels.

Evidence for (modified) CDW intrusions underneath an East Antarctic ice shelf, grounding line melting and fast inland ice flow

Tison J.L.[1], Leonard K.[2], Matsuoka K.[3], Callens D.[1], Pattyn F.[1]

→ fpattyn@ulb.ac.be

1 Université Libre de Bruxelles, Belgium

2 WSL Institute for Snow and Avalanche Research (SLF), Davos, Swtizerland

3 Norwegian Polar Institute (NPI), Norway

We present the first comprehensive survey of ocean properties at the calving front of the Roi Baudoin Ice Shelf on the Princess Ragnhild Coast of East Antarctica. These new bathymetric and hydrographic results were collected by lowering acoustic depth sounding and conductivity-temperature-depth (ctd) instruments through leads and holes drilled through fast ice along the ice shelf front and ice mélange in rifts within the ice shelf. Ice thickness measurements were also carried out by both overland and airborne radio-echo sounding near the upstream grounding zone.

Our new findings show important contrasts with International Geophysical Year-era bathymetry and with oceanographic measurements collected in the region during JARE expeditions in the 1980s. Useful context is provided by these earlier studies, as they demonstrate that the continental shelf is unusually narrow in this region, and that the Antarctic Circumpolar Current is in close proximity to this region's ice shelves.

The CTD measurements show the presence of (modified) Circumpolar Deep Water onto the continental shelf in a trough underneath the fast-flowing part of the Roi Baudouin Ice Shelf. This observation is rather unique for the East Antarctic ice sheet as such intrusions have not been reported elsewhere. Furthermore, the large ice streams (Ragnhild glaciers) that discharge in the ice shelf have their grounding line at approximately the same depth as the occurrence of CDW further downstream on the continental shelf. This may potentially lead to a penetration of CDW up to the grounding line with consequences for grounding line melt, hence ice flow acceleration as observed on their West-Antarctic counterparts.

A revised evaluation of Antarctic subglacial conditions and the contribution of basal melt to present day sea-level rise

Van Liefferinge B., Pattyn F.

→ bvlieffe@ulb.ac.be

Laboratoire de Glaciologie, Université Libre de Bruxelles, Brussels, Belgium

Antarctic subglacial conditions can be elucidated through several techniques. However, since direct measurements are only limited to a few deep drillings to the bed, there is always a substantial amount of ice sheet and thermodynamical modeling involved. This can either be done based on a fully coupled thermomechanical ice sheet model, or a thermodynamical model coupled to present-day ice sheet geometry and environmental conditions. The latter technique was recently employed by Pattyn (2010) in an attempt to determine the likelihood of basal temperate conditions of the Antarctic ice sheet using a series of existing datasets on mass balance and geothermal heat flux. Here, we made an update of this estimate using new data on bedrock elevation and ice thickness (ALBMAP; Le Brocq *et al.*, 2010) and observed surface velocities obtained from interferometric analysis (Rignot *et al.*, 2011). The latter were further constrained by a hybrid ice sheet/ice shelf model to correct for the interior ice flow (where error of observations are to high) and for correcting the ice flow across subglacial lakes. We coupled the model with a new lake inventory from Wright *et al.* (in review) to improve the contribution of the geothermal heat flux to the temperature. This revised calculation of the temperature allows us to improve our knowledge of basal melting and its contribution to present-day sea-level rise.

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Holocene changes in relative sea-level in the Lützow-Holm Bay region, East Antarctica

Verleyen E.[1], Tavernier I.[1], Hodgson D.A.[2], Imura S.[3], Kudoh S.[3], Sabbe K.[3], Vyverman W.[1]

→ elie.verleyen@ugent.be

1 Ghent University, Protistology & Aquatic Ecology, Belgium

2 British Antarctic Survey, United Kingdom

3 National Institute for Polar Research, Japan

Of the global ice sheets, the Antarctic ice sheet has least field data to constrain its past volume and contribution to global sea-level change since the Last Glacial Maximum. Moreover, little is known about the timing of deglaciation in vast sectors of the continent and ice sheet responses to Holocene climate variability, despite this information being critical for estimating the ice sheet's contribution to future sea-level changes in a warming world. In order to minimize these uncertainties, we developed a new relative sea-level (RSL) curve for Lützow-Holm Bay (East Antarctica) using marine to freshwater transitions in sediment cores from isolation lakes. We combined this with a study of the deglaciation history by radiocarbon dating transitions from glaciogenic to organic-rich sediments in glacial lakes. We focused on West Ongul Island and Skarvsnes, a peninsula 60 km distant. On West Ongul Island, the Holocene RSL maximum was below 17 m above sea-level (a.s.l.). RSL fell from this maximum at a rate of 2.8 to 2.15 mm/yr during the past 4650-4660 calibrated years, which is in agreement with previous findings based on raised beach data. On Skarvsnes, the Holocene RSL maximum could not be determined exactly, but was above 28 m a.s.l. between 4045 and 3200 cal. yr BP. RSL fell at 11.6 mm/yr between 3200 and 915 cal. yr BP, dropping rapidly to 1.6 mm/yr during the past 915 years. This reconstruction differs from previous findings based on raised beach data from the region. The observed patterns may be explained by increasing the modeled maximum ice thickness in this region and by imposing a subsequent melting event, possibly during the mid to late Holocene warm period. If correct this will imply that the East Antarctic ice sheet in this region was probably less stable during the Holocene than previously believed.

A new glacial isostatic adjustment model for Antarctica: calibrated and tested using observations of relative sea-level change and present-day uplift rates.

Whitehouse P.L.[1], Bentley M.J.[1], Milne G.A.[2], King M.A.[3], Thomas I.D.[3]

1 Department of Geography, Durham University, Durham, UK

2 Department of Earth Sciences, University of Ottawa, Ottawa, Canada

3 School of Civil Engineering and Geosciences, Newcastle University, Newcastle upon Tyne, UK

We present a glacial isostatic adjustment (GIA) model for Antarctica which is driven by a new deglaciation history that has been developed using a numerical ice-sheet model, and is constrained to fit observations of past ice extent. We test the sensitivity of the GIA model to uncertainties in the deglaciation history, and seek Earth model parameters that minimise the misfit of model predictions to relative sea-level observations from Antarctica. We find that the relative sea-level predictions are fairly insensitive to changes in lithospheric thickness and lower mantle viscosity, but show good sensitivity to changes in upper mantle viscosity and constrain this value (95% confidence) to lie in the range 0.8-2.0 x 10^{21} Pa s. Significant misfits at several sites may be due to errors in the deglaciation history, or unmodelled effects of lateral variations in Earth structure. When we compare our GIA model predictions to elastic-corrected GPS uplift rates we find that the predicted rates are biased high (weighted mean bias = 1.8 mm/yr) and there is a weighted root-mean-square (WRMS) error of 2.9 mm/yr. In particular, our model systematically over-predicts uplift rates in the Antarctica Peninsula, and we attempt to address this by adjusting the Late Holocene loading history in this region, within the bounds of uncertainty of the deglaciation model. Using this adjusted model the weighted mean bias improves from 1.8 mm/yr to 1.2 mm/yr, and the WRMS error is reduced to 2.3 mm/yr, compared to 4.9 mm/yr for ICE-5G v1.2 and 5.0 mm/yr for IJ05. Finally, we place spatially-variable error bars on our GIA uplift rate predictions, taking into account uncertainties in both the deglaciation history and modelled Earth viscosity structure. This work provides a new GIA correction for the GRACE data in Antarctica, thus permitting more accurate constraints to be placed on current ice-mass change.

Session 02

Greenland's contribution to past and future sea-level change

Chairmen: Antony Long & Philippe Huybrechts

Future projections of the Greenland ice sheet surface mass balance simulated by the regional climate model MAR forced by three CMIP5 global models

Fettweis X., Franco B., Lang C., Erpicum M.

→ Xavier.Fettweis@ulg.ac.be

Department of Geography, University de Liège, belgium

As part of the ICE2SEA project, the regional climate model MAR was forced by the global models HadCM3 and ECHAM5 for making future projections of the Greenland Ice Sheet (GrIS) Surface Mass Balance (SMB) over 1980-2099 at a resolution of 25km. However, the comparison with MAR forced by the ERA-40 reanalysis over 1980-1999 shows that MAR forced by these GCMs is not able to represent reliably the current SMB due to biases in the general circulation and in the free atmosphere summer temperature modelled by these GCMs around the GrIS.

That is why, we present here first results of MAR forced by the next generation of GCMs from the CMIP5 data base (CanESM2, NorESM1 and MIROC5 here). The comparison with the ERA-INTERIM forced MAR simulations over current climate is a lot of better, which increases the reliability and the interest of these new MAR projections. In addition, the new scenarios (RCP 2.6, 4.5, 6.0 and 8.5) of the next IPCC Assessment Report (AR5) are used here. These new simulations show notably that the response of SMB to rising temperature is not a linear function of the temperature anomalies due to the positive albedo feedback which enhances the surface melt. For 2100, in case of extreme rising temperature (RCP 8.5 scenario), MAR simulates a surface GrIS mass loss corresponding to a cumulated sea level rise (SLR) of about 15 cm since 2000! Mainly the changes in SMB and in surface energy balance will be discussed here and estimations of the GrIS surface melt contribution to the SLR using all the CMIP5 outputs will be given.

Future projections of Greenland's ice loss accounting for changes in surface mass balance and dynamic discharge

Fürst J.J., Goelzer H., Huybrechts P.

→ jfuerst@vub.ac.be

Earth System Sciences & Departement Geografie,

Vrije Universiteit Brussel, Brussels, Belgium

Under future climate change, the Greenland Ice Sheet (GrIS) is highly vulnerable as its margins are relatively warm compared to Antarctica making them prone for summer melting. A sustained rise of about three degrees in annual average temperature over Greenland is expected to lead to irreversible ice sheet melting, which makes the GrIS a sensitive element in the Earth's climate system. Moreover, extended coverage and improved observation techniques have revealed high variations in dynamical ice discharge from outlet glaciers around the entire ice sheet. During the last decade, this dynamic discharge has contributed to almost half of the total mass loss. Since variations of the dynamic discharge are limited to the GrIS margin areas, direct inland transmission of these perturbations is necessary to significantly alter the overall GrIS evolution on short time scales. Gradients in membrane stresses hold the potential for direct horizontal coupling and therefore concerns are raised whether direct signal transmission has a significant impact on the ice interior. Because of strong mutual feedbacks between surface mass balance and marginal ice dynamics, our aim is to account for changes in both to assess the future GrIS contribution to sea level rise.

For this purpose, we use a three-dimensional ice sheet model with a Blatter/Pattyn dynamic core that allows for direct signal transmission in ice flow. The surface mass balance is based on a positive degree-day treatment, which accounts for internal accumulation and temporary water storage in the snow cover. The model is initialised by calibrating a glacial cycle spin-up to the present day geometry. For the last half of the 20th century we force the ice sheet model with reanalysis data of surface temperature and precipitation. Future climate scenarios are taken from General Circulation Models (GCM) and used in anomaly mode in the surface mass balance model. These scenarios are based on representative concentration pathways that were suggested for the Fifth Assessment Report by the International Panel on Climate Change. For the dynamic response of the ice sheet, we link the ice discharge of all marine terminated outlet glaciers to an oceanic temperature signal induced by each scenario. The idea is that this oceanic warming reaches the vicinity of the grounding line and directly or indirectly induces a change in local back-stress.

Committed future sea-level contribution from the Greenland ice sheet

Huybrechts P., **Goelzer H.**

→ heiko.goelzer@vub.ac.be

Earth System Sciences & Departement Geografie, Vrije Universiteit Brussel, Brussels, Belgium.

It is widely recognized that anthropogenic greenhouse gases have a long residence time in the atmosphere. Even if man-made emissions were to cease totally, carbon cycle models show that CO_2 concentrations will revert to pre-industrial levels only after many millennia. Combined with the inertia of the coupled climate system this means that cumulated emissions up to one point in time will necessarily lead to already committed climate changes many years later. In long-term climate projections, ice sheets are the largest potential contributors to sea-level rise, one of the major threats of global warming-related climate change. Ice sheets respond to climate changes on time scales up to many thousands of years and are therefore not routinely included in coupled climate projections, mainly due to computational constraints. To overcome this problem, we use a computationally efficient Earth system model of intermediate complexity, which includes fully interactive models of the Greenland and Antarctic ice sheets. We present projections of the millennial constant composition sea-level change commitment for the Greenland ice sheet and analyse the sensitivity to a large range of warming scenarios. Parametric uncertainty of the climate model is addressed by using an ensemble of model versions that covers a wide range of climate sensitivity.

Simulating past and future changes to the Greenland ice sheet using an intermediate complexity modelling approach

Robinson A.[1,2], Calov R.[2], Ganopolski A.[2]

→ robinson@fis.ucm.es

1 Universidad Complutense de Madrid

2 Potsdam Institute for Climate Impact Research

The Greenland ice sheet is highly responsive to climatic changes. At present, it is stable, even given that summer temperatures on the ice sheet induce melting over large areas. With global warming, surface melt will increase substantially and it is likely that Greenland will provide a significant contribution to sea level rise in the future. For this reason it is important to understand the sensitivity of the ice sheet to changes in surface forcing on long time scales.

We use a coupled climate-ice sheet modelling approach to gain insight into the long-term stability of the Greenland ice sheet. An intermediate complexity regional climate model is coupled to a 3-D thermo-mechanical ice sheet model via a surface energy balance model. This approach allows us to capture key feedbacks concerning the climate and surface mass balance that are related to the stability of the ice sheet. Additionally, due to the computational efficiency of the model, we are able to perform ensembles of simulations with many model versions.

We will present results from simulations over several past glacial cycles, including MIS-11 and the Eemian when Greenland is believed to have contributed substantially to sea levels above present day. These results, which also helped constrain the model versions in comparison with paleo data, will be related to the overall stability of the ice sheet and it's potential contribution to sea level rise in the future.

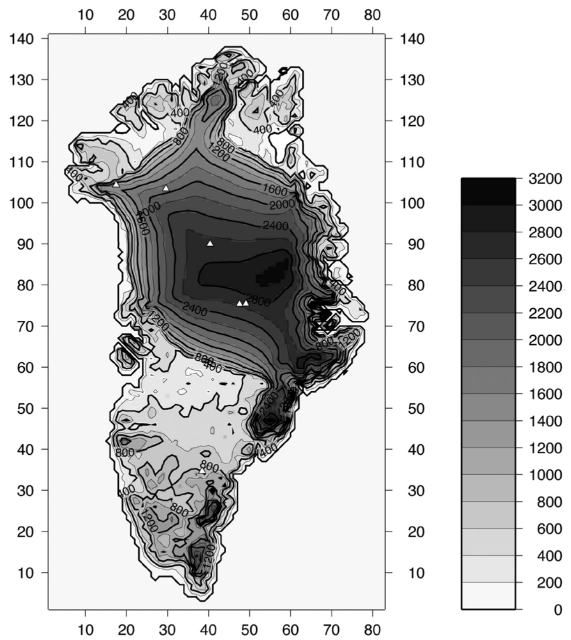
Constraining the minimum configuration of the Greenland ice sheet during the Last interglacial period

Rybak O., Huybrechts P.

→ orybak@vub.ac.be

Earth System Science & Departement Geografie, Vrije Universiteit Brussel, Belgium

The Last Interglacial (LIG) between ca. 130 and 115 ky BP is probably the best analogue for future climate warming for which increasingly better proxy data are becoming available. The volume of the Greenland ice sheet (GIS) during this period is of particular interest to better assess how much and how fast sea-level can rise in a future Earth undergoing gradual climatic warming. Sea-level during the Last Interglacial is inferred to have been up to 8 meter higher than today and a substantial fraction of that must have come from melting of the Greenland ice sheet. Various ice-sheet modeling studies have come up with a very broad range of the LIG volume loss to between 1 and 6 m of equivalent sea-level rise. This wide range is mainly due to the sensitivity of GIS models to the imposed climatic conditions and to poor knowledge of the LIG climate itself, both in terms of the magnitude and precise timing of the maximum warming, as well as in terms of spatial and annual patterns.



Modeled surface elevation (m) of the GIS at 123 kyr BP. This configuration contributes 4 m to the global sea-level rise during the LIG. White triangles indicate deep ice core drilling sites

To circumvent the problem of our poor knowledge of the LIG climatic conditions, in our modeling study we take another approach to constrain the minimum LIG configuration of the GIS. Using a three-dimensional thermomechanical ice-sheet model, we produced an ensemble of 210 possible LIG configurations by varying only three key parameters for temperature, precipitation rate, and surface melting within realistic bounds. The result is a variety of glaciologically consistent GIS geometries corresponding to a wide range of possible "climates" thereby avoiding the complications of having to prescribe the details of the LIG climate itself. Forward numerical experiments were followed by a Lagrangian backtracing of ice particles in order to establish times and places of origin of ice particles from five Greenland ice-cores (GRIP, NGRIP, NEEM, Camp Century and Dye 3). This provides distances travelled by ice particles from an ice core to the place of deposition, latitudinal contrast and surface elevation histories. To constrain the ensemble of GIS geometries, we used data inferred from the above mentioned ice cores such as the presence or absence of LIG ice, borehole temperature and present to LIG δ18O contrast translated into surface elevation changes. Testing against ice-core data enabled us to bracket the mass loss of the Greenland Ice sheet during the LIG to between 3.4 and 5.0 m of sea-level rise with a preferred value of 4 m (see figure). The obtained results are justified for the specific assumptions of a uniform climate change, a constant isotopic-elevation and isotopic-latitudinal gradients, and a fixed precipitation pattern. It cannot be excluded that during the LIG precipitation changes were stronger in the south than in the north of Greenland. This would have led to a larger southern dome than in our runs, but would not entail an essential revision of the final conclusion about the sea level contribution because of pure geometrical restrictions on the size of the southern dome.

Session 03

Magnetic susceptibility: a high resolution stratigraphic tool during greenhouse periods

Chairmen: Anne-Christine Da Silva & Leona Koptikova

Origin of the magnetic susceptiblity signal in a fluviatile succession: the example of the Artsuma Miocene succession from Northeastern Tunisia

Belghithi H.[1,2], Da Silva A.-C.[2], Yaich C.[1], Boulvain F.[2]
→ belghithihanene@gmail.com; ac.dasilva@ulg.ac.be; chokriyaich@gmail.com; fboulvain@ulg.ac.be

1 Sfax engineering school, sedimentary dynamic and environment, 3038 Sfax, Tunisia.

2 Liège University, sedimentary petrology laboratory, B20, Sart Tilman, 4000 Liège, Belgium.

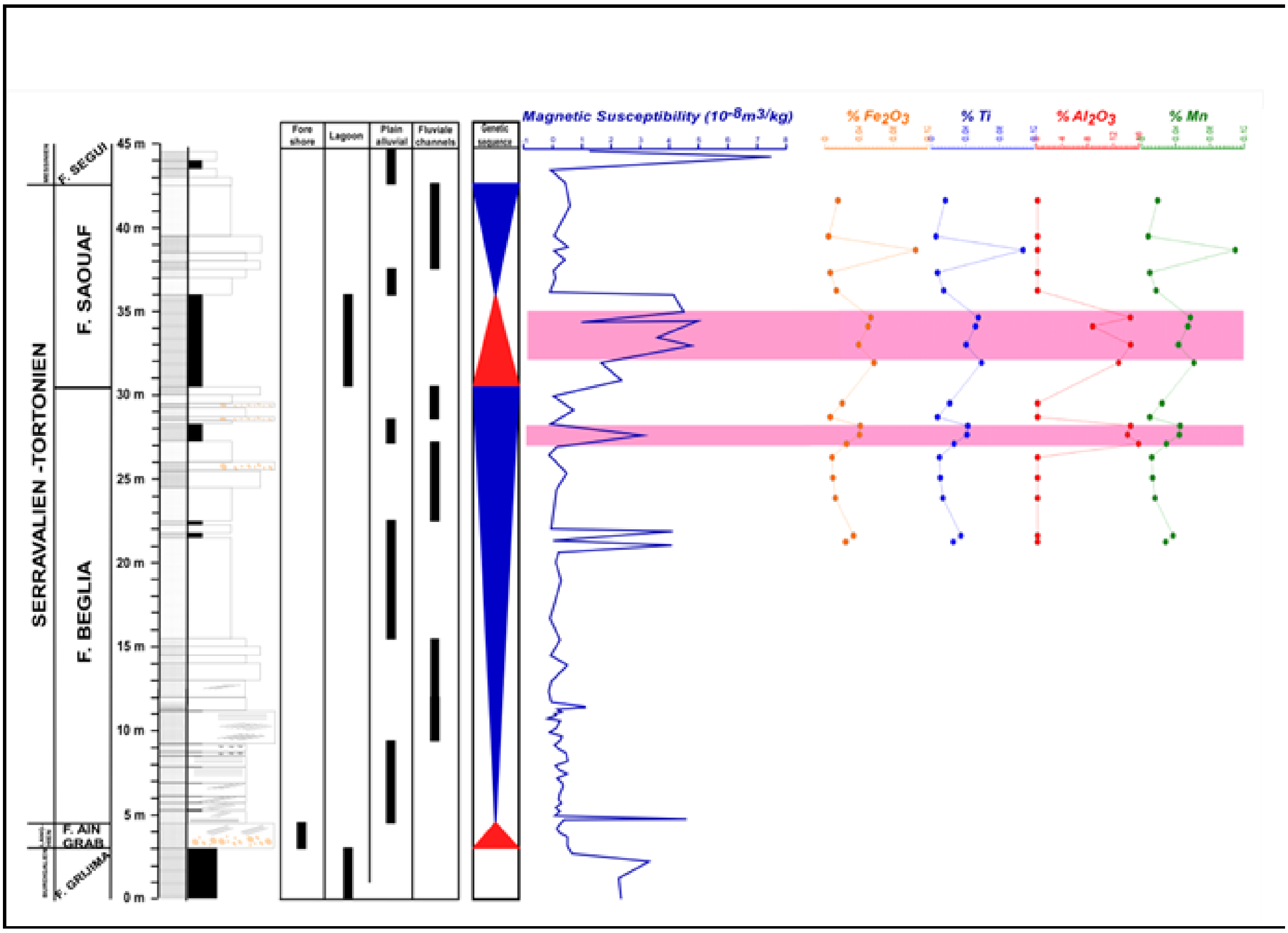
Introduction: In Tunisia, the Miocene succession is mostly constituted of detrital sediments deposited in a coastal and fluviatile setting. The studied section is located in Djebel Khechem el Artsouma, in the center of Tunisia. The present study includes magnetic susceptibility (MS) combined with geochemical analyses.

Geological setting: the stratigraphic succession of the studied section (Castany, 1951; Yaïch, 1984), shows the following Formations:
The base of the Beglia formation, corresponding to coastal sand accumulations is interpreted as a seaward stepping (Serravallien-Tortonian age). The transition between the Beglia and Saouaf Formation, represented by red clayey sands rich in gypsum, corresponding to a landward stepping. The top of the Saouaf Formation (Serravallien – Tortonien age) is the result of a seaward stepping.

Artsouma section: The section is 45m and 98 samples have been collected for MS and calcimetry. Out of these 98 samples, 19 have been selected for further geochemical analyses (major and traces).

Magnetic susceptibility on the Beglia-Saouaf formation transition: the MS values range between $-1.36.10^{-10}$ and $7.33.10^{-8}$ m^3/kg. The highest values are observed between 29 and 37 m, corresponding to the transgression phase at the base of the Saouaf formation.

To be interpreted as related to lithogenic inputs, the magnetic susceptibility signal should show close relationship with other proxies such as selected major or trace elements. Although, Zr (r=0.28), Rb (r=0.35), Ti (r=0.40) and Al_2O_3 (r=0.49) are considered as proxies for detrital inputs (Riquier *et al* 2010) and a positive correlation between these elements and the MS signal would be a good indicator that the MS signal is driven by detrital inputs. The highest MS values recorded at the base of the Saouaf Formation corresponding to clay layers are explained by the presence of iron oxides (Fe_2O_3, Mn,..ect)



Sedimentological log, paleoenvironments, magnetic susceptibility and geochemical analysis of J.Artsouma, Tunisia

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Magnetic susceptibility of Eifelian–Frasnian-Tournaisian carbonate sections (Belgium)

Boulvain F., Bertola C., Da Silva A.-C.

→ fboulvain@ulg.ac.be

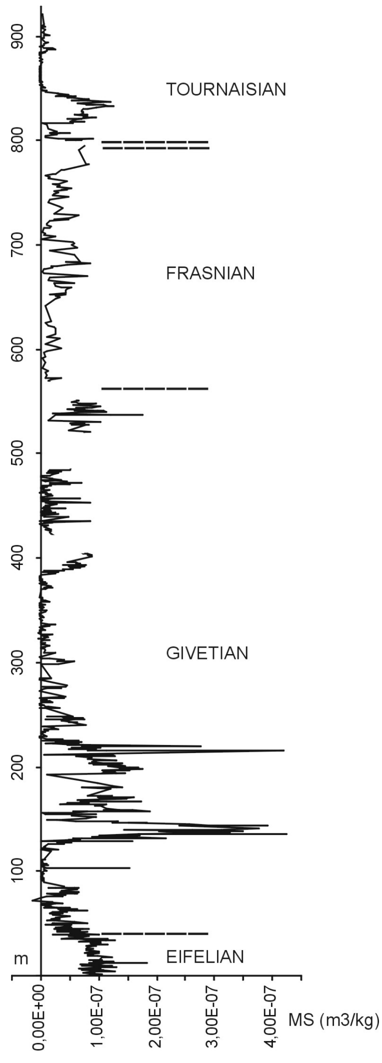
Pétrologie sédimentaire, B20, Université de Liège, B-4000 Liège (Belgium)

Bulk magnetic susceptibility (MS) measurements on sedimentological samples for correlations and reconstruction of climatic or sea-level variations from all geological periods became widely used in the last decades. Studies dealing with the origin of magnetic minerals in sedimentary rocks generally suggest a lithogenic origin for magnetic minerals. The amount of these minerals is supposed to be in relation with sea level changes. A marine regression, increasing erosion rate, increases lithogenic inputs and MS. A transgression has the opposite effect (see Da Silva *et al.*, 2009).

We propose a reflection on a very large scale about the link between MS and environmental parameters. This compilation of MS data and environmental backgrounds is based on 1200 thin sections/MS data from more than 900 m of section ranging from the upper Eifelian to the upper part of the Tournaisian.

The Devonian sections start with an Upper Eifelian mixed detrital-carbonated outer ramp (La Couvinoise), followed by a well-developed Givetian carbonated platform (Fromelennes-Flohimont) with environments ranging from external crinoidal facies to stromatoporoid-dominated biostromes and to lagoonal facies. After the demise of the carbonate factory at the beginning of the Frasnian and the generalization of argillaceous sedimentation, the Middle Frasnian is characterized by the succession of three carbonate mound levels (La Boverie), starting in quiet aphotic water and ending in shallow zone. The Tournaisian section (Rivage, Condroz sedimentation area) is characterized by a bioclastic-dominated sedimentation on a shallow ramp, interrupted by more argillaceous facies related to rapid sea-level rises.

The Devonian part of this section show an extraordinary parallelism of MS curve with a contemporaneous Czech section with different facies (Boulvain *et al*., 2010), characterized by decreasing moderate values during the end of Eifelian (*australis*–*ensensis* conodont zones), a very strong increase at the beginning of Givetian (*hemiansatus* Zone), very low values during the major part of the Givetian (*varcus* Zone) and increasing moderate values during the end of Givetian and Frasnian (*disparilis*–Lower *rhenana* zones). The Tournaisian part of the section shows relatively high values at the beginning of the stage (lower part of the *Siphonodella* Zone) and then decreasing low values (upper part of the *Siphonodella* and *Carina* zones).



MS data from a composite Eifelian-Tournaisian section (carbonates, Belgium).

Variations of magnetic susceptibility (MS) seem to be related to fluctuations in detrital input and carbonate productivity: external ramp settings have low carbonate productivity, low water agitation and high MS, whereas more proximal environments are characterized by higher carbonate productivity, higher water agitation and lower MS. Carbonate buildups show the lowest MS and highest productivity. MS curves are in agreement with the 3rd-order sequential interpretation. LST show the highest MS values while TST are characterized by decreasing values and HST/FSST by the lowest values.

Boulvain F., Da Silva A.-C., Mabille C., Hladil J., Gersl M., Koptikova L., Schnabl P. (2010). *Magnetic susceptibility correlation of km-thick Eifelian–Frasnian sections (Ardennes and Moravia).* Geologica Belgica, Volume 13, n°3, pp 309-318.

Geochemistry, Magnetic Susceptibility and Gamma Ray spectrometry records Across the Frasnian-Famennian boundary at Fuhe, China

Da Silva A.-C.[1], Whalen M.[2], Sliwinski M.[2], Devleeschouwer X.[3], Petitclerc E.[3], Boulvain F.[1], Bertola C.[1], Prasannakumar K.[4], Wang J.[5], Zenghui G.[5], Chen D.[5]

→ ac.dasilva@ulg.ac.be

1 Liège University, sedimentary petrology laboratory, B20, Sart Tilman, 4000 Liège, Belgium.

2 University of Alaska Fairbanks.

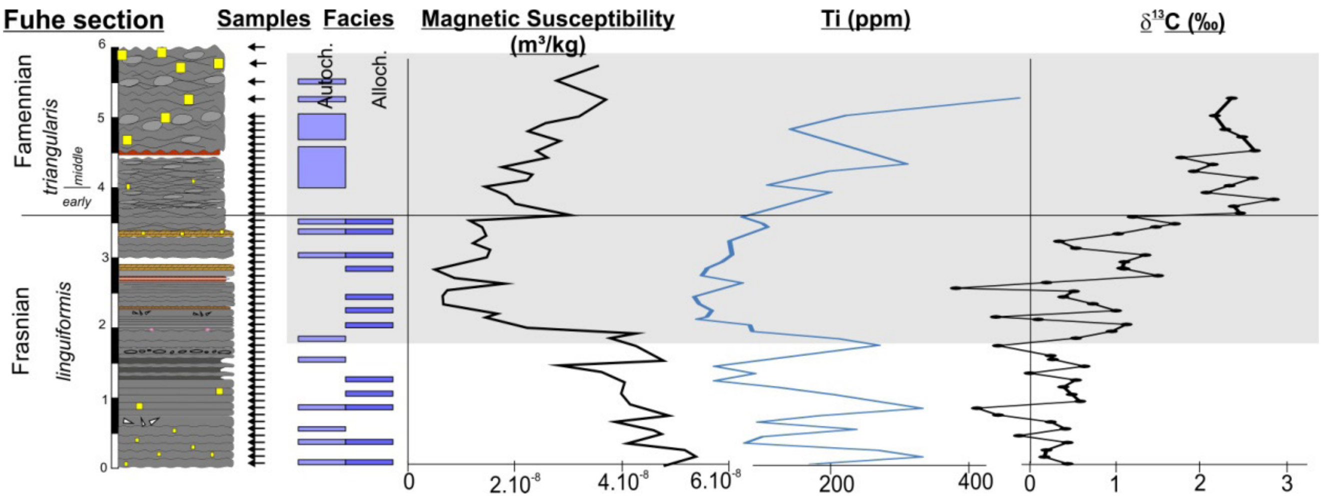
3 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium.

4 University of Kerala, India.

5 Academy of Science, Beijing.

At the 2010 IGCP-580 meeting in Guilin, China; a field party (guided by Daizhao Chen) was organized to sample key Palaeozoic sections. Our team focused on the Frasnian-Famennian (F-F) boundary, at the Fuhe section (40 km south of Guilin, deep water deposits). The section is 33 m thick and cuts from Early to Late *rhenana*, to *triangularis* conodont zones (including the Upper Kellwasser event, UKE).

- Sedimentology: the section is characterized by two main facies: (1) autochthonous pelagic nodular mudstones, with abundant sponge spicule networks, ostracods and some clotted micrite; intercalated with (2) coarser intervals of allochthonous calciturbidites with lithoclastic grainstones, displaying oblique and convolute stratification, grading into bioturbated mud-wackestones (T_{c-e} Bouma subdivision).
- Magnetic susceptibility (MS): mean MS value for the entire Fuhe section is $3.23.10^{-8}$ m³/kg, which is in the range of the MS marine standard of 5.5×10^{-8} (Ellwood *et al.*, 2011). The MS values range between $-1.46.10^{-9}$ and $9.25.10^{-8}$ m³/kg. The first part of the section (0-9 m) is dominated by turbiditic deposits and the MS values are relatively low (~ 9.10^{-9} m³/kg). Then, between 9 and 27 m, the facies are dominated by authochthonous mudstone with *in situ* sponges and MS is higher ($6.45.10^{-8}$ m³/kg), with some sharp variations. The last 6 m, corresponds to the Upper Kellwasser F-F event (Fig. 1). Below the F-F boundary, facies alternate between autochthonous and allochthonous and the MS values decrease from $5.46.10^{-8}$ to $5.23.10^{-9}$ m³/kg. Above the F-F, autochthonous facies dominate once again and MS values sharply increase. (Mention Ti data here?). There is a moderate positive correlation between elements which are proxies for lithogenic inputs (e.g. Ti, Al, Zr; see figure) and magnetic susceptibility (r = 0.6), showing that the MS signal is probably of primary origin, related to lithogenic inputs (e.g. Riquier *et al.*, 2010).
- Gamma Ray Spectrometry (GRS): concentrations of K statistically correlate moderately well with Th concentrations throughout the whole section (r=0.75). Correlated Th and K are usually related to the presence of aluminosilicates (clays, potassium feldspars, micas) in carbonates. The mean value for U/Th ratio corresponds to 0.55. Six distinct peaks are present along the section with values above 0.75 indicating probably local suboxic conditions.
- Geochemistry: the UKE at Fuhe, as is common around the world, is characterized by a significant positive carbon isotope excursion in both $\delta^{13}C_{carb}$ (3.8 ‰) and $\delta^{13}C_{org}$ (3.3 ‰). Although, unlike other localities around the world, values for TOC and elemental proxies for paleoredox conditions do not display appreciable enrichments at the level of the UKE at Fuhe. Only V displays enrichment with a very narrow peak with a maximum value of 18 ppm associated with the UKE. This implies that there was likely a very short interval of suboxic conditions associated with the UKE (in agreement with the GRS results).



Upper part of the Fuhe section (last 6 m) with the F-F boundary; position of sample (arrows), facies (autochthonous or allochthonous), magnetic susceptibility (m³/kg), Ti (ppm) and $\delta^{13}C_{carb}$ (‰). The conodont zonations are from CHEN *et al.* (2005) and the grey area corresponds to the Upper Kellwasser interval.

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Stable isotopes ($\delta^{13}C$, $\delta^{18}O$, $^{87}Sr/^{86}Sr$) versus magnetic susceptibility at the Mid-Devonian La Couvinoise section: Does the astronomical interpretation stand?

De Vleeschouwer D.[1], Da Silva A.-C.[2], Boulvain F.[2], Crucifix M.[3], Belza J.[1], Sinneseal M.[1], Claeys P.[1]

→ dadevlee@vub.ac.be

1 Earth System Sciences and Department of Geology, Vrije Universiteit Brussel, Belgium

2 Pétrologie sédimentaire, B20, Université de Liege, Belgium

3 Centre de recherche sur la Terre et le climat Georges Lemaître, Earth and Life Institute, Université Catholique de Louvain, Belgium

The Devonian period (418 - 361 Ma) was a time of profound changes in terrestrial and aquatic ecosystems. These changes set the stage for the evolution of tetrapods and their expansion onto the land, the development of plant rooting systems and the appearance of the first forests. All these important steps in the evolution of life on Earth are inextricably linked with climate change. Therefore, it is important to better document and understand the drivers of Devonian climate change, including astronomical forcing. In previous research on the Mid-Devonian magnetic susceptibility (MS) record obtained on limestones ranging from the Uppermost-Eifelian to the Lower-Givetian from the La Couvinoise section (southern border of the Dinant Synclinorium, Belgium), high-frequency cycles were interpreted as astronomically forced precession cycles (De Vleeschouwer *et al.*, 2012). These metre-scale variations in the MS-signal were interpreted as changes in the flux of magnetic minerals towards the marine system, most likely controlled by variations in monsoon rainfall-intensity.

To better understand the response of the monsoonal dynamics to astronomical forcing in this equatorial setting, additional proxies ($\delta^{13}C$, $\delta^{18}O$, $^{87}Sr/^{86}Sr$) were measured on the La Couvinoise section. For the Eifelian and Givetian in the southern border of the Dinant Synclinorium, diagenesis did not obliterate the primary isotopic signal, as the $\delta^{13}C$ and $\delta^{18}O$ signals remain strongly related to depositional environment. Moreover, the range of absolute isotopic values ($\delta^{13}C$: 0.38 - 2.73‰, $\delta^{18}O$: -8.43 - -5.46 ‰) fall within the isotopic range of Devonian seawater (Veizer *et al.*, 1999). Preliminary results show that oxygen isotopes are strongly anti-correlated with magnetic susceptibility, suggesting that intensified monsoonal circulation occurs during relatively warm periods. This result is in line with the hypothesis presented in De Vleeschouwer *et al.* (2012): During precession minima, as well as during precession maxima, respectively the northeasterly and southeasterly monsoonal circulation is enhanced. Thanks to the additional isotopic measurements, it is now suggested that during periods of extreme precession, and consequent increased moisture transport, one of the half-yearly wet seasons seem to be warmer than average.

The statistically significant correlation between oxygen isotopes on the one hand and magnetic susceptibility on the other hand suggests that in sections characterized by a moderate burial depth magnetic susceptibility can be successfully used as a palaeoclimatological proxy and hence as a stratigraphic tool. Strontium isotopes are measured to test to what degree magnetic susceptibility can be used as a proxy for variations in continental runoff.

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Magnetic susceptibility and carbon isotopic record across the Eifelian – Givetian boundary in the Carnic Alps

Kido E.[1], Suttner T.J.[1], Pondrelli M.[2], Corradini C.[3], Corriga M.G.[3], Simonetto L.[4], Vodrážková S.[5,6], Koptíková L.[7]

→ erika.kido@uni-graz.at

1 Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology & Paleontology), Austria

2 Università D'Annunzio, International Research School of Planetary Sciences, Italy

3 Università di Cagliari, Dipartimento di Scienze Chimiche e Geologiche, Italy

4 Museo Friulano di Storia Naturale, Italy

5 Czech Geological Survey, Czech Republic

6 GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

7 Institute of Geology AS CR, v.v.i. , Czech Republic

In the Carnic Alps across the Austrian-Italian border, a calcareous interval with black shales and chert is recognized in the Middle Devonian distal slope and pelagic deposits in several localities. Our study focused on the Eifelian – Givetian boundary section of the Carnic Alps in order to define the late Eifelian Kačák Event (House, 1985) by using microfacies analysis, conodont biostratigraphy and the application of magnetic susceptibility (MS)- and geophysical analyses.

The Eifelian – Givetian boundary within two units deposited in different environmental settings, the Hoher Trieb Formation of Mt. Zermula, Lanza (Italy) and the Valentin Limestone of the Wolayer Glacier section (Austria), was studied. The Hoher Trieb Formation is characterized by gray to dark gray flaser and platy limestone with black shale and chert layers which are interpreted as distal slope deposits (Pondrelli *et al.*, 2011). In total 64 rock samples were collected for MS from the formation cropping out at Zuc di Malaseit Basso (ZMB; thickness of the section sampled is about 4.5 m). A depression in MS-values from 55.73 to 2.44 is observed between sample nos. ZMB34 middle2 and ZMB7 middle, which might be related to the Kačák Event. A distinctive negative shift in carbon isotopes from 2.2 (ZMB23 top1) down to 0.1 (ZMB20-1) is observed within the interval of a depression in the MS curve.

The Valentin Limestone is characterized by highly condensed sediments of pelagic facies. The upper part of the Eifelian is unconformably overlain by beds of Givetian age, with the boundary allocated between sample-no. 70 and 71 (Schönlaub, 1985). We collected 15 limestone samples in distances of somewhat less than 2 cm across the Eifelian – Givetian boundary within gray tentaculite wacke- and packstones (no. 69 to 72; in total ca. 25 cm thick) for MS. The MS-patterns show a trend which is documented by a decrease in values (47.45 to 27.71) within the interval of sample nos. 69 top to 70a top, where the dark colored horizon of about 3 to 5 mm is intercalated (70a middle). This trend could represent the Kačák Event. Carbon isotopes shift slightly (2.0 to 1.8), whereas oxygen values show a distinctive positive excursion (-8.9 to -6.8).

Research is funded by FWF P23775-B17 and project 334000 of the Czech Geological Survey and GACR P210/12/2018. This is a contribution to IGCP 580 and IGCP 596.

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Magnetic susceptibility and gamma-ray spectrometric logs across the Basal Choteč event (Middle Devonian) in different palaeogeographical settings from the Perigondwanan terranes (Prague Synform, Barrandian Area), Laurussia (Central Great Basin, Nevada) and Central Asia terranes (South Tien-Shan): a reflection of global palaeoclimatic change?

Koptíková L.[1], Hladil J.[1], Slavík L.[1], Šlechta S.[1], Frýda J.[2], Manda Š.[2], Čáp P.[2], Ferrová L.[2], Vodrážková S.[2]

→ koptikova@gli.cas.cz

1 Institute of Geology AS CR, v. v. i., Czech Republic

2 Czech Geological Survey, Czech Republic

Magnetic susceptibility (MS) and gamma-ray spectrometric (GRS) logs of the Basal Choteč event interval close above the Lower-Middle Devonian boundary have been studied in three different palaeogeographical positions: Perigondwanan Perunica microcontinent (Prague Synform, Barrandian Area, Czech Republic), Laurussia (Central Great Basin, Nevada, U.S.A.) and Central Asian terranes (South Tien-Shan in the Zeravshan-Gissar Mountain Region, Kitab, Uzbekistan).

Similar features of the logs and similar lithological characteristics were revealed and observed. Increased delivery of shallow-water detrital skeletal material as well as increased turbidite activity marks the event interval and the incipient environmental changes. GRS logs show elevated concentrations of U at the expense of Th (total GRS is driven rather by the U contents than the Th contents) at the event base whereas U and Th concentrations below and above the critical interval become similar or Th concentrations dominate (holding true in the Prague Synform and in the Central Great Basin, Nevada). MS logs show reduced oscillations and a drop (distinct to slight) in the values at the event datum regardless to the lithology. This might be indicative of the change in the environment, in the ways of the input of detrital material driving the MS signal, calming down of the processes (atmospheric circulation, ocean currents etc.) which drive the input of magnetic material.

Acknowledgment: IGCP 580, 596, GAP210/10/2351, GAP210/12/2018, ME08011, AV0Z30130516, RVO 67985831.

Orbital signal of the Hauterivian-Barremian GSSP candidate from clay minerals and magnetic susceptibility (Río Argos section, Southeastern Spain)

Martinez M.[1], Moiroud M.[1], Deconinck J.-F.[1], Pellenard P.[1], Monna F.[2], Boulila S.[3], Riquier L.[1], Company M.[4]

→ Mathieu.martinez@u-bourgogne.fr

1 UMR/CNRS 5561 Biogeosciences, Université de Bourgogne, 6 bd Gabriel, 21000 Dijon, France (mathieu.martinez@u-bourgogne.fr)

2 UMR/CNRS 5594 ARTéHIS, Université de Bourgogne, 6 bd Gabriel, 21000 Dijon, France

3 Université Paris VI, UMR/CNRS 7193 ISTeP 'Institut des Sciences de la Terre-Paris', case 117, 4 place Jussieu 75252 Paris cedex 05, France

4 Departamento de estratigrafía y de paleontología, Facultad de Ciencias, Campus de Fuentenueva s/n, 18002 Granada, Spain

The Río Argos section (Subbetic Domain, Southeastern Spain) displays rhythmic marl-limestone alternations deposited during the Early Cretaceous. The section is currently the GSSP candidate for the Hauterivian-Barremian transition since all ammonite zones and the Faraoni Oceanic Anoxic Event were identified. Spectral analyses were performed on clay minerals, carbonate calcium content and magnetic susceptibility (MS) to (1) detect the presence of sedimentary cycles linked to orbital forcing and (2) provide accurate durations for the Faraoni Event and for ammonite biozones at the Hauterivian-Barremian transition.

Clay mineral assemblages display an alternating pattern following the rhythmic lithology. Marls are enriched in kaolinite and illite whereas limestone beds are enriched in mixed-layers illite-smectite. This rhythmicity can traduce climate change from tropical humid climate during marl deposits to semi-arid conditions during limestone deposits. Spectral analyses were performed on clay mineral assemblages which allowed the eccentricity, obliquity and precession orbital cycles to be recognized but, during the Faraoni Event, the record of eccentricity is disturbed due to an enhanced preservation of kaolinite.

Spectral analyses were performed on magnetic susceptibility to provide robust durations. The MS series is negatively correlated to the carbonate calcium content series, showing that lithology mainly controls MS fluctuations. Spectral analyses allowed the identification of eccentricity, obliquity and precession. We assess the duration of the *Pseudothurmannia ohmi* ammonite zone (Late Hauterivian) at 0.78 Myr and the duration of the *Taveraidiscus hugii* ammonite zone (Early Barremian) at 0.57 Myr. These durations are significatively different from those proposed by the Geologic Time Scale but are similar with previous estimates from Southeastern France based on direct cycle counts on the field. Based on the proposed time frame, we correlated the Río Argos section to the Angles section (Vocontian Basin, Southeastern France), which is a reference for the Early Cretaceous. We show that the Angles section is affected by a short-term hiatus and, therefore, the Río Argos section appears to be a valuable candidate for the Hauterivian-Barremian GSSP. Finally, the duration of the Faraoni Event is assessed at 100-150 kyr which is similar to previous assessments.

Sedimentary development and correlation of Mid-Late Devonian fore-reef deposits from Central Europe

GB 2012 Contestant for Best Oral Presentation

Pas D.[1], Da Silva A.-C.[1], Cornet P.[1], Suttner T.[2], Königshof P.[3], Boulvain F.[1], Bultynck P.[4]

→ dpas@ulg.ac.be

1 Sedimentary Petrology, B20, Université de Liège, Sart-Tilman 4000, Liège, Belgium; dpas@ulg.ac.be

2 Austrian Academy of Sciences (CPSA) c/o University of Graz, Institute for Earth Sciences (Geology and Paleontology), Graz, Austria; thomas.suttner@uni-graz.at

3 Senckenberg, Forschunginstitut und Naturmuseum Frankfurt, Senckenberganlage 25, 60325 Frankfurt, Germany; peter.koenigshof@senckenberg.de

4 Department of Paleontology, Royal Belgian Institute of Natural Sciences, rue Vautier 29, BE-1000 Brussels, Belgium

INTRODUCTION: Despite the interest for the reconstruction of environmental changes over a long period of time, long-term successions have been relatively poorly investigated using a mutli-disciplinary approach compared to short-term intervals such as Kačák, Taghanic, *punctata*, Kellwasser and Hangenberg events. Recently, Boulvain *et al.* (2010) compared two km-thick Eifelian-Frasnian sections from Belgium and Czech Republic using magnetic susceptibility (MS) technique. Regardless the very different background of palaeogeography, sedimentary rate, facies and local sea-level changes history, a remarkable similarity in the MS trends can be observed between these two sections. These similarities brought questions on the nature of the long-term forcing parameters that were active at the inter-regional scale. In order to get a better understanding of the factors responsible of the inter-regional forcing, a detailed records of microfacies observations, MS measurements, selected trace and major elemental concentrations and conodonts biostratigraphy have been performed on two Middle to Upper Devonian successions from Germany (Sauerland, Burgberg) and Austria (Carnic Alps, Freikofel).

CONODONT BIOSTRATIGRAPHY: In the Burgberg section, conodont biostratigraphy allowed us to confirm that the studied section extend from the Middle Givetian to the Lower Carboniferous. In the Freikofel section, it allowed to precisely identify the Eifelian-Givetian and the Frasnian-Famennian boundaries.

SEDIMENTOLOGY: The field and microfacies observations allowed us to reconstruct the sedimentary environment and to highlight several major variations of this environment. In the Middle Devonian, both sections are mainly characterized by fore-reef sediments. In the Burgberg section, those fore-reef sediments, mainly correspond to bioclastic grainstone and rudstone related to gravity flow deposits derived from the shallow-water area. In the Freikofel section, the fore-reef area is dominated by breccia sediments suggesting a strong debris flow influence. Through the Upper Devonian the sedimentary setting evolves to an off-reef pelagic environment in both sections and even a basinal setting in the Burgberg section. Sediments are then dominated by thin-bedded and nodular limestone. In this Upper Devonian part, locally both sections, debris coming from the shallow-water area are still observed (suggestion: Even in the Upper Devonian, occasionally debris deriving from shallow water areas has been observed in both sections.

MAGNETIC SUSCEPTIBILITY AND GEOCHEMISTRY: The mean MS values for the Burgberg and Freikofel sections are respectively $1{,}88 \times 10^{-8} m^3/kg$ and $7{,}72 \times 10^{-9} m^3/kg$. Compared to the $MS_{\text{marine standard}}$ of $5.5 \times 10^{-8} m^3/kg$ defined by Ellwood *et al.* (2011) on the basis of ~11,000 marine rocks samples, our values are low, mostly in the Freikofel section, which could indicate a low terrestrial influx seaward during the Middle and Upper Devonian. Regarding the magnetic susceptibility curves from these two sections, several large-scaled trends can be highlighted. The evolution curves of some selected clastic input proxies such as Zr, Si, Al, Ti, Sr display similar large-scaled trends. This indicates that clastic input proxies and MS are inherently linked and MS techniques can thus be used here as a proxi for changes in source or amount or type of weathering (Riquier *et al.* 2010).

Most of the long-term MS variations occurring in both sections are interpreted as being related to second order eustatic variations (T-R Cycles).

Through this multi-disciplinary investigation, we would like to get a better idea on the causes of long-term trends in MS variations and to document the sedimentary changes in response to these long-term variations. Further aim is to develop the application of MS techniques as a correlation tools.

Boulvain F., Da Silva A.-C., Mabille C., Hladil J., Gersl M., Koptikova L, Schonabl P. (2012). *Magnetic susceptibility correlation of km-thick Eifelian-Frasnian sections (Ardennes and Moravia).* Geologica Belgica, Volume 13, n°4, pp 309-318.

Ellwood B.B., Algeo T.J., El Hassani A., Tomkin J.H., Rowe H.D. (2011). *Defining the timing and duration of Kačák Interval within the Eifelian/Givetian boundary GSSP, Mech Irdane, Morocco, using geochemical and magnetic susceptibility patterns.* Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 304, Issues 1-2, pp 74-84

Riquer L., Averbuch O., Devleeschouwer X., Tribovillard N. (2010). *Diagenetic versus detrital origin of the magnetic susceptibility variations in some carbonate Frasnian-Famennian boundary sections from Northern Africa and Western Europe: implications for paleoenvironmental reconstructions.* International Journal of Earth Sciences, Volume 99, Issue 1 Supplement, pp 57-73.

Geophysical signal of the Beringhauser Tunnel section (Rhenish Massif, Germany): New insights for environmental reconstructions of Late Devonian events

GB 2012
Contestant for Best Oral Presentation

Riquier L.[1], Devleeschouwer X.[2], Breziat C.[3], Averbuch O.[4], Riboulleau A.[4], Tribovillard N.[4]

→ laurent.riquier@upmc.fr

1 Université Pierre et Marie Curie-Paris 6, UMR CNRS 7193 Institut des Sciences de la Terre de Paris, F-75252 PARIS cedex 05, France

2 Royal Belgian Institute of Natural Sciences, Dpt VII: Geological Survey of Belgium, Rue Jenner 13, B-1000 Brussels, Belgium

3 Université de Bourgogne, UMR CNRS 6282 Biogeosciences, 6 Boulevard Gabriel, F-21000 Dijon, France

4 Université Lille 1, UMR CNRS 8217 Géosystèmes, bâtiment SN5, F-59655 Villeneuve d'Ascq cedex, France

In marine sediments, magnetic susceptibility (MS) and gamma-ray spectrometry (GRS) measurements are frequently used to obtain information on change of fluxes and/or source of detrital inputs. MS signal integrates variable contributions of diamagnetic (calcite) minerals, paramagnetic (clays) matrix and ferromagnetic *s.l.* components residing generally in iron oxides whereas GRS signal yields concentrations of three elements: potassium linked to aluminosilicates (clays, micas), thorium, linked to clay and heavy minerals (zircon) and uranium associated to organic matter. Both signals could be affected by authigenic/diagenetic phases, which may prevent to a straightforward interpretation of their variations, more particularly in ancient sediments.

A detailed record of geophysical measurements (MS and GRS), have been performed from the Beringhauser Tunnel section (Rhenisch Massif, Germany) in order to determine the possible influence of authigenic/diagenetic phases and to bring new insights on the evolution of detrital input during the Late Devonian.

It clearly appears that K and Th concentrations show similar evolutions, i.e., an increasing trend during the middle of Frasnian following by a decreasing trend at the end of Frasnian, then a gradual increase at the base of Famennian and lastly a slight decrease during the middle of Famennian. The strong (r= 0.91) and positive correlation between K and Th argues for an admixture of fine-grained materials (essentially aluminosilicates), probably dominated by illite as indicated by the Th/K ratio always lower than 6. Unlike to K and Th, U signal is relatively stable and only marked by some noticeable peaks, which are also observed in the signal of the redox U/Th ratio. They are thus interpreted as episodes of O_2-depletion, three of them being linked to anoxic Lower and Upper Kellwasser Horizons and the Nehden Event.

By coupling MS measurements with hysteresis parameters, it appears that MS signal is mainly controlled by the ferromagnetic fraction. More precisely, hysteresis ratios suggest the coexistence of two ferromagnetic mineral phases: (1) a dominant fraction of low-coercivity magnetite grains and in a minor way (2) a fraction of high coercivity minerals (hematite). MS evolution is quite similar than those of K and Th concentrations, arguing for a detrital signature of both signals. In addition, three well-marked negative peaks of MS coeval with high U/Th ratios are also observed.

To summarize, both signals record evidence of a Late Frasnian period of detrital input changes marked by a positive peak following by two negative peaks in the levels corresponding to the Kellwasser-equivalent beds, whereas the base of the Famennian records an increase of detrital components. Then, the signals slightly decrease up to the middle of Famennian. This decrease of detrital input is perturbed by a noticeable short-term negative pulse corresponding to the Nehden Event.

The geophysical proxies indicate that the F-F boundary is marked in the Rhenish Massif by significant variations of detrital input, mainly recorded during the Kellwasser and the Nehden events. These changes are linked to sea-level rise likely associated to climatic evolution toward more humid conditions. Such environmental perturbations probably triggered increased continental weathering and the onset of O_2-depleted conditions.

Depositional facies and magnetic susceptibility of Mobarak formation (Lower Carboniferous in central and eastern Alborz Mountains, North of Iran)

Sardar Abadi M.[1], Da Silva A.-C.[1], Boulvain F.[1], Mosadegh H.[2]

→ Mehrdad.SardarAbadi@student.ulg.ac.be

1 Pétrologie sédimentaire, Département de Géologie, Bat. B20, Université de Liège, Sart-Tilman, B-4000 Liège

2 Department of geology, University Damghan, Iran

At the northern margin of Gondwana, after the Paleotethys opening, the first step of development of the carbonate factory corresponds to the Mobarak Formation, during the Lower Carboniferous (Tournaisian-Visean). In this study, sedimentology, magnetic susceptibility (MS) and biostratigraphy have been used to obtain a better understanding of the Shahmirzad and Aruh sections in the central and eastern Alborz Mountains. These 300 m thick lateral equivalent sections are distant of about 200 kilometres and belong to two different sedimentation areas: (1) central Alborz Mountains (Aruh section), where the sedimentation is relatively shallow, with bioclastic shoals (crinoids, peloids, shell fragments and algae); and laterally grades into (2) eastern Albroz Mountain (Shahmirzad section): deeper-water facies with an alternation of dark grey brown siliceous mudstone with fine grained bioclastic wackstone to packstone. Paleoenvironments correspond to a carbonate ramp platform dominated by crinoids with frequent storm deposits. Different facies that have been observed are, ranked from proximal to distal: (1) crinoid banks; (2) in-situ bioherms, mainly constituted by accumulations of tabulate corals, shell fragments and crinoids steams; (3) distal to proximal tempestites and (4) bioturbated dark argillaceous mudstone. The main sedimentological trend from the base to the top of the two sections is a shallowing-upward trend.

Magnetic susceptibility data were used for correlation between the two sections and to get a better understanding of sedimentary dynamics (through the link between MS and lithogenic inputs). It appears that MS values are the lowest for the more energetic environments which corresponds to the trends observed in the Devonian carbonate ramp in Belgium (da Silva *et al.*, 2009).

Da Silva A.-C., Mabille C., Boulvain F. (2009). *Influence of sedimentary setting on the use of magnetic susceptibility: examples from the Devonian of Belgium*. Sedimentology, Volume 56, Issue 5, pp 1292-1306.

Session 04

Black shales formation during anoxic event: climate and biodiversity variations

Chairmen: Nicolas Tribovillard and Karl Föllmi

Key-note speaker: Karl Föllmi

The Matagne black shale Formation and the Late Devonian mass extinction

Casier J-G.[1], Kaiho K.[2], Yatsu S.[2], Oba M.[2]

→ casier@naturalsciences.be

1 Royal Belgian Institute of natural Sciences, Department of Paleontology, Vautier street, 29, B-1000 - Brussels, Belgium.

2 Institute of Geology and Paleontology, Tohoku University, Sendai 980-8578, Japan.

In the Neuville railway section (Dinant Synclinorium, Belgium), the paroxysmal phase of the Late Devonian mass extinction may be fixed with precision in a continuous relatively thick (5.5 m) series of shales belonging to the second bed (or member) of the Matagne Fm (Casier, 2003, 2008). This formation consists of fine dark-greenish-brown to black shales characterized by the presence of a particular fauna principally composed of *Buchiola* (Pelecypopoda), lingulids and chonetids (Brachiopoda), entomozoids and cypridinoids (Ostracoda). The paroxysmal phase of the Late Devonian mass extinction coincides with the boundary between the *splendens* Zone and the *sigmoidale* Zone of the Parachronology established on entomozoid ostracods, and to the Adorf Stufe / Nehden Stufe boundary of the German historical subdivisions. In the Neuville railway section, Bultynck *et al.* (1998) have discovered *Palmatolepis linguiformis* in the top of the underlaying Valisettes Fm, and the contact with the overlaying Senzeilles Fm is by fault. A synthetic log combining the results of the study of the Neuville and Senzeille sections, allows to schematise the succession of events (stepwise extinction and stepwise recovery of the fauna) close to the F/F boundary in the type region for the definition of these two stages.

In the Sinsin section, located 54 km east of Neuville and Senzeille, the Matagne Fm is reduced to about 10 cm of grey-shales below the first occurrence of *Palmatolepis triangularis* (Casier & Devleeschouwer, 1995). This bed contains small pelecypods and ostracods belonging to the Myodocopid Mega-Assemblage (Cypridinoidea and Entomozoidea), a proxy for hypoxic water conditions (Casier, 2004). The study of the organic geochemistry (Dibenzofuran, coronene, benzo(ghi)perylene, benzo(e)perylene, cadalene, 2,3,6 trimethylarylisoprenoids and dibenzothiophenes) performed in the Department of Geology and Paleontology of the Tohoku University, displays that intensive soil erosion during the Late Frasnian provided abundant soil-derived nutrients and massive mud supply to marine ecosystems, whom contributed to the extinction of shallow marine organisms.

Bultynck P., Helsen S., Hayduckiewich J. (1998). *Conodont succession and biofacies in upper Frasnian formations (Devonian) from the southern and central parts of the Dinant Synclinorium (Belgium) – (Timing of facies shifting and correlation with late Frasnian events).* Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre, n°68, pp 25-75.

Casier J.-G. (2003). *Ostracods from the late Frasnian of the Neuville railway section (Dinant Synclinorium, Belgium): relation to the Kellwasser Event*. Bulletin de la Société geologique de France, n°174(2),pp 149-157.

Casier J-G. (2004). *The mode of life of Devonian entomozoacean ostracods and the myodocopid mega-assemblage proxy for hypoxic events.* Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre, n°74 supplement, pp 73-80.

Casier, J-G. (2008). *Guide de l'excursion: Les Ostracodes du Devonien Moyen et Superieur du Synclinorium de Dinant. In:* Resumes des communications et guide de l'excursion de la 22e Réunion des Ostracodologistes de Langue Française (Bruxelles, 2-4 Juin), Institut royal des Sciences naturelle de Belgique, pp 25-79.

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The astronomical rhythm of Late-Devonian climate change (Kowala section, Holy Cross Mountains, Poland)

De Vleeschouwer D.[1], Rakocinski M.[2], Racki G.[2], Bond D.P.[3], Sobien K.[4], Claeys P.[1]

→ dadevlee@vub.ac.be

1 Earth System Sciences and Department of Geology, Vrije Universiteit Brussel, Belgium

2 University of Silesia, Faculty of Earth Sciences, Poland

3 Norwegian Polar Institute, Tromsø, Norway

4 Energy Security Program, Polish Geological Institute - National Research Institute, Warszawa, Poland

The Devonian period (418-361 Ma) was a time of profound changes in terrestrial and aquatic ecosystems. These changes set the stage for the evolution of tetrapods and their expansion onto the land, the development of plant rooting systems and the appearance of the first forests. Thomas Algeo and Stephen Scheckler (1998) proposed the expansion of terrestrial plants as the cause for enhanced organic matter and nutrient input in the shallow inland seas of North America and Eurasia and linked this with the massive burial of organic carbon and global anoxia. To better understand the influence of astronomical forcing on the pacing and triggering of these Late-Devonian widespread shortages of dissolved oxygen, we studied the rhythmical alternations between limestone and shales or marls at the famous Kowala section (Holy Cross Mountains, Poland).

Two intervals of this section were studied in terms of orbital cyclostratigraphy. The older interval spans the Frasnian - Famennian boundary, deposited under one of the hottest greenhouse climates of the Phanerozoic, but interrupted by two cooling episodes (i.e. anoxic Kellwasser Events). The youngest encompasses the Devonian - Carboniferous boundary, a pivotal moment in Earth's climatic history between greenhouse and icehouse. For the Frasnian - Famennian interval, lithogical variations are consistent with 405-kyr and 100-kyr eccentricity forcing and a cyclostratigraphic floating time scale is presented. The interpretation of observed lithological rhythms as eccentricity cycles is confirmed by amplitude modulation patterns in agreement with astronomical theory and by the recognition of precession cycles in high resolution stable isotope records. The resulting relative time scale suggests that ~800 kyr separate the Lower and Upper Kellwasser Events (LKE and UKE, resp.), two periods of anoxia and massive biodiversity loss at the end of the Frasnian. The Th/U and pyrite framboid record indicate that during the UKE, oxygen levels remained low for 400 kyr and $\delta^{13}C_{org}$ measurements demonstrate that more than 600 kyr elapsed before the carbon cycle reached a steady state after a +3‰ UKE excursion. During the Famennian - Tournaisian interval, eccentricity and precession related lithological variations occurred. Precession related alternations clearly demonstrate grouping into 100-kyr bundles. The Upper Famennian part of this interval is characterized by 4 distinct anoxic black shales: the Annulata, Dasberg, Kowala and Hangenberg shales. Applying our high resolution cyclostratigraphic framework, those shales were deposited at 2.2, 1.1 and 1.2 Myr intervals respectively. These durations strongly suggest a link between the long period (~2.4 Myr) eccentricity cycle and the development of the Annulata, Dasberg and Hangenberg anoxic shales. Based on these results, we propose an explicit link between astronomical forcing, eustatic transgression and marine anoxia for the Late Devonian: It is assumed that Upper Famennian black shales form under transgressive conditions, when extremely high eccentricity promoted the collapse of small continental ice sheets at the australmost latitudes of western Gondwana Associated global warming, widespread wildfires and enhanced monsoonal circulation lead to the establishment of optimal conditions for increased primary production and bottom-water anoxia.

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The black marble of Mazy (Belgium): a multi-proxy approach on anoxic Frasnian limestones

Devleeschouwer X.[1], Sotiriou C.[2,1], Fournier L. [3]

→ xdevleeschouwer@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

2 National and Kapodistrian University of Athens, Faculty of Geology and Geo-environment , Greece

3 University Francois Rabelais of Tours, Department of Geosciences and Environment, France

The black marble of Golzinnes corresponds to black limestones belonging to the Rhisnes Formation (Frasnian, Upper Devonian) cropping out in the Namur basin. The Rhisnes Formation is subdivided into three Members named successively Watiamont, Golzinnes and Falnuée in the stratigraphical order from base to top. The sedimentary section is located in the quarry Lagasse and in the underground quarry exploited by room and pillars, close to the village of Mazy, 20 km north west of Namur. These marbles are very fine-grained black limestones characterized by deep black colour due to the absence of macrofossils or calcite veins. TheTwo veins of black limestones are known and separated by a bed named “Gros Mâle”. The section has been sampled at high-resolution, every 7 cm in average, for magnetic susceptibility and rock magnetic measurements. Gamma-ray spectrometry (GRS) measurements were also made along the section each 25 cm with handheld equipment.

For the samples already measured, the low-field magnetic susceptibility (or X_{LF}) is relatively high and the average value is above the mean value of 5.5 x 10^{-8} m^3/kg for 11,000 marine lithified rocks (Ellwood *et al.*, 2011). X_{LF} is highly fluctuating indicating that the signal is not related to the lithology. At large scale, two successive trends can be depicted: from the base, a decrease of the X_{LF} values is progressively observed up to the end of the “Gros Mâle” bed and then a decreasing trend of the X_{LF} values is recorded until the end of the second black vein. The X_{LF} curve can be subdivided in several smaller positive or negative trends.

No significant evolutions are depicted from the GRS measurements. The correlation coefficient (r=0.35) between K (%) and Th (ppm) concentrations is positive but relatively weak indicating that the signal is not controlled only by the influx of fine-grained detrital aluminosilicates minerals in the limestones. Along the section and specifically during the two intervals of the black limestone veins, U/Th ratios are relatively high with values above 1.25 and ranging between 0.58 and 5.3. These data suggest that the sediments have been deposited in anoxic environments. To evaluate the importance of this parameter, SEM analyses have revealed the presence of framboidal pyrite crystals and statistical analyses will be made to determine the size range of these framboids in order to determine if the water column is anoxic or oxic and to deduce the position of the redox front.

A multidisciplinary study is thus needed to determine the environmental conditions of these unusual black facies in the Frasnian, to assess the importance of the anoxic conditions and to identify the magnetic minerals and their origin with the objective to estimate the preservation of a primary signal recorded by the X_{LF} fluctuations which could be related to the influx of detrital particles.

Recent anoxic cohesive sediment deposits in the Belgian near-shore area: sedimentological context and anthropogenic impact

Fettweis M.[1], Baeye M.[2], Francken F.[1], Houziaux J.-S.[1], Lee B.J.[3], Van den Eynde D.[1], Van Lancker V.[1]
→ m.fettweis@mumm.ac.be

1 Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Belgium

2 Universiteit Gent, Renard Center of Marine Geology, Belgium

3 Katholieke Universiteit Leuven, Department of Civil Engineering, Hydraulics Laboratory, Belgium

The recent cohesive sediments of the Belgian nearshore zone consist of Holocene back-barrier black muddy deposits dating back to 3000 years ago (Mathys, 2009) and freshly deposited grey or black muds occurring as ephemeral fluid mud layers or, locally, as increasingly more consolidated, thicker anoxic packages (>0.3 m). These deposits are associated with the occurrence of elevated concentration of suspended particulate matter (SPM). The distribution of muddy deposits depends on hydrodynamics, meteorological condition, climate, biological activity (primary production) and – in our case – anthropogenic influence. The latter is related to engineering works such as deepening of navigation channels, construction of harbours, dredging and disposal activities, and the anthropogenic induced eutrophication of the near-shore area. As a consequence SPM concentration, mud deposits, primary production and benthic life has changed during the last 100 years (Borges and Gypens, 2010; Fettweis *et al.*, 2009, Houziaux *et al.*, 2011).

The aim of the research is to show the effects of human impact on the SPM dynamics and on the deposition of anoxic cohesive sediments. In the beginning of the 20th century the freshly deposited mud layers were the result of natural morphological processes. Today, they are more concentrated in areas affected by engineering works. These changes have resulted in a larger extent of the turbidity maximum zone and in higher SPM concentrations. Organic matter and biogenic particles influence flocculation and thus SPM dynamics. Changes in nutrient loads of rivers has a strong influence on the primary production and thus on the carbon cycle in coastal areas (Borges and Gypens, 2010). The increase of organic matter concentration during spring algae bloom has an effect on the partitioning of sticky organic molecules to mineral flocs and thus on the settling of organic rich flocs and the formation of organic rich deposits. The changes associated with climate are related to variations in the North Atlantic Oscillation (NAO). As a consequence, the mud content of the sediment may vary considerably according to meteorological and climate condition.

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Borges A.V., Gypens, N. (2010). *Carbonate chemistry responds more strongly to eutrophication than ocean acidification in the coastal zone*. Limnology and Oceanography, n°55, pp 346-353.

Fettweis M., Houziaux J.-S., Du Four I., van Lancker V., Baeteman C., Mathys M., Van Den Eynde D., Francken F., Wartel S. (2009). *Long-term influence of maritime access works on the distribution of cohesive sediment: Analysis of historical and recent data from the Belgian nearshore area (southern North Sea)*. Geo-Marine Letters, n°29, pp 321-330.

Houziaux J.-S., Fettweis M., Francken F., van Lancker V. (2011). *Historical (1900) seafloor composition in the Belgian-Dutch part of the North Sea: A reconstruction based on calibrated visual sediment descriptions.* Continental Shelf Research, Volume 31, Issue 10, pp 1043–1056.

Mathys M. (2009). *The quaternary geological evolution of the Belgian Continental Shelf, southern North Sea.* PhD thesis, Ghent University, Belgium. 382 p..

Paleoenvironmental change and oceanic anoxia during the Early Cretaceous

Föllmi K.B.

Institut de Géologie et Paléontologie, University of Lausanne, CH-1015 Lausanne, Switzerland

Early Cretaceous life and the environment were strongly influenced by the accelerated break up of Pangea, which was associated with the formation of a multitude of rift basins, intensified spreading, and important volcanic activity on land and in the sea. These processes likely interacted with greenhouse conditions, and Early Cretaceous climate oscillated between "normal" greenhouse, predominantly arid conditions, and intensified greenhouse, predominantly humid conditions. Arid conditions were important during the latest Jurassic and early Berriasian, the late Barremian, and partly also during the late Aptian. Humid conditions were particularly intense and widespread during shorter episodes of environmental change (EECs) - the Valanginian Weissert, the latest Hauterivian Faraoni, the latest Barremian to earliest Aptian Taxy, the early Aptian Selli, the early late Aptian Fallot and the late Aptian to early Albian Paquier Episodes. Arid conditions were associated with evaporation, low biogeochemical weathering rates, low nutrient fluxes, and partly stratified oceans, leading to oxygen depletion and enhanced preservation of laminated, organic-rich mud (LOM). Humid conditions enabled elevated biogeochemical weathering rates and nutrient fluxes, important runof and the buildup of freshwater lids in proximal basins, intensified oceanic and atmospheric circulation, widespread upwelling and phosphogenesis, important primary productivity and enhanced preservation of LOM in expanded oxygen-minimum zones. The transition of arid to humid climates may have been associated with the net transfer of water to the continent due to the infill of dried-out groundwater reservoirs in internally drained inland basins. This resulted in shorter-term sea-level fall, which was followed by sea-level rise. These sea-level changes and the influx of freshwater into the ocean may have influenced oxygen-isotope signatures. Climate change preceding and during the Early Cretaceous EECs may have been rapid, but in general, the EECs had a "pre"-history, during which the stage was set for environmental change. Negative feedback on the climate through increased marine LOM preservation was unlikely, because of the low overall organic-carbon accumulation rates during these episodes. Life and climate co-evolved during the Early Cretaceous. Arid conditions may have affected continental life, such as across the Tithonian-Berriasian boundary. Humid conditions and the corresponding tendency to develop dys- to anaerobic conditions in deeper ocean waters led to phases of accelerated extinction in oceans, but may have led to larger vegetation covers on continent, such as during the Valanginian, when herbivores thrived. During Early Cretaceous EECs, reef systems and carbonate platforms in general were particularly vulnerable. They were the first to disappear and the last to recover, often only after several million years.

The late Hauterivian Faraoni Event at Río Argos (southern Spain): is it really an OAE?

GB 2012 Contestant for Best Oral Presentation

Sauvage L.[1], Riquier L.[2], Thomazo C.[3], Baudin F.[2], Martinez M.[3]

→ lsauvage@crpg.cnrs-nancy.fr

1 Centre de Recherches Pétrographiques et Géochimiques (CRPG) CNRS-UPR 2300, 15 rue Notre Dame des Pauvres, BP 20, 54501 Vandoeuvre-lès-Nancy Cedex, France.

2 UPMC Univ. Paris 06, CNRS, UMR 7193 – ISTEP, 4, place Jussieu, 75252 Paris Cedex 05, France.

3 Université de Bourgogne, UMR CNRS 6282 Biogéosciences, 6 Bd Gabriel, 21000 Dijon, France.

First described in the Umbria-Marche basin of Italy (Cecca *et al.*, 1994), the Faraoni Level is thought to be associated with a short-lived oxygen-deficient period extended through the Tethyan realm, and is interpreted as an Oceanic Anoxic Event (OAE) of regional extend (Baudin *et al.*, 2002; Baudin, 2005). Recently, on the base of palaeontological and sedimentological correlations, a new equivalent of the Faraoni Level has been identified in Betic area (SE Spain) in the Río Argos section (Company *et al.*, 2005). The triggering mechanisms for the Faraoni Event are however still debated and the timing and vertical extend of water-column oxygen variations in the Subbetic realm should be precised.

We performed an integrated study of multiple geochemical proxies around the Faraoni Level along the Río Argos section. A chemiostratigraphy approach was used along this 8 m thick section. We measured major and trace elements, Fe speciation, organic matter characterization by Rock-Eval analysis and $\delta^{13}C_{carb}$ in order to link oxygen variations to carbon cycle modifications during the Faraoni Event.

Except for one sample at the base of the Faraoni Level, where TOC reaches 1.5 wt.%, the C_{org} content remains relatively low (< 0.5 wt.%) and may result from a secondary alteration of organic matter. The $\delta^{13}C_{carb}$ curve is characterized by a minor long-term increase, attributed to an enhanced organic matter burial. Nevertheless, possible diagenetic overprint to primary isotopic signal cannot be ruled on. At Río Argos, the Faraoni Level is not associated with high TOC content or noticeable increase of $\delta^{13}C_{carb}$ values unlike the other late Hauterivian sections reported in literature (France, Switzerland and Italy). Moreover, absence of major excursion in the stratigraphic distribution of redox sensitive trace elements (U and V) and productivity proxies (P and Ni) within the Faraoni Level reveals signatures of a rather oxic environment and a moderate productivity, where oxygen concentrations appear to vary on small time scale suggesting rapid turnover. Only, the base of the Faraoni Level shows evidence for oxygen-depleted conditions (higher TOC values, redox sensitive trace element enrichments, positive peaks of Fe ratios) and enhanced primary productivity (P, Cu, Ni) with no major detrital inputs (Ti and Zr), which may be linked to short-lived local anoxic conditions.

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Analysis of marine environmental conditions based on molybdenum-uranium covariation — Applications to Mesozoic paleoceanography

Tribovillard N.[1], Algeo T.J.[2], Riboulleau A.[1]

→ Nicolas.tribovillard@univ-lille1.fr

1 Université Lille 1, Laboratoire Géosystèmes, UMR CNRS 8217, bâtiment SN5, 59655 Villeneuve d'Ascq cedex, France

2 Department of Geology, University of Cincinnati, Cincinnati, Ohio 45221-0013, USA

Uranium and molybdenum stand among the trace metals the most commonly used as paleoredox proxies. Their respective enrichment factors relative to crustal abundances (EF), determined for various modern marine environments, allowed us defining a multi-domain chart. This U-EF vs. Mo-EF crossplot is designed to reconstruct paleoredox conditions and was tested with the reconstruction of Paleozoic settings of North America, characterized by restricted communications with open seas (landlocked intracratonic seas and silled seaways). Here we test this chart with Mesozoic formations reputed to have undergone oxygen-restricted (suboxic to euxinic) conditions in open-marine settings. Our results from well-known formations show that the U-Mo relationships defined with present-day situations may be applied confidently to interpret Mesozoic conditions of deposition. In addition, this approach allows us identifying paleoenvironments where the flux of Mo to the sediment through Mn-Fe oxi-hydroxide shuttles was active. We conclude that the U-EF vs. Mo-EF chart is a robust tool helping accurate reconstructions of past environments more or less prone to organic matter accumulation, even in the absence of any information about organic matter.

Session 05

Paleocene-Eocene Thermal Maximum: sedimentology, geochemistry and the biotic response

Chairmen: Malcolm Hart & Johan Yans

The Late Paleocene - Early Eocene interval as a potential period for weathering in Western Europe: the case of the Morialmé section (Belgium)

GB 2012 Contestant for Best Poster Presentation

Barbier F.[1], Quesnel F.[2], Dupuis C.[3], Yans J.[1]

→ francois.barbier@fundp.ac.be

1 FUNDP- Namur, Department of Geology, Namur, Belgium

2 BRGM (French Geological Survey), Geology /Regolith & Reservoir, Orléans, France

3 UMons, Faculty of Engineering, Mons, Belgium

Dating of weathered rocks based on radiometric K/Ar and Ar/Ar methods on potassic manganese oxides (cryptomelane of hollandite group) is considered as suitable by the scientific community (Vasconcelos, 1999). These methods have been widely used to highlight many weathering phases around the world.

Refined dating of weathering related minerals allows 1) to place the weathering phases in their paleo -geological and -geomorphological contexts and 2) to better decipher the different weathering processes leading to the formation of these rocks. In Wallonia, weathering took place in several relatively short phases: Late Permian – Early Triassic, Early Cretaceous, "middle" Cretaceous, Late Paleocene – Early Eocene and Early Miocene.

In the Entre-Sambre-Et-Meuse region (Belgium), a single weathering phase, Late Paleocene – Early Eocene in age, 55.75 +/- 2.35 Ma, has been identified based on radiometric dating (K/Ar) on birnessite (hydrated form of hollandite) in concretions coating cracks crossing the upper and lower part of the weathering profile (Barbier, 2012). In this area, the weathered profile is overlain by a fluvial channel not weathered and dated as earliest Eocene. Given the geological and geometric relationships of the dated Mn oxides with the whole weathering profile developed and the terrestrial sediments deposited at Morialmé, this age is supposed to be the last weathering phase affecting the area. This does not preclude that any older phases could have contributed to the weathering profile, and as shown by Yans (2003) in the Haute-Lesse area (Belgium).

The mineralogy and geochemistry related to the weathering have also been studied in details at Morialmé. The result of the XRD analysis of the clay fraction and the Weathering Index confirm the presence of different weathering degrees along the profile, defined on macroscopic criteria. The main characteristic of Morialmé's quarry is the presence of an alloterite (*sensu* Wyns *et al.*, 2004) at the top of the profile. Such a degree of weathering (i.e. very strongly weathered rocks) is most probably quite rare in Wallonia.

The PETM and ETM2: Reset buttons for benthic ecosystem evolution?

GB 2012 Contestant for Best Oral Presentation

D'haenens S.[1], Bornemann A.[2], Speijer R.P.[1]

→ simon.dhaenens@ees.kuleuven.be

1 Department of Earth and Environmental Sciences, KU Leuven, Belgium

2 Institut für Geophysik und Geologie, Universität Leipzig, Germany

Ever since its discovery, the Paleocene-Eocene Thermal Maximum (~PETM; 55.8 Ma) has intrigued micropaleontologists. This geologically brief global warming event - possibly caused by the dissociation of ^{12}C-rich methane hydrates – drove the extinction of ~30-50% of all deep-sea benthic foraminifera. As such, the PETM can be considered as a "reset" button in the evolution of benthic ecosystems, eliminating certain taxa (e.g. *Gavelinella*) – for reasons actually still unknown - and subsequently propelling other taxa (e.g. *Nuttallides*) as common components in the Eocene. This particular transition from the "Cretaceous fauna" to the Paleogene fauna was kick-started by the PETM, yet the fully mature Eocene fauna only developed in the course of the Early Eocene.

With the recent discovery of several other global hyperthermal events in Eocene sedimentary sequences, a number of questions arise. What role – if any – did these hyperthermals have in shaping Paleogene deep-sea benthic communities? Did they exert a noticeable effect on the (disrupted post-PETM) deep-sea benthic ecosystem on short time scales or did they also produce more longer-lasting effects?

To answer these questions, we investigated latest Paleocene to early Eocene (NP9-NP12) pelagic deposits of DSDP Site 401 (North Atlantic Ocean). In this interval, lithological changes and stable isotope records reveal the presence of the PETM and Eocene Thermal Maximum 2 (ETM2). Using a detailed quantitative benthic foraminiferal record for this interval, we were able to 1) compare the faunal patterns of the PETM with those of ETM2 and 2) assess these patterns in a longer-term perspective. Our dataset confirms the extinction of several Paleocene species at the onset of the PETM, although at ~15-20%, the extinction rate is significantly lower than the global average. The PETM itself shows a marked increase in *Nuttallides umbonifera*, *Tappanina selmensis*, *Bulimina tuxpamensis* and several abyssaminid taxa. This perturbed assemblage is quickly replaced by an *Epistominella minuta*/*Bulimina* cf. *simplex* assemblage, which is associated with an expanded and clay-enriched sequence. Near the top of Biozone NP10, the clay content decreases and the assemblage subtly changes: *Cibicidoides eocaenus* and *Bulimina virginiana* become common up to ETM2. Just like the PETM, ETM2 is dominated by *N. umbonifera*, but more striking is that directly following it, the assemblage permanently changes: *C. eocaenus*, *E. minuta*, *B. virginiana* and *Brizalina carinata* truly dominate, while previously common *B. tuxpamensis*, *Bolivina huneri* and other minor components virtually disappear from the record.

Differences in magnitude aside, the ETM2 resembles the PETM: a similar excursion fauna characterizes both events and they both initiate a permanent change in an otherwise relatively stable benthic foraminiferal assemblage. Hence, we suggest that hyperthermal events are transient climatic/paleoceanographic perturbations, partially "resetting" benthic ecosystem evolution, creating a stepwise developmental pattern. Whether the punctuated changes at DSDP Site 401 are truly representative of Eocene deep-sea foraminiferal evolution remains to be seen, as global benthic records encompassing Eocene hyperthermals are still in development at the moment.

Rock magnetism before, during and after the CIE: a comparison between marine and continental sections

Devleeschouwer X.[1], Storme J.-Y.[2], Spassov S.[3], Yans J.[2]

→ xdevleeschouwer@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

2 FUNDP, University of Namur, Department of Geology, Belgium

3 Royal Meteorological Institute, Laboratory of Paleomagnetism, Dourbes, Belgium

The Palaeocene–Eocene Thermal Maximum (PETM at 55.8 Ma) was a short-lived episode of extreme global temperatures, often regarded as a past analogue of the ongoing global warming. The PETM is defined chemostratigraphically by a carbon isotope excursion (CIE) recognized globally in both marine and terrestrial sections. The onset of this ca. 150-200 ka event marks the Palaeocene ⁄Eocene (P⁄E) boundary. Zumaia is the most complete and representative section of the early Palaeogene hemipelagic succession of the Pyrenees. Concerning the P/E boundary, the position of the CIE is now clearly identified in the Zumaia section using carbon isotope chemostratigraphy on organic matter ($\delta^{13}C_{org}$). Based on a detailed rock magnetic study, several magnetic susceptibility (MS) fluctuations are recognised and interpreted in terms of sea-level fluctuations and stratigraphic system tracts before, during and after the PETM. The MS signal on the whole section is mostly controlled by paramagnetic minerals (clays) and more specifically by the presence of different ferromagnetic phases during the CIE. The Hysteresis parameters (e.g. the viscosity index, the remanence coercivity, the contribution of a high-coercivity phase to the IRM curve) are highlighted with higher values only during the PETM interval and could partly be explained by the influx of detrital iron-oxide minerals derived from the nearby emerged continental areas. A comparison of the rock magnetic properties between this deep marine section on the Atlantic margin (Zumaia) and a Tethyan basin section (Sidi Nasseur, Tunisia) reveals at large-scale a similar signal of the low-field magnetic susceptibility fluctuations. In details, small-scale fluctuations precisely during the PETM are not influenced similarly as in Zumaia revealing a clear difference in continental derived material supply to the marine environment during the CIE. A comparison of the same rock magnetic properties and MS signal in continental sections (Vastérival and Sotteville-sur-Mer) from the Paris basin are really difficult taking into account the different hiatuses and the continental environments. No clear correlations are thus possible between the continental sections of the Paris basin and the marine Tethyan or North-Atlantic sections.

Environmental and hydrological changes at the Paleocene-Eocene boundary in the terrestrial sediments of the Cap d'Ailly core (Upper Normandy, France)

Garel S.[1,2,3], Schnyder J.[1], Jacob J.[2], Boussafir M.[2], Dupuis C.[4], Le Milbeau C.[2], Baudin F.[1], Quesnel F.[3]

→ sylvain.garel@upmc.fr

1 UPMC Univ Paris 06 et CNRS, UMR 7193 ISTeP, 4 place Jussieu, 75005 Paris, France.

2 ISTO, Université d'Orléans UMR 7237 du CNRS/INSU, 1A rue de la Férollerie, 45071 Orléans Cedex 2, France.

3 BRGM (French Geological Survey), Geology Department, Regolith & Reservoir Unit, 45060 Orleans Cedex 2, France

4 UMONS, GFA, rue de Houdain 9, B-7000 Mons, Belgium

The Paleocene-Eocene Thermal Maximum (PETM, 55.8 Ma, Aubry *et al.*, 2007) is regarded as one of the most rapid global warming of the Cenozoic era, with temperature increase of 4-8°C in about 10-20 ka. Thus, it is often proposed as a potential analogue of future climatic conditions expected in the screenplays provided by the International Panel on Climate Change (IPCC). The PETM is recorded in both marine and terrestrial deposits by an abrupt negative Carbon Isotope Excursion (CIE) associated with other sedimentary and biological anomalies. The consequences of the PETM in terrestrial environments are less documented than in marine ones. This limits our regional- and global-scale understanding of the impact of such a drastic climate change on continents and the ecosystems response.

This study focuses on the Cap d'Ailly core (Seine-Maritime, France) drilled by the BRGM in 2008 in the southern part of the Dieppe-Hampshire Basin, an area where the PETM has already been attested in a few sections by the presence of the CIE and the *Apectodinium* acme (Magioncalda et al, 2001; Dupuis et al, 2006; Storme et al, 2012). These sections consist of terrestrial and lagoonal organic matter-rich deposits that are typical of the Sparnacian facies (latest Paleocene - earliest Eocene; Aubry *et al.*, 2005). The lower part of the "Sparnacian" is dominated by fluvial, lacustrine and swamp deposits such as marls and lignites. It is overlain by two units of lagoonal deposits rich in shell debris separated by terrestrial deposits. The uppermost part of the section is constituted by a 1 m-thick marine clay rich in glauconite (Dupuis & Steurbaut, 1987).

Global organic geochemical, palynofacies and isotopic analyses reveal that the onset of the CIE is located in the lowermost swamp deposits. The total organic carbon ranges from 0.02 % for paleosols to 43 % for lignite beds. The organic matter is mainly of Type III (terrestrial higher plants) and immature. These interpretations are reinforced by palynofacies observations that show a large amount of ligno-cellulosic phytoclasts in many samples. In marine and lagoonal deposits, the presence of many *Apectodinium* specimens would suggest the continuation of the PETM up to the top of the Sparnacian deposits, although this has to be confirmed by carbon isotopes analyses.

Palynofacies, distribution of specific lipid biomarkers as well as their hydrogen and carbon isotopic compositions show important changes coincident with the CIE onset. This is consistent with important environmental and hydrological changes in the Cap d'Ailly area during the earliest Eocene that could be linked to the PETM climatic change

The PETM record revealed by a new integrated high-resolution dinoflagellate cyst and geochemical data from the "Sparnacian" sediments in the Paris and adjacent basins

Iakovleva A.I.[1], Quesnel F.[2], Dupuis C.[3], Storme J.-Y.[4], Breillat N. [5,2], Magioncalda R.[6], Yans J. [4], Smith T.[7], Roche E.[8], Iacumin P.[9], De Coninck J.[10], Fléhoc C.[11]

→ alina.iakovleva@gmail.com

1 Russian Academy of Sciences, Geological Institute, Russia
2 BRGM (French Geological Survey), Geology / Regolith & Reservoir, France
3 Mons University, Faculté Polytechnique, Belgium
4 FUNDP, Department of Geology, Belgium
5 Bourgogne University, Biogéosciences, France
6 Geonumeric, France
7 Royal Belgian Institute of Natural Sciences, Department of Palaeontology, Belgium
8 Liège University, Department of Palaeobotany, Belgium
9 Parma University, Department of Earth Sciences, Italy
10 Ghent University, Department of Geology & Soil Science, Belgium
11 BRGM (French Geological Survey), MMA laboratories, France

The Paris Basin represents an historical cradle of the Paleogene stratigraphy, where the Paleocene Epoch and the "Sparnacian Stage" have been erected (Schimper, 1874; Dollfus, 1880). As highlighted by Aubry *et al.* (2005), whereas the chronostratigraphic connotation of the Sparnacian Stage occurred to be controversial since its definition, modern studies of the Late Paleocene - Early Eocene interval have revealed that the so-called "Sparnacian" deposits encompass a remarkable and short (~170 kyr) episode in the Cenozoic history, the Paleocene-Eocene Thermal Maximum (PETM, ~55.8-55.6 Ma).

However, due to a large development of diverse and laterally variable, predominantly lagoonal and non-marine facies, the Paris Basin Upper Paleocene-Lower Eocene succession is still poorly documented and needs an updated chronostratigraphic correlation with other Paleogene records in adjacent basins and worldwide. Since almost 45 years the dinoflagellate cyst stratigraphy has significantly contributed to correlations of the Thanetian-Ypresian deposits in the Paris and adjacent basins (Châteauneuf & Gruas-Cavagnetto, 1968, 1978; Gruas-Cavagnetto, 1974; Costa and Downie, 1976). Nevertheless, data published on dinoflagellate cysts distribution in the Paleogene sediments of those basins remain too scattered (see Aubry *et al.*, 2005) and need to be calibrated to the most recent biozonations.

With the aim at reconstructing the "Sparnacian" palaeoenvironments as well as ensuring correlation with the PETM (and its Carbon Isotopic Excursion, CIE) events and related processes, new or already well known "Sparnacian" Dieppe-Hampshire and Paris Basins key localities (Cap d'Ailly and Sotteville-sur-Mer sections, Therdonne and Sinceny cores) have been investigated in details palynologically and chemostratigraphically. According to our new high-resolution data, the CIE begins within the Mortemer Fm in terrestrial or coastal environments and continues until the top of the Soissonnais Fm (Quesnel et al, this meeting). Within the CIE, $\delta^{13}C_{org}$ values fluctuate between -25 and -30 ‰, while above and below they fluctuate between -22 and -26 ‰. The CIE interval contained in the lagoonal and shallow marine units reveals an extremely pronounced (compared with other PETM records worldwide) *Apectodinium*-acme (70-98% of dinocyst assemblage), sometimes accompanied by *Pediastrum*-blooms (fresh water algae).

As mentioned by Gruas-Cavagnetto (1974), dinoflagellate assemblages from the Dieppe-Hampshire and Paris Basins "Sparnacian" do not contain the key species *Apectodinium augustum* (nominate species of the A. augustum zone corresponding the PETM-interval worldwide, Crouch *et al.*, 2001), whereas it is present in the northern Belgian Basin Tienen Fm (De Coninck, 1975, 1999) and is coeval there with the CIE and *Apectodinium*-acme interval (Steurbaut *et al.*, 2000, 2003). However, our calibration of the *Apectodinium*-acme to the CIE in the Dieppe-Hampshire and Paris Basins suggests its attribution to the A. augustum zone. As it was previously noted from southern England (Powell *et al.*, 1996), the absence of species *A. augustum* in the Anglo-Paris Basin may be explained by its restriction to more offshore conditions. In localities studied here dinocyst assemblages dominated by *Apectodinium* spp. are characterized by a significant number of longer (compared to the holotype) specimens of *A. parvum*, which could represent an ecological onshore substitute of species *A. augustum* during the PETM.

Can the PETM events be recognized in the geochemical compositions of phosphatic fossils of Morocco?

Kocsis L.[1], Gheerbrant E.[2], Mouflih M.[3], Cappetta H.[4], Yans J.[5], Ulianov A.[1], Amaghzaz M.[6]

→ laszlo.kocsis@unil.ch

1 Institut de Minéralogie et Géochimie, Université de Lausanne, Switzerland

2 CNRS and Muséum National d'Histoire Naturelle, UMR 7207, Paris, France

3 Faculté des Sciences Ben M'Sik, Casablanca, Morocco

4 "Institut des Sciences de l'Evolution", Université de Montpellier II, France

5 Facultés Universitaires Notre-Dame de la Paix à Namur, FUNDP, Belgium

6 Groupe Office Chérifien des Phosphates, Centre Minier de Khouribga, Morocco

Fossil rich shallow marine phosphorites are widespread along the western coast of Morocco. They were deposited during the late Cretaceous-early Eocene in three, first order transgressive-regressive cycles, with main discontinuities between them. The ages of these series are Maastrichtian, Danian-Thanetian and Ypresian based on the abundant selachian fauna[1]. These sediments give the opportunity to investigate the major global changes (e.g. K/T and P/E transitions) in this shallow marine milieu and to verify if the characteristics of these events are preserved and/or identifiable.

Here we focus on the early Paleogene beds and the Paleocene-Eocene transition. During comprehensive fieldwork marine fossils, mainly shark teeth and coprolites were collected bed by bed in the Ouled Abdoun Basin at Sidi Chenanne quarries. These fossils were analyzed for stable isotope ($\delta^{18}O$, $\delta^{13}C$) and trace element compositions to better assess paleoenvironmental conditions and to test whether these fossils reflect any of the early Paleogene climatic events and the related negative carbon isotope excursions[2].

The phosphate oxygen isotope compositions of shark teeth vary a lot across the entire series, which partly relate to the habitat of the sharks. Despite the large variation, a general isotope trend is apparent with decreasing $\delta^{18}O_{PO4}$ values from the Danian till the Ypresian, which shift can be linked to the globally recognized Early Eocene Climatic Optimum[2].

The carbon isotope composition of shark teeth enameloid have mostly positive $\delta^{13}C$ values, which might relate to dissolved inorganic carbon (DIC) in seawater at the time. Dentine, bones and coprolites always yielded negative $\delta^{13}C$. Coprolites vary the most, reflecting the burial environment, where the pore-fluid's DIC was dominated by intensive organic matter recycling. Bone-beds show larger variations in $\delta^{13}C$ values that could be caused by reworked specimens and by possible enhanced oxidation in these levels. From the base of the Ypresian the relatively more negative $\delta^{13}C$ values are compatible with global observation[2]. Some of the lowest $\delta^{13}C$ values appear in the intercalary bed between the phosphorite beds II and I, which might relate to the Paleocene-Eocene boundary event, in agreement with selachian faunas, although gap in sedimentation between these levels makes very tentative any interpretation here.

The trace element data revealed the general fossilization patterns of biogenic apatite with enhanced rare earth element (REE) concentration linked to the early diagenetic environment. All the fossils shows very alike REE pattern that mimic modern seawater composition with negative Ce-anomaly and heavy REE enrichment. A gradual shift towards more pronounced Ce-anomaly from older to younger beds is evident, which may relate to changes in seawater depth and/or influx of more oxygenated seawater in the basin.

Additionally, preliminary data from the Paleocene-Cretaceous beds of the Ganntour Basin is also presented as an extension of the Ouled Abdoun dataset.

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Stratigraphy and palaeoenvironment of the Paleocene/Eocene boundary interval in the Indus Basin, Pakistan

Hanif M.[1], Hart M.B., Grimes S.T.

→ mhart@plymouth.ac.uk

School of Geography, Earth & Environmental Sciences, Plymouth University, Drake Circus, Plymouth PL4 8AA, United Kingdom.

1 Now at Centre for Excellence in Geology, Peshawar University, Peshawar 25120, Paksitan

Marine sedimentary sections across the Paleocene/Eocene (P/E) boundary interval are preserved in the Patala Formation (Upper Indus Basin) and Dungan Formation (Lower Indus Basin), Pakistan. The P/E interval of the Patala Formation is composed of limestone and shale inter-beds indicating deposition on a carbonate platform. The analysis of larger foraminifera across the P/E interval from the Patala Formation (Kala Chitta Ranges), allows the recognition of the Larger Foraminiferal Turnover (LFT). The Larger Foraminiferal Turnover (LFT) observed in the Patala Formation is associated with the Paleocene Eocene Thermal Maximum (PETM) global event and allows the recognition of the P/E boundary in the shallow water carbonates of the Indus Basin. This turnover is already reported from other Tethyan sections and from the Salt Range (Upper Indus Basin), Pakistan. The recognition of the LFT allows the inter-basinal and intra-basinal correlation of the P/E interval in the shallow-water carbonates of the Indus Basin, Pakistan.

Four dinoflagellate zones in the P/E interval of the Rakhi Nala section (Lower Indus Basin) are identified and correlated. The quantitative analysis of the dinoflagellate cyst assemblages together with geochemical data are used to reconstruct the paleoenivronment across the P/E interval. The dinocyst assemblages in general, and the last occurrence (LO) of *Wetzeliella astra* in particular, can be used to define the P/E boundary. The dinocyst assemblages allow the local correlation of the Dungan Formation (part) of the Sulaiman Range with the Patala Formation (part) of the Upper Indus Basin and global correlation of the Zone Pak-DV with the *Apectodinium* acme Zone of the Northern and Southern hemispheres.

The onset of the carbon isotopic excursion (CIE) associated with PETM is used globally to identify the P/E boundary. The CIE for the total organic carbon (fine fraction) $\delta^{13}C_{FF}$ is of a magnitude of -1.7‰ and its onset is synchronous with the LO of *W. astra*. In the Indus Basin the *Apectodinium* acme precedes and straddles the onset of the CIE. This *Apectodinium* acme is also accompanied by a planktic and benthic foraminifera 'barren zone'. The CIE in the Indus Basin, coupled with the changes in the dinocyst distribution and the benthic and planktic foraminifera assemblages, provide evidence of the changes associated with the PETM in this little-known part of the world.

The Paleocene/Eocene Boundary in Egypt: Litho- and Biostratigraphic Studies

Obaidalla N.A.

→ obaidala@yahoo.co.uk

Geology Department, Faculty of Science, Assiut University, Assiut, Egypt

The Paleocene/Eocene (P/E) boundary sections are well represented all over the geographic provenances of Egypt and marked by the occurrence of distinctive litholostratigraphic unit known by Dababiya Quarry Member. The present work deals mainly with the litho- and biostratigrphy of the Dababiya Quarry Member at five sedimentary sections in the Nile Valley, Western Desert, north Eastern Desert and Sinai. These sections are distributed from south to north as follow: Dababiya (GSSP), Qreiya, Um El-Ghanayium, Wadi Maheer and Wadi Nukhul sections. Lithostratigraphically, the Dababiya Quarry Member consists of five beds in stratigraphic order: organic rich-clay layer (bed 1), fish debris rich-shale (bed 2), coprolite rich-shale bed (bed 3), calcareous shale (bed 4) and calcarenitic limestone (bed 5). The thicknesses of these beds are variable and change from place to other may be due to the change in the rate of sedimentation. Biostratigraphically, according to the global planktic foraminiferal events the Paleocene/Eocene boundary is complete at all the studied sections, whereas, the latest Paleocene *Morozovella velascoensis* (P5) Zone and the Earliest Eocene *Acarinina sibaiyaensis* (E1) and *Pseudohastigerina wilcoxensis/M. velascoensis* (E2) zones are recorded. The P/E boundary lies at the base of the Dababiya Quarry Member (at the base of organic rich-clay layer, bed 1) which correlated with *Morozovella velascoensis* (P5) *Acarinina sibaiyaensis* (E1) zonal boundary. The organic-rich clay layer represents an Oceanic Anoxic Event (OAE) and closely coincides with the Benthic Foraminiferal Extinction Event (BFEE). This layer marked by the extinction of both palnktic and benthic foraminifera except for the occurrence of simple and rare agglutinated foraminiferal taxa of low diversity and abundance. The planktic foraminiferal species re-appear immediately within the fish debris rich-shale (bed 2). The Planktic Foraminiferal Excursion Taxa (PFET) such as *Acarinina africana, A. sibaiyaensis* and *Morozovella allisonensis*) appear for the first time within this bed. On the other hand, benthic foraminiferal species extinct severely within all the Dababiya Quarry Member.

Palynological response to early Paleogene warming: A case study from Indian subcontinent

Prasad V.[1], Garg R.[2]

→ prasad.van@gmail.com

1 Birbal Sahni Institute of Palaeobotany, Lucknow, India

2 Department of Geology, Lucknow University, India

Late Paleocene-early Eocene warm climate has been the focus of study for past several decades leading to generation of vast amount of data from mid-high latitudinal regions across the globe. However, data from low equatorial latitudes is limited. The Indian subcontinent was located within the equatorial zone at the time of Paleocene-Eocene transition during its northward journey and eventually collided with Eurasia in the early Palaeogene. The early Paleogene warming resulted in the appearance and spread of tropical flora and fauna over the Indian subcontinent. Early palaeogene warming accounts for two prominent events represented by Paleocene Eocene Thermal Maxima (PETM) 55.5 Ma, and Eocene Thermal Maxima (ETM2) 53.7 Ma. Both are well documented with prominent carbon isotopic excursion peaks calibrated with biotic records in the early Paleogene sedimentary successions of western and north-eastern region of the Indian subcontinent. In order to assess the vegetational response to Paleogene warming, palynological records across PETM and ETM2 have been evaluated from two sedimentary successions: Jathang, Khasi Hills, in the northeastern region (PETM), and Vastan lignite mines from western India (ETM2). We have observed a rapid and distinct increase in diversity pattern of palynoflora, post-PETM interval. The study shows highly diverse tropical angiospermic rain forest elements during early Eocene were introduced to the stock of pre-existing Paleocene flora. We infer that rapid increase in warm and humid climate at the onset of PETM led to a sudden bloom of tropical rain forest community that expanded in a highly diverse rain forest community due to prolonged early Eocene warming. We have attempted to trace the affinity of these fossil palynomorphs with extant palynomorphs. The study shows morphological similarity of palynomorphs of most tropical extant endemic vegetation of Western Ghat region with few fossil palynomorphs, suggesting that highly diverse tropical rain forest community once widespread across the Indian subcontinent is now restricted to a small area of Western Ghats as refugia. High precipitation and low seasonality due to lesser dry periods during early Paleogene seems to be the key factor in widespread distribution of the diverse tropical rain forest community in the equatorial Indian subcontinent.

A new Palaeocene Eocene Thermal Maximum record from India: Implications to carbon cycling and tropical hydrology in a past super-greenhouse globe

GB 2012 Contestant for Best Poster Presentation

Samanta A.[1], Sarkar A.[1], Bera M.K.[1], Jyotsana Rai[2], Prasad V.[2], Rathore S.S.[3]

→ arpitas25@gmail.com

1 Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur, 721 302, India

2 Birbal Sahni Institute of Palaeobotany, Lucknow 226007

3 KDM Institute of Petroleum Exploration, Dehradun 248195

Series of transient warming (hyperthermal) events viz. PETM (Paleocene-Eocene thermal maximum), H1, ETM2/ELMO, H2, I1, and I2 and associated negative carbon isotope excursions (CIEs) between Late Paleocene and Early Eocene (~56 to 51 Ma) have conventionally been explained by the massive release of ^{13}C depleted carbon from marine hydrate reservoir to the exogenic carbon cycle. Recent evidences, however, suggest alternative sources (e.g. terrestrial peat or wet lands) of light carbon input into the ocean-atmosphere system. Apart from the source, model simulation results of this super-greenhouse climate have consistently failed to reproduce the warm continental interior temperatures. Whether or not continents were equally warm (like ocean) could not be model-tested due to the paucity of terrestrial records across the globe particularly in the tropics between 30°N and 30°S (Huber and Caballero, 2011). For example, almost no records of either the PETM or definitive early Eocene hyperthermals (EEH) are yet available from terrestrial realm in the tropics except from Colombia and Venezuela (Jaramillo *et al.*, 2010). Response of the tropical biosphere to these warming events is also unknown. Further, the relationship between the PETM and other contemporary global events namely, collision of island India with Eurasia and appearance of modern mammals are not clearly understood. A tropical terrestrial record of these hyperthermal/CIE events encompassing the earliest modern order mammal bearing horizon from India, can, therefore, be vital in understanding climatic and biotic evolution during the earliest Cenozoic time. Here we report high resolution carbon isotope ($\delta^{13}C$) stratigraphy, calcareous nannofossils, and pollen assemblages from the Cambay shale formation of Western India, which show complete preservation of all the above CIE events including the PETM, hitherto unknown from terrestrial record. The data suggest persistence/proliferation of tropical rain forest plant communities across the PETM in a possible intensified rainfall regime consistent with General Circulation Model (GCM) prediction. Our data suggest that the post-PETM CIEs are indeed global in nature. Magnitude of these tropical CIEs indicate that apart from gas hydrate terrestrial carbon reservoir (peat and wet-lands) may have also played important role in modulating the exogenic carbon cycle. $\delta^{13}C$ chemostratigraphy further suggests that the present early Eocene mammal bearing horizon, recently discovered at Vastan, is younger than the PETM.

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The Paleocene/Eocene Thermal Maximum (PETM) Interval at Gabal Nukhl Section, Sinai (Egypt): Lithostratigraphy, Mineralogy and Geochemistry

Soliman M.F.

→ msoliman20032003@yahoo.com

Geology Department, Faculty of Science, Assiut University, Assiut- Egypt

In a detailed investigation of the sedimentology, mineralogy and geochemistry of the stratigraphic interval spanning the Paleocene/Eocene (P/E) boundary in the Gabal Nukhl section, the author attempts to reconstruct environmental changes across the boundary especially for the interval representing the Paleocene-Eocene Thermal Maximum (PETM). As in the Gabal Dababiya section (the GSSP section of the P/E), the PETM interval (Dababiya Quarry Member) consists of three distinct units of phosphatic shales followed by two calcareous phases. The basal unit is a laminated clay layer, whose base represents the base of the Eocene. It is enriched in pyrite grains, silica and aluminum and is slightly phosphatic (bone-bearing). The middle unit is $CaCO_3$-rich and bone-bearing, with a higher proportion of phosphatic components than the basal clay layer. The upper phosphatic unit is coprolite-rich. The PETM interval at Gabal Nukhl is characterized by high anomalies in chalcophiles (Zn, Co, Ni, Pb and Cd) and organic association elements (Mo, V and Cr)especially in the basal clay layer and the bone-bearing bed. It is concluded that these trace elements are incorporated into the phosphatic components (fish debris and coprolites) and organic matter. The three phosphatic shale units reflect anoxic marine environment and deposition in H_2S-containing bottom waters rich in organic matter. The association of S, and P_2O_5 enrichment with an abundant of organic matter pyrite and enrichment in chalcophile elements within the first three beds of Dababiya Quarry Member, indicates high biologicalproductivity throughout their deposition. The increase in biological productivity may be related either to the development of upwelling conditions, or, more likely, to an increase in the flux of nutrients to marginal marine settings because of an enhanced hydrological cycle. The high Ti/Al ratios in the basal DQM may indeed reflect invigorated hydrodynamic conditions on the seafloor as a result of increased river discharge.

Variable benthic foraminiferal ecosystem responses to the PETM in shelf environments

Stassen P.[1], Thomas E.[2,3], Steurbaut E.[1,4], Speijer R.P.[1]

→ Peter.Stassen@ees.kuleuven.be

1 KU Leuven, Department of Earth and Environmental Sciences, Belgium

2 Yale University, Department of Geology and Geophysics, Connecticut, USA

3 Wesleyan University, Department of Earth and Environmental Science, Connecticut, USA

4 Royal Belgian Institute of Natural Sciences, Department of Paleontology, Belgium

The Paleocene-Eocene thermal maximum (PETM) is characterized by a worldwide 5-8 °C warming of Earth's surface as well as the deep oceans, major global faunal and floral turnovers and large changes in ocean chemistry. In order to establish clear biogeographic patterns of how shallow benthic foraminiferal communities responded to these climate changes, we compare shallow marine ecosystems in three separated regions and provide a synthesis of the short-term biotic responses. These regions are located in Tunisia (Northern and Gafsa Basin), Egypt (Nile Basin) and the North Atlantic Coastal Plain (Salisbury Embayment, United States).

In Egypt, widespread anoxia during PETM peak warming led to the collapse of Paleocene deep shelf communities and a basin-wide downslope migration of pioneering shallow water taxa (*A. aegyptiacus*) during the initial recovery phase. In the shallower Tunisian settings, the PETM is marked by dysoxia, increased water depth and an elevated sedimentation rate. This resulted in the migration of deeper-dwelling species (lagenid and buliminid fauna) at the onset of the PETM, replacing the former shallow water community. At the onset of the PETM in the North Atlantic Coastal Plain, deposition occurred in a basin-wide mud belt, inhabited by opportunistic deep shelf taxa. Increased eutrophication, high sedimentation rates and widespread hypoxia are linked to the establishment of a river-dominated shelf during the PETM. As a result, in shallow and deep shelf settings, diverse Paleocene assemblages were replaced by characteristic river-outflow assemblages (*P. prima*, *A. acutus*, *T. selmensis*), either by upslope migration or increased abundances of these background taxa.

Due to the magnitude and tempo of global warming, the PETM exerted worldwide environmental stress on benthic foraminiferal communities, triggering prominent transient changes in population structure and biodiversity, yet the evolutionary impact was minor compared to the deep-sea extinction event. This implies the existence of refugia on the shelves. In general, stable latest Paleocene benthic foraminiferal assemblages were abruptly replaced by more stress-tolerant faunas, reflecting stressed dysoxic to anoxic eutrophic environments, due to higher nutrient delivery (increased runoff and upwelling) and stratification. These hypoxic conditions occurred in the early stages of the PETM continually or with high frequencies and evolved towards periodic (seasonal?) oxygen depletion during the latter stages of peak warming or initial recovery. The final recovery phase reflects a reoxygenation of the sea floor and a distinctive buliminid bloom (*B. callahani*) occurred at both sides of the Atlantic Ocean. These eutrophic conditions remained stable and continued in the aftermath of the PETM, yet the oxygenation of bottom waters became restored. The PETM sequences thus document a progression of environmental regimes that is somewhat similar in all studied settings, indicating a widespread mutual response to the massive injection of carbon dioxide at the onset of the PETM.

Carbon organic isotope analysis: methodology and application in stratigraphy

Storme J.-Y.[1], Magioncalda R.[2], Rochez G.[1], Yans J.[1]

→ jean-yves.storme@fundp.ac.be

1 FUNDP, University of Namur, Department of Geology, Belgium

2 UMons, Faculty of Engineering, rue de Houdain 9, B-7000 Mons, Belgium

Most of the chemostratigraphic studies about $\delta^{13}C$ deal with carbon of carbonates. Shells of the foraminifers or bulk rocks are the most common carbonated supports in marine setting; as pedogenic soil-nodules are for continental setting. The measurement of stable carbon isotope offers a larger range of applications in any kind of environment and constitutes a complementary tool for correlation, especially at the Paleocene/Eocene boundary (P/EB). However, in some section, carbonate rocks lack or diagenetic effects overprinted the rocks and the samples are not suitable for carbonate $\delta^{13}C$ analysis. The Dababiya section (Egypt), international GSSP of P/EB, the Zumaia (Spain) reference section for P/EB and the Sidi Nasseur section (Tunisia) are eloquent examples. Here we show the limits of $\delta^{13}C_{carb}$ methodology when the analysed supports have a low or zero content in $CaCO_3$ (%). In this case, the $\delta^{13}C_{carb}$ isotopic curves usually do not provide a strong negative isotopic anomaly easily identified. On the contrary, the curves issued from the same levels, but based on $\delta^{13}C_{org}$, show a stable and progressive decrease of isotopic values followed by a recovery to normal values. The isotopic analyses of the carbon from organic matter (OM) precisely reproduce the CIE in a much more obvious and distinct way than the curve from $\delta^{13}C_{carb}$. In this type of section (e.g. Dababiya (GSSP), Zumaia and Sidi Nasseur) $\delta^{13}C$ analyses must be performed on carbon from OM. However, methodologies used in different laboratories are various, and may influenced results of numerous studies, in the last decade. To obtain reliable measurement results, an accurate and reproducible methodology for the extraction of C_{org} has been developed and would be considered as a reference.

The Palaeocene/Eocene boundary section at Zumaia (Basque-Cantabric Basin) revisited: new insights from high-resolution magnetic susceptibility and carbon isotope chemostratigraphy on organic matter ($\delta^{13}C_{org}$)

Storme J.-Y.[1], Devleeschouwer X.[2], Schnyder J.[3], Cambier G.[2], Baceta J.I.[4], Pujalte V.[4], Di Matteo A.[5], Iacumin P.[5], Yans J.[1]

→ jean-yves.storme@fundp.ac.be

1 FUNDP, University of Namur, Department of Geology, Belgium

2 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

3 Univesity Paris 06, UPMC-CNRS, France

4 Universidad del País Vasco, Departamento de Estratigrafía y Palaeontología, Spain

5 Parma University, Earth Sciences, Italy

The Palaeocene–Eocene Thermal Maximum (PETM at 55.8 Ma) was a short-lived episode of extreme global temperatures, often regarded as a past analogue of the ongoing global warming. The PETM is defined chemostratigraphically by a carbon isotope excursion (CIE) recognized globally in both marine and terrestrial sections. The onset of this ca. 150-200 ka event marks the Palaeocene ⁄Eocene (P⁄E) boundary. Zumaia is the most complete and representative section of the early Palaeogene (hemi)-pelagic succession of the Pyrenees, recognised as a key reference section for the Cretaceous-Palaeogene and Palaeocene–Eocene boundaries, and recently ratified as the Global Stratotype Boundary Sections and Points (GSSP) for the bases of the Selandian and Thanetian Stages. Concerning the P-E Boundary, Schmitz *et al.* (1997) provided the unique $\delta^{13}C_{carb}$ curve based on bulk carbonate samples. However, conclusions of this pioneering isotopic study were partially problematic due to dissolution processes just above the P/E, leading to chemostratigraphic uncertainties of several key levels of the section. Here, we refine the position of the P/E in the Zumaia section by using carbon isotope chemostratigraphy on organic matter ($\delta^{13}C_{org}$), to avoid effects of carbonate dissolution. New high-resolution $\delta^{13}C_{org}$ of the Zumaia section (-23.8 to -28.8‰) confirms the position of the Carbon Isotope Excursion and enhances the distinction between the different steps of the CIE/PETM event. Moreover, based on a detailed study of palynofacies and high-resolution magnetic susceptibility profile in which several cycles of susceptibility variations can be identified, we discuss the duration of the CIE and speculate about the palaeoenvironmental and sea-level changes that took place across the P/E boundary. According to new magnetic susceptibility data and detailed cycle counting, the entire duration of the CIE/PETM in Zumaia is estimated in ~168 ± 16 ka. Moreover, the investigation of palynofacies and low-field magnetic susceptibility reveal significant detrital influx during the interval. Several magnetic susceptibility phases and trends are recognised and are interpreted in terms of sea-level fluctuations before, during and after the PETM. Coupled with results from other sections, our data reveal the presence of an unconformity followed by an eustatic sea-level rise (TST) in the latest Palaeocene.

Fish otolith stable isotope paleothermometry in the early Paleogene: limitations and future directions

Vanhove D.[1,2], Speijer R.[1], Steurbaut E.[2]

→ daan.vanhove@ees.kuleuven.be

1 Department of Earth and Environmental Sciences, Celestijnenlaan 200E, Box 2410, B-3001 Heverlee, Belgium

2 Department of Paleontology, Royal Belgian Institute of Natural Sciences, Vautierstraat 29, B-1000 Brussels, Belgium

The climate of the early Paleogene is characterized by short-scale temperature variations which are superimposed on a general trend of rising temperatures culminating during the late early Eocene (early Eocene climatic optimum, EECO). These include several transient periods of abrupt climate warming or 'hyperthermals', such as the PETM (~55 Ma). Profound proxy development is needed to successfully extract shorter-scale variability from suitable records and unravel its underlying mechanisms. This study assesses and extends the use of fossil fish otolith O and C stable isotopes as a paleotemperature and seasonality proxy for early Paleogene marginal marine sedimentary environments. Well-known limitations include the lack of accurate estimates for the oxygen isotope composition of ambient water, and potential bias when applying paleotemperature equations. Moreover, taxon inconsistencies for both O and C were observed, complicating data interpretation (Vanhove *et al.*, 2011).

A single locality test case in the southern North Sea Basin has been performed to address this observation (Egem, Belgium, coastal sands). In each of four fossiliferous levels sampled, the same three demersal otolith species were analyzed (*Platycephalus janeti*, *Paraconger papointi* and "genus Neobythitinorum" *subregularis*). Cross-plots of $\delta^{18}O$ and $\delta^{13}C$ isotopes show three statistically different data clouds, corresponding to the three taxa. Several processes can cause such discrepancies. The most likely option is the influence of freshwater influx. According to this interpretation, *Paraconger sp.* and *Platycephalus janeti* lived in coastal areas prone to freshwater influx, while *"genus Neobythitinorum" subregularis* inhabited more distal realms. This is confirmed by similar analyses on *Callista* sp. and *Venericardia* sp. bivalves of the same locality, because these were deposited relatively in situ compared with otoliths, which predominantly arrive in the sediment after post-mortem predation-related transport. Taxon-sensitive differential diagenesis is disproved by SEM, cold cathodoluminescence and X-ray diffraction investigations, revealing the presence of pristine aragonite in all cases. Bias resulting from variability in the amount of summer or winter carbonate deposition is contradicted by visual inspection of growth ring thicknesses, and cyclical incremental stable isotope patterns of individual growth bands.

Taxon inconsistencies were not described previously by authors working on the same taxa and in the same area, hence the paleoecological interpretation of this data could indicate enhanced runoff and freshwater influx during the EECO relative to later time intervals, or the presence of a large river mound close the investigated location. Temperature calculations based on *"genus Neobythitinorum" subregularis* reveal mean annual temperatures around 27.5 °C and a seasonality of 9 °C for the EECO interval. Given the mentioned assumptions, future directions should include other quantitative, preferably salinity-independent paleotemperature proxies to test these data interpretations.

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The onset of the negative Carbon Isotope Excursion on dispersed organic matter as criterion for the Paleocene-Eocene boundary: uses, biases and limits

Yans J.[1], Storme J.-Y.[1], Iacumin P.[2], Dupuis C.[3], Gingerich P.D.[4], Smith T.[5], Magioncalda R.[6], Quesnel F.[7], Steurbaut E.[5]

→ Johan.yans@fundp.ac.be

1 FUNDP, University of Namur, Department of Geology, rue de Bruxelles, 61, B-5000 Namur, Belgium

2 Department of Earth Sciences, University of Parma, Via Usberti 157/A, I-43100 Parma, Italy

3 UMons, Faculty of Engineering, rue de Houdain 9, B-7000 Mons, Belgium

4 Museum of Paleontology, University of Michigan, 1514 Ruthven Museums Building, 1109 Geddes Ave., Ann Arbor, MI 48109-1079, Michigan

5 Department of Paleontology, Royal Belgian Institute of Natural Sciences, rue Vautier, 29, B-1000 Bruxelles, Belgium

6 Geonumeric, 145, rue Michel Carré, ZI Les Algorithmes - Bât. Platon, BP 73, F-95100 Argenteuil, France

7 BRGM (French Geological Survey), GEO/G2R, BP 36009, F-45060 Orléans Cedex 2, France

The primary criterion ratified by the International Subcommission on Paleogene Stratigraphy (ISPS) to define the Paleocene-Eocene (P/E) boundary, and the beginning of the Paleocene-Eocene Thermal Maximum (PETM), is the onset of a prominent negative Carbon Isotope Excursion (CIE; Aubry *et al*., 2007), located in the lower to middle part of Chron C24r, in calcareous nannofossil Zone NP9 and at the base of planktonic foraminiferal Zone E1 of Berggren & Pearson, 2005 (see also Wade *et al.,* 2011), also termed Zone P5 in Aubry *et al*. (2007). Based on cyclostratigraphy, the CIE is estimated to have spanned 150 ± 20 kyr and would reflect a major perturbation of the global carbon cycle. Organic matter (OM) may be judged as a (very) reliable material for isotopic chemostratigraphy, in both marine and terrestrial settings. Here we show several examples of successions (Belgium, Egypt, France, Spain, Tunisia, USA-Wyoming) where:

1. isotopic analyses on OM are necessary to define the P-E boundary (lack of carbonates and/or diagenetic alteration of the isotopic signal on carbonates, including calcitic shells, bulk rocks and pedogenic nodules),
2. organics are probably not the best material to precise the P-E boundary,
3. geological processes, such as hiatuses, and potential reworking of OM in channels and turbidites, may perturb the reliability of the carbon isotope results (on both organics and carbonates).

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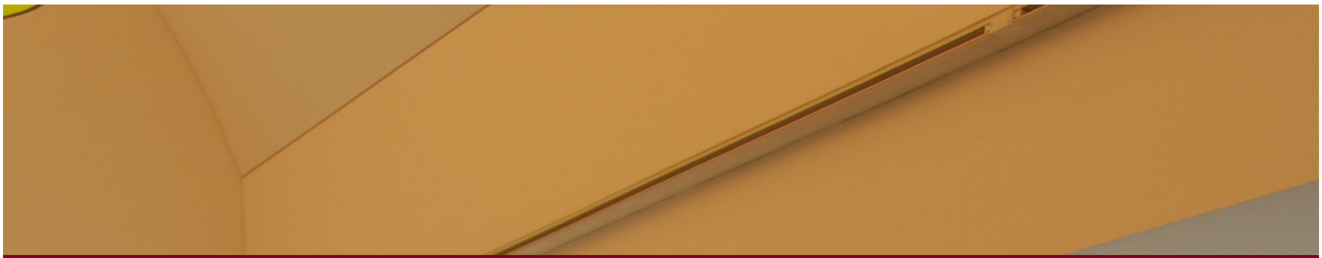

Session 06

Event-scale and permanent flooding of coasts, floodplains and continental shelves

Chairmen: Vera Van Lancker & Sytze van Heteren

Sedimentology and age of superimposed storm-surge units at Keremma barrier spit, Brittany, France

Bakker M., Van Heteren S.

→ marcel.bakker@tno.nl

Geological Survey of the Netherlands

Despite its protection from high-energy open-ocean waves, the bay side of Keremma barrier spit (Figure 1a) in northern Brittany, France, is gradually being eroded. A continuously migrating tidal channel undercuts the steep bluff that characterizes the landward side of the spit (Figure 1b). The bluff averages more than 5 m in height and reaches to 10-12 m above nivellement général de la France (NGF, about mean sea level). Backside erosion, which has taken place for decades or longer as the tidal channel has changed its course, has exposed a series of storm-surge units that were first described by Maurits Lindström in 1979. He concluded that alternating beds of coarse and fine to medium sand well above spring tide were deposited by storm surges. Deformation structures are common in these beds (Figure 1c). They have amplitudes of 2–25 cm. In October 2008, the site was revisited for OSL sampling and for surveying by ground-penetrating radar (GPR) to constrain and establish the age and lateral extent of the storm-surge units. GPR data were collected along several shore-parallel and shore-perpendicular transects (Figure 1d). The resulting GPR profiles suggest that the storm-surge units extend under large parts of the spit. OSL samples were collected at two vertical exposures, created by removal of slumped material from the naturally formed scarp on the backside of the spit. Five OSL analyses suggest that the storm-surge units were formed during the 17th and 18th century. Given the magnitude of recent storm surges, it is likely that some storm surges during the Little Ice Age were high enough to flood major parts of the spit, creating strong currents and saturating the top layer the unsaturated sand that usually marks the surface of the barrier. This difference in saturation would have caused pressure gradients that in turn resulted in soft-sediment deformation. The superposition of multiple horizons of convolute bedding at the exposure sites does not indicate that the higher, younger beds are associated with higher peak water levels. More likely, they reflect gradual landward migration of the backside of the barrier spit, in a depositional mechanism similar to that of a washover complex expanding in a landward direction during subsequent surge events. The number of convolute beds suggests that major flooding was very frequent at the time. It highlights the present vulnerability of this barrier and its sedimentary record of past storm surges, which is relentlessly erased by erosion from all sides.

a. Keremma barrier spit, viewed from the east;
b. backside erosion of the spit by a tidal channel;
c. GPR profiling on a shore-parallel trail;
d. 60-cm vertical section of barrier sand in one of the exposures.

Holocene Rhine delta evolution: resolving larger flooding events amidst gradual trends.

Cohen K.M.[1,2], Toonen W.H.J.[1,2], Hijma M.P.[1,3], Kleinhans M.G. [1], Minderhoud P.S.J.[1], Hoek W.Z. [1], Stouthamer E.[1], Middelkoop H.[1], Prins M.A.[4], Erkens G.[2]

→ k.m.cohen@uu.nl

1 Utrecht University, Dept. of Physical Geography, Utrecht, Netherlands

2 Deltares, Unit BGS, Dept. Applied Geology and Geophysics, Utrecht, Netherlands

3 Tulane University, New Orleans, U.S.A.

4 Vrije Universiteit Amsterdam, Fac. Earth and Life Sciences, Amsterdam, Netherlands

Flooding, overbank deposition and channel network change in the lower Rhine has traditionally been studied from multiple perspectives. Mapping flood deposits has typically traced overbanks from proximal to distal settings, distinguishing packages formed over longer periods of flood sedimentation rather than resolving individual events. Their distribution resembles successive avulsions that successively changed the network. In understanding delta evolution and in morphodynamic behaviour of deltaic rivers, a major challenge was to be able to reconstruct and numerically simulate channel initiation and abandonment, through stages of bifurcation functioning. Whether avulsion principally relates to major flood events or whether it should be understood as a process requiring the passage of multiple flood peaks to succeed or fail is a critical question, that was difficult to attack with traditionally collected data.

Our current research is on resolving marked Holocene flooding events. We have updated our sea level history (Hijma & Cohen, 2010) and the dating of channel belts and the associated avulsion history (Stouthamer *et al.*, 2011), in interaction with the Netherlands' professional archaeological user community. We have quantified the sediment budget received by the delta over the Holocene (Erkens, 2009) and progressive changes in grain size therein (Erkens *et al.*, 2012). In interaction, we are numerically modelling and sedimentologically reconstructing the evolution of sediment and water division of bifurcations for Late Holocene cases (Kleinhans *et al.*, 2011; Toonen *et al.*, 2012). We are making an inventory of the large floods as recorded in sedimentary archives such as residual channels (Minderhoud *et al.*, 2011; Toonen *et al.*, 2012) to improve flood frequency-magnitude analysis.

The resolved events are superimposed on gross trends known from earlier studies, and clarifies control interplays in the evolution of the delta, in the transgressive and in the high stand stage. Furthermore, the event-minded approach is benefitting the integration of 'process-based' and 'mapping-based' lines of research in the delta, especially where the pacing of channel abandonment and the maturing of new channels is considered.

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The historical development of creeks and sedimentation patterns in the low lying areas along the Schelde located North of Antwerp: past and future

Gessese A., Peeters P., Claeys S., De Schutter J.

Flanders Hydraulics Research, Antwerp, Belgium

In the 16th and 17th century, widely spread and important inundations occurred in the low lying areas along the Schelde located north of Antwerp. These inundations were organised during the 80 Years' War for strategic reasons. Following the strategic importance of the inundated land (food production for the city of Antwerp) together with the strategic importance of the inundations itself, breach formation as well as the development of creeks was well documented. Detailed information can be found in historical archives, eg. Felix-archief Antwerpen and at Flanders Hydraulics Research. In addition to cartographical data indicating how flow channels evolved with time, data regarding creek depths and sedimentation within the low lying areas can be found from core penetration tests and drilling reports.

In order to better understand the mechanisms of channel formation and sedimentation in (flood) inundation areas (ie. low lying areas), in perspective of water management today, especially along the Schelde where numerous flood control areas of which some will experience a controlled reduced tide will be installed, an analysis of the available historical data is very important. The available dataset would make it possible to follow the evolutions over an era of 100 years, which is quite unique.

Major issues to cover are:

- Linking historical tide data with breach formations
- Hydraulic aspects of creek formation
- Sedimentation in inundation areas over long time
- Comparing actual with historical sedimentation rates, and linking with sediment loads

With this presentation, interested parties are invited to work on this (historical) data.

Paleo-tsunamis in South-Central Chile: evidence from coastal lakes

Kempf P.[1], Moernaut J.[1,2], Vandoorne W.[1], Van Daele M.[1], Pino M.[3], Urrutia R.[4], De Batist M.[1]

→ philipp.kempf@ugent.be

1 Renard Centre of Marine Geology (RCMG), Department of Geology & Soil Science, Ghent University, Belgium

2 Geologisches Institut, ETH Zürich, Switzerland

3 Instituto de Geociencias, Universidad Austral de Valdivia, Chile

4 Centro EULA, Universidad de Concepción, Chile

Recent megathrust earthquakes such as the Great Sumatra-Andaman Earthquake (M_w: 9.3) 26.12.2004 in Indonesia, also remembered as the Boxing Day Tsunami, the Maule Earthquake (M_w: 8.8) 27.02.2010 in Chile and the Tohoku Earthquake (M_w: 9.0) 11.03.2011 in Japan, have shockingly illustrated how little is still known about megathrust earthquakes and their associated tsunami hazards. After the large number of victims and the vast damages to infrastructure the probabilistic risk evaluation of these hazards needs to be reconsidered. This reconsideration needs to include more detailed studies on recent tsunamis and tsunamis from the historic and pre-historic record in order to avoid redundancy. Coastal lakes have the potential of recording and preserving tsunami inundations within their sediments.

In winter 2011/2012 a field survey was conducted on Lake Cucao and Lake Huelde on Isla de Chiloé. High resolution 2D-seismics data and composite piston- and gravity cores were collected. Based on preliminary results of the analyses of the acoustic data and the sediment the tsunami history is discussed. The background sedimentation of both lakes is gyttja with preserved leaves and twigs, which allows good age control. Decimetre-scale, detrital layers are ascribed to tsunami inundation into the lakes. The tsunami deposits are correlated with the paleoseismologic record of the region. By comparing the pre-historic tsunami deposits to the more recent events conclusions can be drawn about the size of paleo-tsunamis. The inundation behaviour of the tsunami is analysed by interpreting lateral changes of single tsunami layers through the lakes. The record of large megathrust earthquakes on the Chilean coast is thus complemented and (hopefully) extended further back in time. This increases the statistical meaning of tsunami hazard risk analyses.

Sea level change, climate and vegetation change in the Ganges delta, India during the last 20 ka

Sarkar A.[1], Filley T.[2], Bera S.[3]

→ sarkaranindya@hotmail.com

1 Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur, west Bengal 721 302, India

2 Department of Earth and Atmospheric Sciences and the Purdue Climate Change. Research Center, Purdue University, West Lafayette 47907, U.S.A

3 Department of Botany, Calcutta University, Kolkata 700 019

Sedimentology and sequence stratigraphic analysis of subsurface sediments from western part of Ganges-Brahmaputra delta plain shows that during the last glacial maximum (LGM) sea level lowering of >100m produced a regional unconformity (type 1), represented by palaeosols and incised valley. Carbon isotope ($\delta^{13}C$) compositions of bulk organic matter as well as extracted higher plant derived lignin biomarkers, along with the recovery of grass phytoliths provide first direct evidence of existence of extensive grass land (C4) vegetation over the tropical Gangetic plain in this ambient dry glacial climate. At ~9 ka transgression inundated the lowstand surface pushing the coastline and mangrove front ~100 km inland. Simultaneous intensification of monsoon and very high sediment discharge (~4-8 times than modern) caused a rapid aggradation of both floodplain and estuarine valley fill deposits between 8 and 7 ka. The Hoogli River remaining along its present drainage acted as the main conduit for transgression and sediment discharge that was subsequently abandoned. C3 vegetation dominated the delta plain during this time. The earliest Holocene is also marked by pronounced ^{13}C depletion in the lignin phenols coinciding with rapid sea level rise, intensified monsoon and replacement of grassland vegetation by mangroves. From 7 ka onward progradation of delta plain started and continued till recent. This period experienced a mixed C3-C4 vegetation with localized mangroves in the mid-Holocene to dominant return of C4 vegetation in the late Holocene period. Both the LGM and late Holocene C4 phases coincide with the well known monsoon minima. The study indicates that while the initiation of western part of GB delta occurred at least 1 ka earlier than the global mean delta formation age, the progradation started at ~7 ka, at least 2 ka earlier than thought before. The study suggests that change in pCO_2 might not be the singular driver of vegetation change as proposed recently and the climate models must take the monsoon like mega-climate processes into account for reconstructing the glacial biomes.

Late Holocene vegetational and coastal environmental changes from Pichavaram record in south east coast of India

Srivastava J.[1], Farooqui A.[1], Hussain S.M.[2]

→ caprice2628@yahoo.com (Srivastava J.)

1 Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow -226007, U.P. (India)

2 University of Madras, A.C. College Campus, Chennai-600025, Tamil Nadu (India)

New data on climate and ecologically induced changes in coastal vegetation is presented here in chronological order from Pichavaram Estuary, SE coast of India. Late Holocene vegetation and climate have been reconstructed by means of sediment and pollen analysis in a 250 cm deep core from the central part of Pichavaram (11°25.838'N, 79°47.206'S) estuary. Textural analysis shows the overall predominance of fine clay with intermittent phases of sand. The palynological climatic period inferred in Zone I (3700-2112 ^{14}C yrs BP) shows a warming trend with moderate monsoon condition, conducive for mangrove vegetation along with a hinterland moist deciduous/evergreen forest, indicating a stabilized estuarine ecosystem. Zone II (2112-1327 ^{14}C yrs BP) shows abundance of salt tolerant mangroves along with a mixed forest suggesting climatic amelioration from warm and humid to dry and arid. Zone III (1327-650 ^{14}C yrs BP) shows marked coastal environmental changes characterized by rejuvenation of mangroves along with a greater diversity of moist deciduous taxa indicating a warm and wet climate. Zone IV (650-100 ^{14}C yrs BP) is characterized by a decline in mangroves as well as the moist deciduous taxa and a high percentage of *Suaeda sp.* thereby indicating a dry and arid period. Zone V (since ~100 ^{14}C yrs BP) with evidences of reemergence of true mangroves and high percentage of salt tolerant species along with the dry deciduous palynotaxa suggests a relatively warm/wet condition but with an increase in salinity induced by weakened monsoon and enhanced anthropogenic activity. It is inferred that during the past 3 millennium climate ameliorated from warm/wet to dry/arid with an evolution of vegetation from moist to dry deciduous forest. The quantitative and qualitative study shows a decline in mangrove diversity since the last millennium which is interpreted as a response to autocyclic sedimentary discontinuity (channel displacement) enhanced by anthropogenic factors, rather than episode of sea level fall.

Multi-proxy analysis of annually laminated sediments from three neighboring lakes in South-Central Chile: a continuous record of regional volcanic activity for the past 600 years

Van Daele M.[1], Moernaut J.[1,2], Silversmit G.[3], Schmidt S.[4], De Clercq M. [1], Heirman K.[1], Vandoorne W.[1], Van Acker J.[5], Wolff C.[6], Pino M.[7], Urrutia R.[8], Roberts S.J.[9], Vincze L.[3], De Batist M.[1]

→ Maarten.VanDaele@UGent.be

1 Renard Centre of Marine Geology (RCMG), Department of Geology and Soil Science, Ghent University, Krijgslaan 281/S8, B-9000 Gent, Belgium.

2 Geological Institute, ETH Zürich, Sonneggstrasse 5, 8092 Zürich, Switzerland.

3 X-ray Microspectroscopy and Imaging Group (XMI), Department of Analytical Chemistry, Ghent University. Krijgslaan 281/S12, B-9000 Gent, Belgium.

4 Environnements et Paléoenvironnements Océaniques (EPOC), CNRS, Université Bordeaux 1, Avenue des facultés, 33405 Talence cedex, France.

5 Department Forest and Water Management, Ghent University, Coupure Links 653, B-9000 Gent, Belgium.

6 Helmholtz Centre Potsdam GeoForschungsZentrum (GFZ—German Research Centre for Geosciences), Section 5.2 ClimateDynamics and Landscape Evolution, Telegrafenberg, D-14473 Potsdam, Germany.

7 Instituto de Geociencias, Universidad Austral de Chile, Casilla 567, Isla Teja, Valdivia, Chile.

8 Centro EULA, Universidad de Concepción, Casilla 160-C, Concepción, Chile.

9 British Antarctic Survey (BAS), High Cross, Madingley Road, Cambridge, CB3 0ET United Kingdom.

Lake sediments contain valuable information about past volcanic and seismic events that affect the lake catchment, and provide unique records of the recurrence rate and magnitude of such events. This study uses a multi-lake and multi-proxy analytical approach to obtain reliable and high-resolution records of past natural catastrophes from c. 600 year old annually-laminated (varved) lake sediment sequences extracted from three lakes, Villarrica, Calafquén and Riñihue, in the volcanically and seismically active Chilean Lake District. Using a combination of µXRF scanning, microfacies analysis, grain-size analysis, color analysis and magnetic susceptibility, we detected and characterized four different types of event deposits (EDs) (lacustrine turbidites; tephra fall-out layers; very-fine-ash laminae; lahar deposits) and constructed a new eruption record for the nearby volcanoes (i.e. Villarrica, Mocho and Carrán-Los Nevados Volcanic Complex) which is unprecedented in its continuity and temporal resolution. Time series analysis shows that there were 112 eruptions with a Volcanic Explosivity Index (VEI)≥2 from Villarrica Volcano in last c. 600 years. The Mocho Volcano has been significantly less active since 1900 A.D. compared to preceding centuries. Only three eruptions from Carrán-Los Nevados Volcanic Complex were identified in lake sediments. The last VEI≥2 eruption of the Villarrica Volcano dates back to 1991 A.D. We estimate the probability of the occurrence of future eruptions from the Villarrica Volcano, and statistically demonstrate that the probability of a 21-year repose period without eruptions is ≤1.8 %. This new perspective on the reoccurrence interval of eruptions and historical lahar activity will help to improve hazard assessments for this rapidly expanding tourist region.

Basin-wide landsliding and complex density-flow successions in Aysén fjord after the 2007 M_w 6.2 earthquake (Chilean Patagonia)

Van Daele M.[1], Cnudde V.[2], Greinert J.[3], Duyck P.[4], Versteeg W.[1], Pino M.[5], Urrutia R.[6], De Batist M.[1]
→ Maarten.VanDaele@UGent.be

1 Renard Centre of Marine Geology (RCMG), Department of Geology and Soil Science, Ghent University, Krijgslaan 281/S8, B-9000 Gent, Belgium
2 Department of Geology and Soil Science - UGCT, Ghent University, Krijgslaan 281/S8, B-9000 Gent, Belgium
3 Royal Netherlands Institute for Sea Research (NIOZ), Landsdiep 4, 1797 SZ't Horntje (Texel), Netherlands
4 Department of Radiology and Medical Imaging, Ghent University Hospital, De Pintelaan 185, B-9000 Gent, Belgium
5 Instituto de Geociencias, Universidad de Austral Chile, Casilla 567, Valdivia, Chile
6 Centro EULA, Universidad de Concepción, Casilla 160-C, Concepción, Chile

Fingerprinting well-documented, historical events in sedimentary basins and detecting similar event deposits in the sedimentary record can help us understand the recurrence of these events. In this study we characterize the sedimentary imprint of the M_w 6.2 Aysén earthquake, which occurred on 21 April 2007. It was the largest earthquake of a seismic swarm that lasted more than 3 months, and its hypocentre was located at a depth of <9 km, underneath the fjord. The earthquake caused several subaerial mass movements (landslides, rockfalls) along the slopes of Aysén fjord, some of which triggered destructive tsunamis.

We conducted a multidisciplinary study of the recent sedimentary infill of Aysén fjord using multibeam bathymetry, high-resolution reflection seismics and a multiproxy analysis on 20 short gravity cores (i.e. CT-scanning (0.5 mm), grain-size analysis (1-5 mm), XRF-scanning (2 mm), magnetic-susceptibility (2.5 mm) and loss-on-ignition at 550°). Bathymetric and seismic data reveal the presence of multiple, superficial, submarine landslides, the largest of which occur where subaerial rockfalls and debris flows entered the fjord. We argue that for tsunami formation the submarine landslides are more important than the subaerial rockfalls. The tsunami-induced seiche also resulted in locally >1 m thick homogenite deposits filling the bathymetric depressions adjacent to the major landslide deposits. Sediment core analysis shows that the distal parts of the landslide deposits range from hyperconcentrated density flows (incl. centimetre sized clasts), through concentrated density flows (incl. traction carpets, parallel- and cross-stratification) to turbidity flows. Moreover, sedimentary structures such as imbricated grains and ripples reveal relative flow direction. Orientating the cores, by directing the lowermost flow direction in the core away from the nearest landslide deposit, allows determining the successive absolute flow directions and source areas of the deposited sediment. Finally, the seismic data reveal three similar, prehistoric events in a sedimentary sequence that we believe represents ~10,000 years. The new insights obtained in this study will help to determine areas prone to landslides and improve hazard assessments for the region.

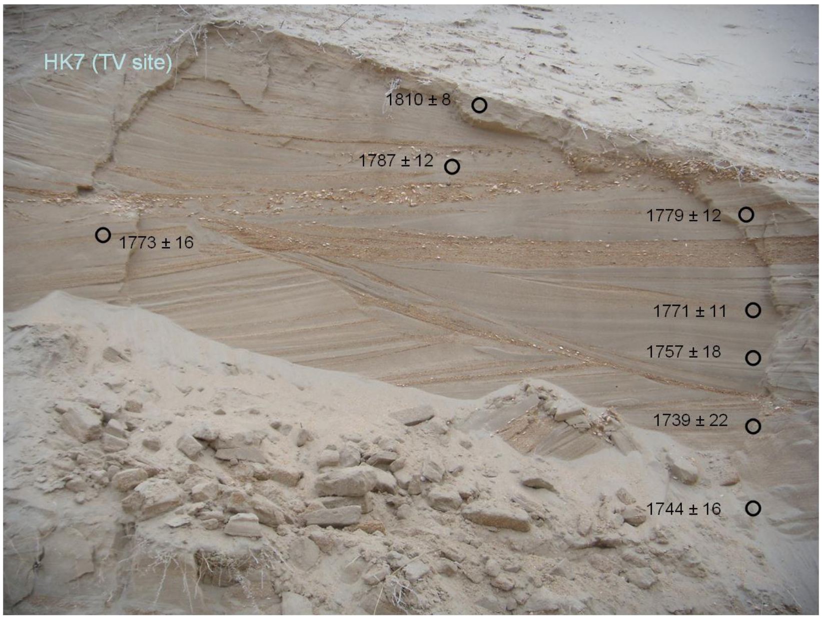
Application of luminescence dating in Netherlands coastal studies

Van Heteren S., Bakker M.

→ Sytze.vanheteren@tno.nl

Geological Survey of the Netherlands

It has been about ten years since coastal sand samples from the Netherlands were first collected for optically stimulated luminescence (OSL) dating. They were the key element in a systematic dating study of Dutch coastal sand on the island of Texel, and marked the starting point of the Netherlands Centre for Luminescence dating (NCL). This first study focused on the calibration of OSL ages, using historical documents on coastline position. To maximize the likelihood of success, all samples were collected from similar positions on the seaside of preserved dune ridges that mark a period of coastal accretion on the southwestern side of the island. By sampling dune sand, key problems of partial bleaching and heterogeneity of the beta dose were minimized. The resulting chronology matched that of the independent age control. During the next five years, all coastal sand samples submitted to the NCL for OSL dating were collected in a geo-archeological context. They provided a chronological framework for the habitation history of coastal regions during the past few thousand years, and increased our understanding of the closure of the former IJ estuary about 2,000 years ago. Systematic OSL dating of coastal sand resumed after a storm surge in November 2007 exposed older storm-surge deposits in the eroded frontal dune at Heemskerk. The deposits consisted of shell beds intercalated with sand, providing methodological challenges of varying degree, related to partial bleaching and to heterogeneity of the dose rate. By tackling these challenges, an NCL research group was able to assign the deposit to the historical storm surges of 1775/1776 (see figure), and simultaneously to open up a new (geological) source of information for understanding long-term storm-surge risk. Building on experiences from Danish Wadden Sea research, a final systematic OSL-dating study is presently being carried out on the Balgzand tidal flat south of Texel. A 60-cm-long core with intertidal sand was sampled at 5-cm intervals. The associated OSL ages show steady accretion of about 1 cm per year, with a possible hiatus between 1980 and 1992. The most likely cause of this hiatus is the major storm of February 1990, which destroyed many of the mussel beds in the Dutch Wadden Sea. Thus far, 'Dutch' OSL-dating studies of coastal sand have focused on calibration aspects, on methodological improvements, and on specific environmental issues related to foredune formation, storm-surge events and tidal-flat accretion. Several challenges remain in coastal research, given that quantification of long-term process-response relationships to predict 21st-century barrier behavior is only possible when accurate volume and flux estimates are complemented by reliable age constraints. Dating of sedimentary sequences and event markers will become increasingly important, and sediment budgets for entire coastal tracts must be improved. For some records still present today, time is running out as coastal erosion is slowly removing valuable geological evidence of past coastal change.



Sedimentology and OSL ages (years AD) of a Heemskerk storm-surge section.

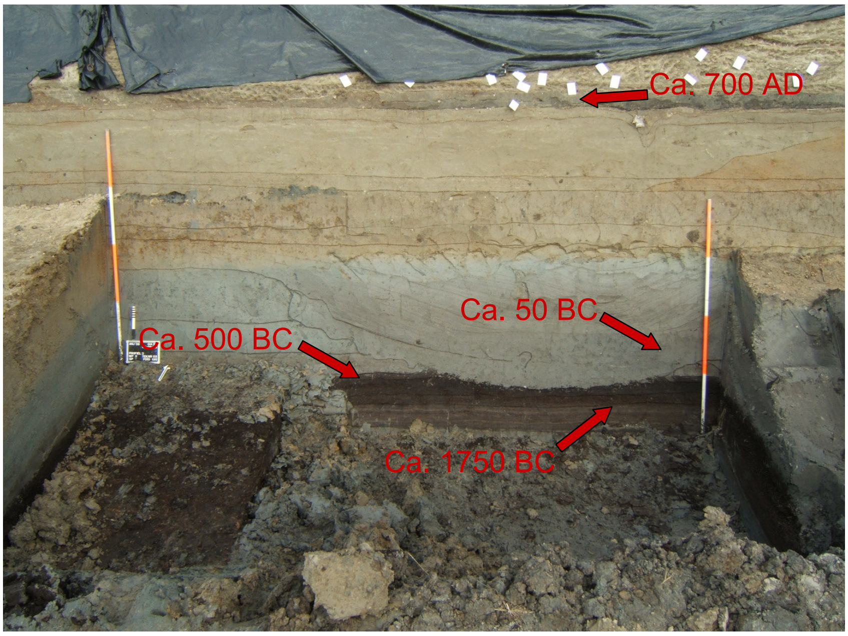
Genesis of the coastal plain of the Northern Netherland, driving mechanisms including the role of Man

Vos P.C.

→ peter.vos@deltares.nl

DELTARES, Dutch Institute for Water and Subsurface Issues, Utrecht, The Netherlands

Man has played an increasing role in the landscape formation of the Holocene coastal area of Northern Netherlands. The impact of human interference on the coastal landscape could be reconstructed because of the extended geological, archaeological and historical research in this coastal region during the last decades. At the beginning of the Holocene the coastal areas moved inland due to the then rapidly rising sea level. During the Mid Holocene this development turned: the rise in the sea level began to decrease and as a result the coastal zone of the northern Netherlands started to silt up and the area of the salt marshes expanded. From the Iron Age the salt marshes were occupied by Man. By constructing dwelling mounds (*terpen*) the settlers created safe havens in the area which was flooded during storm tides. Later, from the late Middle Ages onwards, Man protected himself against marine flooding by the large-scale construction of dikes. Due to the extended embankments of the higher silted up salt marshes of the Northern Netherlands, together with the closing of tidal creeks by dams, the tidal processes in the area have been drastically influenced by these interferences. Storm flood levels increased while the embanked areas were lowered by artificial drainage and by digging off peat and clay. This development created a vulnerability to storm flood catastrophes, which was not present in the period before the embankments.



Example of geological data derived from the key-site Anjum. A Scrobicularia plane shell (from a small salt-marsh creek) and peat could be dated with the radiocarbon method.

In the presentation, the change of the Holocene coastal landscape will be shown in a series of palaeogeographic maps and the natural and anthropogenic processes that caused the coastal changes will be discussed. The excavation pits of the archeological sites supplied valuable geological and palaeo-environmental data for the reconstructions. One example of a ''key-sites or building stone'' in the palaeogeographical reconstruction is shown in the figure: dating of the natural deposits below the antropogene *terp* layers from the early Middle Ages at Anjum, Northeast Friesland (Vos & De Langen, 2010).

Vos P. C., de Langen G.J. (2010). *Geolandschappelijk onderzoek: de vorming van het landschap voor en tijdens de terpbewoning en het ontstaan van de Lauwerszee. In:* Nicolay J. A. W. (red.). *Terpbewoning in oostelijk Friesland. Twee terpopgravingen in het voormalige kweldergebied van Oostergo.* Groningen (Groningen Archaeological Studies), pp 63-94.

The 1421 St.Elisabeth flooding 'event' and the loss of "De Groote Waard", the Netherlands.

Weerts H.J.T.[1], Cohen K.M.[2,3], Kleinhans M.G.[2]

→ h.weerts@cultureelerfgoed.nl

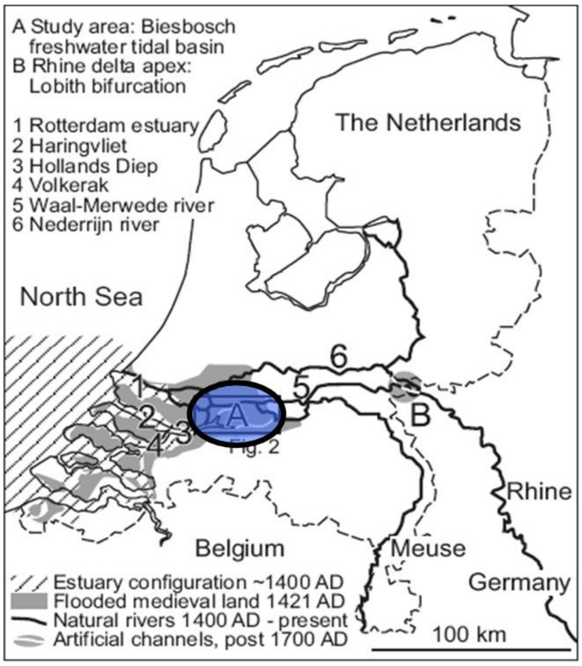
1 Cultural Heritage Agency, Department Landscape, Amersfoort, The Netherlands

2 Utrecht University, Faculty of Geosciences, Department of Physical Geography, Utrecht, The Netherlands

3 Deltares BGS, Department of Applied Geology and Geophysics, Utrecht, The Netherlands

According to legend, a very severe storm in November 1421 caused catastrophic flooding and overnight loss of the larger part of "De Groote Waard", a prosperous polder area in medieval The Netherlands. Allegedly, more than 25 villages were lost and thousands of people were killed. But what had really happened?

De Groote Waard had become a flood-protected polder area after construction of dikes and damming of smaller rivers was completed in 1283. By 1421, the land surface of most of this area had lowered to below Mean Sea Level, owing to subsidence due to ditch-drainage for agriculture and peat digging for fuel. In November 1421 a severe storm surge struck the area, the St.Elisabeth flood proper. Dikes along the southwestern side of the polder broke and subsided land was flooded. In February 1422, dikes along the tidal river Merwede (lowermost river Rhine) along the north of the polder gave way as well, due to flooding and presence of ice jams in the river bed. River discharge routed through the flooded polder had a gradient advantage relative to the old route. Half-hearted attempts to repair the dikes followed, but regional discord severely hampered adequate repair ("Hoeksche en Kabeljauwsche twisten"). In the autumn of 1424, both the dikes in the southwest (storm surge) and in the northeast (Rhine peak discharge) broke again. In 1425, the larger part of the 1421-1424 inundated land was given up. There is evidence for careful dismantling of stone buildings in the now deserted villages.



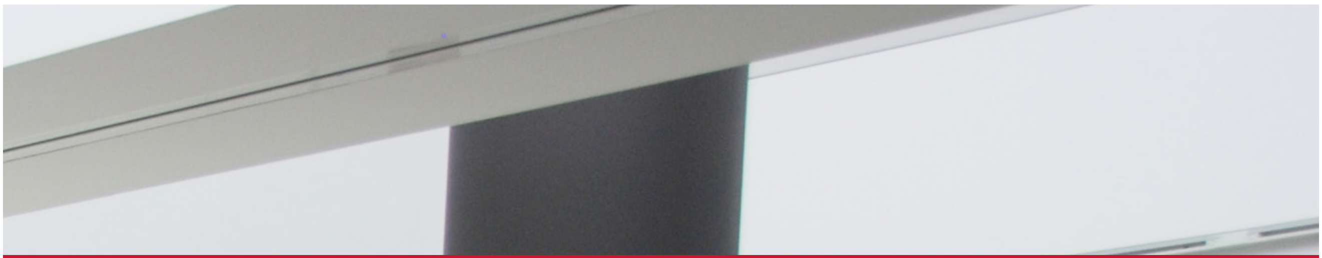
Area affected by the 1421 St.Elisabeth flood and location of "De Groote Waard".

The area ("Biesbosch") was a large, shallow, fresh-water mesotidal basin, with river sediment entering through the dike breach channel in the northeast. Palaeogeographical reconstructions from old maps shows the formation of a river delta between 1460 and 1680 (Zonneveld, 1960). Both geological reconstruction and sedimentary modelling results suggest that for some twohundred years, the equivalent of the full Rhine river bed load sand was trapped in the area (550,000 to 900,000 m^3 / year; Kleinhans *et al.*, 2010). Only centuries later, after natural river sedimentation had healed this man+sea+river created scar in the delta, could the Biesbosch lost medieval polder be partially reclaimed for agriculture once again.

So what had really happened? Not so much the severity of a single storm surge, but the combination of land subsidence and socio-economic forces and several flood events were fatal to the prosperous polder. The 1421 – 1424 floods were catastrophic only because of the preceding sinking of the land. Peat digging had been declared illegal, but there was no control on it. Dike maintenance was inadequate, and initial dike repairs failed, probably because of absence / weakness of a central organising power.

Zonneveld I. (1960). *De Brabantse Biesbosch, a Study of Soil and Vegetation of a Freshwater Tidal Delta.* Vol. A,B,C. PUDOC Centrum voor Landbouwpublicaties, Wageningen, The Netherlands, published PhD-thesis.

Kleinhans M. G., Weerts H. J. T., Cohen K. M. (2010). *Avulsion in action: Reconstruction and modelling sedimentation pace and upstream flood water levels following a medieval tidal-river diversion catastrophe* (Biesbosch, The Netherlands, 1421-1750 AD). Geomorphology, n°118, pp 65-79.



Session 07

Geohazards and environmental changes in an archaeological context

Chairmen: Tine Missiaen, Dorit Sivan & Vanessa Heyvaert
Key-note speaker: Dorit Sivan

Anthropogenic and climate impact on Holocene sediment fluxes in Southeast Spain

Bellin N., Vanacker V.

→ nicolas.bellin@uclouvain.be

Earth and Life Institute. Georges Lemaître Centre for Earth and Climate Research.

Université Catholique de Louvain-la-Neuve. Place Louis Pasteur, 3. 1348 Louvain-la-Neuve (Belgium)

In Europe, Southeast Spain was identified as one of the regions with major treat of desertification in the context of future land use and climate change. During the last years, significant progress has been made to understand spatial patterns of modern erosion rates in these semi-arid degraded environments. Numerous European projects have contributed to the collection of modern erosion data at different spatial scales for Southeast Spain. However, these data are rarely analyzed in the context of long-term changes in vegetation, climate and human occupation. In addition, the climatic and anthropogenic control on Holocene sediment fluxes is not well constrained for the Western Mediterranean basin. Nevertheless, this is crucial to better understand (i) the evolution of long-term soil erosion processes, (ii) and the present-degraded landscape.

In this research, we analyzed the evolution of the Holocene sediment fluxes in the context of regional climatic conditions, land cover and human occupation based on an extended compilation of recently published high-resolution paleoenvironmental proxy data from both terrestrial and marine environments. The palaeoenvironmental reconstruction allowed us to identify ten main aridification (A) episodes during the Holocene. Most of the severe aridification phases were climatically induced, not human-driven and well correlated with a large dataset of paleoenvironmental records from the Western Mediterranean Basin and North Atlantic Ocean. The phases of enhanced aridity are all associated with enhanced sediment fluxes, independent of the intensity and type of human occupation. In contrast, wet climatic conditions are found to be associated with both high and low sediment fluxes dependent on the human impact on the environment. The mid-late Phoenician, Phoenician II/Republican Rome civilizations and the Christian Reconquest are all associated with high human impact on the environment, and high erosion rates are reported for the Vera basin and NE Spain despite the improved hydrological conditions. Human occupation is not necessarily associated with elevated sediment fluxes, as shown by the Post Argaric, Omeya and Nazarene periods that are associated with low erosion rates and sediment fluxes.

Palaeoenvironments and human activities during the Neolithic in Wallonia (SE Belgium) as inferred from Pollen and Non-Pollen Palynomorphs

Court-Picon M.[1], Collet H.[2], Bosquet D.[3]

→ mona.courtpicon@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Department of Palaeontology, Belgium

2 Service de l'Archéologie de la Direction du Hainaut I, Spiennes, Belgium

3 Service de l'Archéologie en Province de Brabant wallon, Wavre, Belgium

It is now widely accepted that human impact has been the most important factor effecting vegetation change, at least in Europe, during the last 6000 years. With the onset of agriculture and stock breeding, at the so-called Neolithic revolution, the human role changed from a passive component to an active element which directly affects nature. This change had dramatic consequences for the natural environment and landscape development. During this important period of transition, arable and pastoral farming, the actual settlements themselves and the consequent changes in the economy significantly altered the natural vegetation and started to create the cultural landscape with its many different and varying aspects. Conversely, human settlements and economic activity throughout the Neolithic are often closely related to natural environments and their changes induced by climatic variability.

In this context, and in order to better understand anthropogenic/natural processes interactions in lowland ecosystems, an integrated research based on a multi-proxies approach has recently been undertaken in Wallonia (SE Belgium) within the framework of a convention between the "Service Public de Wallonie" and the Royal Belgian Institute of Natural Sciences, which aims at investigating the archaeological sites of the area in terms of palaeoenvironmental potentials. As a part of the archaeobotanical studies of this broader research, we present here the results of palynological analyses (pollen, NPPs, micro-charcoal) realised at two Middle Belgian sites: an Early Neolithic village (Belgian LBK) with two occupation phases (Fehxe-le-Haut-Cloché), and a Middle-Late Neolithic flint mines areaof around one hundred hectares exploited for more than 1 800 years (Spiennes).

The purposes of this work are (1) to reconstruct the vegetation around each site and its evolution between the different occupation phases, (2) to elucidate human action on the vegetation history and questions relating to the vegetal economy during the Neolithic, and (3) to try to characterize local settlement dynamics, nature and function of different structure types, and specialized activities such as animal husbandry, cultures, waste management or mining.

Our data represent the first "non-pollen palynomorphs" (NPPs) records in Wallonia and accent will be made here on these new biological indicators. In recent years the demand for more comprehensive past climatic and environmental reconstructions has stimulated the expansion of this new set of complementary microfossils. It is a broad group representing a wide variety of micro-remains of bacteria, protozoa, fungi, invertebrates, testate amoeba, algae and higher plant remains, which are encountered (but frequently ignored) during standard pollen analysis. They provide complementary insight into climate and/or human-driven processes, as well as vegetation shifts, even where pollen is scarce or absent (which is often the case in sediments from archaeological sites). If the value of NPPs as paleoenvironmental indicators has now been demonstrated, their identification (up to now more than one thousand NPPs have been described!) is still progressing and more and more studies are needed to improve our knowledge about their ecology and representativeness.

Investigating soil geochemical trends across archaeological sites in South-Western Turkey

Dirix K.[1], Muchez P.[1], Degryse P.[1], Kaptijn E.[2], Vassilieva E.[1], Mušič B.[3], Poblome J.[2]

→ katrijn.dirix@ees.kuleuven.be

1 KU Leuven, Department of Earth and Environmental Sciences, Belgium

2 KU Leuven, Sagalassos Archaeological Research Project, Belgium

3 University of Ljubljana, Department of Archaeology, Slovenia

Various authors have demonstrated that ancient human occupation and cultivation of the landscape has caused changes on the chemical characteristics of soils, thereby providing an opportunity for soils at archaeological sites to be used as an interpretational tool to identify and delineate sites and to interpret functionality of ancient activity areas. While during the past decades much research has been performed on the interpretation of geochemical variations on exposed archaeological layers and floor levels of excavated archaeological sites, only limited research has been carried out on the applicability of multi-element soil geochemistry as a prospection tool to outline and characterise archaeological sites that are not (yet) excavated. This study aims to address this aspect through an extensive geochemical survey across two Classical-Hellenistic to Roman-Late Roman archaeological sites within the territory of ancient Sagalassos (Taurus Mountains, SW-Turkey).

Approximately 150 soil samples were collected in regular grids at both sites. Additionally, several drill cores with depths between 0.7 and 2.5 m were made. After Aqua Regia destruction of the samples, Al, As, Ba, Ca, Cu, Co, Cr, Fe, K, Mn, Mg, Na, Ni, Pb, P, Sr, Ti, V and Zn were measured by inductively coupled plasma optical emission spectrometry (ICP-OES), using a Varian 720-ES apparatus.

At the first study area, the presumed farming estate of Çatal Oluk, geomagnetic data indicate the presence of buried kilns. Here, exploratory descriptive statistics indicate the absence of element enrichments when compared to regional background data. However, multivariate statistics such as cluster analysis and principal component analysis reveal spatial trends in the data, showing concentrations of P, Ca, Cr, Ni, Co, and Mg on the location of the buried kilns. This signal likely reflects the remnant signature of ophiolitic clays that were transported to the kilns, to be used as a raw material for the production of ceramics. At the second site, comprising the 6 ha large industrial quarter of Sagalassos, Cu, Pb, Zn and P show significant elevations across the ancient activity area. Additionally, a cluster comprising exceptionally high concentrations of Fe, Ti and V is detected. As this element association corresponds with the geochemical composition of iron mineralisations occurring around ancient Sagalassos, these results might indicate that iron metals were processed on this location. However, also the possibility of a local change in bedrock, enriching the soils with Fe, Ti and V needs to be considered. While the ongoing research will yield more insight in the spatial trends of the chemical data, the presented results demonstrate that the use of geochemical prospection to obtain information on unexcavated archaeological sites is a complex matter, requiring a good understanding of variations of local geology.

Human-climate-environment interactions during the late-glacial and early Holocene in the Moervaart area (northwestern Belgium)

Gelorini V.[1], Crombé P.[2], Verniers J.[1] and project collaborators

→ Philippe.Crombe@UGent.be; Vanessa.Gelorini@UGent.be

1 Ghent University Department of Geology and Soil Science, Research Unit Palaeontology, Belgium

2 Ghent University, Department of Archaeology, Prehistory Unit, Belgium

Due to the high variability in natural landscape elements (e.g., topography, hydrology, soil conditions, and food resources) and human occupation patterns, the Moervaart depression in northwestern Belgium is a very suitable region from which to assess the response of hunter-gatherers to rapid environmental change during the late-glacial (ca. 14,5-11,5 ka cal BP) and the early Holocene (ca. 11,5-9 ka cal BP). Over the past 20 years, archaeological fieldwork has yielded numerous prehistoric sites, dating back to different chronological stages. Additionally, multiple-proxy analyses of physical parameters (bulk sediment composition and magnetic susceptibility) and biotic remains (palynomorphs, plant macroremains, diatoms, freshwater molluscs, ostracods and chironomids) from high-quality lacustrine and fluvial sediment records have resulted in a considerable amount of valuable data concerning the climate and palaeoenvironment in this region. The climatic cycles observed in the late-glacial and early Holocene significantly affected the local vegetation and water shed, which forced hunter-gatherers to migrate permanently and organize their residential sites more rigorously. The milder Bølling interstadial (ca. 14,5-14,1 ka cal BP), characterized by shallow swamps and an open vegetation of mainly birch, grasses, willow and juniper, was abruptly interrupted by a short cold phase, the Older Dryas (ca. 14,1-13,8 ka cal BP), in which a dry and open grass tundra occurred. From these stages, no evidence of human presence is currently known. During the successive Allerød interstadial (ca. 13,8-12,6 ka cal BP), a more dense birch forest (1st phase), accompanied by pine (2nd phase), was continuously present in the surroundings of a shallow, large palaeolake. These favourable environmental conditions stimulated human occupation (Federmesser Culture), which concentrated along the dry northern bank of the palaeolake. Extreme cold climatic conditions during the Younger Dryas (ca. 12,6-11,5 ka cal BP), however, caused major hydrological changes, which originated in the development of an east-west trending palaeochannel system across the (nearly-)desiccated lake area. Simultaneously, hunter-gatherers probably left the area temporarily. Notwithstanding the area became inhabited again from ca. 10,5 ka cal BP onwards, the local hunter-gatherer mobility shifted from occupation patterns alongside the large palaeolake to the palaeochannels. As such, in the Moervaart depression we can clearly observe at the last glacial-interglacial transition a strong human adaptation to environmental change and availability of food resources, based on an efficient subsistence strategy.

Was there a Roman shipwreck at Rio de Moinhos (Esposende, NW Portugal)?

Granja H.[1], Morais R.[2], Fernández A.[2]

→ hgranja@dct.uminho.pt

1 CIIMAR/ Department of Earth Sciences, University of Minho, Portugal

2 UI&D-CECH/ Department of History, University of Minho, Portugal

Archaeological discoveries at the beach of Rio de Moinhos (Esposende), on the low-water swathes, have revealed the presence of several evidences of Roman occupation. Among them we highlight the existence of a high number of amphorae fragments, datable to the Augustan / Tiberian period.

The area where the archaeological remains were found is included in a geomorphological unity characterized by the presence of dark, fine and humic sediments aged from Late Holocene. The facies of these sediments points to a confined wetland - a lagoon or palaeo-estuary environment - that extended north and south of this place, and westwards of the present coastline.

In 2005, intense erosive process removed sand from the beach face, uncovering older deposits. Tree stumps, wooden artefacts and numerous pieces of ceramics were exposed during low tide.

The stumps are of *Alnus glutinosa*, with an age of 5590±80 yrBP. The wooden artefacts are also from the same species and aged of 4570±80 yrBP. The area was soon covered by sand, which did not allow further observations. Though there are not any dating from the lagoon deposit exposed in this place, dating from the same sedimentary unit in neighbouring areas that point a time interval between 4470±50 (peat at 5m depth, Belinho) and 2320±90 yrBP (peat, outcrop, Foz do Neiva) are available.

The palaeo-forest, corresponding to a lower relative sea level, was inundated somewhere about 4400-4500 yr BP, creating a wetland. An interesting point is an indicator of increased marine influence (a "sudden" flooding?) in Cávado palaeo-estuary occurred prior to 1780±50 yrBP when the marsh was already evolving to a supra-tidal position. If this event had happened at Marinhas, too, it would correspond to a sea penetration along the low wetland, increasing its water depth. Could vessels enter at that time in this kind of embayments?

The concentration of the finding, the homogeneity and the highlighted presence of Haltern 70 Baetican amphorae from the Gaudalquivir, leads us to believe that the come from a vessel that transported wine products and its derivatives. One of the fragments, which correspond to a spike with a graffiti of one of these amphorae, still conserves remains of resin and of the transported good. Truly interesting, however, was the finding of two fragments of *dolia* with a similar fabric to that of the Haltern 70 amphorae which seems to indicate that we are dealing with a small and rare ship of the tank type. Apparently these vessels did not last long. All the shipwrecks date from a very limited period, namely from Augustus to Nero (*id. ibidem*).

Even though the data are scarce, we think that there might have existed a small Roman harbor near the place where the fragments were found. This harbor would have then been responsible for the supply of the surrounding region. The appearance of the remains of a Y-shaped vessel in the place where these fragments were collected seems to corroborate this possibility.

Climatic signature and chronostratigraphic background of the Last Interglacial and Early Glacial loess-palaeosol successions at the scale of the Eurasian Continent

Haesaerts P.[1], Gerasimenko N.[2], Spagna P.[1], Pirson S.[1,3]

→ paul.haesaerts@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Department of Palaeontology, Belgium

2 Taras Shevchenko National University of Kiev, Department of Botany, Ukraine

3 Service Public de Wallonie, DG04, Direction de l'Archéologie, Belgium

Complementary stratigraphic record conducted recently at the Romont Quarry near Liège (Belgium) has increased the consistency of the Last Interglacial Early Glacial loess-palaeosol sequences established for Northern France, Belgium and the Middle Rhine Area, on high-resolution reproducible pedological events and specific sedimentary markers. Here we will show how this interregional correlative scheme which encompasses a large number of various Middle Palaeolithic occurrences, has been extended across the Central and Eastern European loess belt, up to Central Siberia. In such system, each regional sequence records a complex succession of nine to ten episodes of soil development ranging from brown forest soil with B2t horizon or chernozem like soil, to weak humic soils. Moreover, the palynological data gathered in Central Ukraine for this pedosedimentary succession shows a consistent signature of the vegetation, from broad-leaved forest to dry forest-steppe, with regard to the soil development. It allows for the first time to correlate vegetation development phases from the loess-palaeosol sequences with those of long lacustrine reference pollen sequences of Europe, as well as with the marine and Greenland records. This correlative scheme which combines pedostratigraphic records and palynological data on a large geographic scale, demonstrates the global significance of the high-resolution climatic signature recorded for the Last Interglacial and the Early Glacial, from the Atlantic Front to Central Siberia.

Tsunami evidence in a Bronze age settlement (Ras al Hadd, Sultanate of Oman)

Hoffmann G.[1,2], Rupprechter M.[1,3]

→ Goesta.hoffmann@gutech.edu.om

1 Department of Applied Geosciences, German University of Technology in Oman, PO Box 1816, Athaibah, Muscat, PC 130, Sultanate of Oman

2 RWTH Aachen University, Institute of Neotectonics and Natural Hazards, Aachen, 52056, Germany

3 Salzburg University, Department of Geography and Geology, Hellbrunnerstr. 34, 5020 Salzburg, Austria

The Sultanate of Oman is situated in the north-eastern part of the Arabian Peninsula. The Arabian Plate is characterized by a northward movement forming a continent-continent collision zone in the west and the Makran Subduction Zone (MSZ) in the east. The MSZ is known to have produced tsunamigenic earthquakes in the past. The last event is known to have occurred in 1945. However, boulder deposits along the coast are seen as evidence for numbers of tsunami to have hit during the Holocene.

We analyzed a bronze-age coastal settlement in Ras al Hadd (RH-6). Archaeological evidence proves 2 settlement phases. The archaeological site is located directly on the shores of the Indian Ocean. Geomorphological, sedimentological and dating evidence is presented that support the hypothesis that the settlement was inundated by a tsunami event around 2800 BC during the first settlement phase.

Evaluating the impact of earthquakes on Late Minoan IIIB (c. 1300-1200 BC) archaeological sites (Crete, Greece)

Jusseret S.[1,2,3,4], Langohr C.[1,2], Sintubin M.[3]

→ Simon.Jusseret@uclouvain.be

1 Université catholique de Louvain, Aegean Interdisciplinary Studies (AegIS-CEMA-INCAL), Belgium

2 FNRS postdoctoral researcher

3 Katholieke Universiteit Leuven, Geodynamics and Geofluids Research Group, Belgium

4 Francqui postdoctoral intercommunity collaborator

Late Minoan IIIB (LM IIIB, c. 1300-1200 BC) represents a critical period in the history of Crete, witnessing the demise of Minoan society and heralding the transition to the so-called Dark Ages. Although the causes underlying societal transformations during LM IIIB remain unclear (internal conflicts, invasions of the Sea People, technological innovations, increased aridity), earthquakes have been suggested as possible mechanisms behind site destructions and abandonments throughout the Eastern Mediterranean c. 1225-1175 BC, including at Knossos and Khania on Crete (Nur & Cline, 2000). However, such conclusions rely on a generalising approach to the Cretan archaeological record and take little account of the seismotectonic setting of the island characterised by frequent earthquakes of magnitude up to 7.0. The objective of this contribution is to reassess the value of LM IIIB archaeological data as evidence for ancient earthquake effects. Such an evaluation represents a prerequisite for assessing the impact of earthquakes on LM IIIB Minoan society.

In the frame of this research, archaeoseismological appraisal of LM IIIB evidence is based on the recognition of potential seismic effects on archaeological remains (hereafter Potential Earthquake Archaeological Effects or PEAEs). PEAEs were mainly derived from available excavation reports. Comparison between the spatial distribution of PEAEs and theoretical damage zones associated with the reactivation of normal faults was used as a basis to assess the reliability of PEAEs as true indicators of ancient earthquakes. Indeed, active normal faults represent the most likely cause of earthquake-related archaeological damage during LM IIIB (Jusseret & Sintubin, forthcoming). Synchronisms between PEAEs observed at different sites were established by considering associated pottery material. This methodology allowed attributing PEAEs to two chronological sub-phases of LM IIIB: LM IIIB1/early (c. 1300-1250 BC) and LM IIIB2/late (c.1250-1200 BC).

The results of this research indicate that seismic shaking is likely to be the true cause of PEAEs observed in central-east Crete during LM IIIB1/early. Consideration of theoretical seismic damage zones point to the Kastelli Fault as the most likely cause of the observed archaeological damage. Although PEAEs described in central-north Crete are compatible with this interpretation, chronological and/or interpretive uncertainties do not rule out alternative causes of destruction. During LM IIIB2/late, earthquakes do not represent a satisfactory explanation for the observed PEAEs (contra Nur & Cline, 2000). These results do not support the idea that widespread, catastrophic earthquakes struck the island of Crete during LM IIIB. This conclusion invites reconsideration of the importance of seismic events in the collapse of Minoan society.

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The chronology of Lateglacial and Holocene fluvial dynamics in the Lower Scheldt basin (N-Belgium), and its relation with the archaeological record

Meylemans E., Bogemans F.[1], Storme A., Perdaen Y., Verdurmen I., Deforce K.

→ Erwin.meylemans@rwo.vlaanderen.be

Flemish Heritage Agency, Koning Albert II-laan 19 bus 5, 1210 Brussels, Belgium

1 Geological Survey of Belgium, Jennerstraat 12, 1000 Brussels, Belgium

In light of tidal restoration and nature development projects, several alluvial areas in the Lower Scheldt Basin (LSB) have been subjected to geo-archaeological surveys and excavations. An analysis of 80 radiocarbon dates obtained in these studies shows several trends in the chronology of Lateglacial and Holocene fluvial activity in the LSB. Similar evolutions are observed in other lowland river basins in NW Europe, and can be related to both climatic changes, and from the 4th millennium cal BP onwards, also to anthropogenic influences.

In general a low energy aggradation regime dominates the built up of the alluvial area throughout most of the early and middle Holocene. In several areas of the LSB fluvial activity increases in the 1st millennium BC, with the incision and following aggradation of local channels. From the Roman period onwards the aggradation of alluvial fines again dominates the fluvial regime, extending the area of overbank sedimentation.

The comparison between these radiocarbon dating results and the observed archaeological record allows to draw conclusions concerning the interplay between landscape development and the presence and preservation of the archaeological record.

Geophyisical exploration of an intertidal archaeological site along the Belgian coast

Missiaen T.[1], Evangelinos D.[1], Demerre I.[2], Van Meirvenne M.[3]

→ Tine.missiaen@ugent.be

1 Renard Centre of Marine Geology (RCMG), Ghent University, Belgium

2 Flanders Heritage Agency, Brussels, Belgium

3 Research group soil spatial inventory techniques (ORBit), Ghent University, Belgium

Intertidal areas are often rich in archaeology but they pose major technological challenges. A geophysical study was performed on a test site along the Belgian coast. The site was subject to peat & salt exploitation in Roman and Medieval times. Due to coastal erosion the Medieval settlement was lost to the sea. Today the archaeological evidence is buried beneath a few meters of sand. The goal of this study was to trace the remnants of peat digging and settlement structures, and map the pattern of (natural and man-induced) palaeochannels.

The study combined measurements at sea (ultra-high resolution seismic at high tide) and on land (electromagnetic induction (EMI) at low tide). Additionally some shallow cores were collected. Despite the salty environment the EMI results showed a distinct pattern that seems to agree with peat extraction. They are confirmed by the seismic data that show a complex pattern of interrupted, shallow reflectors believed to be peat horizons and possibly also wood or stone remains. The geophysical results agree well with old photographical evidence of the site, previous to the sand accretion. This study clearly shows the potential of complementary geophysical techniques for the archaeological exploration of intertidal areas.

Coastal environmental changes and palaeohazards: the archaeological site of Caesarea, Israel, as a test case

Sivan D.

The Department of Maritime Civilizations, the Charney School of Marine Sciences, and the Leon Recanati Institute for Maritime Studies, University of Haifa, Israel

Throughout the Plio-Pleistocene, the progressive closure of the Eastern Mediterranean basin continued across the Cyprus, Hellenic, and Calabria arcs at variable rates. During the late Pliocene–early Pleistocene, the subduction at the Cyprus Arc was partly transformed into collision, due to the arrival of Eratosthenes Seamount – a trend that has prevailed ever since. Present-day seismic activity indicates that the Eastern Mediterranean has experienced continuous subduction and seamount collision. This excludes the northern African margins, which remain passive. To the east, the Dead Sea Rift forms a transform border between the Arabian and the African plate, forming a sinistral slip of 105 km since the Middle Miocene, with the present configuration of the northern part being active for the last 4-5 m.y. Historical records, GPS measurements, and seismic activity indicate that tectonic activity continues at present, as can also be witnessed in archaeological sites along the rift. Between these two tectonically and seismically active areas, the coast of Israel is stable in the late Pleistocene-Holocene period. Even along the Carmel fault, one of the rift extensions that continues to the Mediterranean Sea, geological, geomorphological, geodetic, seismic, and paleoseismic records suggest almost negligible vertical movements in the last thousand years. This stability is demonstrated in archaeological remains and in bio-constructions along the coasts. Unlike the coast of Israel, to the north, different NW-SE fault segments are predominantly dictated by the convergence of the Sinai and Arabian plates with Anatolia and Eurasia, across the Cyprus arc and Zagros belt; and by the northward increase in convergence components across the sinistral Dead Sea plate boundary were active during the last few thousand years. The isostatic vertical movements of Israel were also found negligible, as concluded by different models. The coasts of Israel, mainly south of the Carmel, are, therefore, a “stable island” between active areas.

Caesarea, on the central coast of Israel, is chosen as a test case for examining this stability. In 22 BC, Herod the Great started the construction of Caesarea Maritima and Port Sebastos. In 10 or 9 BC, the city and its harbour was completed. The port city was build to honour Herods’ patron, the emperor Caesar Augustus. Thanks to the detailed description of the city and the port by the historian Josephus Flavious, and to many years of excavations, a complete picture of the city exists. The outer harbour was comprised of wide curving breakwater that extended 450m offshore. At present, most of the breakwater is under water, at depths of 5-7m. Even the parallel wall that served as a forward breakwater, and whose role was to absorb most of the full force of the storm waves, is now 4.2 to 4.8 m below sea level. The causes for the submergence of the harbour were, and still are, controversial: it has been called a catastrophic destruction originating from an earthquake, the result of a tsunami, or the result of sand erosion and sea currents moving the sand beneath the harbour structures. At present, the sand erosion, together with the self-loading of the structures, seems the most acceptable explanation. Inland, there are no indications for tectonic destruction, and the preservation of an effective gradient in the Roman aquaduct – along 7km parallel to the coast – demonstrates this stability.

A new research on the coastal morphology of Caesarea during the last 2000 years, with an emphasis mainly on the last 150 years, presents very minor changes, mainly caused by human interference from Roman times to modern days, with no signs of catastrophic events. Analysis of historical records mentioning tsunami damages in coastal Israeli sites leads to the conclusion that most of the tsunamis originated outside the coast: from Dead Sea rift seismicity that caused underwater slumps or from earthquakes in the Hellenic and Cyprus arcs. Potential tsunami hazard map surveys carried out lately by the Israel Geological Survey indicate that the potential of modern tsunami inundation along the coast of Israel is relatively low, mainly as a result of the geomorphological character of most of the coast.

The green amphibole abundance as a stratigraphic tool in Palaeolithic sites: examples from Belgium

Spagna P.[1], Haesaerts P.[1], Baele J.-M.[2], Pirson S.[1,3]

1 Department of Paleontology, Royal Belgian Institute of Natural Sciences, 1000 Brussels, Belgium;

2 Department of Fundamental and Applied Geology, University of Mons, 7000 Mons, Belgium;

3 Direction de l'Archéologie, Service public de Wallonie, 5100 Namur, Belgium.

Variations in the green amphibole abundance of the Belgian and surrounding loess deposits have been studied for more than sixty years. Different ratios were defined in the literature, and subsequently used for stratigraphic purpose to quantify the green amphibole (generally associated to green hornblende- gh) in the heavy mineral assemblage of the loess (e.g. Gullentops 1954; Juvigné 1978). Firstly confined to the last glaciation deposits (MIS 4 to 2), high MI loesses have then been recognized in the penultimate glaciation deposits (MIS 6) by Balescu & Haesaerts (1984; see also Meijs, 2002). Now used as a parameter on its own, the gh abundance is synthesized in the reference loess sequence in Middle Belgium (Haesaerts & Pirson, *in* Pirson 2007).

Recently, new samples were studied in the Belgian loess belt. Our research objectives consist in completing and homogenizing the mineralogical stratigraphy of the Belgian loess reference sequence by (re)analysing sections in Romont (Eben-Emael), Remicourt, Harmignies and Maisières-Canal. Moreover, an attempt to determine the exact composition of these so-called 'green amphibole' has been made. The green minerals have long been grouped under the 'green hornblende' appellation in previous papers. However, our preliminary observations suggest a more diversified mineralogical assemblage based on optical anisotropy, which shows both B^+ and B^- species, had to be confirmed. The chemicals results obtained both in Mons (UMons-GFA laboratory) and Bochum (Ruhr Universitaet - Zentrale Elektronen-Mikrosonde), confirm the dominance of magnesio-hornblende in the assemblage, followed by pargasite (and ferro-pargasite), actinolite, edenite, and tschermakite.

We also applied mineralogical stratigraphy to totally different depositional environments such as cave entrances, where pedostratigraphic markers are often missing. This has been made in two sites: Scladina and Walou caves. Trends observed in the studied loess and cave sequences are consistent with the gh trend of the reference loess sequence (cf. Pirson, 2007), even if they present lower values. One of our goals is to refine the chronostratigraphic frame of some Palaeolithic sites in Belgium. Results from Scladina and Walou caves will illustrate this approach.

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On the origin and the chronology of the sediments underlying the city of Ghent (East Flanders, Belgium): a contribution from OSL dating

GB 2012 Contestant for Best Poster Presentation

Van Nieuland J.[1], Vandenberghe D.[1], Gelaude[2] F., Van den haute P.[1]

→ jasper.vannieuland@ugent.be; frank.gelaude@artesis.be

1 Laboratory of Mineralogy and Petrology (Luminescence Research Group), Department of Geology and Soil Science, Ghent University, Krijgslaan 281 (S8), B-9000 Ghent, Belgium

2 Conservation of monuments and sites, Artesis University College Antwerp

Historical and archaeological studies hold strong evidence that the city of Ghent (East Flanders, Belgium) originated near the confluence of the rivers Scheldt and Lys nearby a hill that represents an erosional outlier of Tertiary sediments (locally known as the Blandijnberg). This setting influenced the perspective of many studies on fluvial processes. Although the current course of the Scheldt river has been largely dictated by erosion and sedimentation processes related to Late Weichselian aeolian activity, the influence of these processes on the development, functioning and expansion of the city has rarely been considered.

During the Late Weichselian, strong westerly winds caused sand drifting, coversand deposition, and the formation of inland and river dunes (Derese *et al.*, 2010). Localized and discrete phases of pronounced aeolian activity persisted throughout the Holocene until the beginning of the 20th century. As the city of Ghent developed, inhabitants may have been confronted with this late Quaternary windblown sedimentary environment. Historical maps and pictures of Ghent show numerous hills while over 40 “berg” toponyms suggest their occurrence in the area. The current urban landscape has been largely flattened as a result of the city growth and development, and only small, short slopes and talus testify to an original relief of windblown dunes and ridges.

By combining evidence preserved in historical records and Quaternary maps with toponymical research, several possible coversand ridges and dunes underlying the area occupied by the city of Ghent, could be identified.

This paper reports on a chronological study of these deposits using quartz-based optically stimulated luminescence (OSL) dating. The main aim of this study is to contribute to an improved understanding and re-appreciation of the history of Ghent in its past environmental setting.

Urban improvement works allowed us to access dune and coversands at four difficult localities and 21 samples were taken for OSL dating. The Quartz OSL signal in the samples investigated so far is dominated by the fast component and procedural checks confirm the suitability of the applied SAR methodology. At the time of writing, analysis is ongoing but our first results already indicate that sand deposition occurred – in the Ghent city area – from ~ 16 ka onwards. As such, our study supports the idea that the hills, depicted in many historical images may have been more important morphological features, than previously assumed. They probably formed an essential component of the landscape, which should not be undervalued when studying the historical development of the city of Ghent from its earliest days to the onset of the 20th century.

An archaeological survey of the land-sea transition zone at Doelpolder Noord: impact of sea level rises on the palaeolandscape and human occupation from prehistory to the middle ages. Results of the first fieldwork campaign

Verhegge J.[1], Missiaen T.[2], Crombé Ph.[1]

→ Jeroen.Verhegge@ugent.be

1 Ghent University, Department of Archaeology, Belgium

2 Ghent University, Department of Geology & Soil Science, Belgium

After the formation of the late Pleistocene sand-ridge landscape of north-western Flanders, increased fluvial and marine influences have defined human occupation of the alluvial plain of the lower Scheldt river. Through this study we aim to reconstruct its preserved Late Pleistocene and Holocene landscape and model the impact of environmental change through time.

In a first phase, the subsurface is mapped using geophysical techniques, revealing the project area's spatial geological variation. Electromagnetic induction survey (EMI) is used to map the horizontal extent of the electrical properties of the subsoil at multiple depth extends, while electrical resistance imaging (ERI) records vertical variations. In addition, shallow seismic surveys, both on land, on creeks and on the Scheldt river, are used to image the buried geological features.

Cone Penetration testing (CPT), manual and mechanical coring is applied both as calibration for the geophysical data and as an additional mapping technique where geophysical data fail to reveal the preserved landscape. Collected samples are also used for radiocarbon dating and archaeological prospection.

The first results in 'Doelpolder Noord' indicate that all EMI datasets clearly reveal the undulating sandy substrate. The ERI data show the geological layering above the overlying peat but the limited depth penetration does not allow to reveal the transition to the top of the Pleistocene sands (except when above ground water). However, the latter stands out clearly on the preliminary terrestrial seismic data. Marine seismic results, though hampered by shallow gas most likely resulting from the peat, showlocally strong reflectors that can possibly be related to peat layers and palaeogullies.

Hand-augering has been able to map and sample a micro-sandridge flanking an early Holocene gully, situated centrally in the study area. Sample sieving has revealed the presence of a prehistoric site preserved in the Pleistocene sand to peat transition. Unfortunately, the collection of archaeologically relevant samples by hand was impossible on the deeper flanks of the ridge. The CPT data allow a clear distinction between the major geological units, but the existing soil classification charts do not (as yet) allow their interpretation. Further CPT sampling is needed to provide an independent interpretation framework for the region. Nevertheless the CPT data seem to provide a rapid and cheap solution for the calibration of geophysical data.

The Scheldt polders are rich in Final Palaeolithic, Mesolithic and early Neolithic archaeological sites, yet the occupation history of the proto- and early historic peat-landscape is still badly known. At the same time this cultural heritage has become under serious threat by harbour expansion works. Through this study a cost-efficient archaeological evaluation strategy will be proposed, combining onshore and offshore surveys, using the Scheldt polders as principal area of interest.

Changes in precipitation as inferred from a Holocene speleothem from the Hotton cave (Hotton, Marche–en-Famenne, Belgium)

Verheyden S.[1,2], Genty D.[3], Keppens E.[2], Van Strydonck M. [3], Quinif Y.[4]

→ sophie.verheyden@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

2 Departement Geologie - Vrije Universiteit Brussel, Pleinlaan2, 1050 Brussels, Belgium

3 Royal Institute for Cultural Heritage, Parc du Cinquantenaire, 1 B-1000 Brussels, Belgium

4 Faculté Polytechnique, Université de Mons, Rue de Houdain9, B-7000 Mons, Belgium.

The Hotton cave opens in Givetian limestone of the Calestienne limestone belt crossing southern Belgium from West to East. The Hotton cave is a typical sinkhole-to-spring multi-level cave. A candle-shaped stalagmite of 68 cm long was sampled in the lower level in a narrow passage above siphon 2. The longitudinal section of the stalagmite is of rather constant milky white compact aspect without macroscopically visible lamination. Several clayey layers occur in the lower part of the stalagmite, among which one, very clear, around 47 cm from the top of the stalagmite. (Figure). The stalagmite was deposited between (11 023 to 10 477) cal yr BP and (2 868 to 2 692)cal yr BP as dated by the 14C method, taking into account 12% dead carbon.

Overall, the deposition of the stalagmite indicates climatic favourable conditions: relatively warm and humid. The position of the stalagmite near the underground river and just before a narrowing of the gallery, makes it an efficient indicator of flood levels linked to wet periods. During wet periods, the narrow passage downstream of the stalagmite acts as a natural dam, rapidly amplifying the high-water stand due to the constriction of the passage. Former studies on the detrital deposits in front of the narrow passage (Bessems *et al.*, 1999), indicate the existence of a lake during the last glacial period. Nowadays, high-water stands only rarely occur, creating a small muddy lake in front of the narrow passage. During these periods water levels never reach the studied stalagmite, but arrive close to its base. Based on the existence of floodings in nowadays and older times, the clay layers observed in the lower part of the Hotton stalagmite are interpreted as successive flooding periods occurring at ~10.2, 10.0, 9.2, 8.7and 5.6 cal ka BP (interpolated between 14C ages). During these periods, wet conditions prevail in the region of Hotton and can be related to known climatic and/or environmental events or characteristic periods as found in other proxies. Some of the changes recorded in the Hotton stalagmite are also related to changes in human settlements in Europe.

The Hotton stalagmite is a candle-shaped stalagmite of 68 cm long. The speleothem was sampled in the lower level in front of the narrowest passage above siphon 2 of the Hotton cave.

About canals and qanats: long-term human impact on Late Quaternary alluvial landscapes

Walstra J.[1], Heyvaert V.M.A.[1]

→ Jan.Walstra@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

For many thousands of years the Upper Khuzestan plain (SW Iran) has been subject to intensive settlement and agriculture. At various times in history the region was the focus of urban civilizations, centred around the Elamite and Sassanian capitals. Throughout the plain ancient irrigation and settlement patterns are visible, although these traces are rapidly disappearing due to expanding land use. Valuable information on landscape and archaeology only survives through available historical imagery, which can be unlocked using appropriate techniques.

In this study a variety of historical and modern imagery were exploited to map the archaeological landscapes of Upper Khuzestan. The utilized data sources notably include aerial photographs from the 1940s and 1950s, CORONA satellite images from the 1960s, and recent Landsat and SPOT data. Supported by the evidence from earlier field surveys, archaeological elements were identified, mapped and incorporated in a GIS database. A geomorphological map was produced in order to provide a landscape-wide context of current and past landforms and their underlying alluvial processes. The resulting map layers reveal a dynamic environment of shifting river channels, changing settlement patterns and immense irrigation networks extending across the plain.

This study clearly demonstrates the significance of human impact on alluvial processes. It therefore provides valuable insights in the complex landscape evolution of this region, both from geological and historical perspectives. The vital role of remote sensing techniques in this research context is unquestionable.

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Session 08

Dispersal of land vertebrates during the Paleogene

Chairmen: Thierry Smith & Gregg F. Gunnell
Key-note speaker: Gregg F. Gunnell

The early Eocene lizards fauna of Le Quesnoy (Paris Basin, France) and its paleobiogeographic implications

Augé M.[1], Folie A.[2], Smith R.[2]

→ axuxgxex@aol.com

1 Muséum national d'histoire naturelle, Paris, France

2 Royal Belgian Institute of Natural Sciences, Brussels, Belgium

The early Eocene is a critical period in the history of mammals but it also represents a major faunal turnover in lizard evolution. However, the lizard record is often considered as patchy and that hinders inference about change across the Paleocene/Eocene boundary.

The Lizard fauna from Dormaal (Earliest Eocene, MP7, Belgium) has been reported on in three preliminary studies indicating that the Dormaal Sands have produced important remains representing at least eleven taxa of lizards in nine genera.The penecontemporaneous locality of Le Quesnoy (Paris Basin, France) and some other early Eocene localities also yielded numerous lizard remains in Europe: Silveirhina (Portugal), Meudon and Sotteville-sur-Mer (Paris Basin, France) and Rians (Provence, France). However, only a small number of these taxa have already been described. Comparisons between the herpetological faunas from the Eocene sites are thus difficult but will be here tentatively done using the lizard diversity of Dormaal as a reference. We thus here mainly focus our research on the early Eocene lizard fauna from le Quesnoy.

Varanidae (Saniwa), Platynota (Necrosaurus), Iguanidae (Geiseltaliellus), glyptosaurine Anguidae (Placosaurus), purported Helodermatidae and a lacertid-like lizard of indeterminate affinities (Eolacerta) are present at Dormaal and Le Quesnoy. Conversely, the agamid lizard 'Tinosaurus', amphisbaenians and the purported lacertid lizard Dormaalisaurus are only known from Dormaal. Their absence at Le Quesnoy may be the result of a different environment or a bias due to its less well-documented fauna.

Biogeographically, numerous early Eocene European taxa have close relatives in North America like Agamidae ('Tinosaurus'); Varanidae (Saniwa); 'higher' amphisbaenians like Anniealexandria, Glyptosaurinae, Iguanidae, Helodermatidae (?), prompting comparisons between the European and North American faunas.

Those widespread taxa certainly reveal several episodes of dispersal between North America and Europe during the early Eocene. It is worth noting that during the early Eocene iguanid, varanid and agamid lizards are found at sites located very far North (such as Ellesmere Island). These lizards certainly dispersed via terrestrial route(s) between Europe and North America. The high-latitude connexion was only intermittent and many taxa (as ectotherm lizards) would have found dispersal opportunities only during limited warm intervals when their requirements for higher temperatures were met.

The agamid 'Tinosaurus' is a case in point: this lizard is distributed on both side of the Atlantic Ocean (North America and Eurasia) in the early Eocene and disappears from both continents during the Eocene. The continuous presence of agamids in Asia (and India) since the Mezosoic supports an Asian (or Indian) origin of this group and a dispersal of Tinosaurus from Asia to Europe and North America.

Tarsal diversity in the Earliest Eocene mammal fauna of Dormaal, Belgium

GB 2012
Contestant for Best Oral Presentation

Coillot T.[1], Smith R.[2], Gigase P.[3], Smith T.[2]

→ tiphaine.coillot@univ-poitiers.fr

1 SFA – Institut International de Paléoprimatologie, Paléontologie Humaine: Evolution et Paléoenvironnements (IPHEP) – UMR CNRS 7262, Université de Poitiers, 6 rue Michel Brunet, 86022 Poitiers Cedex, France

2 Department of Paleontology, Royal Belgian Institute of Natural Sciences, Rue Vautier 29, B-1000 Brussels, Belgium

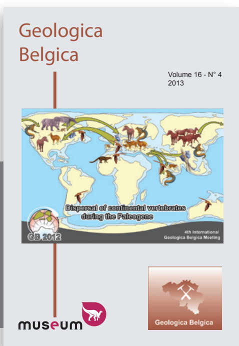
3 Prins Albertlei 15 bus 11, 2600 Berchem, Belgium

Mammal teeth bring important information regarding phylogeny and diet, but postcranial elements, although poorly studied for small Paleogene mammals, can provide other important data about their paleoecology. Tarsal bones are particularly interesting in having strong functional and sometimes phylogenetic signals, but they need to be associated to the corresponding dental remains for a systematic identification. For this reason, most of the described tarsal bones are known from rare complete or partial skeletons preserving teeth. Very few is known about the tarsal diversity within a same mammal fauna.

In order to analyze the diversity of tarsal bones associated to their corresponding teeth from the same fauna we studied one of the richest Paleogene mammal fauna from a key period in the mammal evolution. We thus chose the Belgian locality of Dormaal (Tienen Formation, Flemish Brabant), the reference level MP7 of the mammalian biochronological scale for the European Paleogene that has yielded the earliest Eocene mammals of Europe. This particularly rich fauna is constituted by archaic mammals, more diversified during the Paleocene ("condylarthrs", arctocyonids, plesiadapiforms, "insectivorans") and by earliest modern mammals (artiodactyls, rodents, carnivorans, primates). Moreover, important paleoecological data are already available from a forty taxa defined on the basis of about 14 000 dental remains. Indeed, ischyromyid rodents are the most diversified, followed by louisiniid "condylarths". The lack of multituberculates, even abundant during late Paleocene, could be explained by competition with the latter. The very important specific abundance of the louisinid *Paschatherium dolloi*, reaching 71% of the global fauna, is in agreement with this hypothesis. Lipotyphlan insectivores are also well represented, with 2/3 of the specimens belonging to the erinaceomorph *Macrocranion vandebroeki*. Herpetotheriid marsupials and omomyid primates are just known from one species but each displays a relative abundance of 5-6%. The latter belongs to the genus *Teilhardina*, the oldest euprimate known from Asia, Europe and North America, which has undergone a rapid geographic dispersal associated with important morphological character evolution during the Paleocene-Eocene Thermal Maximum, about 55.8 My ago.

In total, 488 tarsal specimens (astragalus and calcaneum) were studied according to three ways: relative abundance, relative size and general morphology (by means of comparisons with original specimens, casts and bibliography).

The number of recognized morphotypes (12 for astragali and 18 for calcanei) is lower than that of the species present in Dormaal: tarsal bones are more fragile than teeth, less numerous per individual, and some of them look very similar inside a same genus. However, these morphotypes are well discriminated by multivariate analysis. Some of them can be attributed to a single species with certainty (e.g. the marsupial *Peratherium constans*), others are more characteristic to a family (e.g. Ischyromyid rodents). Inferences on locomotion show several arboreal characters for many of the taxa, but others are more adapted for a running and jumping locomotion. These data are in accordance with the other studies describing a woody cover in Dormaal.



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Tarsal diversity in the earliest Eocene mammal fauna of Dormaal, Belgium
by Coillot T., Smith R., Gigase P., Smith T.

New mammal specimens from the marine Selandian of Maret, Belgium, and their implications in the age estimation of the continental deposits of Walbeck, Germany

GB 2012
Contestant for Best Oral Presentation

De Bast E., Smith T.

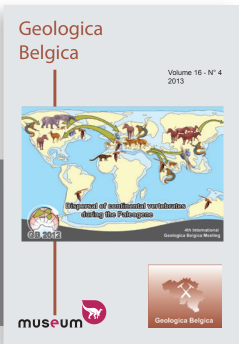
→ eric.debast@naturalsciences.be

Royal Belgian Institute of Natural Sciences

The Heersian (Selandian) sands of Orp-le-Grand at Maret have been well known by collectors of shark teeth for decades. Among the abundant vertebrate remains, extremely rare mammal specimens have been found. Two fragmentary teeth have already been reported by Herman and Sigé (1975). The purpose of this study is to present new well-preserved specimens from the same deposits. A small fragmentary jaw of an adapisoriculid, exhibiting p4 to m3, constitutes the best preserved specimen of the family ever discovered. The morphological comparisons indicate that it is very close to the species *Afrodon germanicus*, present in Walbeck. However, the association of characters visible on the lower molars of *A. germanicus* and especially p4 indicate a more advanced evolutionary stage than in the type species *Afrodon chleuhi* from Morocco, closer to the species *Bustylus marandati* and *B. folieae* from Hainin. Another interesting specimen from Maret is a labial fragment of upper molar that we refer to the species *Adunator lehmani*, also present in Walbeck. The match in morphology and size of the preserved part of the tooth with the German species is sufficient to assess it to *A. lehmani* with confidence. The last new mammal tooth is an anterior premolar of a large arctocyonid. The tooth is difficult to assess with certainty due to the lack of diagnostic features; based on the size it could belong to the species *Arctocyon primaevus* or *Mentoclaenodon walbeckensis*. The morphology does not match well that of either species, but the great variability in size and morphology observed in anterior premolars of these taxa does not allow reaching definite conclusions. Of the two teeth reported by Herman and Sigé (1975), one was a DP4 belonging to *Adapisorex* sp., and seemed to be closer to the species *A. abundans* from Walbeck than to *A. gaudryi* from Cernay. The other was a fragment referred to a possible arctocyonid; Smith and Smith (2003) considered the tooth as *Arctocyonides* cf. *weigelti*, the species being known from Walbeck only. The results concerning the mammals tend to indicate that the age of Maret is close to the age of Walbeck. Because the deposits in Walbeck consist of crack filling, the precise age could never be determined. It was usually thought to be slightly older than the late Thanetian of Cernay. Thanks to the mammal specimens found in Maret, we infer that the age of Walbeck is likely to be Selandian or early Thanetian.

Herman J., Sigé B. (1975). *Présence du genre Paléocène Adapisorex (Lipotyphla, Mammalia) dans les sables d'Orp-le-Grand (Heersien) à Maret en Brabant (Belgique)*. Geobios, Volume 8, n°4, pp 231-239.

Smith T., Smith R. (2003). *Terrestrial mammals as biostratigraphic indicators in upper Paleocene-lower Eocene marine deposits of the southern North Sea Basin*. *In:* Wing S. L., Gingerich P. D., Schmitz B., Thomas E., eds. *Causes and Consequences of Globally Warm Climates in the Early Paleogene: Boulder, Colorado*. Geological Society of America Special Paper, n°369, pp 513–520.



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New mammals from the marine Selandian of Maret, Belgium, and their implications for the age of the Paleocene continental deposits of Walbeck, Germany

by De Bast E., Steurbaut E., Smith T.

Morphology and phylogenetic relationships of the middle Eocene alligatoroid *Diplocynodon deponiae* (Frey, Laemmert and Riess, 1987)

Delfino M.[1,2], Smith T.[3]

→ massimo.delfino@unito.it

1 Dipartimento di Scienze della Terra, Università di Torino, Italy

2 Institut Català de Paleontologia, Universitat Autònoma de Barcelona, Spain

3 Département de Paléontologie, Institut royal des Sciences naturelles de Belgique, Bruxelles, Belgium

The crocodilian clade Diplocynodontinae Brochu, 1999, alternatively called Diplocynodontidae Hua, 2004, currently hosts two genera: Diplocynodon Pomel, 1847 and Baryphracta Frey, Laemmert and Riess, 1987. The several species referred to *Diplocynodon* have been identified in numerous European localities ranging from the late Paleocene or early Eocene to middle Miocene age, whereas *Baryphracta* is a monotipic genus known exclusively from the middle Eocene of Messel (Germany). The *Baryphracta* remains studied so far are represented by specimens embedded in resin slabs, showing one side only and therefore providing only limited information. The recent analysis of the only 3 dimensionally-prepared specimen of *Baryphracta deponiae* Frey, Laemmert and Riess, 1987 (housed in the collections of the Royal Belgian Institute of Natural Sciences in Brussels, Belgium), and the revision of all the specimens housed at the Hessisches Landesmuseum (Darmstadt, Germany) and Senckenberg Museum Frankfurt (Germany), allowed us to significantly improve the knowledge of its morphology and to revise its phylogenetic relationships. According to a parsimony analysis, *Baryphracta* is nested within *Diplocynodon*. They share several features including the presence of two subequal alveoli in the maxilla and dentary, the exclusion of the splenial from the symphysis, and the shape of the iliac blade. *Diplocynodon deponiae* is a small species (about 1 m in total length) characterized by several features as the presence of stout, enlarged teeth and extension of the osteoderms along the limbs and tail. Such osteodermal cover, developed very early in ontogeny, easily distinguishes even small sized specimens of *D. deponiae* from *Diplocynodon darwini* Ludwig, 1877, the only the co-occurring *Diplocynodon* species. The Fossil-Lagerstätte of Grübe Messel is the only Paleogene European locality hosting an astonishing diverse crocodyliform fauna including at least seven taxa, two of them belonging to the same genus. *D. darwini* and *D. deponiae* exhibit differences in dentition and size that likely determined niche partitioning that minimized competition, thereby allowing them to be syntopic.

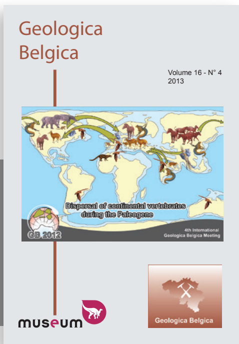
New basal amphisbaenian lizards from the Middle Paleocene of Hainin and its implication in the evolution of European amphisbaenians

Folie A., Smith R., Smith T.

→ annelise.folie@naturalsciences.be

Royal Belgian Institute of Natural Sciences, Brussels, Belgium

Amphisbaenians are burrowing, wormlike limbless lizards characterized by a robust skull and by short, reduced jaws with usually five to nine teeth in modern forms. Their origin is thought to be in the Jurassic of Gondwana, based on the abundance of amphisbaenians in Africa and South America today. In Europe, the oldest clearly identified amphisbaenian is known from the Campanian of Laño (Spain), although this record is only based on vertebrae. Here we describe three new amphisbaenian lizards from the Early Palaeogene of Western Europe. Two new basal forms, from the Middle Paleocene of Hainin (MP1-5, Belgium) and from the Late Paleocene of Cernay (MP6, France), are characterised by a long dentary that do not form a strong angle at the level of the intermandibular symphysis, and bearing 10 to 12 pleurodont and heterodont massively build and conic teeth. A third new amphisbenian is also described from the Early Eocene of Dormaal (MP7, Belgium), Condé-en-Brie (MP8+9, France) and Prémontré (MP10, France) representing the oldest modern amphisbenian lizard of Europe, characterised by a reduction of tooth number and by the presence of a strong angle at the symphysis level. Palaeobiogeographic analysis confirms that as for the scincoid lizard *Scincoideus haininensis* Folie, *et al.* 2005, primitive amphisbaenian lizards were present in Europe from the Palaeocene or maybe even before the Cretaceous/Palaeogene boundary and were replaced by modern forms such as true amphisbaenids and blanids with typical reduced jaws at the beginning of the Early Eocene. The origin of the latter two families in Europe was very likely related with the dispersal of the earliest modern mammals around the Paleocene-Eocene boundary. Because the contemporaneous North American amphisbaenian faunas are exclusively composed of the morphologically different rhineurids, with strong longitudinal striae and a denticulate posterior border of the neural arch on the vertebrae in dorsal view, North America is unlikely to be the region of origin for the European modern amphisbaenians.



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New amphisbaenian lizards from the Early Paleogene of Europe and their implication in the early evolution of modern amphisbaenians
by Folie A., Smith R., Smith T.

A new early/middle Eocene vertebrate fauna from South France

Godinot M.[1], Erfurt J.[2], Franzen J.[3], Labarrère H.-P., Lange-Badré B.[1], Lapparent de Broin F.[1], Vidalenc D.

→ godinot@mnhn.fr

1 UMR 7207 CR2P, Muséum National d'Histoire Naturelle, Paris

2 Insititut für Geologishe Wissenschaften, Martin-Luther-Univesität Halle-Wittenberg

3 Forschungsinstitut Senckenberg, Frankfurt am Main

The new Vertebrate locality of Rouzilhac is located toward the base of the Mollasse de Carcassonne, not far away from Issel (Aude, France). The fossiliferous bed is a lense of unconsolidated conglomerate with gravels, sand and stromatolithes, i.e. a typical river channel deposit. Its fauna includes mainly middle-sized and large vertebrates, due to taphonomic conditions (high energy flow). The reptiles include at least four crocodyles, *Iberosuchus crassiproratus*, *Diplocynodon* sp., aff *Asiatosuchus* sp., *Pristichampsus rollinati*, and four turtles, *Neochelys eocaenica*, *Trionyx* s.l. sp., *Allaeochelys* aff. *gracilis*, aff *Hadrianus* sp. The mammals include two creodonts, *Oxyaenoides bicuspidens* and *Leonhardtina* cf *gracilis*, a rodent, *Ailuravus* sp., two primates species, one *Europolemur* and one species probably representing a new genus. The artiodactyles are diverse, including *Aumelasia* n.sp., *Protodichobune* sp., and a new species pertaining to a new genus. The dominant group of mammals is the Perissodactyla, with abundant remains of equids, which are referred to *Propachynolophus gaudryi*, *P. maldani*, *Pachynolophus livinierensis*, and cf *Lophiotherium*. There is one rhinocerotoid, *Hyrachyus stehlini.* A relatively large assemblage of *Lophiodon* shows the high morphological variability, which has led to controversies concerning the number of species present at Issel. The many variations in the details and proportions of the upper premolars, in the more or less triangular outline of the M3/, in the orientation of the posterolophid of the lower molars, do not allow the separation of groups. We thus interpret the assemblage as pertaining to one species, which shows a marked sexual dimorphism. Comparison with other species shows this one to be more primitive than *L. isselense* from Issel, and also confirms previous studies which distinguished a group of forms present in the Paris Basin from a group of species present in Southern France.

Several of the reptiles and mammals are unknow in typical MP 10 faunas, like *Iberosuchus*, however the two *Propachynolophus* fit in lineages which imply an age older than Messel (MP 11). We propose an age between MP 10 and MP 11, a large time interval corresponding to a hiatus between Cuisian and Lutetian localities in the Paris Basin.

Several species are close to species known in the Paris Basin and in Germany, Messel or Geiseltal, providing arguments for a biochronologic dating. However a number of others are new and reinforce the endemicity of southern faunas in comparison with northern France and Germany. Such is the case for the *Lophiodon*, very close in evolutionary grade to the species of Argenton but pertaining to a southern lineage. This endemic character is even more clearly shown by one artiodactyl and one primate, which need the description of new genera.

Biogeography and the Legacy of Alfred Russel Wallace

Gunnell G.F.

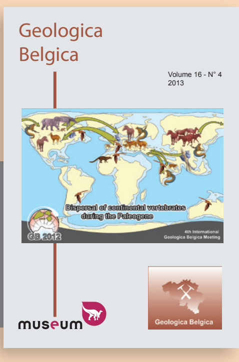
→ gregg.gunnell@duke.edu

Division of Fossil Primates, Duke Lemur Center, 1013 Broad Street, Durham, NC 27705, USA

Alfred Russel Wallace, the great 19th Century British naturalist is, perhaps, best known as Charles Darwin's protagonist and the man most responsible for Darwin publishing *Origin of Species*. Both Darwin's "natural selection" and Wallace's "struggle for survival" explained the basis for understanding differential survival of biotic populations and thus evolution. Subsequently, while Darwin continued to document the processes of evolution, Wallace focused on documenting distributions of animals across geographic areas, largely founding the science of biogeography. Wallace spent 8 years living in Malaysia and Indonesia. While traveling and collecting specimens, Wallace noticed a very distinct pattern of biotic distribution with western islands having an Asiatic fauna and eastern islands an Australasian fauna. The now famous Wallace line separates these two faunal provinces, most distinctly between Bali (western) and Lombok (eastern), separated by only a narrow strait of 20 km. Wallace's observations now have a geological causal mechanism, plate tectonics.

Since Wallace, new phylogenetic, physiologic and geological methods have helped to elucidate seemingly intractable biogeographic problems. Two such puzzles revolve around the presence of unique groups of primates on Madagascar and South America. The lemurs of Madagascar are unique and probably arrived in Madagascar from the African mainland at some point in the Cenozoic, but when and how? Madagascar is separated from Africa by a 400 km expanse of Deep Ocean across the Mozambique Channel and currents trend westward from Madagascar to Africa yet these animals must have crossed the channel. How could ancestral lemurs have survived crossing 400 km of open ocean with no water and against opposing currents? The most primitive living lemurs, cheirogaleids, are capable of relatively long periods of torpor during which they neither consume food nor drink water. A newly reported current model for the Eocene indicates a reversed flow from Africa to Madagascar at a rate that could have been capable of carrying large mats of floating vegetation with sleeping lemurs across the Mozambique Channel in 3-4 days.

Another biogeographic puzzle, concerns New World Monkeys and when and how they arrived in the western hemisphere. Based on phylogenetic analysis, New World platyrrhines probably branched from all other higher primates around 40 Ma. Their closest known fossil relatives lived in Egypt in the late Eocene at 35 million years ago and must have somehow gotten across or around the Atlantic Ocean near that time. Even under the most favorable late Eocene reconstructions, a transatlantic crossing would require traversing about 1000 km of open ocean, a seemingly impossible journey. There are no other fossil platyrrhines known until 24 Ma in South America which could conceivably be as much as 10 million years after their arrival on that continent. Current geological evidence supports the ephemeral presence of emergent mid-oceanic ridges and islands and favorable winds and currents that would have aided these early sailors in their westward journey but ultimate resolution of this puzzle is still lacking.



Full paper in Geologica Belgica, Volume 16, n°4
Biogeography and the legacy of Alfred Russel Wallace
by Gunnell G.F.

Functional Morphology of the cochlea in Eocene echolocating Bats

Habersetzer J.[1], Gunnell G.F.[2]

→ joerg.habersetzer@senckenberg.de

1 Palaeoanthropologie and Messel Research, Senckenberg Forschungsinstitut, Senckenberganlage 25, D 60325 Frankfurt, Germany

2 Division of Fossil Primates, Duke Lemur Center, 1013 Broad Street, Durham, NC 27705, USA

Preserved inner ears are found in various fossil bats from the early and middle Eocene representing six different families. These fossils were interpreted, on the basis of their cochlear size, to already represent the broad spectrum from non-echolocators to acoustically extremely specialized echolocators when compared with similar parameters of extant bats

In addition to 2D-microradiography more morphological parameters and more precise measurements of the cochlea can be obtained by means of 3D micro-CT and nano-CT. In this study we focus on the primitive European middle Eocene bat *Hassianycteris messelensis*, the emballonurid *Tachypteron franzeni*, both from Messel in Germany, and *Tanzanycteris mannardi* from the middle Eocene locality of Mahenge in Tanzania. The latter is one of only a very few Paleogene mammals known from south of the Sahara and is preserved by a single partial skeleton. This extraordinary find among the earliest fossil bats from Africa was ultimately placed in its own family, Tanzanycteridae, based on the unique presence of a highly enlarged cochlea. Moreover, *T. mannardi* is the only known Eocene bat species with greatly enlarged inner ears. Thus, *T. mannardi* was hypothesized to have possessed a highly sophisticated echolocation system (high duty-cycle echolocation where-in constant frequency emission is employed) which is comparable to that of acoustically extremely specialized extant taxa.

Recently, basilar membrane length of *Tachypteron franzeni* was reconstructed from micro-CT-data and compared with that of extant bats. We undertook to re-examine the holotype of *T. mannardi* in order to compare the 3D-shape of the cochlear endocast and the sparse bony remains with digitally produced endocasts from more completely preserved fossil bats and extant bats as well. While in *T. mannardi* most of the bone itself was dissolved, it was possible to reconstruct a cochlear endocast that represented the 3D-shape of the former inner ear.

Our results indicate that, compared with other Eocene and extant bats, the cochlear size of the Tanzanian bat is relatively enormous, comparing especially well with living hipposiderids, rhinolophids and the mormoopid *Pteronotus parnellii*, all of which employ highly sensitive echolocating capabilities. The presence of echolocating abilities utilizing long CF (constant frequency) sounds in a middle Eocene bat from Africa indicates that sophisticated echolocation was developed early in the radiation of bats and that the complex aerial hawking behaviours associated with high duty-cycle echolocation were present in the *Tanzanycteris* lineage. The development of constant frequency echolocation may have been in response to the increased ability of insect prey (in particular moths and other large flying insects) to detect and avoid low duty-cycle bat predators. In addition, high duty-cycle echolocation would have increased the ability of bats to hunt in cluttered and complex habitats in order to increase access to insect prey.

The Indian raft and biotic dispersal: the India-Asia collision scenario

Kumar K.[1], Rana R.S.[2], Sahni A.[3]

→ kumark@wihg.res.in

1 Wadia Institute of Himalayan Geology, 33 GMS Road, Dehradun 248001, India

2 Department of Geology, HNB Garhwal University, Srinagar 246175, India

3 Department of Geology, Lucknow University, Lucknow 226007, India

In a geodynamic earth, the movement of landmasses greatly influences biotic dispersals and palaeoclimates. One such example is separation of the Indian Plate from Madagascar, its northward drift as a ferry or raft carrying biotic-cargo inherited from its former association with the Gondwanaland, and its ultimate collision with the Asian Plate. Obviously, this had a profound influence on the distribution of faunas and floras. In the last three decades, considerable advances have been made in understanding the India-Asia collision process and its wider consequences, particularly from sea floor studies. However, several questions still remain unanswered: along the western margin of the Indian Plate, the oldest marine sediments in Gujarat and Rajasthan are Jurassic in age, suggesting an early separation from the western Gondwanaland, yet biotic affinities with Madagascar remain strong until the end of the Cretaceous; geophysical models for the drifting Indian Plate portray it as an isolated island subcontinent for about 100 my between ~160-55 million years ago, yet the evidence and opinion are divided upon the nature of the faunas and floras that inhabited it, whether these are largely endemic, cosmopolitan, Gondwanan, Laurasian or mixed and if so, their palaeobiogeographic implications.

Prolonged isolation of a landmass is expected to result in biotic endemism because of lack of genetic interaction with outside forms. Whereas the Early Mesozoic life on India had dominantly Gondwanan character, the succeeding Late Cretaceous biotas included Gondwanan as well as Laurasian elements. Faunas of typical Gondwanan affinity known from the Maastrichtian Deccan trap-associated continental successions (=Intertrappean and Infratrappean beds) comprise Abelisauridae and Titanosauridae dinosaurs, Myobatrachinae frogs, Madtsoiidae snakes, Pelomedusidae turtles and Sudamericidae mammals. Biotas of unequivocal Laurasian affinity, such as Palaeoryctidae mammals, Alligatoridae crocodiles, Pelobatidae and Discoglossidae frogs and Anguidae lizards apart from charophytes also occur in the same horizons. Osteoglossidae and Lepisosteidae fish and some dinosaurs are the only cosmopolitan elements in the Late Cretaceous biotas from India. There is little evidence of any endemism in faunas of this time except in some ostracodes. Paleogene vertebrates on India, known thus far mostly from the Eocene have no Gondwanan elements.

Recent studies emphasize that for several vertebrate groups including, euprimates, bats, perissodactyls, artiodactyls, lagomorphs, and paenungulates (hyracoids, proboscideans, and sirenians), the oldest record is expected to be found on the Indian Raft, implying thereby an evolutionary radiation common in island ecosystems. Nonetheless and to the contrary, the reported occurrence in pre-collision India of diverse Asiatic and European elements (mammals as well as other land vertebrates) suggests the existence of dispersal routes to both these continents during the Early Eocene or even before.

Recently it has been demonstrated that the first widespread angiosperm-dominated tropical lowland rainforests with Dipterocarpaceae elements (trees with winged seeds, e.g., *Shorea*) occur in the Lower Eocene of India. Asian dipterocarps are known to share a common ancestor with the Sarcolaenaceae, a tree family endemic to Madagascar. *Shorea* forests now occupy nearly 80% of the canopy in South East Asia, suggesting that the Indian Raft may have helped in their dispersal “out of India”.

Greenhouse world, high latitude dispersal and the origin of the alligatoroid Diplocynodon

Martin J.E.[1], Delfino M.[2,3], de Lapparent de Broin F.[4], Escuillié F.[5], Smith T.[6]

→ J.E.Martin@bristol.ac.uk

1 School of Earth Sciences, University of Bristol, Wills Memorial building, Queen's Road, BS8 1RJ, Bristol, United Kingdom

2 Dipartimento di Scienze della Terra, Università di Torino, Via Valperga Caluso 35, I-10125 Torino, Italy

3 Institut Català de Paleontologia, Universitat Autònoma de Barcelona, Edifici ICP, Campus de la UAB s/n, E-08193 Cerdanyola del Vallès, Barcelona, Spain

4 CR2P, Centre de Recherches sur la Paléobiodiversité et les Paléoenvironnements, Département « Histoire de la Terre » du Muséum national d'histoire naturelle, UMS 203, UMR 7207 du CNRS, CP 38, 8, rue Buffon, 75231 Paris cedex 05, France

5 Eldonia, 03800 Gannat, France

6 Département de Paléontologie, Institut royal des Sciences naturelles de Belgique, 29 rue Vautier, B-1000 Bruxelles, Belgium

A prerequisite to the understanding of the reaction of climate sensitive vertebrates across periods of unprecedented climate changes, such as the greenhouse events of the Paleocene-Eocene Thermal Maximum (PETM) and the Early Eocene Climate Optimum (EECO), requires a clarification of their systematic attribution and stratigraphic distribution. Here, we present a synthesis on the morphology and affinities of the alleged oldest *Diplocynodon* from the continental Late Thanetian of Mont Berru, Champagne, France on the basis of several cranial and postcranial remains. Recent investigations did propose an affinity with *Borealosuchus*, a basal eusuchian taxon known from contemporaneous deposits of North America. Further comparison shows that the 'Mont Berru form' does not belong to the alligatoroid genus *Diplocynodon*, although a sister group relationship with it seems to be the most parsimonious hypothesis. Additionally, the 'Mont Berru form' shares derived characters with *Borealosuchus*, making its affinities equivocal. These seemingly conflicting results highlight two issues: the phylogenetic framework at the base of the crocodilian crown group is not robust; although equivocal, there is suspicion that *Diplocynodon* from Europe and *Borealosuchus* from North America share a common ancestry. Therefore, questions related to the dispersal of freshwater organisms through the Greenland route sometime during the Paleocene comes to scrutiny, a pathway also known for mammals showing exchange between North America and Europe. Possibly, this faunal dispersal is related to favourable conditions allowing travelling through high latitudes. Therefore, did the ancestors of *Diplocynodon*, including the 'Mont Berru form' arrive from North America? Another issue comes to light: that of the tolerance of ectothermic vertebrates to greenhouse conditions. The 'Mont Berru form' occurs before the PETM and has never been reported in any European strata postdating this dramatic event. A renewal of crocodilian faunas is questionable because the majority of taxa are recovered before and after this event (e.g. *Asiatosuchus*-like taxa, small alligatorines). While prevailing warm climates expand the latitudinal distribution of ectotherms, it is also known that beyond an upper limit, high temperatures can affect their survival. However, temperature sensitivity is different from one taxon to another, for example in Europe *Diplocynodon* has survived the temperature decline of the end-Eocene while other freshwater crocodilians did not. The fossil record of crocodilians across the Paleocene-Eocene boundary is briefly reviewed and the origin of the European endemic *Diplocynodon* is discussed.

Reassessment of the diomedeoidid bird Rupelornis from the early Oligocene of Belgium and the basal divergences among extant Procellariiformes

Mayr G.[1], Smith T.[2]

→ Gerald.Mayr@senckenberg.de

1 Senckenberg Research Institute and Natural History Museum, Frankfurt am Main, Germany

2 Royal Belgian Institute of Natural Sciences, Brussels, Belgium

The Diomedeoididae represent an extinct family of Paleogene birds, which are among the earliest representatives of procellariiforms (albatrosses, tubenoses, and allies). They had a wide distribution across Europe and the Middle East in the early Oligocene, and their taxonomic history is convoluted. Although several fossils of these birds have been reported in the past years, many details of their osteology remained unknown. Here we describe a comprehensive collection of diomedeoidid fossils from the Rupelian stratotype in Belgium, which was found more than 100 years ago. The specimens include all major limb elements as well as other cranial and postcranial bones, and allow the recognition of previously unknown features of phylogenetic significance. Based on these new osteological data, diomedeoidids are for the first time subjected to a phylogenetic analysis, which resulted in a position outside a clade including Hydrobatidae, Pelecanoididae, and Procellariidae, either as sister taxon of Diomedeidae or as that of all crown group Procellariiformes. It is detailed that the latter placement is better supported by the osteological evidence and that diomedeoidids lack several apomorphies of crown group Procellariiformes. Based on the new diomedeoidid fossils *Diomedeoides lipsiensis* (Fischer, 1983) is synonymized with *Rupelornis definitus* van Beneden, 1871, a species which exhibits a large size range.

Toward an ecophyletic origin of anthropoid primates

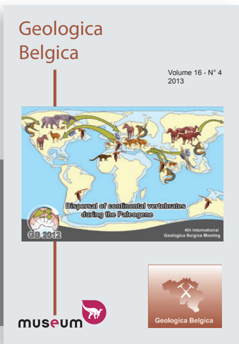
Miller E.[1], Rosenberger A.[2], Gunnell G.[3]

→ millerer@wfu.edu

1 Wake Forest University, Department of Anthropology, USA
2 Brooklyn College (CUNY), Department of Anthropology, USA
3 Duke Lemur Center, Division of Fossil Primates, USA

The purpose of this study is to develop a better understanding of the time and place of the origin of anthropoid primates, emphasizing that this origination cannot be separated from the broader context of mammalian evolution. We investigated paleobiogeographic distribution patterns of late Paleocene through middle Eocene mammals across a number of Paleogene faunal provinces, in order to evaluate competing hypotheses of anthropoid evolution. Data for these patterns came from records of animals present in five regions: East Asia (China, Thailand, Burma); South Asia (Indo-Pakistan), Europe, North America, and Africa. In general, late Paleocene faunas are broadly shared across Laurasia, while Africa was relatively isolated with only a few taxa shared in common with Eurasia and North America. In the early Eocene, strong faunal connections are maintained across Laurasia, with all provinces sharing groups such as plesiadapiforms, rodents, primitive artiodactyls, hyaenodontans, carnivores, and euprimates. Unlike Laurasia, the African early Eocene is distinctive in having strepsirhine primates, macroscelidians, hyracoids, and proboscideans, as well as unique rodents and endemic hyaenodontans. By the middle Eocene, faunal exchange across Laurasia had become more limited. Although significant interchange was still available between East Asia and North America, a pattern of increasing regional endemism is evident in all faunal provinces.

Given these faunal patterns and what is now broadly accepted concerning anthropoid evolution, the following statements can be made. Primates likely originated in Laurasia – molecular evidence indicates that the closest primate relatives are part of an Asian radiation (Dermoptera, Scandentia). Morphological and molecular analyses also suggest that the phylogenetic origin of anthropoids is deep within the primate radiation, and therefore anthropoids may also have originated in Laurasia. However, the earliest undisputed anthropoids are known from Africa and are present on that continent at least by the middle Eocene and perhaps significantly earlier (late Paleocene). Therefore, one conclusion from this study is that primitive primates must have reached Africa early in the primate radiation, with the result that any important "anthropoid" features shared between African anthropoids and middle Eocene to younger Asian forms (e.g. amphipithecids, eosimiids) must have arisen in parallel. Corroborating evidence of the existence of an early African anthropoid radiation can be found in the presence of true strepsirhines in Africa by the middle Eocene, and this requires that members of their sister-group be present in Africa at the same time or earlier. Perhaps more importantly, an ecophyletic approach emphasizes that the recognition of Laurasia as the geographic area of anthropoid origins is unsatisfactory as an explanation for the radiation and diversification of the group. We argue that it is not only cladogenesis of an anthropoid stem lineage that is important but that stochastic elements such as time and place are critical components of defining this radiation. It is not trivial information that the early anthropoid radiation took place in Africa in the early Paleogene.



Full paper in Geologica Belgica, Volume 16, n°4
Toward an ecophyletic origin of anthropoid primates
by Miller E., Gunnell G.

New material of *pseudoloris* (omomyidae, primates) from the Headonian (Late Eocene) of Spain

Minwer-Barakat R.[1], Marigó J.[1], Moyà-Solà S.[2]

→ raef.minwer@icp.cat

1 Institut Català de Paleontologia Miquel Crusafont, Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Barcelona

2 ICREA at the Institut Català de Paleontologia Miquel Crusafont, Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Barcelona

Discovered in the 1940s decade during the works in a lignite mine, Sossís (Southern Pyrenean Basin, Northeastern Spain) is one of the most important Eocene fossil sites from the Iberian Peninsula. The large amount of vertebrate material recovered from this locality has allowed the identification of more than thirty mammal taxa, including marsupials, insectivores, rodents, carnivores, creodonts, perissodactyls, artiodactyls and primates, and the assignation of the site to MP17a (Headonian, Late Eocene).

Crusafont-Pairó (1967) documented the existence of three primates from Sossís, based in all cases in few specimens. The published material consisted of two isolated teeth of a large adapine determined as *Adapis* cf. *parisiensis*, a mandible and three maxillae with several teeth ascribed to *Necrolemur erinaceus* (including erroneously the species *erinaceus* in the genus *Necrolemur* instead of in *Microchoerus*) and, finally, a right mandible with p4-m3 assigned to *Pseudoloris parvulus*. Subsequent field campaigns in this fossil site led to the recovery of a large number of mammal remains, including additional specimens of the three mentioned primates. Moreover, some of the recently discovered teeth have allowed the identification of a fourth taxon, which most probably belongs to a still undefined genus of Anchomomyini.

Here we present a preliminary report of the new material of *Pseudoloris* found in Sossís. This material consists of nine fragments of mandibles bearing several teeth, and more than eighty isolated teeth, with almost all the dental elements being represented. The population from Sossís shows clear differences with other species of *Pseudoloris* found in the Iberian Peninsula. It differs from *P. isabenae* in the absence of a tubercular paraconid in the lower molars; it can be distinguished from *P. pyrenaicus* and *P. cuestai* by the smaller size, the lower and sharper paracristid in the lower molars and the better developed hypocone in the M1 and M2, and it differs from *P. godinoti* in its much smaller size and the absence of distinct paraconid in the lower molars. Further detailed study of the material from Sossís and comparisons with other European samples of *Pseudoloris parvulus* will allow confirming this specific determination and will shed light on the relationships between the different species of this genus that inhabited Europe from the Middle Eocene to the Early Oligocene.

Crusafont-Pairó M. (1967). *Sur quelques prosimiens de l'Eocène de la zone préaxiale pyrénaïque et un essai provisoire de reclassification. In:* Evolution des Vertébrés, Colloque International du Centre National de la Recherche Scientifique, n°163, pp 611-632.

Crossing epoch and international boundaries: The earliest Eocene Erquelinnes mammal fauna from the Mons Basin and its correlation

Missiaen P.[1,5], Quesnel F.[2], Dupuis C.[3], Storme J.-Y.[4], Smith T.[5]

→ Pieter.Missiaen@ugent.be

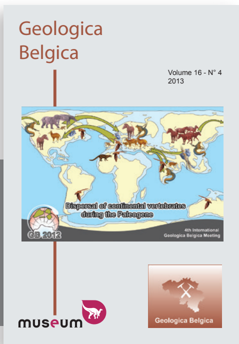
1 Ghent University, Department of Geology & Soil Science, Belgium
2 BRGM, GEO/G2R, France
3 UMons, Faculté Polytechnique, Belgium
4 FUNDP, Department of Geology, Belgium
5 Royal Belgian Institute of Natural Sciences, Department of Palaeontology, Belgium

In 1880, the fluvial “Upper Landenian” deposits (Tienen Formation) of the Erquelinnes sand quarry in the southern part of the Mons basin near the Belgian-French border yielded their first mammal fossil, a well preserved jaw of a primitive perissodactyl. By 1927, about 40 mammal specimens had been found at Erquelinnes and had been attributed to *Adapisorex*, ‘*Protomomys*’, *Paramys*, *Plesiadapis*, *Arctocyonides*, *Hyracotherium*, *Coryphodon* and ‘*Oxyaena* or Miacidae’. By that time however, the Erquelinnes fauna had already been eclipsed by the contemporaneous Dormaal fauna from northeastern Belgium, which yielded thousands of specimens and has since become the international MP7 reference level for the earliest Eocene of Europe. Meanwhile, attention for the Erquelinnes fauna has been limited to passing mentions of referred specimens in the formal descriptions of the new plesiadapiform *Platychoerops georgei* and of the miacid carnivoran *Gracilocyon solei*.

Here we present an updated faunal list for the complete Erquelinnes mammal fauna. We show that also hyaenodontids, mesonychids, hyopsodontids, and dichobunid artiodactyls are present, and some of the earlier identifications are corrected or detailed further. This update of the Erquelinnes mammal fauna almost doubles its diversity, and strengthens the correlation with the Dormaal MP7 reference fauna.

The results of the $\delta^{13}C_{org}$ analysis of the strata underlying and coeval with the fluvial unit containing the Erquelinnes mammal fauna seem to independently support the faunal correlation and earliest Eocene age Sedimentological observations and $\delta^{13}C_{org}$ analysis recently obtained in fluvial and lignitic sediments from the nearby Avesnois area in northern France (Quesnel et al, this meeting) moreover allow the correlation of the “Upper Landenian” fluvial deposits from the Belgian Erquelinnes locality with those of the “Sparnacian” in France.

Remaining faunal differences between Erquelinnes and Dormaal are most likely the result of subtle differences in depositional environments and thus in taphonomic bias except, possibly, for the perissodactyl jaw collected in 1880. This specimen was not collected from the basal gravel bed of the Erquelinnes Sand Member like all other specimens, but from the overlying, cross-stratified sands. Iits morphology is unlike that of the perissodactyl found in the basal gravel bed at Erquelinnes or of any other Dormaal aged perissodactyl. Instead, it matches *Cymbalophus cuniculus* from slightly younger deposits in the London Basin. The perissodactyl jaw from Erquelinnes therefore either indicates an earlier first appearance for *Cymbalophus*, an unexpectedly long phase of deposition for the Erquelinnes Sand Mbr, or a combination of both.



Full paper in Geologica Belgica, Volume 16, n°4
The earliest Eocene mammal fauna of the Erquelinnes Sand Member near the French-Belgian border
by Missiaen P., Quesnel F., Dupuis C., Storme J.-Y., Smith T.

Early Palaeogene vertebrate-bearing deposits in Cambay and Kutch Basins, India: A review of foraminiferal biostratigraphy and strontium isotope stratigraphy

Saraswati P.K.

→ pratul@iitb.ac.in

Department of Earth Sciences, Indian institute of Technology, Mumbai, India

The Palaeogene sediments overlie Deccan basalt in Cambay and Kutch basins in India. The succession is marginal marine, clastic in Cambay and a largely marine, mixed carbonate siliciclastic in Kutch. A diverse assemblage of fossil vertebrates, including mammals, is reported from the lower part of the sequence, broadly referred to Early Eocene, in both the basins. The significance of these findings on vertebrate evolution, particularly in reference to the isolation of the drifting Indian subcontinent and the globally known period of hyper-thermal events, calls for a better estimate of age of the vertebrate-bearing horizons. Some recent studies have tried to constrain the age on the basis of improved biostratigraphy and Sr isotope stratigraphy. In the Cambay basin, the mammal-bearing formation, known as Cambay Shale, is assigned to the shallow benthic zone SBZ 10, on the basis of the presence of foraminifera *Nummulites burdigalensis burdigalensis* and *N. burdigalensis kuepperi*. The strontium isotope data constrain the age between 53.8 and 54.3 Ma and the organic carbon $\delta^{13}C$ excursion recorded in this section has been justifiably referred to ETM2. The vertebrates are also recorded from stratigraphically equivalent Naredi Formation in Kutch. The Naredi Formation in the type locality is assigned to SBZ 8 to SBZ 11. A somewhat extended section has recently been recorded from a borehole and its basal part, immediately overlying the Deccan basalt, is referred to SBZ 6 on the basis of the assemblage *N. solitarius, N. fraasi* and *N. burdigalensis kuepperi.* The biostratigraphically constrained Sr isotope values indicate that the age of the Naredi Formation ranges from 50 to 55Ma. The hitherto reported vertebrate fauna from both the basins in western India thus appear to be post-PETM.

New data on the Early Eocene lizards from Vastan Lignite Mine, Gujarat, India

Rana R.S.[1], Folie A.[2], Augé M.[3], Rose K.D.[4], Kumar K.[5], Singh L.[1], Sahni A.[6], Smith T.[2]

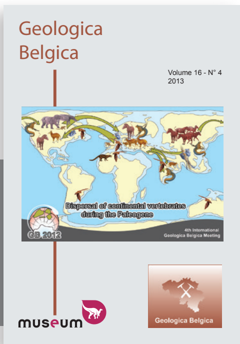
→ Rajendra.Rana1@gmail.com

1 H.N.B. Garhwal University, Srinagar, India
2 Royal Belgian Institute of Natural Sciences, Brussels, Belgium
3 Muséum national d'histoire naturelle, Paris, France
4 Johns Hopkins University School of Medicine, Baltimore, U.S.A.
5 Wadia Institute of Himalayan Geology, Dehradun, India
6 Lucknow University, Lucknow, India

The lower Eocene (Ypresian) Cambay Shale Formation at Vastan Lignite Mine, located northeast of Surat in Gujarat, western India, has yielded a rich vertebrate assemblage including the earliest modern mammals and oldest birds of the Indian subcontinent. Among the herpetological faunas, snakes, lizards and amphibians are abundant, but strangely, lizards are only represented by agamids. Two species, *Vastanagama susani* and *Tinosaurus indicus*, have already been described.

Here we present new data on the Vastan lizards based on numerous isolated remains including nearly complete dentaries, premaxillaries, and maxillaries. At least four taxa are recognized. *Vastanagama susani* is represented by well-preserved dentaries presenting the following diagnostic characters: a large symphyseal facet, three anterior pleurodont teeth followed by acrodont teeth presenting a main cusp bordered by two lateral crests. The original material described in 2008 was based on anterior parts of three dentaries so that only the first anterior teeth have been described. The new material indicates that teeth of *V. susani* increase in size posteriorly toward the coronoid process. *Tinosaurus indicus* is characterized by the presence of a subdental ridge between the tooth row and the Meckelian canal, pleurodont symphyseal teeth with one of them that can be caniniform, and acrodont and tricuspid posterior teeth on which the lateral cusps are poorly differentiated. Two other taxa represent two new genera and species. The first taxon presents multicuspid acrodont teeth with the main cusp surrounded by two or three progressively smaller lateral cusps. The second taxon presents pleurodont anterior teeth followed by a few acrodont teeth and ending with three or four subacrodont teeth near the coronoid process.

Our results confirm that Agamidae (assigned to the Acrodonta) is the only lizard group present in Vastan, whereas many other groups are already present from the Early Eocene on the other continents. Agamidae is considered to have had a Gondwanan origin, with 52 genera and 420 species of extant agamids known from Asia, Australia, Africa and a few from Southern Europe. The oldest occurrence of formally recognised Acrodonta is found in the Jurassic of India. Other fossil agamids are known in the Upper Paleocene of Kazakhstan, Paleocene and Eocene of China, Early Eocene of Europe, Eocene of North America, and Middle Eocene of Pakistan. The diversity of the agamids in India and the absence of other lizard groups in Vastan tentatively support the Out-of-India hypothesis for agamids.



Full paper in Geologica Belgica, Volume 16, n°4

High diversity of acrodontan lizards in the Early Eocene Vastan Lignite Mine of India

by Rana R.S., Folie A., Augé M.

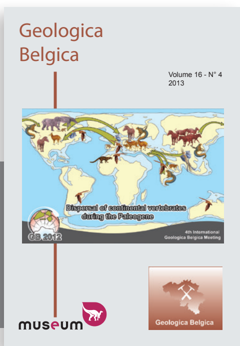
A land micro-mammal fauna from the early Eocene marine Egem deposits (NP12, Belgium) and the first occurrence of the peradectid marsupial Armintodelphis outside North America

Smith T., Smith R.

→ thierry.smith@naturalsciences.be

Royal Belgian Institute of Natural Sciences, Brussels, Belgium

Dental remains of land mammals are sometimes discovered in shallow marine Paleogene deposits of the North Sea Basin and they can then be used for biostratigraphic correlations. Such is the case for ten specimens we describe here from the early Eocene Egemkapel Member in the lower part of the Tielt Formation, found in the Egem quarry (West Flanders, Northwestern Belgium). The small fauna consists of 5 taxa, including the multituberculate *Neoplagiaulax*, the erinaceomorph insectivore *Macrocranion*, the nyctitheriid *Leptacodon*, a primitive eochiropteran bat and a new species of the peradectid marsupial *Armintodelphis*. The latter represents the first European occurrence of a genus that was previously only known from two species, *A. blacki* and *A. dawsoni*, from the late early Eocene Wind river Formation of Wyoming in North America. Biogeographical and biostratigraphical analysis of peradectid marsupials allows us to suggest that the genus migrated from North America to Europe around the time of the Early Eocene Climatic Optimum. The Egemkapel Member has been dated as middle NP12, early late Ypresian, whereas the Egem mammal fauna can be correlated to the fauna of Avenay from the Paris Basin, which is the international reference-level MP8+9 of the mammalian biochronological scale for the European Paleogene. Taphonomical analysis explains the presence of land micro-mammals in marine layers either through the action of predatory sea birds or through fluvial transport. The large quantity of shark and ray teeth discovered together with the micro-mammal teeth indicates an additional concentration effect of the material in the marine deposit.



Full paper in Geologica Belgica, Volume 16, n°4

A land micro-mammal fauna from the Early Eocene marine Egem deposits (NP12, Belgium) and the first occurrence of the peradectid marsupial Armintodelphys *outside North America*by

by Smith T., Smith R.

Dispersals of the placental carnivorous mammals (Carnivoramorpha, Oxyaenodonta & Hyaenodontida) around the Paleocene-Eocene boundary: an almost worldwide story

Solé F.

→ fsole@naturalsciences.be

Royal Belgian Institute of Natural Sciences, Department of Paleontology, Belgium

During the Late Paleocene and around the Paleocene-Eocene boundary, there were important mammalian dispersals in Laurasia involving "modern" mammals such as primates, perissodactyls, and artiodactyls. The placental carnivorous mammals, which are represented by several groups during the Paleogene and represented important components of the ecosystems, importantly took part in these dispersals.

The different groups of carnivorous placental mammals appeared convergently during the Paleocene: the Hyaenodontida probably appeared in Africa, the Oxyaenodonta and Viverravidae in North America, and the "Miacidae" probably in Asia. The fossils show that all these groups were importantly diversified since the Middle and Late Paleocene.

However, the first evidences of dispersals of placental carnivorous mammals date from the Late Paleocene (Figure 1A). Because, the different genera of carnivoramorphan "miacids" appeared about the same time in North America and Europe, the "miacids" probably dispersed from Asia in two different ways: to Europe and to North America. The presence of the carnivoramorphan viverravids in Late Eocene of Asia evidenced a dispersal between North America and Asia. Finally, the presence of Limnocyoninae (subfamily of Hyaenodontida) in the Late Paleocene of Asia raises problems because it supposed dispersal between Africa and Asia.

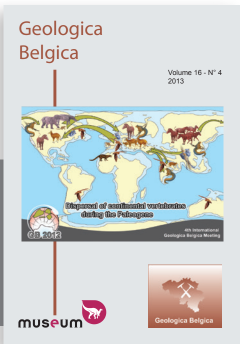
Besides new dispersals of the Viverravidae and "Miacidae" into Laurasia, the Paleocene-Eocene boundary is characterized by the dispersals of both Hyaenodontida and Oxyaenodonta (see figure B). Several hyaenodontidans dispersed from Africa to Europe, and then to North America and to Asia. The Limnocyoninae dispersed from Asia to North America. The Oxyaenodonta dispersed from North America to Europe and to Asia. The dispersals that occurred around the Paleocene-Eocene boundary thus show a more complex pattern than those that occurred during the Late Paleocene (see figure).

These dispersals lead to a homogenization of the carnivorous fauna in Laurasia: indeed Oxyaenodonta, Hyaenodontida, Viverravidae and "Miacidae" are present in the three Laurasiatic landmasses. Only Africa remains apart; indeed the carnivoramorphans did not disperse to Africa before Late Oligocene: the Hyaenodontida thus are the sole carnivorous mammals in this area during the major part of the Paleogene.

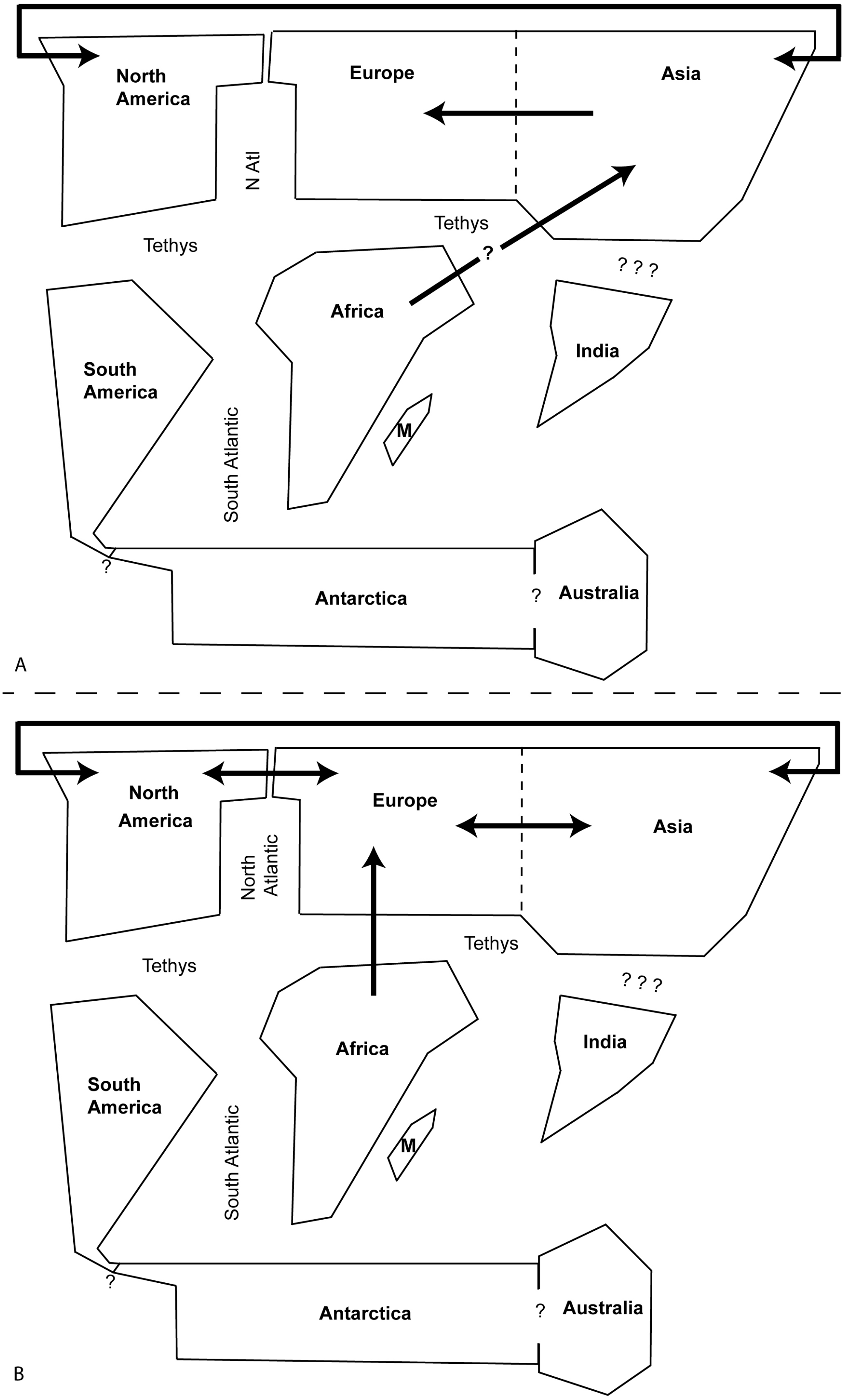
After the two important periods of faunal exchanges, the carnivorous mammals show endemic evolution on each continent. This period ended around the Late Eocene.

It is worth noticing that the placental carnivorous mammals dispersed as soon as the climatic events favoured dispersals. The Paleocene-Eocene Thermal Maximum (PETM) notably triggered these migrations by favouring the establishment of temporary land bridges and of a continuous evergreen forest belt at high latitudes.

Finally, the placental carnivorous mammals evidenced several dispersal ways into Laurasia, but also into Africa and India, and their dispersals thus present a very complex pattern.



Full paper in Geologica Belgica, Volume 16, n°4
Dispersals of placental carnivorous mammals (Carnivoramorpha, Oxyaenodonta & Hyaenodontida) near the Paleocene-Eocene boundary: a climatic and almost worldwide story
by Solé F., Smith T.



Faunal dispersals illustrated by the carnivorous mammals at the Late Paleocene (A) and P/E boundary (B). Abbreviations: ? = uncertain connections.

Session 09

Micro-organisms, palynomorphs and paleogeography

Chairmen: Stephen Louwye & Volker Wilde

Palaeoenvironments and palaeoclimate records at the Eocene-Oligocene Transition from the Rennes Basin, France. New insight from de CDB1 borehole (CINERGY project).

Bauer H.[1], Châteauneuf J.J.C.[2], Bourdillon C.[3], Saint-Marc P.[4], Guillocheau F.[5]

→ h.bauer@brgm.fr

1 BRGM, 3 avenue Claude Guillemin, 45060 Orléans Cedex 2, France.

2 8 quai du Châtelet, 45000 Orléans, France.

3 ERADATA, 170 avenue Félix Geneslay 72100 Le Mans, France.

4 SEMM LOGGING, Les Maufras - 18360 Vesdun, France

5 Université de Rennes 1, UMR 6118 Géosciences Rennes, Campus de Beaulieu, 35042 Rennes Cedex, France.

On behalf the CINERGY project, a 675m-long borehole was cored through the sedimentary column (405m), then the weathered basement (120m) and finally the fresh bedrock (150m).

The studied interval encompasses 3 lithostratigraphic units, from 66m to 405m depth. The chronostratigraphic framework of the sedimentary series relies on benthic foraminifera and palynology. Palaeoenvironmental reconstruction is based on sedimentology, pollen analysis and clay mineralogy.

The *Natica* Marls Fm (66-85m) is a lagoon-marine unit exhibiting metric sequences from restricted bay to salt marsh (schorre). Pollen grains, Mollusks and Dinocysts assemblages give a Rupelian age.

The Lower Sapropels Fm (85-375m) is the thickest unit and exclusively made of lacustrine and palustrine clay deposits. Clays are either thinly laminated (varve-like) or massive, blocky with pedoturbation, alternating in thick (20-40m) sedimentary sequences. Both facies show varying organic content, up to 40% TOC. Pollen assemblages show a bimodal repartition between the laminated and massive facies. The former are interpreted as an open lacustrine system and the latter, as a closed lacustrine system whose floating mats vegetation, characterized by papyrus and lotus is typical of permanent flooded areas.

The first occurrence of the Early Rupelian marker *B. hohli* is observed at 195.13m. The pollen assemblage observed 30cm beneath at 195.42m is typical of the uppermost *Ludian* from the Paris Basin, equivalent to the Late Priabonian. The Eocene-Oligocene boundary could coincide with a facies change in between laminated and massive clays at 195.26m.

The Eocene-Oligocene Transition is thus recorded in a detailed, continuous depositional environment.

The basal sandy clays Fm (375-405m) correspond to alternating sandy and clayey deposits. Depositional environments range from fluvio-lacustrine to fluvio-marine settings with occasional mangal development as attested by *Avicennia*.

The formation is assigned to the Bartonian by benthic foraminifera and palynology. The lowermost samples yielded a characteristic pollen assemblage of the *Biarritzian*, which is equivalent to the Early-Middle Bartonian. Rare reworked foraminifers from the Late Cretaceous were also found in these samples.

The palynological record shows a gradual palaeoclimate change from the basal sandy clays upwards. The Bartonian is quite similar to the Lutetian of the Paris Basin, with a warm and humid “tropical” climate. The Early Priabonian, up to 278m, is still under humid and warm conditions, but development of herbaceous vegetation attests for a slight seasonality. During the Late Priabonian (above 206m), a large development of Pinaceae coeval with a decrease in megathermic flora points to the EOT major climatic change. Indeed, Early Rupelian assemblages show even greater percentages in Pinaceae (above 50%) despite a steady lacustrine environment. The very last megathermic elements disappear at the base of the *Natica* Marls Fm.

The clay mineralogy evolution looks more abrupt. The clay assemblage from the Bartonian to the Late Priabonian is fully kaolinitic. The Early Rupelian assemblage is still dominated by the kaolinite but chlorite-smectite appears in a significant amount (up to 60%). Whether the sudden mineralogical change across de E/O boundary is related to a change in source material or to a change in the hydrolysis in soil clay production, a climatic origin is very likely.

A climate model from 200 AD to 1200 AD for the Hautes Fagnes plateau (Belgium), based on pollen grains, testate amoebae, and humification analyses

GB 2012 Contestant for Best Poster Presentation

Beghin J., Gerrienne P., Javaux E., Streel M.

→ Jeremie.Beghin@doct.ulg.ac.be

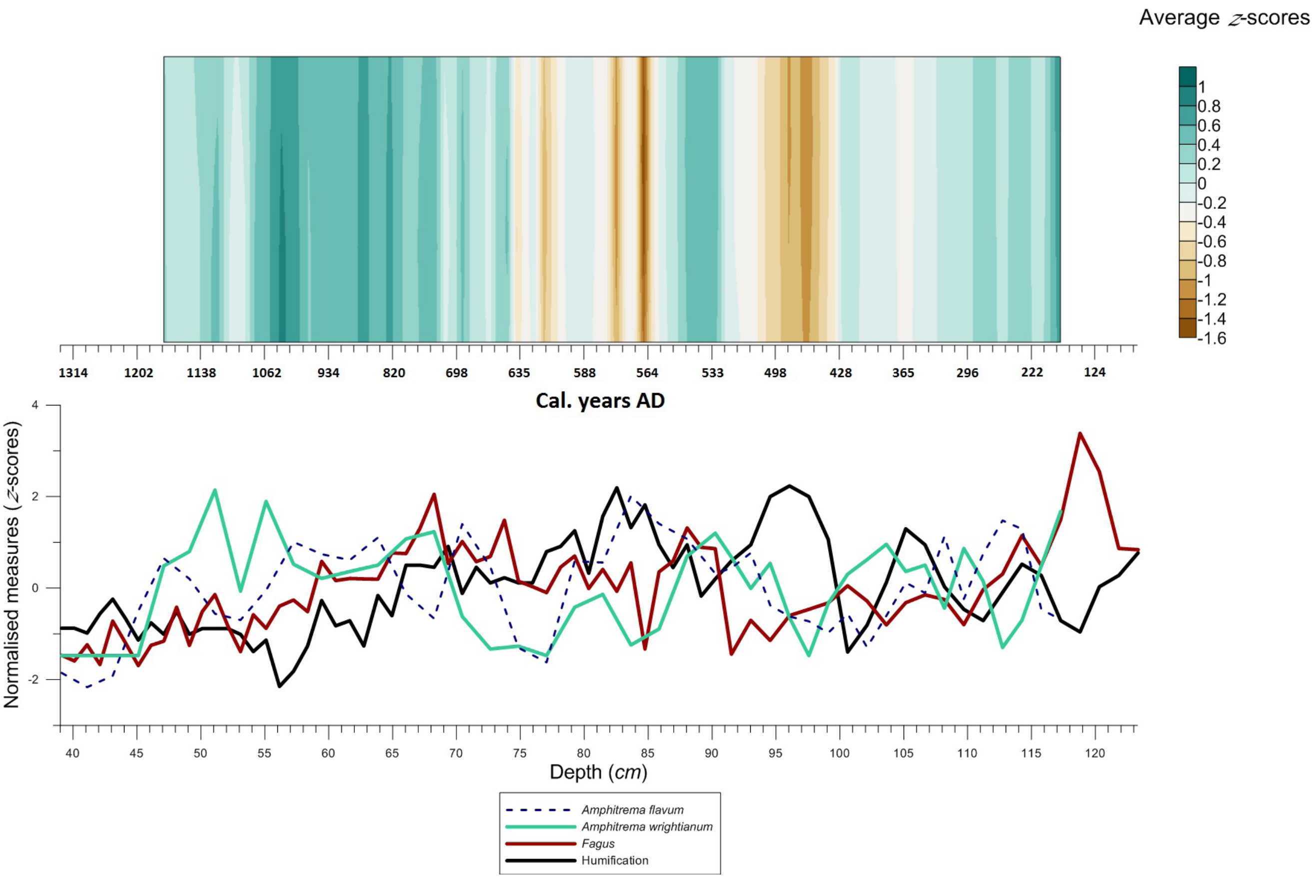
Palaeobiogeology-Palaeopalynology-Palaeobotany, Dept. of Geology, University of Liège, Belgium

The Misten bog is located on the Hautes Fagnes plateau (eastern Belgium). It includes thick peat deposits with more than 7 m of peat accumulation in ombrotrophic situation. Several palaeoclimatic and/or palaeohydrological proxies such as pollen grains, S*phagnum* remains, and testate amoebae have been fossilized under anoxic conditions. Several peat cores were extracted from the bog for a project conducted by the University of Liège and the field laboratory of the Hautes Fagnes (De Vleeschouwer *et al.,* 2010). The peat was cored using a Wardenaar corer for the top first meter and a Belarus corer for the layers below. The lateral distance between cores 01 and 07, which are considered in this paper, is 1.5 m. The highest (youngest) parts of the Belarus sections of cores 01 and 07 were correlated by means of pollen.

An age-depth model was elaborated for the 01 core using ^{14}C AMS dating and was calibrated with the IntCal09 radiocarbon age calibration curve. Our pollen analysis was combined with the results of the preliminary study in order to obtain a continuous high-resolution (≈ 1 cm for the Wardenaar monolith and 1.5 cm for the Belarus section) profile, representing approximately one thousand years. The degree of peat humification was measured by spectrophotometry. The degree of peat humification of core 01 was compared with the pollen diagram. We also analyzed the relative abundance of species of testate amoebae of the Wardenaar section of core 01 and of the Belarus section of core 07.

Taxa indicative of wet conditions or high water table are *Fagus* in the palynological assemblage and, *Amphitrema wrightianum* and *Amphitrema flavum* in the testate amoebae populations. Low humification was also considered, in first approximation, as being linked to high water table level. On the basis of (i) the diagrams of the relative abundance of these three taxa, and (ii) the results of humification, we constructed a *palaeo-hydroclimatological model (Fig. 1: lower graph)* from 200 AD to 1200 AD. In that model, the four records have been standardised using *z*-scores ($z_i = (x_i - \mu)/\sigma$), ($i = 1,\dots, n$). The upper graph shows the climatic "average *z*-scores" that we used to divide the studied time span in wetter (blue) and drier (brown) climatic phases.

According to the model, the maxima and minima "average *z*-scores" represent respectively wet and dry climatic conditions during the Subatlantic stage.



Reconstruction of Subatlantic Misten bog surface wetness (BSW) using three proxies: color gradient from brown (dry) to blue (wet).

De Vleeschouwer F., Luthers C., Streel M., Fagel N., Gerrienne P., Javaux E., Wastiaux C., Leclercq L. (2010). *Recherche d'intérêt général et pluridisciplinaire relative aux modalités de l'accumulation récente de la tourbe dans la tourbière ombrogène du Misten (Hautes-Fagnes) en relation avec les changements climatiques et les effets des activités humaines*. Convention SPW (DGOARNE) – ULg (SSHF), Visa 08/13701, unpublished. Available on http://etat.environnement.wallonie.be/index.php?page=etudes-detaillees (ref. July 6, 2010).

Late Holocene human activities/climate interactions and biodiversity evolution in mountainous areas (French Alps): Pollen-based quantitative reconstructions

Court-Picon M.[1], Ortu E.[2], Correa-Metrio A.[3], Guiot J.[4], de Beaulieu J.-L.[5]

→ mona.courtpicon@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Department of Palaeontology, Belgium

2 EPOC, UMR CNRS 5805, Université Bordeaux 1, France

3 Instituto de Geología, Universidad Nacional Autónoma de México, México

4 CEREGE, UMR CNRS 6635, Europole Méditerranéen de l'Arbois, Aix-en-Provence, France

5 IMEP, UMR CNRS 6116, Europole Méditerranéen de l'Arbois, Aix-en-Provence, France

The period since the emergence of humans has displayed an ongoing biodiversity reduction named the Holocene extinction. Caused primarily by human impacts and climate change, this reduction is increasingly growing and has become a reason of global concern. In Europe, mountainous vegetation is prized as sources of high biodiversity and has been shown to be particularly sensitive to human action and climate changes. Otherwise palynological data represent the most widely available quantitative record of past environments and are an efficient tool for the reconstruction of vegetation and its responses to anthropogenic disturbances and/or abrupt climate changes. Mountainous pollen sequences therefore represent ideal archives for the study of the effects of past climate change and land-use on biodiversity over time scales that go beyond human life span. Within this framework, this work proposes to reconstruct the history of the landscape in the Champsaur Valley (French Alps) during the last 3400 years by means of a multidisciplinary approach. We also try to explain how and to which degree biodiversity have been affected by complex human/climate relationships.

For that purpose, two high resolution pollen and NPPs records have been produced, one situated at the bottom of the valley and the other in the montane belt. They show in detail the local vegetation and human occupation history in two different types of topographic environments, covering the last 2000 and 3400 years respectively. Palynological richness and several diversity indexes have also been calculated for these sequences in order to reconstruct the evolution of biodiversity at the two different locations. On the other hand, modern pollen data and vegetation surveys from 49 sites, selected within different environmental and land-use contexts in the Champsaur Valley, were used to create a pollen-based transfer-function to quantify the pasture pressure, which has been the major human activity in the alpine valleys throughout the Late Holocene. Its application to the two well-dated pollen sequences allowed reconstructing the evolution of pasture-pressure through time. The pollen-based reconstructions were compared with changes in percentages of palynological and NPP pastoral indicators, but also with archaeological and historical evidences for the region. Comparisons show a good correlation but differences in the inferred intensity of the pastoral pressure. Pollen and NPPs assemblages, as well as biodiversity indexes and the pasture pressure estimated by our model, were also related to the Holocene climate variable, inferred from independent proxies such as lake level fluctuations and evolution of glacier advance. All the data underline a continuous human presence surrounding the two sites since the Antiquity, with a peak in pollen diversity during the Medieval Warm Period. On the contrary, an unprecedented fall of diversity is recorded at the beginning of the climate deterioration of the Little Ice Age. Data suggest that the interaction between human activities and climate changes produced important transformations in the composition of the local flora, resulting in a weakened ecosystem highly dependent on Human cares and more sensitive to climate variability.

Palaeogeographic insights from differences among Upper Cretaceous palynological record of the Iberian Central System and south-eastern Pyrenees (Spain)

Fernández Marrón M.T.[1], Gil Gil J.[2]

→ emarron@geo.ucm.es

1 Instituto de Geociencias (CSIC-UCM), Facultad de Geológicas. 28040 Madrid (Spain);

2 IBERCRETA Research Team, Área de Estratigrafía, Depto. Geología. Universidad de Alcalá. 28871 Alcalá de Henares, Madrid (Spain)

Upper Cretaceous palynological assemblages known from two areas of the Iberian Peninsula, now distant about 500 km are compared in order to analyze the differences detected.

A southerly area, the Southern margin of the Guadarrama Mountains, in the Iberian Central System, formed by inner carbonate platform dated as Upper Santonian - Lower Campanian and a northerly area in the South-central Pyrenees dated as Campanian to upper Maastrichtian by means of correlations with more marine deposits.

The palynological assemblages from the uppermost Cretaceous of the Southern Guadarrama are mainly composed by Dicot Angiosperms producing abundant Normapollen-type pollen (*Oculopollis, Trudopollis, Papillopollis, Vacuopollis, Interporopollenites*). They are associated to abundant Conífers (*Araucariacites, Classopollis*). The spores are scarce and Dinocysts appears only exceptionally. The dominance of Dicots in relation to Conifers, the significant presence of *Classopollis* (pollen from the Cheirolepidaceae *Frenelopsis*, also frequent in the macroremain assemblages), the rarity of ferns and the absence of algae suggest a forested landscape in the emerged lands of a coastal-littoral margin.

The palynological assemblages from the uppermost Cretaceous of the northerly area (South-central Pyrenees) are dominated by lycopods and ferns, mostly trilete spores (*Leiotriletes, Cyathidites, Biretisporites, Polypodiaceoisporites, Zlivisporis, Gabonisporis*, etc.) Pollen of cycads is well represented, as well as those of Araucariaceae, Pinaceae and Taxodiaceae. The angiosperms are scarce but rather diversified, with only exceptional Normapolles. Some palynological assemblages have a significant number of zygospores from freshwater algae or marine phyto- and zooplancton remains. The dominance of Lycophyta – Pteridophyta in relation to Angiosperms suggests a wet warm evergreen subtropical forest in a lagoonal – marginolittoral landscape, where Laurasian and Gondwanian elements coexist. Therefore, they are the remarkable differences in their palynological assemblages, regardless the chronological difference in the palynological record of these two areas.

The abundance of Cheirolepidaceae *Classopollis* in the Guadarrama flora and its rarity in the Pyrenean flora, the Gondwanian influence in the northerly Pyrenean flora, more similar to the other cretaceous assemblages of the Africa (El Kef, Tunisia), and its absence in the southerly Guadarrama flora with abundant Normapolles–type pollen grains and palynomorphs characteristic of the Upper Cretaceous Normapolles province European flora, like Gulpen and Maastricht Formations pollen assemblages, suggest a change in the palaeogeographic connection between Basque-Pyrenean (N) and Tethyan (S) domains, episodically materialized through the Iberian basin (nowadays, Iberian Range) until the Santonian. The gondwanian influence of Pyrenean flora as well as the existence of aquitano–Pyrenean rudist faunas in upper Maastrichtian successions of the Prebetic area (S Valencia) suggest that the connection between both Atlantic and Tethyan domains remained effective during Campanian–Maastrichtian time through the Levantine–Catalonian Basin, located between Ebro and Corso–Sardinian Massifs. Moreover, the presence of warm tethyan currents into the Pyrenean Basin would have favored the prevalence of wet warm subtropical littoral ecosystems at higher latitudes than those of the Iberian Central System.

Pragian to Lower Givetian Conodont Biostratigraphy and Conodont Apatite $\delta^{18}O$ Results of the Grand Tower and Saint Laurent Formations: Southern Illinois Basin-Reel Foot Embayment (Illinois, USA)

Gouwy S.A.[1], Day J.E.[2], Macleod K.G.[3]

→ sofiegouwy@yahoo.com

1 Department of Palaeontology, Royal Belgian Institute of Natural Sciences, Belgium

2 Department of Geography - Geology, Illinois State University, Campus Box 4400, Normal, IL 61790-4400, USA

3 Department of Geological Sciences, University of Missouri-Columbia, Columbia, MO 65211, USA

New studies of conodonts from three Devonian sections from the Southern Illinois Basin-Real Foot Embayment (Illinois, USA) refine interregional biostratigraphic correlations and constrain paleoenvironmental variation. Samples were collected from the type area of Grand Tower (Jackson County, Ill.) and the White County Core (White County, Ill.) and indicate the sections include older material than shown in an earlier study which placed Emsian-Eifelian and Eifelian-Givetian boundaries at or near the contacts of the Clear Creek-Grand Tower and the Grand Tower-St. Laurent Formations, respectively (Orr, 1964 and Collinson *et al.*, 1967).

New data reveal a Pragian age for the upper part of the Clear Creek Formation in White County based on the presence of *Latericriodus claudiae* and *L. steinachensis* typical of the *kindlei* and *sulcatus* zones. In addition, the lower 7 m of the overlying Dutch Creek Member (sandy grainstones) of the Grand Tower Formation contain *L. nevadensis*, *L. alces* and *L. robustus* characteristic of the Upper Emsian (*serotinus* Zone). The appearance of *Polygnathus partitus* 7 m above the base of the Dutch Creek Member pinpoints the base of the *partitus* Zone at this level. In the upper portion of the Dutch Creek Member, the *costatus* Zone (lower Eifelian) is recognized based on the first appearances of *Icriodus orri*, *I. angustus* and *I. stephensoni*. The overlying "upper Member" (skeletal wackestones and packstones) of the Grand Tower Formation is bracketed by marine flooding surfaces but contains a conodont fauna dominated by the same Eifelian *Icriodus* species as in uppermost Dutch Creek Member. The appearances of *P. pseudofoliatus* a few meters above the base of the "upper Member" and *I. calvini* at one third from the top of the Grand Tower Formation fix the bases of the *australis* and *kockelianus* zones respectively. The index species for the *ensensis* zone was not found. The overlying St. Laurent Formation (fossiliferous argillaceous wackestone) has a lowermost Givetian age based on the identification of *I.* aff. *I. obesus* in the Grand Tower section, and the appearance of *P. timorensis* and *P. xylus* in the lower part of the Saint Laurent Formation mark the base of the *timorensis* Zone.

Oxygen isotope analysis of apatite of Icriodid P_1 elements gives $\delta^{18}O$ values ranging between 17.4 and 21.2 ‰V-SMOW through the section. Within the upper Grand Tower Formation, $\delta^{18}O$ values decrease by 4‰ then increase by 2.5‰. In the overlying St. Laurent Formation, values decrease by 1‰. If solely due to temperature, these values would suggest very large temperature swings with warming of up to 16°C during the middle Eifelian followed by an 11°C cooling in the Late Eifelian and 4°C warming in the Early Givetian. The magnitude of these changes argue temperature alone does not control observed isotopic variability, and we propose significant changes in the isotopic composition of Eifelian and Early Givetian seawater, perhaps related to sea level variations, occurred in the southern Illinois Basin.

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The diversification of early eukaryotes

Javaux E.J.

→ ej.javaux@ulg.ac.be

Palaeobiogeology-Palaeobotany-Palaeopalynology, Department of Geology, University of Liège, Belgium

The origin of the domain Eucarya is not constrained and limited to debated Archean biomarkers. Unambiguous eukaryotic microfossils only appear around 1.8 Ga in the fossil record. Recent geochemical and biological studies suggest that early eukaryotes did not require as much oxygen as previously thought, implying the possibility of an earlier origin. Comparative morphology, wall ultrastructure and microchemistry of acritarchs, filamentous and multicellular microfossils allow the identification of early eukaryotes, permitting to date their order of branching and to calibrate molecular phylogenies. The pattern and timing of eukaryotic diversification and biological innovations (with or regardless of taxonomy) can then be examined, as well as hypotheses regarding their possible biological, ecological, and environmental causes.

I recently proposed a macro-evolutionary pattern of diversification for early eukaryotes, divided into three steps involving different taxonomic levels (Javaux, 2011). During Period I (?-1.8 to ~1.1 Ga), moderately diverse (mostly stem) eukaryotes appeared, showing evidence for a recalcitrant wall, a flexible lipid membrane, and a cytoskeleton. Assemblages of acritarchs from marine sediments of Australia, India, North China, the USA, and Siberia, are mostly similar. During Period II (~1.1 to 0.63 Ga), a key diversification occurred at the supergroup level, in mildly oxygenated shallow-water above sulfidic and/or ferrous anoxic deep waters, and coincided with major environmental changes, including the formation and fragmentation of the supercontinent Rodinia and low-latitude glaciations. More diversified but again broadly similar assemblages preserved in Australia, Baltica, Canada, Congo, India, North China, the USA, Siberia, Spitsbergen and West Africa included members of all extant supergroups (but one) and unidentified eukaryotes. Notable exceptions include the multicellular Bangiophyte red algae (the oldest eukaryotes that can be related to an extant clade) from the Hunting Fm of Somerset Island, arctic Canada; and biomineralized protist scales from the Lower Tindir Gp, Alaska and Yukon. Major biological innovations consisted of eukaryotic multicellularity, cellular differentiation, sex, biomineralisation, heterotrophy, photosynthesis, and freshwater adaptation, leading to ecological tiering and complex food webs and interactions. During Period III (0.63–0.54 Ga), a second diversification occurred, this time within the supergroups. The Ediacaran recorded highly diversified acanthomorph acritarchs, microscopic animal embryos and encysting protists, macroalgae, the macroscopic Ediacara fauna and mineralized metazoans. Complex multicellularity and animal biomineralization and predation evolved in spreading oxygenated niches, leading to more complex ecosystems and diversification within supergroups. Provincialism is reported from the Ediacaran, although the limited phenotypic diversity of the older assemblages may have masked genotypic heterogeneity. More gentle preparation of material and ongoing microchemical and ultrastructural analyzes may also reveal higher diversity in the future. However, much remains to be done to refine deep time paleogeographic reconstructions, to increase sampling of the Precambrian marine and terrestrial record, and to determine the ecology and evolution of early eukaryotes.

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Towards a standard calpionellid zonation of the Mediterranean Realm (Tithonian to Valanginian)

Lakova I., Petrova S.

→ lakova@geology.bas.bg

Geological Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria

1. Objectives and methodology.

The intensive recent calpionellid studies in many regions of the Early Cretaceous Mediterranean Realm led to accumulation of comprehensive and precise record of successive calpionellid bioevents in the time interval from the mid-Tithonian to Lower Hauterivian. These bioevents are often directly correlated to ammonite zonations, magnetic polarity chrons and the evolutionary events in calcareous nannofossils and calcareous dinoflagelate cysts. Calpionellid zonation is crucial in detailed subdivision of early Lower Cretaceous pelagic and hemipelagic carbonate sequences. This report aims at synthesizing the achievements in calpionellid biozonation in the Mediterranean in the last 25 years and proposing a zonal standard valid from Mexico to Iran.

The summary of calpionellid zonations of the publications referred is confirmed and refined by the present authors with results from Bulgaria and Serbia.

2. Results.

The successive events in the calpionellid evolution shown in Fig. 1 are used in definition of the zonal/subzonal boundaries. These events are mostly first occurrences, with exception of the "explosion of sphaerical form of *C. aplina*", marking the base of Calpionella zone. As a result of direct correlations between ammonite and calpionellid zones, the following calpionellid zones and subzones enhanced their chronostratigraphical value, thus their bases surving as indicators of the lower stage/substage boundaries of the GTS:

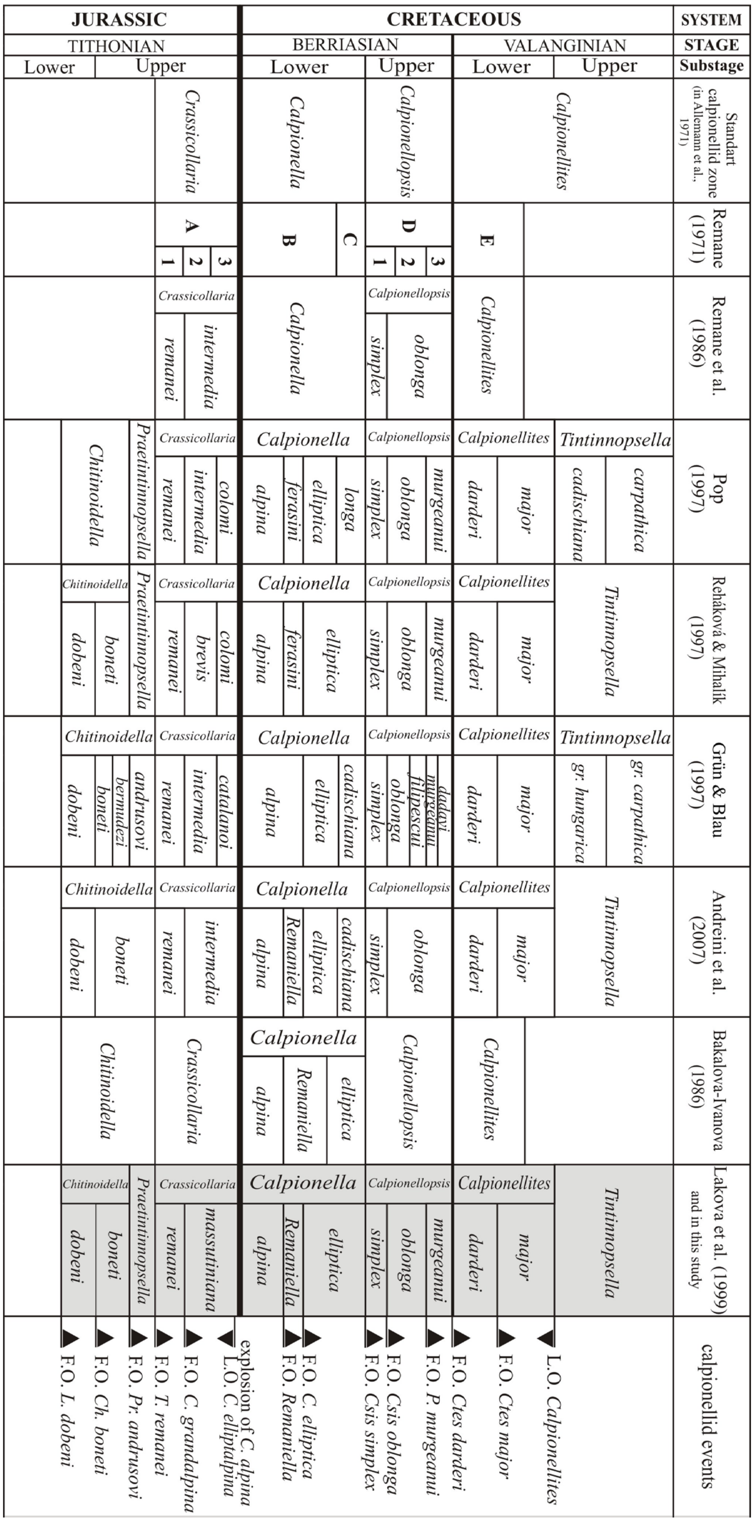
- Chitinoidella boneti for the Upper Tithonian,
- Calpionellopsis for the Upper Berriasian,
- Calpionellites for the Valanginian,
- Tintinnopsella for the Upper Valanginian.

The base of Calpionella alpina is slightly above the base of Berriasian, i. e. the base of Berriasella Jacobi ammonite zone.

Wimbledon *et al.* (2011) focused on detailed succession of calpionellid events in the Upper Tithonian and Lower Berriasian tied to ammonite and nannofossil ones, as well as magnetic polarity chrons with the purpose to define the base of Berriasian in a way to be applicable in both the Tethyan and Boreal realms. The avalanche of joint microfossil and magnetostratigraphic studies in 21th century has shown, however, that none of the magnetic polarity chron boundaries coincides with a calpionellid zonal/subzonal boundary. A promising exclusion is the base of Kysuca reverse magnetosubzone within M20n zone in the Upper Tithonian Transitorius ammonite zone. Its base coinsides almost exactly with the bases of the calpionellid Crassicollaria Zone, the nannofossil NJK-A Zone and the calcareous dinocyst Fortis Zone (Michalik *et al.*, 2009).

3. Conclusions.

The modern detailed calpionellid zonal and subzonal scheme which was first eatablished in the Western and Southern Carpathians in Romania and Slovakia, respectively, (Pop, 1994, 1997; Reháková & Michalik, 1997) and confirmed in Sicily (Italy) is being applied in the Balkan Mts of the west Bulgaria and east Serbia (Lakova *et al.*, 1999 and this study). It works also in the Tithonian to Valanginian pelagic carbonates in Cuba, Spain, Poland, Hungary, Austria, Iran, etc. On the other hand, the fairly different zonation by Grun & Blau (1997) from Italy is only partly applied in its Tithonian part in Morocco and Tunisia. Thus, the "Carpathian" calpionellid zonation needs just insignificant refinement and precision towards its formal approval as standard for the Mediterranean Realm.



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Lacustrine Eocene oil shales as archives for palaeoclimate and palaeoenvironment in Central Europe

Lenz O.K.[1], Wilde V.[2], Riegel W.[2,3]

→ lenz@geo.tu-darmstadt.de

1 TU Darmstadt, Institute of Applied Geosciences, Applied Sedimentology, Germany

2 Senckenberg Forschungsinstitut und Naturmuseum, Dept. Palaeobotany, Frankfurt am Main, Germany

3 Georg-August-Universität Göttingen, Geoscience Centre, Geobiology, Germany

A series of about half a dozen isolated occurrences of Paleogene sediments can be found on the Sprendlinger Horst (Hesse, Germany), the northern extension of the Odenwald basement which is flanking the Upper Rhine Graben to the northeast in Southwest-Germany. Among them, Lake Messel, a meromictic maar lake formed 47.8 +- 0.2 Ma ago, is the best known of these occurrences, most of them representing the filling of volcanic structures, respectively maar lakes. Another Eocene maar is known from Eckfeld (Eifel Hills, W-Germany).

The annually laminated oil shale from the early Middle Eocene maar lake at Messel provide unique palaeoenvironmental and –climatological data from a time interval of ~640 kyr during the Paleogene. The lamination in the lake was caused by annual algal blooms forming light layers that were superimposed on the terrigenous background sedimentation as represented by dark layers. Therefore, the character of these “varved” sediments allowed studies at an unprecedented resolution with regard to Paleogene times, the most recent greenhouse period on Earth.

A temporally highly resolved pollen record from the oil shale of Messel now provides insights into the dynamics of a climax vegetation and serves as a record for vegetation changes and their potential cyclicity within the Paleogene greenhouse system. Since annually laminated sediments of Quaternary maar lakes have been widely used as ideal archives of vegetation response to rapid climate change in an icehouse system, the Messel oil shale is now an important reference for understanding the effects of orbital forcing on vegetation under an equable warm climate.

Time series analyses of the pollen record clearly show cyclic variation in the quantitative composition of palynomorph assemblages during the 640 kyr interval of the Middle Eocene. The observed cycles closely correspond to the short eccentricity, obliquity and precession periods and to some extent to sub-Milankovitch periods. Periodicities of 82/83yr, 200/210 yr, ~600 yr and 1100 to 1600 yr comparable, for instance, to Gleissberg (~87 yr) De Vriess/Suess (~210 yr) or Dansgaard-Oeschger (1470 yr) events of the Quaternary can be recognized.

To support these results, our study is now extended to other nearby Paleogene deposits. In three of these deposits (“Offenthal”, Groß-Zimmern” and “Prinz von Hessen”) scientific wells have been drilled. They revealed also undisturbed clastic sediments and more than 70 m of finely laminated bituminous oil shales. Based on preliminary stratigraphical data the lake deposits are probably also of Middle Eocene age, although an exact age relationship of these deposits is still unknown. First results of palynological investigations show that they will significantly add to our understanding of vegetation and climate variability during the Eocene “hothouse”. Further comparisons can be made with results of previous studies of the Eckfeld maar sediments.

Middle/Upper Givetian ostracodes from the Aisne quarry (Heyd, Durbuy area, Belgium): stratigraphy, diversity, paleoecology and bioevents

GB 2012 Contestant for Best Poster Presentation

Maillet S.[1,2], Milhau B.[1], Nicollin J.-P.[1,2]

→ sebastien.maillet@icl-lille.fr

1 Laboratoire de Paléontologie Stratigraphique, Faculté Libre des Sciences et Technologies & Institut Supérieur d'Agriculture, 41 rue du port, 59046 Lille Cedex, France

2 Géosystèmes, UMR 8217 CNRS, Université Lille1 Sciences et Technologies, Cité Scientifique, Bâtiment SN5, Avenue Paul Langevin, 59655 Villeneuve-d'Ascq, France

The Middle Devonian deposits of the Dinant Syncline (Ardenne Allochtone) set on a wide carbonate platform extending on the northern passive margin of the Rheno-Hercynian Ocean. Eastwards of Durbuy (Belgium), the Aisne quarry exposes a carbonate series of 265 meters-thick, from Middle to Upper Givetian (Middle Devonian). The Fromelennes Formation, reaching 235 meters-thick, shows clear contacts with the Mont d'Haurs and the Nismes formations. The contact Flohimont/Moulin Boreux members is also accessible, but not the contact Moulin Boreux/Fort Hulobiet members.

Fifty rock samples were collected through the series and disaggregated by acetolysis. More than 1500 ostracodes were sorted under binocular lens.

Fifty one species of ostracodes are recognized throughout the series, of which twenty five are in formal description. They all belong to the Erisdostraca, the Paleocopida and the Podocopida orders. These species are well representative of the Assemblages I, II or III of the Eifelian Mega-Assemblage, respectively indicative, on the continental shelf, of semi-restricted, of fore-reef with high hydrodynamics or of deeper open-sea paleoenvironments.

The ostracode stratigraphical distribution put forwards two faunal cycles: the first one in the lower part of the Flohimont Member (base of the Fromelennes Formation), the second one in the upper part of the Fort Hulobiet Member (top of the Fromelennes Formation). For the two cycles, a quick diversification of the ostracode fauna and an increase of the Metacopina/Podocopina ratios put forwards deepening events, related to the two Givetian major sea-level rise episodes.

The first faunal cycle displays a well diversified fauna with Givetian typical species, as *Quasillites fromelennensis* Milhau, 1983 or *Poloniella tertia* 1953. Then, the diversity and the number of specimens by species decrease from the upper part of the Flohimont Member. The Givetian ostracode fauna finally disappears in the lower part of the Moulin Boreux Member, just below a massive bed providing abundant *Stringocephalus burtini* (Defrance, 1825). Then, a low diversity interval occurs with rare ostracodes mainly belonging to the Podocopina suborder. Higher, monospecific beds provide *Cryptophyllus* sp. 3 *sensu* Magne, 1964 in the upper part of the Moulin Boreux Member and then *Cavellina rhenana* Krömmelbein, 1954 in the lower part of the Fort Hulobiet Member. This low diversity/high specimen abundance interval put forwards salinity variations. Finally, Frasnian typical species take over in the second faunal cycle. Particularly, the base of the *Polyzygia beckmanni beckmanni* Krömmelbein, 1954 Zone is recognized in the uppermost part of the Fort Hulobiet Member.

The Middle/Upper Givetian period is characterized by an important faunal renewal within the benthic ostracode fauna, marked by the disappearance of the Givetian typical species in the lower part of the Moulin Boreux Member (late Middle Givetian). This phenomenon is also observable in other sections in Ardenne (Flohimont, Nismes, Sourd d'Ave) and in Boulonnais (Ferques). Consequently, this significant renewal could be related to the global Taghanic Biocrisis, seriously affecting the benthic communities of the continental shelf around the Middle/Upper Givetian boundary.

Process length of dinoflagellate cysts as salinity proxy

Mertens K.N.[1], Louwye S.[1]

→ kenneth.mertens@ugent.be

1 Ghent University, Department of Geology & Soil Science, Belgium

In this presentation we will discuss the application of process length variation of dinoflagellate cysts to reconstruct salinity. Two species have been the focus of intensive morphological study: *Lingulodinium polyedrum* and *Protoceratium reticulatum*. Study of cysts from global surface sediment show a relation to both salinity and temperature, and distinct differences in the calibration of open ocean sites vs. marginal/landlocked sea sites. On the other hand size of cysts is not related to salinity/temperature variations, but rather to variations in productivity. Furthermore, molecular data shows differences between strains of *Protoceratium reticulatum*, whereas no differences are recorded for *Lingulodinium polyedrum*. We will show that despite these complications, process length variation can still be used to reliably reconstruct salinity, using examples from the Baltic Sea and Black Sea.

The Madot and the Brûtia Formation along the Ri de Coercq, Hennuyères, Belgium (Brabant Massif)

Mortier J.[1], Van den haute P.[2], Esselens S.[1], De Ridder A.[1,2], Verniers J.[1]

→ jsmortie.mortier@ugent.be

1 Research Unit Palaeontology, Department of Geology and Soil Sciences (WE13), Ghent University, Krijgslaan 281, building S8, B-9000 Ghent, Belgium.

2 Research group Mineralogy and Petrology, Department of Geology and Soil Sciences (WE13), Ghent University, Krijgslaan 281, building S8, B-9000 Ghent, Belgium.

Along the valley of the Ri de Coercq, Hennuyères, Belgium (Brabant Massif) two lithostratigraphical units are cropping out: the Madot Formation in the north and the Brûtia Formation in the south. The Brûtia Formation forms the southernmost outcrop of the Brabant Massif in the Ri de Coercq.

The Madot Formation contains here mainly volcaniclastic sediments (sand to clay fraction) with some thin sedimentary interlayers of non-volcanic grey to dark grey mudstone. The Brûtia Formation contains bioturbated, grey green to grey and dark grey mudstone with some macrofossil-bearing horizons (brachiopods, trilobites)

A petrographical study of the volcaniclastic layers of the Madot Formation by means of thin sections shows that the volcaniclastic layers are mainly the result of the breaking up of volcanic layers. They may contain fossils.

A micropalaeontological study by means of chitinozoans of the two formations have been effectuated with a total of 26 samples. The chitinozoans are moderately well to badly preserved with an abundance of generally less than 1 chitinozoan/gram rock, which is lower than the average of the Brabant Massif. However index fossils are present. The Madot Formation contains *Lagenochitina baltica*, *Lagenochitina prussica* and *Conochitina rugata* as most important species. The presence of *Conochitina rugata*, the index fossil of a total range biozone, indicates a possible late Cautleyan to early Rawtheyan age (Late Katian, Vandenbroucke, 2008). This implicates that the part of the Madot Formation in this section is younger than in the type section of the Sennette valley. The Brûtia Formation contains another index fossil, *Spinachitina oulebsiri*, together with *Hercochitina* spp. This implies that the Brûtia Formation here is not younger then Ordovician in age (Paris *et al.*, 1999). The presence of *Spinachitina oulebsiri* indicates Hirnantian in age. It is for the first time that Hirnantian rocks are found in outcrops of the Brabant Massif.

Paris F., Grahn Y., Nestor V., Lakova I. (1999). *A revised chitinozoan classification*. Journal of Palaeontology, Volume 73, n°4, pp 549-570.

Vandenbroucke T.R.A. (2008). *An upper Ordovician chitinozoan biozonation in British Avalonia (England and Wales)*. Lethaia, Volume 41, n°3, pp 275-294.

A litho- and biostratigraphical study with chitinozoans of two sections of Neuville-sous-Huy (upper Silurian), Condroz Inlier, Belgium

Mortier J., Deckers J., Verniers J.

→ jsmortie.mortier@ugent.be

Research Unit Palaeontology, Department of Geology and Soil Sciences (WE13), Ghent University, Krijgslaan 281, building S8, B-9000 Ghent, Belgium.

In Neuville-sous-Huy two sections were studied (litho- and biostratigraphy with chitinozoans): the southern part of Parc de la Neuville and a new road cut 300 m west of Parc de la Neuville.

The section of the southern part of Parc de la Neuville along the most southerly pond (approximately 50 m long) can be divided into four units (a-d). The most northerly unit (unit a) contains grey green, olive green and dark grey mudstones sometimes laminated with graptolite levels in the northern part together with other macrofossils (crinoids, brachiopods). The following unit to the south (unit b) contains dark grey, finely laminated mudstones known as laminated hemipelagites with many graptolite levels. Limestone nodules are present. Unit c more to the south contains green grey to grey, sometimes laminated mudstones. The most southerly unit, unit d, contains grey green mudstones.

Chitinozoans were studied in 25 samples from this section. The abundance of the chitinozoans are generally less than 1 chitinozoan/gram rock. In unit a the chitinozoans are moderately well preserved. They contain amongst other: *Eisenackitina lagenomorpha*, *Eisenackitina toddingensis*, *Eisenackitina intermedia* and *Conochitina rudda*. These are typical species from the lower Ludlow. The other units contain only poorly preserved chitinozoans and the lack of index species does not allow to date the units.

Along a new road cut 300 m west of Parc de la Neuville an approximately 250 m long outcrop became available for study with the presence of two units: unit 1 in the north and unit 2 in the south. Unit 1 contains dark grey, finely laminated mudstones, known as laminated hemipelagites with many graptolite levels and some levels with other macrofossils as conularia. Most of the time this unit is weathered into a brown grey colour. This unit contains five centrimetric, whitish clayey layers parallel to the bedding possibly of volcaniclastic origin. Unit 2 contains grey green compact mudstones. A total of five samples of this section were studied for their chitinozoan content. The chitinozoans are poorly preserved and scarce, and hence not giving much information about the age of the two units.

Bacterial diversity and seasonal changes in iron microbial mats formed in neutrophilic, fresh-water environments

Papier S.[1], Baele J.-M.[1], Gillan D.[2], Wattiez R.[2]

→ severine.papier@umons.ac.be

1 UMons - University of Mons, Faculty of Applied Sciences, Dept. of Geology

2 Umons - University of Mons, Faculty of Sciences, Dept. of protéomic and microbiology

Microorganisms play an important and sometimes underestimated role in the cycling of elements in Earth's subsurface environments. Iron-bacteria are particular microorganisms which use ferrous (Fe2+) to ferric (Fe3+) iron oxidation as an energy source through chemolithotrophic process. These bacteria produce cm- to dm-thick ochre deposits called ferruginous or iron bacterial mats. Such mats are commonly observed in natural or anthropogenic environments such as quarries where iron-rich groundwater flows out at spring mouths. Similar deposits also form in mine drainage systems and may cause clogging problems in drinking water wells. The importance of iron bacterial mats in geology and industry is demonstrated by the large number of studies devoted to them. The retention capacity of heavy metals in these mats is actively investigated for its importance in environmental problems. The sorption properties of iron oxi-hydroxides such as ferrihydrite are often put forward against biotic processes but few studies have investigated the role of bacteria so far. In this study, we focus on iron bacterial mats which develop in neutrophilic freshwater environments. Two sites in natural environment (Trô Maret Valley near Malmédy and the Helle Valley near Eupen) and one site in anthropogenic environment (Hautrage quarry near Mons) are currently being analyzed on the basis of a two years sampling survey. The samples were first analyzed using chemical (FTIR, ICP-MS), mineralogical (XRD) and biological techniques such as 4'6'-diamidino-2-phenylindole (DAPI) and denaturing gradient gel electrophoresis (DGGE). Filamentous structures (morphotypes) were studied and counted under the optical microscope. Their relative abundance is clearly varying over time and could relate to seasonal change in bacterial activity. DAPI stains show a consistent trend. Variations of environmental parameters such as pH, temperature and dissolved species are recorded but not fully understood at the moment. Biodiversity as reflected by DGGE shows that iron bacterial mats are favorable for bacterial growth since up to 30 different bacterial species were detected. Morphologically-distinct iron-oxidizing bacteria such as *Gallionella* and *Leptothrix* were observed under the optical microscope but they seemingly represent only a portion of the bacterial community in the mat. The identification of all the bacteria in the community is necessary to first investigate the biotic processes that are taking place in the system and secondly to assess their sensitivity to environmental factors. The identification of the different bacteria is currently in progress using cloning and sequencing of the 16S rRNA.

Middle Miocene environmental change: a multi-proxy study from the eastern Atlantic Ocean at the Porcupine Basin (IODP Leg 307)

Quaijtaal W.[1], Schouten S.[2], Donders T.[3], Louwye S.[1]

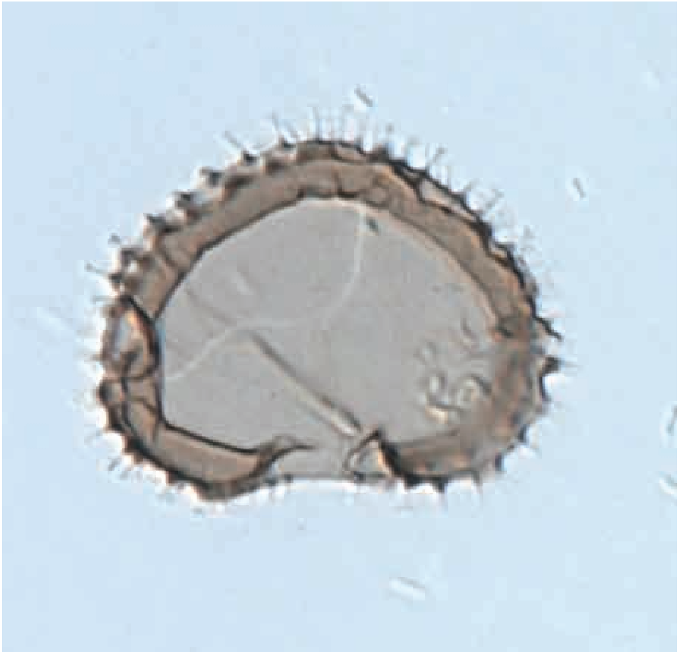
→ willemijn.quaijtaal@ugent.be

1 Research Unit Palaeontology, Department of Geology and Soil Science, Ghent University, Belgium

2 Department of Marine organic Biogeochemistry, Royal Netherlands Institute for Sea Research (NIOZ), The Netherlands

3 TNO Geobiology, Geological Survey of the Netherlands, the Netherlands

During the Middle Miocene Climatic Optimum (MMCO; 17-14.5 Ma) the relatively warm climate of the Miocene reached peak values. After the MMCO, the global climate started cooling. This happened through several short-lived cooling events, represented by positive oxygen isotope excursions: the Mi-events. Associated events are East Antarctic Ice Sheet growth and potential Northern Hemisphere ice expansion. The causes and consequences of the Mi-events are not well constrained yet. For this reason we aim to examine the role of the Gulf Stream in the cooling and subsequent warming of the Mi-events, since it is a possible mechanism to amplify or reduce regional changes in North-western Europe.



The heterotrophic dinocyst taxon *Selenopemphix brevispinosa*, indicative of enhanced primary productivity.

Integrated Ocean Drilling Program (IODP) Leg 307 recovered a high resolution record from the Middle Miocene of the Porcupine Basin (offshore south-western Ireland), a region under influence of the Gulf Stream. We have extracted well-preserved palynomorphs (mainly organic-walled dinoflagellate cysts (see figure), acritarchs, some pollen) and organic molecules for paleothermometry (e.g. TEX_{86} and $U^{K'}_{37}$) from core 1318B. With these proxies, the development of the Mi-4 event is reconstructed on high resolution, by assessing e.g. temperature, sea level, thermocline depth and productivity. First results indicate a pronounced cooling during Mi-4 as recorded simultaneously in dinoflagellate cyst assemblages, TEX_{86} and $U^{K'}_{37}$. The presented results will focus in detail on the phasing and rates of change in the reconstructed Mi-events.

The Eocene-Oligocene transition at St. Stephens Quarry, Alabama, USA: environmental- and sea-level change revealed by dinoflagellate cysts

GB 2012 3 Student Competition for Best Poster Presentation

Quaijtaal W.[1,2], Houben A.J.P.[2], Wade B.S.[3], Schouten, S.[4] , Rosenthal Y.[5], Miller K.G.[6], Brinkhuis H.[2,4]

→ willemijn.quaijtaal@ugent.be

1 Research Unit Palaeontology, Department of Geology and Soil Science, Ghent University, Belgium

2 Marine Palynology, Laboratory of Palaeobotany and Palynology, Department of Earth Sciences, The Netherlands

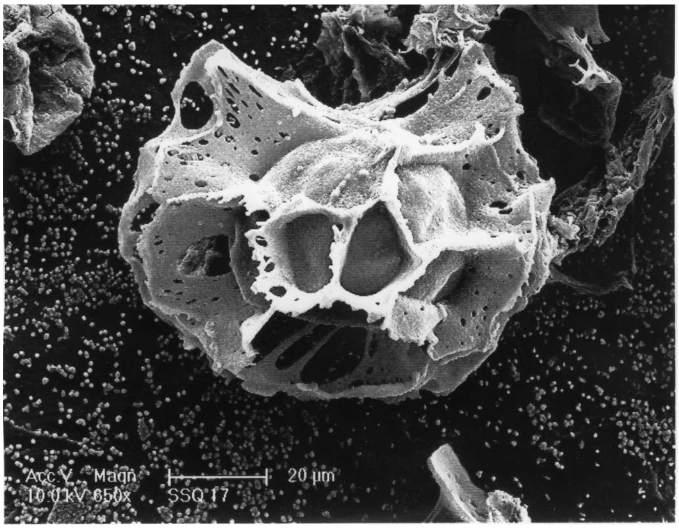
3 Sellwood Group for Palaeo-Climatology, School of Earth and Environment, University of Leeds, Leeds, United Kingdom,

4 NIOZ Royal Netherlands Institute for Sea Research, Department of Marine Organic Biogeochemistry, Texel, The Netherlands,

5 Marine Biogeochemistry & Paleoceanography, Institute of Marine and Coastal Sciences, Rutgers University, New Jersey, USA,

6 Department of Earth and Planetary Sciences, Rutgers University, New Jersey, United States

The Eocene-Oligocene transition (EOT, 34-33.5 Myr ago) represents the final transition from the early Paleogene “Greenhouse” into the present “Icehouse” through the growth of continental-scale ice caps on Antarctica. Foraminiferal oxygen isotopes ($\delta^{18}O$) record the EOT as two positive steps, ~200 kyr apart. However, the relative contributions of cooling and increasing ice-volume cannot be separated from such $\delta^{18}O$ records. To understand the order of events enveloping the onset of Antarctic glaciation, independent temperature- and sea-level reconstructions are crucial.



Scanning electron microscope photograph of *Pentadinium alabamensis*, a new dinocyst taxon found at St. Stephens Quarry, Alabama, USA.

A classic reference section for the Eocene-Oligocene boundary, St. Stephens Quarry (SSQ) in Alabama, USA, contains a relatively expanded neritic succession. Previous studies at SSQ have already provided magneto- and biostratigraphy, benthic foraminiferal stable isotope- and Mg/Ca based temperature information across the EOT. Sea surface temperatures were reconstructed using TEX_{86} and planktonic Mg/Ca analyses. Altogether, these data show that the first step of the EOT (precursor or EOT-1) primarily reflects cooling, while the second step (the Oi-1) only shows a minor temperature decrease.

Here, we report on biotic change revealed by evaluating assemblages of organic remains of dinoflagellates (dinocysts). Dinoflagellates (see figure) are a group of unicellular surface dwelling algae, sensitive to environmental changes, e.g. temperature, coastal proximity and productivity. We integrate dinocyst assemblage data with lithostratigraphic studies to propose an updated sequence stratigraphy for the SSQ-borehole. We document a sea-level fall associated with the EOT-1 and a distinct sea-level fall at the Oi-1 level, the latter being a feasible result of increasing continental ice volume. Furthermore, we recorded typical cold water taxa at the EOT-1, in line with sea surface temperature reconstructions. In addition, early Oligocene dinocyst assemblages above the Oi-1 are indicative of more productive settings, along with larger amplitude environmental changes in the shelf environments. The latter could be related to the inception of Oligocene glacial-interglacial cycles and the subsequent far-field sea level response. Our records thus show that the EOT was a period of profound environmental change, also in the (sub)tropics.

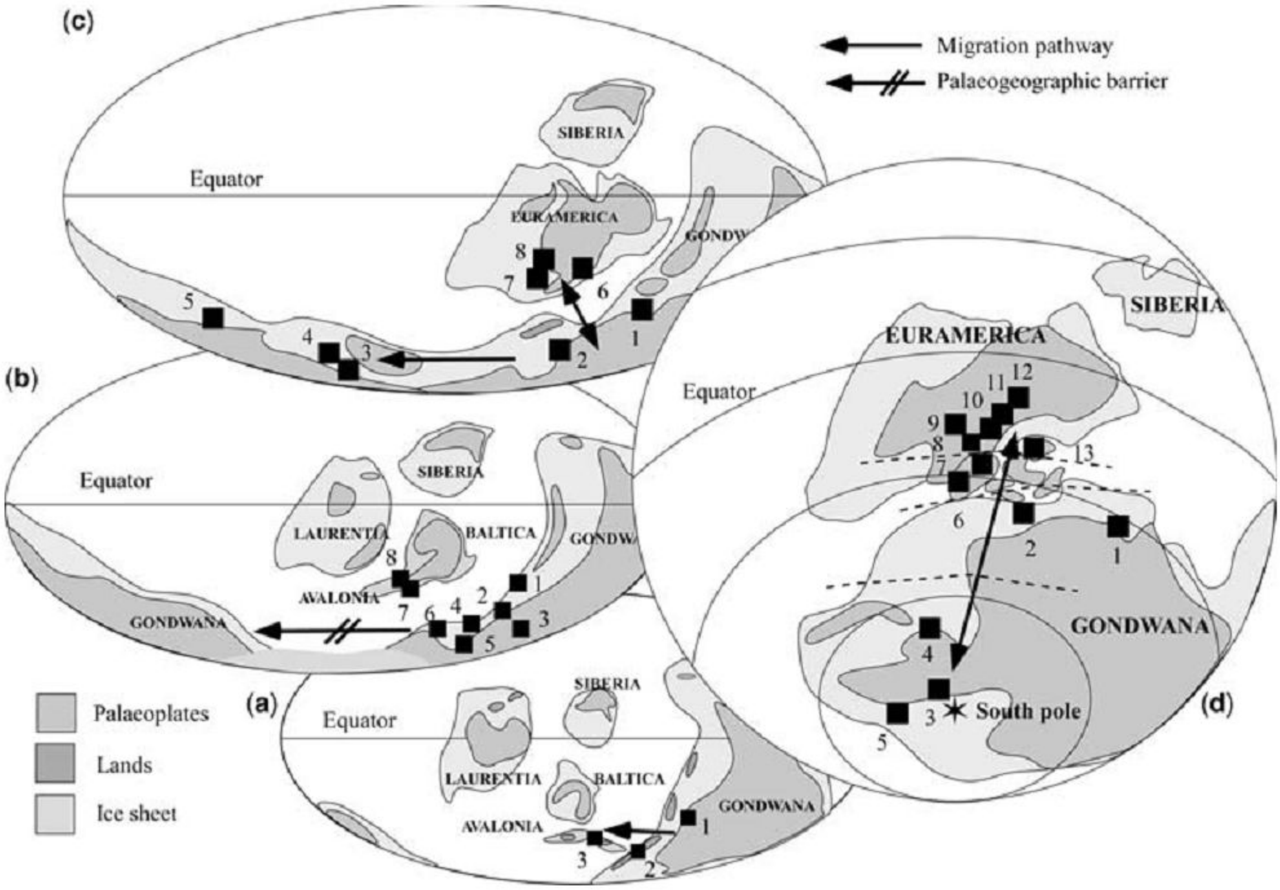
Small is beautiful: Paleozoic miospores, a powerful tool for paleogeography

Steemans P., Gerrienne P.

→ p.steemans@ulg.ac.be

NFSR researchers, University of Liège, Paleogeobiology-Paleopalynology-Mircopaleontology, Belgium

The focus of this presentation is to review the paleophytogeography of the Paleozoic vegetation in conjunction with the paleocontinental reconstructions (Steemans *et al.* 2010). This exercise sheds new light on the distribution and evolution of vegetation over this time range. Miospores are, by far, the most abundant continental fossils. Their study sometimes leads to paleocontinental reconstructions different from those mainly based on marine fossils and paleomagnetism. We believe that paleophytogeographical data are too often overlooked, while they may provide important constraints for longitude, and, to a lesser extent, for latitude, in the same way that paleomagnetism is important for latitudinal constraints.



Example of paleogeographic reconstructions based on miospores (see legend in Steemans *et al.* 2010).

Steemans P., Wellman C.H., Gerrienne P. (2010). *Palaeogeographic and paleoclimatic considerations based on Ordovician to Lochkovian vegetation. In:* Vecoli M., Clément G., Meyer-Bertaud B. (eds.). *The terrestrialization process: modelling complex interactions at the biosphere-geosphere interface.* London: Geological Society, London, Special Publications, pp 49-58.

Revision of the late Famennian miospore zonation scheme in eastern Belgium, correlation with the conodont zonation and consequence for intercontinental correlations

Streel M.[1], Higgs K.[2], Prestianni C.[3], Thorez J.[1]

→ Maurice.Streel@ulg.ac.be

1 University of Liège, Geology Department, Allée du Six Août, Bat. B18, Belgium

2 University College of Cork, Geology Department, School of Biological, Earth and Environmental Sciences, University College Cork, Ireland.

3 Royal Belgian Institute of Natural Sciences, Paleontology Department, Belgium

The *Diducites versabilis-Grandispora cornuta* (VCo) Zone was defined by Streel *et al.* (1987) as an Oppel Zone i.e. a zone characterized by an association or aggregation of selected miospore species of restricted and largely concurrent range. Judgement may vary as to how many and which of the selected diagnostic taxa need to be present to identify the zone (Hedberg 1976). The VCo Zone was defined by the first appearance of *Grandispora cornuta* and *Rugospora radiata* (then *flexuosa*) in the Upper Famennian of the Ourthe Valley sections in Eastern Belgium. A major problem had arisen with regard to the use of *Rugospora radiata* as a zonal index species for the VCo Biozone, because of difficulties in discrimination between *R.radiata* and the morphologically similar late Frasnian-early Famennian taxon *Rugospora bricei* Loboziak & Streel (1989). These identification difficulties resulted in the older stratigraphical extension of the VCo Zone range in some regions. Consequently, a morphological redefinition of *Rugospora bricei* and *R. radiata* is presented here, which permits a redefined *R. radiata* to be used to mark the base of a new *Rugospora radiata* (Rad) interval zone which coincides with the former base of the VCo Zone.

A detailed morphological analysis of the VCo zonal species *Grandispora cornuta* and other related *Grandispora* species is presented from new material obtained from the Namur and Dinant synclinoria in Belgium and old published material. This analysis allows a clearer distinction of *Grandispora cornuta* from the similar and more abundant *Grandispora tamarae,* a species known to first appear in the Late Frasnian. A new *Grandispora cornuta* (Cor) Interval Zone is defined with its base corresponding to the top of the *radiata* (Rad) Interval Zone and its top corresponding to the base of the overlying *Apiculiretusispora verrucosa-Vallatisporites hystricosus* (VH) Oppel Zone as defined by Maziane *et al*. (1999). The VH Oppel Zone is here subdivided into two interval zones, the *verrucosa* Interval (Ver) Zone and succeeding *hystricosus* Interval (Hys) Zone. These four successive miospore interval zones are here correlated with the Upper Famennian *trachytera* to Middle *expansa* conodont zones known in the Ourthe Valley. In addition, palynological correlations of these miospore interval zones between Western Europe, Eastern America and Western Gondwanan regions are attempted.

Hedberg H.D. (ed.) (1976). *International Stratigraphic Guide*. Wiley, N.Y., 200 p.

Higgs K.T., Avkhimovitch V.I., Loboziak S., Maziane-Serraj N., Stempien-Salek M., Streel M. (2000). *Systematic study and stratigraphic correlation of the Grandispora complex in the Famennian of northwest and eastern Europe*. Review of Palaeobotany and Palynology, Volume 112, Issue 4, pp 207-228.

Loboziak S., Streel M. (1989). *Middle-Upper Devonian Miospores from the Ghadamid Basin (Tunisia-Lybia): systematics and stratigraphy*. Review of Palaeobotany and Palynology, n°58, pp 173-196.

Maziane N., Higgs K.T., Streel M. (1999). *Revision of the late Famennian miospore zonation scheme in eastern Belgium.* Journal of Micropalaeontology, n°18, pp 17-25.

Richardson J.B., McGregor D.C. (1986). *Silurian and Devonian spore zones of the Old Red Sanstone*. Geological Survey of Canada Bulletin, n°364, pp 1-79.

Streel M., Higgs K.T., Loboziak S., Riegel W., Steemans P. (1987). *Spore stratigraphy and correlation with faunas and floras in the type marine Devonian of the Ardenne-Rhenish regions*. Review of Palaeobotany and Palynology, Volume 50, Issue 3, pp 211-229.

Full paper in Geologica Belgica, Volume 16, n°1-2

High resolution miospore stratigraphy of the Upper Famennian of eastern Belgium, and correlation with the conodont zonation

by Higgs K., Prestianni C., Streel M., Thorez J.

Sea level changes interacting with vegetation: a palynological study on the Plio-Pleistocene Tjörnes beds (North Iceland)

GB 2012 Contestant for Best Oral Presentation

Verhoeven K.[1], Louwye S.[1], Eiríksson J.[2]

→ Koen.Verhoeven@ugent.be

1 Research Unit Palaeontology, Ghent University, Krijgslaan 281/S8, 9000 Ghent, Belgium

2 Earth Science Institute, University of Iceland, Askja, Sturlugata 7, IS-101 Reykjavik, Iceland

The Plio-Pleistocene sediments preserved in cliffs on the Tjörnes peninsula (North Iceland) give a unique insight in the changing biotic life during a major cooling period. The marginal marine deposits at Tjörnes hold terrestrial signals (pollen, spores, plant macro remains) as well as marine signals (ostracods, molluscs, foraminifers, dinoflagellates), although the signal is not always continuous. Organic-walled palynomorphs such as pollen/spores and dinoflagellate cysts however bypass pitfalls such as decalcification and saturation by silica. A simultaneous research on both proxies was possible throughout the entire Tjörnes beds and four interglacials of the overlying Pleistocene Breidavík Group.

Dinoflagellate cysts are an excellent biostratigraphical tool and allowed the construction of a robust age model for the section (Verhoeven *et al.* 2011). Eighty-eight samples and a total of more than 38,000 terrestrial palynomorphs were counted. Six Pollen Zones (PZ) could be defined (Verhoeven *et al.* submitted). Pollen types are seldom determined to species level, and it is consequently difficult to assess the exact position of the producing plant in the different habitats of the coastal area (vast marshes, levee forests, dry heathland, foothill forests, hill vegetation and higher situated basaltic plateaus). The preferred position of plants however became clearer through the combination of sedimentological data, mollusc data and pollen data.

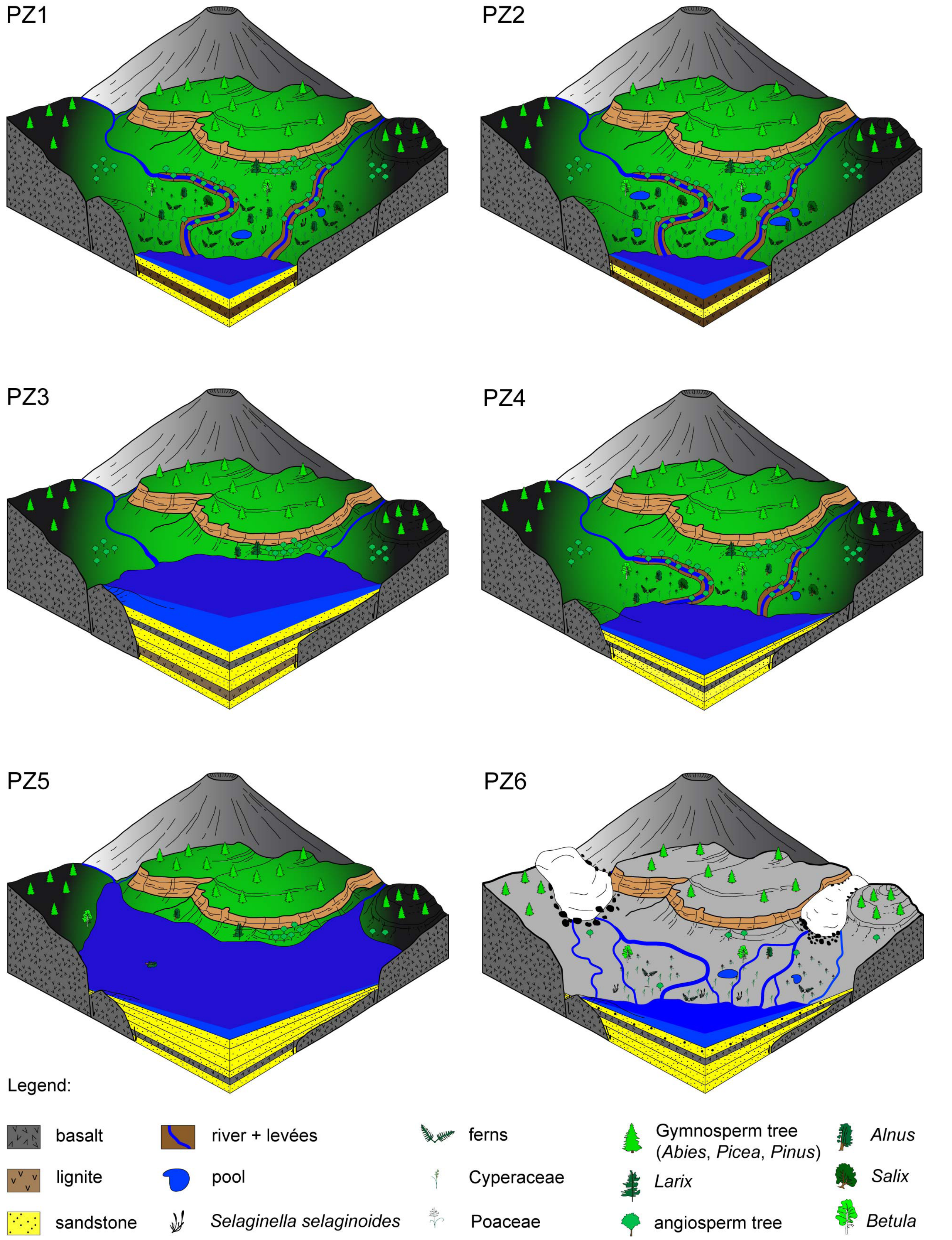
Molluscs with a specific water depth preference, in combination with a sedimentological analysis, allowed a relative sea level reconstruction (Buchardt and Símonarson 2003). The pollen zones are in agreement with this reconstruction and permitted moreover a refinement of the palaeoecological signal. In the first part of the Tjörnes beds (PZ1, 2), a vast marsh area existed that progressively increased in wetness. The pollen influx was local, and changed drastically in favour of the regional pollen derived from the plateaus during the upper part (PZ3), induced by a significant relative sea level rise. Gymnosperm trees dominate here the signal, and specific marshes and levees plants disappeared. During the deposition of the Early Pliocene Tjörnes beds, no temperature changes are visible in the pollen record.

The pollen indicate a clearly warmer climate then today during the deposition of the Tjörnes beds, Hörgi Formation and the Svarthamar Member. Within these deposits, warmth-demanding taxa as *Ilex*, *Quercus*, *Tilia*, *Sambucus*, *Viscum album*, *Castanea*, *Juglans* and *Acer* are recorded. An impoverished assemblage is observed in the Thorfhóll Member with *Pinus*, *Alnus* and *Betula* as the most important tree taxa, together with *Cyperaceae* and *Poaceae* as the dominant herbs, and spore plants.

Buchardt B., Símonarson L.A. (2003). *Isotope palaeotemperature from the Tjörnes beds in Iceland: evidence of Pliocene cooling*. Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 189, Issues 1-2, pp 71-95.

Verhoeven K., Louwye S., Eiríksson J., De Schepper S. (2011). *A new age model for the Pliocene–Pleistocene Tjörnes section on Iceland: Its implication for the timing of North Atlantic–Pacific palaeoceanographic pathways*. Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 309, Issues 1-2, pp 33-52.

Verhoeven K., Louwye S., Eiríksson J. (2012). *Plio-Pleistocene landscape and vegetation reconstruction of the coastal area of the Tjörnes peninsula, northern Iceland, based on a pollen analytical study.* Boreas, Volume 42, Issue 1, pp 108-122.



Evolution of the landscape in relation to the relative sea level variations. Reconstruction based on pollen data, sedimentological and malacological arguments (Buchardt & Símonarsson 2003).

Land sea signals in three different marine settings: the strength and weakness of a combined pollen-dinoflagellate cyst research

GB 2012 Contestant for Best Poster Presentation

Verhoeven K., Louwye S.

→ Koen.Verhoeven@ugent.be

Research Unit Palaeontology, Ghent University, Krijgslaan 281/S8, 9000 Ghent, Belgium

A palynological study was carried out on three different marine settings with a Pliocene-Pleistocene age situated in the northern Atlantic. Pollen and spores, derived from the land, together with dinoflagellate cysts, derived from the photic zone of the ocean, are preserved in the sediments. The wall of the resting cysts of the marine algae as well as from the pollen and spores consists of a very resistant organic material. This allows an extraction with acids out of the sediments from both proxies with a same treatment. While dinoflagellate cysts are an important biostratigraphical tool (Verhoeven *et al.*, 2011), pollen and spores give especially information about the response of the vegetation to climate changes. In this study, we studied the limitations of the scientific significance of the two proxies according to the specific sedimentation environment.

The three localities are 1) the shallow marine sediments of the Tjörnes peninsula, 2) the 5km further seawards situated shelf sediments of the Flatey island and the 3) sediments of the Ocean Drilling Program core 985A, situated north of the Icelandic plateau with a water depth of 2787.6m.

The Tjörnes beds consist of an alternation of terrestrial swamp sediments and marine tidal flat to sublittoral shallow water and estuarine sediments. Dinoflagellate cysts are mostly moderate to scares present, but still give a significant representation of the marine assemblage. Pollen is in this kind of sediments abundantly present and the variation in the assemblages is closely linked to the gain and loss of habitats caused by sea level changes (Verhoeven *et al.*, submitted).

The dinoflagellate concentration in the Flatey sediments is higher and more constant compared to the Tjörnes sediments. The pollen concentration in Flatey is substantial lower, but still represent the vegetation of the island. The conservation of both proxies is good.

The more oceanic position of ODP 985 is clearly visible as can be seen by the dominance of *Impagidinium* species and *Nemathosphaeropsis labyrinthus*. Biostratigraphical species like *Operculodinium tegillatum*, *Reticulatosphaera actinocoronata* and *Batiacasphaera minuta* are present as well in ODP 985 as in Tjörnes. Heterotrophic species however like *Lejeunecysta* sp. and *Selenopemphix* sp. which forms a major part of the shallow marine assemblage of the Tjörnes beds, are not present in ODP 985. The pollen concentration is extremely low and no real signal can be obtained from this proxy in this oceanic environment.

It seems that best results for the combination of both proxies can be achieved in shallow marine sediments with a restricted distance to the coast like in Flatey.

Verhoeven K., Louwye S., Eiríksson J., De Schepper S. (2011). *A new age model for the Pliocene–Pleistocene Tjörnes section on Iceland: Its implication for the timing of North Atlantic–Pacific palaeoceanographic pathways*. Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 309, Issues 1-2, pp 33-52.

Verhoeven K., Louwye S., Eiríksson J. (2012). *Plio-Pleistocene landscape and vegetation reconstruction of the coastal area of the Tjörnes peninsula, northern Iceland, based on a pollen analytical study.* Boreas, Volume 42, Issue 1, pp 108-122.

The Tryon Park controversy: a chitinozoan approach

Verniers J.[1], Van de Moortel I.[1], Steeman T.[1], Mortier J.[1], Vandenbroucke T.[2], Cramer B.[3], Brett C.[4]
→ Jacques.Verniers@UGent.be

1 Research Unit Palaeontology, Department of Geology and Soil Sciences (WE13), Ghent University, Krijgslaan 281, building S8, B-9000 Ghent, Belgium
2. Géosystèmes, Université Lille 1, UMR 8157 du CNRS, F-59655 Villeneuve d'Ascq cedex, France
3. Kansas Geological Survey, University of Kansas, 1930 Constant Ave., Lawrence, Kansas 66047, USA
4. Department of Geology, University of Cincinnati, Cincinnati, Ohio 45221-0013, USA

Classically, two fossils groups are used to date Ordovician and Silurian rocks: graptolites for deeper siliciclastic environments and conodonts for shallower carbonate environments. A third group, the chitinozoans, occur in both environments and can be used for dating this age span, and for correlation between both facies.

The Williamson Shale Formation is a wide-spread lithostratigraphic unit in northeastern USA, dated to the late Llandovery. Loydell *et al.* (2007) identified a controversy, following their study of the type section of this unit in Tryon Park, Rochester, eastern New York State. Index fossils of the graptolite and of the conodont biozonations are mentioned to co-occur in the Tryon Park type section while elsewhere on the palaeocontinent, one is always older than the other. Chitinozoan microfossils were present (Loydell *et al.* 2007), but only in three relatively poorly localised samples.

Here, we present the results of a detailed re-logging and re-sampling, assisted by one of the co-authors of the 2007 paper. Twenty two samples contain a well-diverse Chitinozoa fauna and over 2200 specimens have been photographed and identified. We suggest that inaccurate positioning of the original samples, plus potential misindentification of certain chitinozoans might be partly at the base of the controversy. The distribution of species throughout the section allow to correlate the Tryon Park Chitinozoa biozones with sections in Wales and Belgium situated on the Avalonia palaeocontinent, confirming the validity of the global character of the standard biozonation scheme.

Loydell D.K., Kleffner M.A., Mullins G.L. *et. al.* (2007). *The lower Williamson Shale (Silurian) of New York: a biostratigraphical enigma*. Geological Magazine, Volume 144, n°2, pp 225-234.

Session 10

Evolution and diversity of macro-organisms: general aspects and case studies

Chairmen: Philippe Gerrienne & Massimo Delfino

Mesozoic marine reptile palaeobiogeography in response to drifting plates

Bardet N.[1], Fischer V.[2], Houssaye A.[3], Jouve S.[4], Pereda Suberbiola X.[5], Rage J.-C.[1], Vincent P.[6]
→ bardet@mnhn.fr; nathaliebardet@yahoo.fr

1 CNRS UMR 7207, Dépt. Histoire de la Terre, MNHN, Paris, France
2 Dépt. Géologie, Université de Liège / Dépt. Paléontologie, IRSNB, Bruxelles, Belgique
3 Steinmann Institut für Geologie, Paläontologie und Mineralogie, Universität Bonn, Allemagne
4 Muséum d'Histoire Naturelle, Marseille, France
5 Dept. Estratigrafía y Paleontología, Facultad de Ciencia y Tecnología, Universidad del País Vasco/E.H.U, Bilbao, Espagne
6 Staatliches Museum für Naturkunde, Stuttgart, Allemagne

Mesosaurus Broom, 1913, from the Early Permian, is the first aquatic reptile known in the fossil record. Its co-occurrence in both South Africa (South Africa) and South America (Brazil, Uruguay) made it one of the key-fossils - with the pteridospermatophyta plant *Glossopteris* - used by the German meteorologist / geophysician Alfred Wegener to support his theory of the Continental Drift (Kontinentalverschiebung), first published in 1912.

But *Mesosaurus* was only the "tip of the iceberg" as, during the Mesozoic, various clades of reptiles massively invaded the aquatic, and more especially, the marine realm. They were highly diversified both systematically and ecologically, and some of them were large top-predators of the marine ecosystems. The main groups were, in order of appearance in the fossil record, Ichthyosauria (earliest Triassic – early Late Cretaceous), Sauropterygia (nothosaurs, pachypleurosaurs, placodonts, plesiosaurs; Early Triassic – latest Cretaceous), Thalattosauria (Middle-Late Triassic), Pleurosauria (Early Jurassic–Early Cretaceous), as well as, among others, several lineages of Chelonians (e.g. chelonioids, bothremydids, "thalassemyds"), Crocodyliformes (thalattosuchians, dyrosaurids, pholidosaurids, gavialoids) and Squamates (mosasauroids, "dolichosaurs", marine snakes).

During the Mesozoic, the palaeobiogeographical distributions and the dispersion events of these marine reptiles closely followed the break-off of the Pangea induced by plate tectonic movements. Although marine reptiles can help in determining the possible date of opening of marine corridors, the information they provide are less precise than that delivered by terrestrial faunas, as the marine realm is a more open system and various migration ways are always possible.

Generally, the Triassic taxa were animals with a restricted palaeobiogeographical distribution living near the coastlines of the Pangea. From the end of the Triassic and during the Jurassic, the break-off of the Pangea resulted in the formation of large marine corridors, allowing open-sea marine reptiles such as ichthyosaurs, plesiosaurs and crocodyliformes to spread out over large distances. As an example, similar marine reptile faunas are known from the Jurassic of Europe and southern South America, as a result of dispersion events via the Hispanic Corridor that connected the Tethys / North Atlantic and Pacific realms at this time. During the Cretaceous, and notably with the expansion of the Atlantic Ocean, most of these reptiles were cosmopolite and open-sea forms (plesiosaurs, mosasaurid squamates, chelonioid turtles). However, even if large faunal interchanges were possible, some provinces such as the Northern and Southern margins of the Tethys were characterized by a peculiar faunal identity, notably concerning mosasaurids, despite the apparent absence of barriers. So, if Continental Drift enabled circulation and faunal interchanges, other parameters such as ecological constraints probably also played a role in the distribution of these marine reptile faunas.

On *Plesiocetus* Van Beneden, 1859 (Mammalia, Cetacea, Mysticeti): taxonomy and phylogenetic relationships

Bisconti M.

→ zoologia.museo@provincia.livorno.it

Museo di Storia Naturale del Mediterraneo, via Roma 234, 57100, Livorno, Italy

The genus *Plesiocetus* was established by Van Beneden in 1859 based on fragmentary materials from the Early Pliocene of Antwerp. In the next decades, Van Beneden extended the meaning of the genus to include several and very diverse mysticete fossils with widespread European distribution. Subsequently, other students assigned additional speciments to *Plesiocetus* from America making the genus one of the more widely distributed. Different authors, however, provided different interpretations of the diagnostic features of this genus with the result that now *Plesiocetus* is a sort of taxonomic basket. In this contribution, I present a revision of the type materials originally assigned to *Plesiocetus* by Van Beneden in order to understand what are (if any) the morphological features characterizing the genus. Moreover, I analyze the phylogenetic relationships of the materials for which an assignation is made. This investigation resulted in the observation that the *Plesiocetus* type collection includes at least two different taxa and several indeterminate bones. The determination of two taxa is based on skull materials and ear bones (periotics and tympanic bullae). Apart from the tympanic bullae that show archaic, cetothere characters, both skulls and periotics display a mix of primitive and derivate characters and may illuminate on the early evolution of Balaenopteridae.

Anatomy of a Cetotheriidae s.s. skull from the Miocene of Herenthals, Belgium, and its phylogenetic and paleobiogeographic relationships (Mammalia, Cetacea, Mysticeti)

Bisconti M.

→ zoologia.museo@provincia.livorno.it

Museo di Storia Naturale del Mediterraneo, via Roma 234, 57100, Livorno, Italy

A well preserved mysticete skull is described that includes most of the neurocranium and parts of the posterior portion of the rostrum and of the periotic. The specimen is from Herenthals, Belgium, and was collected in 1958. The skull shows the typical features of the family Cetotheriidae s.s. Comparisons are made with other cetotheriid mysticetes from Europe, north and south America in order to understand its phylogenetic relationships. The results of a Brooks Parsimony Analysis of the family are also presented that are based on the phylogenetic hypothesis in order to make a preliminary assessment of the paleobiogeography of the group. Such an analysis is performed here for the first time and represents the first attempt to phylogenetically interpret the distribution of a completely extinct family of mysticetes.

Climate, global patterns of biodiversity, and Eocene insects

Bruce Archibald S.[1,2], Greenwood D.R.[2], Mathewes R.W.[1], Bossert W.H.[4], Farrell B.D.[4]

→ sba48@sfu.ca

1 Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada

2 Museum of Comparative Zoology, Cambridge, MA, USA & Royal BC Museum, Victoria, BC, Canada

3 Department of Biology, Brandon University, Brandon, MB, Canada

4 Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, MA, USA

We test the effect of climatic factors on global patterns of alpha diversity and montane beta diversity by taking advantage of early Paleogene globally low temperature seasonality. This allowed us to isolate its effect from latitude and solar energy input (light and heat) as is difficult in the modern world, where they generally covary. We evaluated seasonality's affect on alpha diversity by comparing the species richness of insect communities sampled at temperate, mid-latitude, low seasonality Eocene McAbee, British Columbia, Canada; at temperate, mid-latitude, high seasonality Massachusetts, USA; and at hot, low-latitude, low seasonality Costa Rica. We found high diversity at McAbee, comparable with that recovered in Costa Rica, implying a key role of seasonality in driving the modern latitudinal gradient of species diversity. We then tested Janzen's hypothesis that differential seasonality in the context of topography generates greater montane beta diversity in the modern tropics than in the Temperate Zone. We sampled fossil insects across a thousand kilometer transect of montane, mid-latitude, temperate, low seasonality Eocene localities in western North America. We found high beta diversity, as Janzen predicted for modern low-seasonality tropical uplands, consistent with seasonality as driving this pattern independent of latitude. These findings of Eocene high mid-latitude alpha and montane beta diversities support the "pear-shaped Cenozoic" model of high global diversity in equable early Paleogene climates, and decreased global diversity in modern times when attenuated extra-tropical biodiversity is associated with the development of highly seasonal climates there.

Maastrichtian multituberculates from Oarda de Jos, Metaliferi sedimentary area (Transylvania, Romania)

Codrea V.[1], Smith T.[2], Venczel M.[3], Solomon Al.[1] , Fărcaş C.[1]

→ codrea_vlad@yahoo.fr

1 Babeş-Bolyai University, Department of Geology and Palaeontology, Romania

2 Royal Belgian Institute of Natural Sciences, Department of Palaeontology, Belgium

3 Ţării Crişurilor Museum, Department of Natural History, Romania

The latest Cretaceous (Maastrichtian) terrestrial sedimentary sequences in Transylvania are notorious for the so-called "Haţeg Island" fauna, which evolved in endemic environments. Besides representative reptiles (lizards, turtles, crocodiles, dinosaurs etc.), peculiar multituberculate mammals are also recorded, belonging to the family Kogaionidae. They were reported from areas such Haţeg or Rusca Montană sedimentary basins (Codrea *et al.*, 2010; Codrea *et al.*, 2012), but also in the Basin of Transylvania, in the Metaliferi sedimentary area. Now, we report the discovery of a rich sample of multituberculate teeth, recovered from a lens-like accumulation, at Oarda de Jos (Alba district). This outcrop was labeled as "Oarda A" in Codrea *et al.* (2010). The age of these deposits is Maastrichtian and they belong to the Şard Formation. After screen-washing of more than 2.5 tons of sediments, 73 multituberculate teeth are available for study. The simplified morphologic pattern of the cheek teeth is indicative for the family Kogaionidae, peculiar multituberculates firstly described in the Maastrichtian from Transylvania. In spite of several successive tentatives, the teeth morphology variations remain poorly known. For instance, we can compare the Oarda multituberculate teeth with two skulls both preserving the tooth rows: *Kogaionon ungureanui* from Sânpetru (Rădulescu & Samson, 1996, 1997) and *Barbatodon transylvanicum* from Pui. The majority of P4, M1 and M2 from Oarda can be related rather to *Kogaionon*, based on their morphology: similar anterior and posterior widths in the premolar, first upper molar with three lingual cusps and second upper molar with triangular outline. However, in the sample there are also M1 with only two lingual cusps, a feature indicative for *Barbatodon*. Several differences in cheek teeth morphology are now mentioned, probably reflecting intra-specific variations. Kogaionids are a European group, which crossed the K/T boundary and being recorded until now only in Romania, France, Spain and Belgium. Their origin remains unclear, but it may be presumed that they are originating from ancestors probably living in early Cretaceous. Financial support for this research was provided by CNCS grant PN-II-ID-PCE-2011-3-0381.

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Squamate diversity of the Late Cretaceous “Hațeg Island”, Romania - Gondwanan links

Codrea V.[1], Venczel M.[2], Solomon Al.[1]

→ mvenczel@gmail.com

1 Babeș-Bolyai University, Department of Geology and Palaeontology, Romania

2 Țării Crișurilor Museum, Department of Natural History, Romania

Patterns of insular conditions are recognizable in terrestrial vertebrates, due to isolation and limited food availability, when compared to mainland communities. A frequently cited illustration of these circumstances is represented by the famous late Cretaceous Transylvanian “Hațeg Island” fauna with relatively low species diversity and dwarfed dinosaurs discovered more than one century ago by Baron F. Nopcsa. Nevertheless, intensive field works in the latest years revealed new fossil bearing sites within and outside the Hațeg Basin (most of them of early Maastrichtian age) producing a more nuanced picture on these assemblages. Increasing reports on small vertebrates, which remained unknown in Nopcsa’s times, include lissamphibians (albanerpetontids and frogs), squamate reptiles (lizards and snakes) and multituberculate mammals (e.g. see Folie & Codrea 2005 and references therein), most of these groups indicating biogeographic links to America (via western Europe) and Asia. The only Gondwanan connection of the “Hațeg Island” squamate reptiles were represented up to present by madtsoiid snakes. A “teiid” lizard (*Bicuspidon hatzegiensis* Folie and Codrea, 2005), described from the Pui Islaz locality, was placed recently in Borioteiioidea and the genus *Bicuspidon* appears as the sister taxon of Polyglyphanodontini, thus marking important biogeographic links to transversely-toothed North American taxa (*Polyglyphanodon*, *Dicothodon*, *Peneteius* and *Bicuspidon*)(Nydam *et al.* 2007). Here we report on a new specimen representing Teiioidea, a lizard group never recorded in the Cretaceous from Laurasia, which might represent the second group of squamates with Gondwanan relationships. The specimen recovered from Pui Islaz locality (early Maastrichtian, Hațeg Basin, Romania), consists of a tridimensionally preserved partial skull displaying a series of diagnostic morphological characters. Within Teiioidea, based on a preliminary cladistic analysis, the Pui specimen appears as the sister taxon of a clade consisting of *Ameiva*, *Cnemidophorus*, *Kentropyx*, *Teius* and *Dicrodon* (see Nydam *et al.* 2007). If the assignment of this taxon into Teiioidea is correct than another squamate group of Gondwanan origin is added to the Hațeg microvertebrate fauna, which used probably the same dispersal route as the madtsoiid snakes. Furthermore, this report might represent the first unambiguous Cretaceous record of Teiioidea, and the first ante Miocene fossil evidence of this group outside South America.

Financial support for this research was provided by CNCS grant PN-II-ID-PCE-2011-3-0381.

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Megachasma (Chondrichthyes, Lamniformes) and large *Centrophorus* (Chondrichthyes, Squaliformes) of the Belgian Neogene continental shelf

De Schutter P.[1], Wijnker E.[2]

→ somniosus@skynet.be

1 National Institute of Criminalistics and Criminology (NICC), Belgium.

2 Laboratory of Genetics, Wageningen University, the Netherlands.

Isolated fossil teeth of the elasmobranch genera *Megachasma* Taylor, Compagno & Struhsaker, 1983 and *Centrophorus* Müller & Henle, 1837 have been recovered from Neogene sands in the Antwerp area, situated at the south-western margin of the North Sea Basin. Fossil *Megachasma* teeth are recorded for the first time in Europe, while the teeth of *Centrophorus* mark the first occurrence of the genus in the fossil record of Belgium and the North Sea Basin. The precise stratigraphic origin of these teeth could not be established, due to the nature of these localities with the mixing of different horizons. The taphonomic condition of these teeth suggests a Late Miocene or Early Pliocene age, although reworking from older Miocene strata cannot be excluded.

The *Megachasma* teeth are compared with fossil specimens from Greece, Chile, USA and extant specimens. The Belgian teeth seem to fit well in the gap between the Early Miocene teeth from California and those of the extant taxon *Megachasma pelagios* Taylor, Compagno & Struhsaker, 1983; while the megamouth teeth found in Late Miocene to Early Pliocene sediments worldwide (Chile, North Carolina, Florida, and Greece) appear to be giant versions of modern teeth. Juvenile teeth of extant *Megachasma pelagios* are illustrated for the first time, showing a distinct ontogenetic variation in the roots and crown surface.

The *Centrophorus* teeth are remarkable for the presence of serrated cutting edges of both upper and lower teeth as well as their large size. The teeth, that measure up to 1 cm, are the largest fossil *Centrophorus* reported in literature. The subtle differences between the teeth of different *Centrophorus* species and the paucity of comparative extant material prohibit specific attribution, but the teeth pertain to individuals that equalled the largest extant species. The occurrence of these large *Centrophorus* in the Belgian deposits is remarkable as *Centrophorus* usually prefers deeper waters.

Varanus marathonensis Weithofer, 1888: morphology, systematics, and paleobiogeography of the European monitor lizards

Delfino M.[1,2], Alba D.M.[2], Luján À.H.[2], Carmona R.[2,3], Abella J.[4], Robles J.M.[2,3], Galindo J.[2], Almécija S.[5]
→ massimo.delfino@unito.it

1 Dipartimento di Scienze della Terra, Università di Torino, Torino, Italy

2 Institut Català de Paleontologia Miquel Crusafont, Universitat Autònoma de Barcelona. Cerdanyola del Vallès, Barcelona, Spain

3 FOSSILIA Serveis Paleontològics i Geològics, Sant Celoni, Barcelona, Spain

4 Departamento de Paleobiología, Museo Nacional de Ciencias Naturales–Consejo Superior de Investigaciones Cientificas, Madrid, Spain

5 Department of Vertebrate Paleontology & NYCEP, American Museum of Natural History, New York, USA

The fossil record of the European monitor lizards of the genus *Varanus* is limited to about 35 localities whose age spans from the early Miocene to the Pliocene. Due to the poor diagnostic value of these fossils, often represented by isolated vertebrae, it is likely that most of the species described in the past are not taxonomically valid. However, direct examination of the type material of *Varanus marathonensis* Weithofer, 1888, from the Late Miocene of Pikermi (Greece), allowed us conclude that it is a valid, diagnosable species. Furthermore, we report unpublished Spanish material from the Aragonian (middle Miocene) of Abocador de Can Mata (Vallès-Penedès Basin) and the Vallesian (late Miocene) of Batallones (Madrid Basin), which is clearly referable to *V. marathonensis*. These remains open new perspectives regarding the taxonomy, phylogeny, and paleobiogeography of the European monitor lizards. The phylogenetic relationships of *V. marathonensis* could be sought in an eastern clade of *Varanus* instead of the African clade comprising *Varanus griseus*, to which it had been related in the past. Alternatively, *V. marathonensis* could be related to a basal stock preceding the split of the African taxa. Regardless of its phylogenetic relationships, our results indicate that *V. marathonensis* was distributed both in Western and Eastern Europe at least for about 5 myrs, from the Middle (MN 7) to the Late Miocene (MN 12), whereas as a whole the genus *Varanus* inhabited Europe at least from the Burdigalian (beginning of the MN 4, ca. 18 Ma) to the Tortonian (MN 10/12, ca. 8.7 Ma) in Central Europe, further persisting until the Piacenzian (MN 15/16, ca. 3.1-3.3 Ma) in Southern Europe. Due to such wide geographic and chronological range of *V. marathonensis*, most the European fossils of *Varanus* could belong to this species or be closely related to it.

Iconography of Carboniferous landscapes and coal mines

Dusar M.

→ Michiel.dusar@natuurwetenschappen.be

Royal Belgian Institute of Natural Sciences – Geological Survey of Belgium

Coal is important for society. Coal has made possible the industrial revolution during the 19th and early 20th centuries. Coal was mined deep underground, which was a risky business. Coal beds are capricious: they do not necessarily preserve their thickness or suitability for mining and are dislodged by tectonic accidents. Stratigraphical precision is the key requirement for the mining industry to define its targets. The main way to identify the coal layers encountered in an underground mine in the early 20th century was by studying the fossils which define the original ecosystem character. Mining directors were naturally interested in the stratigraphy of the coal measures in their mine, hence in the description, identification and interpretation of fossils, which are mostly fossil plants. Taxonomical and stratigraphical research was conducted by scholars at institutes closely linked to the mining industry. Collections of fossils allowed these scholars to reconstruct the entire plant and its biotope, and the mining engineers to recognize plant assemblages typical for the different coal beds. Although the pragmatic miners did not wait for the Darwinist revolution to make reconstructions of past life forms, realistic reconstructions of past landscapes clearly benefited from public acceptance of the evolution theory and interest in these lost worlds. Scientific illustrations all have the same purpose: correct representation of diagnostic features in an idealized setting, to raise interest and make them correctly understood by the general or specialized public. Scientific illustrations result from a symbiotic cooperation between scientist and artist, the former normally taking the lead.

Different trends in landscape reconstruction can be discerned irrespective of scientific accuracy or esthetic quality: the landscape as a theatre for animal evolution and/or behaviour, the coal swamp depicting the major taxons of the Carboniferous forest, and the schematic ecosystem mapping. The first group is mostly encountered in natural history museums, the second in mining museums (or originally in institutes devoted to coal research), the last in scientific publications but rarely of artistic interest. Artistic rendering of the Carboniferous landscapes needed accurate information on the fossils and ecosystems. Such works ware always commissioned by musea or mining companies and resulted from close collaboration between the scientist and the artist. Most paintings represent a botanical exhibit of the Carboniferous landscape, based on numerous finds of fossil plants from the coal mines. Artistic craftsmanship and museological vision together convey a sense of 'naturalness' of this ante-diluvial world, the standard of which are the murals by Charles R. Knight (1926-1931) in the Field Museum of Natural History, Chicago. Only in rare cases, the artist was allowed to create a romantic landscape, such as the Carboniferous forest painting by Jan Habex (1887-1954), commissioned by the Waterschei colliery, and currently a showpiece of the Manifesta 9 art show in Genk. In this case the artist dominated the scientist and rendered a mysterious landscape of a pristine forest untouched by man, veiled in mist with an unfathomable depth. However, all the leading arborescent plant groups and climatic conditions typical for the Carboniferous era are represented.

Carboniferous forest painting by Jan Habex (1887-1954), a leading artist of the Genk school, commissioned by the Waterschei colliery. In this case the artist dominated the scientist and rendered a mysterious landscape veiled in mist with an unfathomable depth. However, all the leading arborescent plant groups and climatic events (water pond, fallen tree) are represented.

A severe drop in Eurasian ichthyosaur diversity prior to their late Cenomanian extinction: local or global signal?

Fischer V.[1,2]

→ v.fischer@ulg.ac.be

1 Département de Géologie, Université de Liège, B18, Allée du 6 Août, 4000 Liège, Belgium

2 Palaeontology Department, Royal Belgian Institute of Natural Sciences, 29 Rue Vautier, 1000 Brussels, Belgium

During the last decade, our knowledge of the taxonomic diversity of the Early Cretaceous ichthyosaurs (Mesozoic marine reptiles) has increased significantly, with the recognition of new species, genera, and subfamilies from Canada, Europe, and Russia. New data from England, France, and western Russia suggest ichthyosaurs remained diverse and abundant in western Eurasian marine ecosystems up to the late Albian–early Cenomanian, with the co-occurrence of three to four taxa occupying two to three distinct ecological niches in each formation considered (Cambridge Greensand Member, England; Marnes Bleues Formation, France; Stoïlensky quarry, Russia). However, the overlying formations (middle–late Cenomanian), consisting of chalk or glauconiferous sands, have yielded a very depauperate ichthyosaur fauna. These ichthyosaur assemblages are monospecific and comprise medium to large-sized, presumably opportunistic predators belonging the genus *Platypterygius*. This suggests a severe drop in ichthyosaur diversity some 5 millions years before their final extinction, which presumably occurred at or near the Cenomanian–Turonian boundary. However, it is difficult to know if this pattern is biased or genuine: the diversity drop may very well be an effect of preservational/ecological biases as well as a genuine extinction linked to the profound environmental changes occurring during the Cenomanian. The presence of similar impoverished assemblages in Cenomanian sediments worldwide favours the latter hypothesis, but the question remains open for now.

Updating the theories on ammonoid extinction

Goolaerts S.[1], Steurbaut E.[1], Dupuis C.[2]

→ stijn.goolaerts@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Department of Paleontology, Belgium

2 University of Mons, Department of Geology, Belgium

Since Alvarez *et al.* (1980) found new evidence for the impact of catastrophic events on earth's biota, hypothesis and theories explaining the fossil record (re)gained a lot of attention. The extraterrestrial origin of the anomalous iridium concentrations seemed highly controversial at first, but nowadays the Chicxulub 'accident' has become the marker for the start/base of the Paleogene. Its pivotal role in the Mesozoic-Cenozoic faunal turnover cannot be refuted (Schulte et al 2010). However, alternative theories remain being published. Of these, the Deccan volcanism with its widespread flood basalts stepped prominently forward as one of the main triggers, especially when trying to explain the gradual diversity decline within the fossil record.

The inconsistencies between the proposed theories generally root in too narrowly geographically and geologically spread datasets. This applies to most fossil groups, and especially to the ammonoids (Class Cephalopoda, °Early Devonian – †Late Cretaceous). A compilation of ammonoid occurrences of Late Maastrichtian age published by Kiessling & Claeys (2002) evidenced the lack of a globally well distributed dataset. In this compilation, North Africa was left as a blind spot, while Tunisia had been the centre of the K/Pg mass extinction debate for almost three decades, e.g. with the definition of the GSSP for the base of the Paleogene at El Kef.

Both at the GSSP and several other sections in the Tunisian Trough Basin, ammonoids were found within the topmost meters of the Maastrichtian, until very close to the K/Pg boundary level. About 900 uppermost Maastrichtian ammonoids were collected, all from within the last 420.000 years of the Cretaceous. With 22 species on record, belonging to 18 genera and 10 families, and with representatives of each of the four large ammonoid suborders (Phylloceratina, Lytoceratina, Ammonitina and Ancyloceratina), the Tunisian fauna demonstrates that ammonoids were both taxonomically and morphologically diverse until their very end. An updated version of the compilation of latest Maastrichtian ammonoid occurrences documents at least 53 species, 29 genera and 13 families in the ultimate half million year of the Cretaceous, in many more localities and occurring in a wide variety of settings.

When the Tunisian ammonoid species richness data are plotted next to all time constraints of the possible causes, the possibility of Deccan flood basalt volcanism negatively influencing ammonoid diversity must be refuted. A major extinction caused by the Chicxulub impact seems the most plausible theory at present. Through inducing a mass kill of the marine plankton, the juvenile ammonoids lost their primary food source leading to their final extinction.

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The first occurrence of a twig-nest with Phoenicopteriformes eggs in the fossil record and its evolutionary implications

Grellet-Tinner G.[1], Murelaga X.[2], Larrasoaña J.C.[3], Silveira L.F.[4], Olivares M.[2], Ortega L.A.[2], Trimby P.W.[5], Pacual A.[2]

→ locarnolugano@gmail.com

1 Associate Researcher at The Field Museum, Chicago; Associate Researcher at the Journey Museum, Rapid City; Investigador Correspondiente of CONICET, Argentina

2 Euskal Herriko Unibertsitatea, Facultad de Ciencia y Tecnología, Departamento de Estratigrafía y Paleontología, Apartado 644, E-48080 Bilbao.

3 Instituto Geológico y Minero de España, Unidad de Zaragoza, C/ Manuel Lasala 44, 9B, Zaragoza 50006, Spain

4 Seção de Aves, Museu de Zoologia da Universidade de São Paulo, Av. Nazaré 481, Ipiranga, São Paulo, Brazil, PO Box 42594, CEP 04299-970, lfsilvei@usp.br

5 Australian Centre for Microscopy & Microanalysis, The University of Sydney, NSW 2006, Australia

Both a judicious selection of nesting-site and the nest itself are critical for birds, as these mediate between environments and egg incubation to favour successful reproduction. We report here the first occurrence in the fossil record of a twig-nest with eggs (Vs-1) from an Early Miocene lacustrine limestone bed in the Tudela Formation (Ebro Basin, Spain). The fossil nest, built from Fabacea Both a judicious selection of nesting-site and the nest itself are critical for birds, as these mediate between environments and egg incubation to favour successful reproduction. We report here the first occurrence in the fossil record of a twig-nest with eggs (Vs-1) from an Early Miocene lacustrine limestone bed in the Tudela Formation (Ebro Basin, Spain). The fossil nest, built from Fabacea twigs and leaves, and its eggs were floating a few centimetres from the bottom of a sub-oxic and oligohaline endorheic lake. The avian fossil assemblage, throughout this formation, consists of monospecific osteological and oological remains, hereby assigned to a new phoenicopterid (a paleoflamingo). Vs-1 geological evidence suggests that gypsum-saturated waters expelled from the underlying sediments and forced through the existing syn-sedimentary faulting system favoured above-normal gypsum concentrations in the lake system and oligohaline (seasonally mesohaline) conditions prevailed. This might have ensured survival of microbialites and ostracods, which in turn ensured food and created favourable nesting ground conditions for this new phoenicopterid. Interestingly, Vs-1 ecological context is congruent with modern Andean puna environments and the African rift lakes in which modern flamingos could reproduce and where hydrothermal activities linked to tectonism produces haline and alkaline saturated fluids.

This unique discovery combined with our cross-disciplinary approach, provides for the first time unprecedented data that bridges the reproductive, nesting strategy, oological, and ecological gaps between Podicipediformes (grebes) and Phoenicopteriformes (flamingos). Furthermore, our results demonstrate that flamingos, which had a worldwide distribution during the Miocene, acquired their derived ecological and reproductive characters progressively in their phylogeny. Moreover, geotectonic factors seemed to underline the choice of nesting grounds for Phoenicopteridae, thus perhaps their geographical dispersion and conversely provincial extinctions.

Stromatoporoids and tabulate corals through the Devonian: diversity and biogeographical distribution

Hubert B.L.M.[1], Pinte E.[2]

→ benoit.hubert@icl-lille.fr

1Laboratoire de Paléontologie stratigraphique, FLST-ISA, Géosystèmes UMR 8217 CNRS.

2Laboratoire de Paléontologie stratigraphique, FLST-ISA

The stomatoporoids and tabulate corals are two of the major groups participating to the elaboration of reef barrier. In “Ardennes” according the geographical limits given by Hubert *et al.* (2007), these two groups are well diversified during the Devonian period (138 species distributed in 28 genera for the stromatoporoids, and 113 species in 31 genera for the tabulate corals), and more particularly reached their maxima during the Givetian stage (Zapalski *et al.*, 2007) because of the development of a large shallow marine carbonated platform environment, contrasting with previous stages characterized by a silico-clastic ramp model (Mabille *et al.*, 2008). The aim of this work were firstly to perform bio-statistical analysis on the biodiversity of stromatoporoids and tabulate corals using different specific and generic diversity and similarity-index (Shannon-wiener index), using also rarefaction curves to minimize sampling (or database) biases. A second aspect of this work was to establish a palaeogeographical comparison of the distribution of these two groups. Preliminary reports and results showed that 1- Stromatoporoids are generally more diversified than tabulate corals in reefs; 2- *Actinostromatida* and *Stromatoporellida* are the most representative orders for Stromatoporoids, and *Favositida* and *Auloporida* are those for tabulates corals; 3- Massive forms (domal, tabular, etc) were generally better represented than “low-morphological” forms (laminar, dendroid, etc); 4- generic and specific levels to estimate diversity gave generally (with some exceptions for tabulate corals) comparable results 5- Similar patterns of geographical distribution were observed for the two groups with rare exception; 6- Results of palaeogeographical similarities are dependant of numerous and varied factors.

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Rich-stromatoporoids patch-reefs from the Fletcherview section (Australia, Devonian)

Hubert B.L.M.[1], Talent J.A.[2], Mawson R.[2], Mathieson D.K. [2], Mistiaen B.[1]

→ benoit.hubert@icl-lille.fr

1 Laboratoire de Paléontologie stratigraphique, FLST-ISA, Géosystèmes UMR 8217 CNRS

2 Earth and Planetary Sciences, Macquarie University, 2109 Australia

The Fletcherview section, belonging to the Fanning River Group, is situated in the WNW of Townsville (Queensland, northeastern of Australia). The Fanning River Group, exposing a Middle Devonian to Carboniferous succession, is located in the Burdekin Sub-province. The group consists of three formations, successively the Big Bend Arkose, the Burdekin and the Cultivation Gully Formations. The Fletcherview section exposed partly the Big Bend Arkose and largely the Burdekin Formations. The studied patch-reefs consist of the Burdekin limestone (Burdekin Formation) and belong to the upper *Timorensis* – lower *Varcus* conodont zone, Eifelian – Givetian age. The well stratified section is approximately 15 meters thick. The upper part of the section is composed of sparse reef limestone blocks (actual reworked). The lower part of the section is formed by an alternation of slightly argillaceous limestone containing an abundant fauna (small branching tabulate corals, solitary rugose corals and brachiopods) and massive limestone with corals, stromatoporoids and sometimes large cephalopods. The studied patch reef sections correspond to the interval 11 to 13 (thickness in meter from the base of the section) and are characterized by a particular sandstone bed, followed by three thin limestone beds and argillaceous inter-beds, a rich branching corals argillaceous bed surrounded by the large and massive stromatoporoids-lens constituting the patch s.s. The three studied patch-reef are laterally correlated owing to the sandstone bed. The basal levels, corresponding to the branching coral beds, are not always continuous or well developed between each patch. Nevertheless, these beds are considered as having a role of hard sole permitting the anchorage of coral larvae and the growth of the reef lenses. The analyses of biodiversity are performed using the standard index of diversity, as Shannon index. In a same time, the variability of morphologies is correlated with microfacies to estimate the influence of environment on the growth and the stromatoporoid's shape. The systematic determination reveals the presence of some faunas similar to those present in Ardennes as *Stachyodes australe*. Finally, stromatoporoid assemblages are proposed to compare together each patch-reef.

The fossil record of assassin bugs (Heteroptera: Reduviidae) of Messel (Germany) and Green River (USA)

Koch M.[1,2], Wedmann S.[1,2]

→ marianne.koch@senckenberg.de

1 Senckenberg Forschungsinstitut und Naturmuseum, Forschungsstation Grube Messel, Markstraße 35, D-64409 Messel

2 Biodiversität und Klima Forschungszentrum (BiK-F), Senckenberganlage 25, D-60325 Frankfurt am Main

The UNESCO World Heritage Site Grube Messel located in Germany and the Green River Formation in the United States of America are two worldwide popular fossil sites with excellent fossil preservation. Both sites are of similar age with ~ 47 Ma (Messel) and ~ 50 Ma (Green River). While the sediments of Messel are bituminous mudstones (so-called "oilshales") whereas the majority of the sediments of Green River are composited of organic-rich micrite, evaporates and intercalated tuff beds. The sediments of both sites were deposited in lacrustrine environments.

During the last decades, the focus in paleontological research in Messel was on vertebrate fossils. Since a few years, the research on fossil insects from Messel and Green River increased. A very interesting group are the Heteroptera or bugs, until now poorly studied in both sites. More than 1,700 specimens of Heteroptera from Messel and 1,100 specimens from Green River are stored in the collections of Senckenberg Forschungsinstitut und Naturmuseum, Frankfurt am Main (Germany) and the National Museum of Natural History Smithsonian Institution, Washington D.C. (USA). In addition to taxonomical investigations, paleobiogeographic studies will be done.

With more than 6,600 extant species, the Reduviidae are the second largest group within the Heteroptera. Most of them are predators. The systematics of the assassin bugs is still in progress; e.g. different authors classified the Reduviidae from 21 up to 32 subfamilies. More than 60 fossil reduviid specimens of Messel are known and the extant groups Harpactorinae and Elasmodeminae can be identified. Among the Harpactorinae, Harpactorini, Ectinoderini and Apiomerini are determined. Extant Ectinoderini are restricted to the area between Sri Lanka and New Guinea; together with the fossil record from Messel, this enlarges the known geographical range of this group considerably. About 25 reduviid specimens were detected in the Green River collection.

A relative of the Ganges and Indus river dolphins from Miocene deposits of the Amazonian basin: multiple toothed whale invasions of freshwater environments?

Lambert O.[1], Bianucci G.[2], Salas-Gismondi R.[3], Tejada J.[3], Pujos F.[4,5], Urbina M.[3], Antoine P.-O.[6]
→ olivier.lambert@naturalsciences.be

1 Institut royal des Sciences naturelles de Belgique, Département de Paléontologie, Belgium
2 Dipartimento di Scienze della Terra, Università di Pisa, Italy
3 Departamento de Paleontología de Vertebrados, Museo de Historia Natural, Peru
4 Institut Français d'Études Andines, Peru
5 Departamento de Paleontología, Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales, Argentina
6 Institut des Sciences de l'Evolution (CNRS-UMR 5554), Université Montpellier 2, France

During their transition to the marine environment, in addition to numerous morphological changes, early cetaceans had to evolve physiologically to face the excess of salt due to the ingestion of seawater. But evolution is complex, far from being a process with one way. After this critical Eocene step of their evolutionary history, followed by several phases of diversification of fully marine cetaceans (leading to the two extant suborders, Mysticeti, the baleen whales, and Odontoceti, the toothed whales), members of several odontocete clades independently recolonized freshwater environments. Nowadays, four species in the genera *Inia*, *Lipotes* (possibly recently extinct), and *Platanista* (two species), exclusively occupy river and lake habitats, respectively in the Amazon-Orinoco, Yangtse, and Ganges-Indus river basins. Based on morphological and molecular data, as well as on paleontological information on their fossil relatives, it has been demonstrated that *Inia*, *Lipotes*, and *Platanista* are relict members of ancient lineages with distantly related marine ancestors.

Among them, the endangered *Platanista* is interesting for several reasons. In addition to its unusual cranial morphology, this nearly blind dolphin is the sole survivor of the superfamily Platanistoidea, much diversified from the late Oligocene up to the middle Miocene. Among platanistoids, the fossil record of Platanistidae is dominated by members of the extinct subfamily Pomatodelphininae, most of them discovered in marine to estuarine Miocene layers. Only one fragmentary mandible, from marine deposits of the early Miocene of Oregon, has been tentatively referred to the subfamily Platanistinae, the clade typified by the extant *Platanista*.

We report on the discovery of an isolated platanistid periotic (ear bone, one of the most diagnostic elements in crown cetaceans) found in late middle Miocene sediments of the Fitzcarrald Arch area, Peruvian Amazonia. This periotic is identified as belonging to a platanistine, based on several derived characters shared with *Platanista*. Even if fragmentary, this is likely the most significant fossil record of a platanistine, partly filling the temporal gap between the emergence of the subfamily and the Recent *Platanista*. Interestingly, this specimen was found in a geographic area now occupied by *Inia*. Sedimentology and associated fauna indicate that this middle Miocene depositional area corresponds to an inland tidally-influenced freshwater/oligohaline basin. Although a marine origin cannot be discarded for this new fossil platanistine record, it is tempting to hypothesize that it illustrates an early step of the colonization of a freshwater habitat, in a region very far from the area of *Platanista*. If confirmed, this interpretation would further support the scenario of multiple Miocene freshwater invasions by members of several odontocete clades.

Reasons for such drastic ecological changes are not yet clear, and several factors, both biological (competition with diversifying pelagic delphinoids, flight from oceanic predators, migration of prey in freshwater regions) and physical (sea level changes and temperature fluctuation), might have played a role. Species of three strictly freshwater odontocete genera survived until the Holocene, and one of them probably went extinct at the dawn of a twenty-first century that will be decisive for the fate of the remaining others.

The antiarch placoderms: revision of a major (although forgotten) component of the Devonian vertebrate fauna from Belgium

GB 2012 2 Student Competition for Best Oral Presentation

Olive S.[1,2]

→ Sebastien.Olive@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Department of Palaeontology, Belgium

2 University of Liège, Department of Geology, Belgium

New collected and historical material of the paleontological collections of the Royal Belgian Institute of Natural Sciences, University of Liège and University of Louvain-la-Neuve, allow the revision of the poorly-known antiarch (Placodermi, Vertebrata) fauna from the Upper Devonian of Belgium.

The only Belgian species (Leriche, 1931), clearly described in the literature, is *Bothriolepis lohesti* from the Famennian of Chèvremont (Liège Province). It was defined on few isolated dermal elements: some anterior median dorsal plates (AMD), one anterior dorso-lateral plate (ADL) and some elements of the pectoral fin. Here we complete our knowledge of the anatomy of that species thanks to unpublished material found in the Belgian university and institute collections. *Bothriolepis lohesti* is now well known and well defined. This is a species of fairly small size with the dorsal wall of the trunk armor quite flat and reaching a length of about 7-8 cm only.

Bothriolepidid material is recently known from the tetrapod-bearing locality of Strud (Namur Province, Famennian). The material is not substantial, few thoracic and pectoral fin plates, but is enough to state that all elements belong to juvenile individuals: the AMD plate presents anterior oblique dorsal sensory line grooves, the ornament is reticulate to nodose and the dorsal median ridge is well pronounced. Therefore, a determination at species level is not possible, that material is thus put in open nomenclature: *Bothriolepis* sp.1.

The bothriolepidid material from Modave (Liège Province, Famennian) is also attributed to juvenile individuals and also put in open nomenclature: *Bothriolepis* sp.2.

The Tienne-des-Marteaux quarry (Spontin, Namur Province, Famennian) has recently delivered some new interesting elements of quite large antiarchs: AMD, PMD, ADL, MxL, posterior ventro-lateral plate (PVL) and pectoral fin elements. They belong for sure to an asterolepidoid, an important group of antiarch.

The antiarch fauna, and more globally the placoderm fauna, from Belgium is much more diverse and abundant than previously known and will certainly improve our knowledge on the ecology and life environments of the Famennian vertebrate faunas from Belgium.

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Distribution of tabulate corals through the Givetian of the southern part of Dinant synclinorium.

Pinte E.[1], Mistiaen B.[1], Crônier C.[2]

→ emilie.pinte@isa-lille.fr

1 Laboratoire de Paléontologie Stratigraphique, FLST-ISA, France

2 Laboratoire Géosystèmes, UMR 8217 CNRS, France

Tabulate corals know their apogee during the Middle Devonian. At this time and especially during the Givetian, the presence on the southern part of Dinant synclinorium of shallow carbonate platforms and the tropical climate support their installation and their development. This study focuses on the evolution of the biodiversity vis-à-vis of the environment. The analyses were performed on 1230 specimens of tabulate corals (51 species) collected in the Cul d'Houille and the Mont d'Haurs type sections.

The Givetian of the southern Ardenne is divided into six formations (from the Hanonet Formation p. p. to the Nismes Formation p. p.). The Mont d'Haurs fortifications outcrops expose the Hanonet p.p., the Trois-Fontaines, the Terres d'Haurs and the Mont d'Haurs p.p. Formations. The Cul d'Houille section exposes the middle part of the Mont d'Haurs and the Fromelennes Formations.

The analyses of biodiversity show that abundance and specific richness increase from the top of Hanonet Formation to the Mont d'Haurs Formation. The occurrences of tabulate corals are influenced by the environment. Tabulate corals are present in all environments of the reefal platform but they are strongly represented in the reef *stricto sensu.*

For example, the diversity of the Hanonet Formation is low. This formation corresponds to a context of high sea level (open marine type facies), which induces not favorable conditions. Only some characteristic genera of this type of environment, as *Platyaxum,* or cosmopolite genera, as *Alveolites,* are present.

The Mont d'Haurs Formation corresponds to a major regressive episode leading to the installation and development of many large biostromes. This formation relates to the more favorable period to the development of coral. The abundance and diversity of the fauna of this formation are much more important than in the other formations of the Givetian. The genera *Thamnopora*, *Alveolites*, *Scoliopora*, *Crassialveolites* and *Alveolitella* are particularly well represented.

By contrast, the trend is reversed in the Fromelennes Formation. The mid-part of the Fromelennes Formation is characterized by quick variations of the sea-level and by variations of salinity, related to Taghanic event, tabulate corals react strongly to this stressing environment. Diversity is very low. Tabulate corals are reduced to scolioporids even if they are extremely abundant. Scolioporids are small tabulates corals with small corallites. They are considered as opportunist corals and are often present in unfavourable environments.

At the top of the Fromelennes Formation, a renewal of the fauna is observed, with a return of the "classical" Givetian genera, such as *Thamnopora* and *Crassialveolites*. This diversification results to an opening of the environment (from a restricted environment to an open marine environment) related to the beginning of the major transgression of the Frasnian basis.

Historical patterns of distribution and diversity in amiiform and pycnodontiform fishes

Poyato-Ariza F.J., Martín-Abad H.

→ francisco.poyato@uam.es

Unidad de Paleontología, Departamento de Biología, Universidad Autónoma de Madrid, Spain

Amiiformes and Pycnodontiformes are non-teleostean actinopterygians that were key members of most Mesozoic fish assemblages. Here we propose to examine and compare their distribution and diversity throughout time.

Their fossil records started in the Triassic; their highest diversity occurred during the Cretaceous, and decreased from the latest Upper Cretaceous on, leaving just one and no extant species, respectively. However, their diversity and distribution patterns are unexpectedly different.

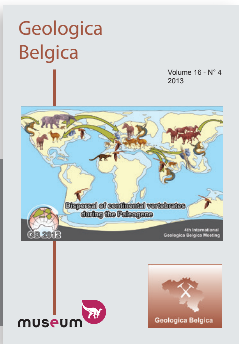
Amiiform fishes follow a clear vicariant pattern that extends from central Laurasia through the Tethys Sea, and the posterior apparition of both marine and freshwater ways, reaching an almost cosmopolite distribution. This distribution matches the phylogeny of the order, at least at the subfamily level, since most of the subfamilies present relatively constricted temporal and spatial ranges of distribution, and the relationships among them can be easily traced in a map of the changing Earth.

In turn, the distribution of the pycnodontiforms, although also initially associated with the Thetys sea, presents a dispersive pattern that begins on central Laurasia and extends worldwide in an intertropical range. Phylogenetically, several waves of distribution can be detected from the Tethys, their centre of radiation and also their final refuge in a sort of expanding-contracting historic distribution. As an ensemble, amiiforms are more related to continental masses and pycnodontiforms to oceans distributions, although they are not exclusively continental or marine, respectively.

The differences between distribution patterns of both groups of fishes might be associated to differences in their diversity as well. Amiiforms were usually less abundant in number of taxa during all the Mesozoic, with a total of 13 genera described versus the 21 genera of pycnodontiforms. Same goes for almost any particular site, with a maximum number of 3 different amiiform taxa and up to 7 or more different pycnodontiform taxa per locality.

This diversity in the number of taxa is associated to considerable differences in ecomorphological disparity. Amiiforms are very similar to each other, with highly hydrodynamic bodies, their disparity being thus relatively low, so that they always seem to occupy the same niche: active swimmers, more or less large, mainly ichtyvorous predators. Pycnodontiforms present a higher disparity, with variable body shapes, that allows them to occupy different niches, from maneuvering to generalistic swimming and a durophagous diets of different types and possible even herviborous diet.

Despite these differences, amiiforms and pycnodontiforms share a common evolutionary trait that is strongly defined by their similar capacity for competing with teleosts. Teleosts constitute the most diversified vertebrate taxa, and have eventually replaced most of the fish faunas that existed during the Mesozoic. This replacement, however, was not important until the Late Cretaceous, even though the origin of the teleosts also occurs in the Triassic. Why teleost kept their ecomoropho-logical homogeneity throughout most of the Mesozoic, and why they did not replace more primitive actinopterygians for such a long time remains unclear and constitutes a challenging field of research in the future. One key factor worth exploring is tectonics as linked to marine transgressions-regressions.



Full paper in Geologica Belgica, Volume 16, n°4
Historical patterns of distribution in Pycnodontiform and Amiiform fishes in the context of moving plates
by Martín-Abad H., Poyato-Ariza F.J.

A new Devonian flora in Argentina: palaeobotanical and stratigraphic implications

Prestianni C.[1], Rustán J.J.[2], Vaccari N.E.[2], Sterren A.F.[2], Steemans P.[3], Rubinstein C.V.[4]

→ Cyrille.prestianni@naturalsciences.be

1 IRSNB, Rue Vautier 29, 1000 Bruxelles, Belgique.

2 CICTERRA (CONICET-UNC), Córdoba, Argentina.

3 Unité PPP, Dpt. de Géologie, ULg, 4000 , Liège, Belgique.

4 Unidad de Paleopalinología, Departamento de Paleontología, IANIGLA, CONICET, Mendoza, Argentina.

Upper Devonian sedimentary rocks have not, up to now, been reliably recognized cropping out in Argentina. The single units considered as most probably recording the Devonian-Carboniferous transition are comprised within the La Punilla Formation, which integrates the main body of the Sierra de La Punilla, in the southwestern area of the La Rioja Province, in central-west Argentina. In this formation, two stratigraphic units were identified: a sandy lower member considered as Middle Devonian in age on basis of the presence of *Malanzania antigua*, and an upper hetherolitic member of probable Mississipian age based on records of *Frenguelli eximia*. The presence of Upper Devonian levels, was inferred there considering the continuity of the section, but without direct paleontological evidences.

Recently a siliciclastic sucession, was surveyed in the southernmost area of the Sierra de Las Minitas, a set of low ranges exhibiting stratigraphic and structurally complex settings, considered to be the northernmost continuation of the Sierra de la Punilla. One section of the Sierra de las Minitas (corresponding to the poorly known Jagüel Formation) is particularly interesting because it includes glacigenic diamictites deposits of discussed Devonian/Carboniferous age. Although radiometric ages of igneous bodies seemed indicate Upper Devonian-Lower Mississippian ages in nearby sections, palynological contents from this locality indicated a Middle Devonian age for the glacigenic deposits. The section is composed of pebbled dark mudstones at the base, a thick bed of (ca.70 m) diamictites above overlied by an hetherolitic interval (alternating sandstones, mudstones and shales) with brachiopod and bivalves coquinas and scarce plants, a thick sandy interval. Towards the top, another transgressive-regressive cycle with faunal records was recognised.

An interesting and surprisingly diversified plant assemblage was discovered in the thick sandy interval. Moderately diverse, it is mainly composed of axis of indeterminate affinities together with vegetative Lycophyte stems, dispersed pinnules and fertile organs.

This assemblage does not fit within the previously recognized Devonian and Lower Carboniferous biostratigraphic scheme of Argentina. None of the guide fossil plants of these two periods were recognized. However a comparison with other coeval localities outside of Argentina allows us to hypothesize an Upper Devonian age at least for these deposits. Thus, this would represent the first direct evidence of cropping Upper Devonian rocks in Argentina with fossiliferous records. This evidence suggests a linkage between the diamictite and the Gondwana Upper Devonian glacial event. Hence, palynological material indicating a Middle Devonian age for this diamictite should better be interpreted as reworked on the bases of these new evidences.

Session 11

Geodynamics, metamorphism and magmatism

Chairmen: Trond Torsvik & Manuel Sintubin
Key-note speaker: Trond Torsvik

Petrology and mineral chemistry of the serpentinized peridotites from The Salmas area, NW Iran

Ahangari M.[1], Oberhänsli R.[2], Moazzen M.[1]

→ ahangari@tabrizu.ac.ir

1 Department of Geology, Faculty of Natural Sciences, University of Tabriz, Iran

2 Institute of Geosciences, University of Potsdam, Germany

The serpentinized peridotites of the Salmas area are a part of a melange complex which is located at the NW Iran. Lithologically, this complex is composed of mixture of serpentinized ultrabasic rocks, serpentinites, metabasites, radiolarite, layered red pelagic limestones and grey and white marbles. According to the petrographic studies, the serpentinization degree of these rocks is variable. Olivine, orthopyroxene, clinopyroxene and spinel, are the relict minerals from the primary rock. The Salmas peridotites are dominantly composed of clinopyroxene bearing harzburgites.

Chondrite normalized rare-earth element patterns of the clinopyroxenes are characterized by LREE depletion, nearly flat HREE and weakly negative Eu anomalies. The REE pattern of clinopyroxene is similar to the most depleted global abyssal peridotites especially for HREEs.

On the basis of the REE composition of clinopyroxenes and Cr content of spinels, the estimated melting degree is varying from 9.1 to 13.2%. However, the LREE composition of the studied clinopyroxenes suggested refertilization of this mineral with the produced melt.

Discrimination diagrams and the composition of the trace elements of the clinopyroxene, suggest abyssal tectonic affinity for the Salmas peridotites.

Numerical modeling of stress fields: a continent moving consistently with the mantle flows

Bobrov A.[1], Baranov A.[1,2]

→ a_m_bobrov@yahoo.com

1 Schmidt Institute of Physics of the Earth, Department of Theoretical Geodynamics, Russia

2 International Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russia

The spatial fields of overlithostatic pressure, the vertical and horizontal stresses in the mantle and in a moving continent are studied in numerical models of mantle convection. The continent moves consistently with time-dependent forces, which act from the viscous mantle. By introducing the variable viscosity, we gain the possibility for taking into account the oceanic lithosphere that surrounds a continent, and the difference between the viscosity of the upper and the lower mantle. The calculations are carried out for three different patterns of the viscosity distribution in the mantle: an isoviscous model, a four-layer viscosity model, and a temperature- and pressure dependent viscosity model. At the considered stages of motion and in different parts, the continent is characterized by the following typical values of stresses: the overlithostatic pressure ranges from –5 to +15 MPa; the horizontal overlithostatic tensile stress amounts up to –4 MPa; and the compressive stress in case of the overriding of the subduction zone attains +35 MPa. The typical overlithostatic horizontal stresses in the main part of the mantle are ±(7–9) MPa; in the highly viscous regions and, particularly, in the subduction zones near continental margins they are about five times larger. We find significant differences between the fields of the horizontal stresses, vertical stresses, and the pressure. The pressure field reveals both vertical and horizontal features of slabs and plumes, clearly showing their long thermal conduits with more broad heads. The horizontal stresses are sensitive to the subhorizontal features of the flows, whereas the vertical stresses mainly reveal the vertical substructures of the flows. These fields exhibit strong concentrations in the areas of descending slabs, where the values are much higher (50 MPa). This agrees with current views on the oceanic slabs as the most important factor of the mantle convection.

New insights into Palaeozoic geography, with focus on Asia

Cocks L.R.M.[1], Torsvik T.H.[2]

1 Department of Palaeontology, The Natural History Museum, London SW7 5BD, UK

2 Physics of Geological Processes, Oslo University, PO Box 1048, N-0316 Oslo, Norway

New palaeogeographical reconstructions have been generated over much of the world from the Late Cambrian until the Permian: maps which have been partly derived from new knowledge on the positioning of Large Igneous Provinces and kimberlites on the margins of long-lived heterogeneities at the core-mantle boundary, and the understanding of their relationships to continental blocks. Oceans, deeper shelves, shallower shelves and land areas plotted on those maps aid in understanding the distribution of provincial plants and animals throughout the Palaeozoic.

Today's Asia chiefly consists of blocks derived from the Gondwana supercontinent in its south and Siberia to its north, but in the eastern sector between Gondwana and Siberia there were other continents, such as North China and Tarim, all of which had adjacent and often transient island arcs, some of which later evolved into microcontinents. In addition, there are the substantial South China and Annamia (Indochina) blocks, which had left Gondwana before the start of the Palaeozoic and were probably initially united into a single continent. That combined continent appears to have been laterally translated northeastwards from today's Middle East parallel to the northern Gondwanan margin until the Early Devonian, when the two principal components started to drift northwards with the opening of the Palaeotethys Ocean and also split into two separate continents at about the same time. The west-central sector of Asia is occupied by a large number of originally independent Palaeozoic terranes (some with Precambrian cores) in Kazakhstan and adjacent countries, and those terranes amalgamated progressively until a continental block named Kazakhstania had formed by the beginning of the Silurian.

Pangea formed progressively from the Mid-Carboniferous onwards, but initially affected only the area to the west (the Americas). In Asia, although the Palaeoasian Ocean closed steadily, it remained open between the former Gondwana and Siberia until the Early Mesozoic. On the northern Gondwana margin the Neotethys Ocean opened in the Permian, with Sibumasu, the Tibetan terranes and others further west all rifting away from Gondwana. However, although firstly Kazakhstania and then Siberia had formed part of Pangea (which already included Gondwana) by the end of the Carboniferous, North China, South China and Annamia did not amalgamate with the supercontinent until well into Mesozoic times, after the main parts of Pangea had started to break up.

Congo Basin: structural evolution in a deforming cratonic plate

Delvaux D.[1], Kadima K.E.[2], Kipata M.L.[2], Mulumba J.-L.[2], Sebagenzi M.N.[2]

→ damien.delvaux@africamuseum.be

1 Royal Museum for Central Africa, Tervuren, Belgium

2 Department of Geology, University of Lubumbashi, Katanga, DRC

The Alfred Wegener theory of plate tectonics is based on the continental drift hypothesis and postulates that the Earth's surface is composed of major tectonic plates that move in response to the sea floor spreading. The plate interior is supposed to be rigid or weakly deforming with tectonic deformation occurring at their boundary. Consequently, continental deformation away from the plate boundaries has long been neglected in the geodynamic models. The Congo basin which develops in the middle of the Congo cratonic plate, has long been regarded as unaffected by tectonic deformation. However, seismic reflection profiles and sismotectonic studies have suggested that the Congo basin could be deforming during his history after its initiation as a failed rift system. A recent review of the tectonic structure and tectono-stratigraphic evolution of the Congo basin confirms this opinion and further shows that the Congo basin was episodically but repeatedly affected by tectonic compression during his long history since the Precambrian-Cambrian transition, due to the action of far-field stresses generated at plate boundaries. This long-lived but episodic deformation history had important consequences in terms of petroleum system development.

The massive Mousny Quartz Occurrence (High-Ardenne slate belt, Belgium), a late-orogenic dilatational jog?

GB 2012 Contestant for Best Oral Presentation

Depoorter S.[1], Muchez P.[1], Piessens K.[2], Sintubin M.[1]

→ simon.depoorter@student.kuleuven.be

1 Geodynamics and Geofluids Research Group, Katholieke Universiteit Leuven, Belgium.

2 Geological Survey of Belgium, Royal Institute of Natural Sciences, Belgium

In and around the village of Mousny, Belgium, multiple large (>m³-scale) bodies of pure milky quartz are exposed in an approximately NNE-SSW orientation. The new geological map of the area (Dejonghe & Hance 2001) seems to suggest that this quartz occurrence is fault-related. Besides these massive quartz occurrences, several other cleavage-parallel, milky quartz veins can be observed in the area.

This study presents the first attempt to characterize and to place the Mousny quartz occurrence in the successive veining events in the High Ardenne slate belt, as demonstrated in previous research of the Geodynamics and Geofluids Research Group at the KU Leuven, and to suggest a model to address the massive nature of the quartz occurrence.

Field work has shown that the Mousny quartz body still contains host-rock inclusions, as well as geodes of clear quartz displaying the typical hexagonal crystal shape. The orientation of the host-rock inclusions corresponds to the regional cleavage trend of 145/55. The host-rock inclusions furthermore display signs of earlier quartz veining.

A petrographic study shows several signs of low to moderate temperature deformation such as recovery, recrystallisation and grain boundary migration as well as chlorite, muscovite and several quartz growth stages. These results were complemented using hot cathodoluminescence microscopy which revealed that the milky quartz matrix itself actually consists of at least 4 quartz growth stages.

The microthermometry and Raman microspectroscopy indicate the presence of several types of fluids. A first type consists of a H_2O-CO_2-N_2-CH_4 bearing fluid which can further be subdivided into three subtypes of fluid inclusions: (i) high-density gas-bearing inclusions characterised by a CO_2 homogenisation temperature which is lower than the clathrate melting temperature; (ii) gas-bearing inclusions without CO_2-homogenisation or CO_2-melting temperatures but still displaying clathrate melting; and (iii) gas-bearing inclusions with CO_2-homogenisation temperatures around or higher than the clathrate melting temperatures. A second type of fluid inclusions consists of a low-salinity H_2O-NaCl fluid with low homogenisation temperatures (between 120 and 180 °C) which represents a late stage of quartz growth.

Total homogenisation temperatures of the gas-bearing fluid inclusions display a wide range between 180 °C and 300 °C. This has been interpreted as the result of the intense deformation which has affected the quartz stretching and deforming the fluid inclusions.

The massive, and localised, nature of the Mousny quartz body poses a geometrical problem. Identical quartz veins in the area – as well as the attitude of the host-rock inclusions – suggests that the Mousny body – at least partly – postdates the Variscan cleavage development. The Mousny quartz body is thus a late orogenic feature, comparable to the discordant veins in the Herbeumont area. A working hypothesis is proposed calling upon a dilatational jog along cleavage planes activated as either normal or reverse faults.

Dejonghe L., Hance L. (2001). *Champlon – La Roche-en-Ardenne.* Notice explicative sur la carte géologique de Wallonie, 60, 44.

Assessment of slip-related microstructures and stylolites in quartz veining related to tectonic inversions by means of EBSD and SEM-CL

GB 2012 Contestant for Best Oral Presentation

Derez T.[1], Pennock G.[2], Drury M.[2], Muchez P.[1], Sintubin M.[1]

→ Tine.Derez@ees.kuleuven.be

1 Geodynamics and Geofluids Research Group, Katholieke Universiteit Leuven, Belgium

2 Department of Earth Sciences, Utrecht University, The Netherlands

Recent studies on quartz veins in the High-Ardenne slate belt (Belgium, Germany) have led to a geodynamic model illustrating the relationship between fluid flow and brittle-ductile deformation during Variscan tectonic inversions. The models comprise the evolution from pre-orogenic bedding-normal veins, early orogenic bedding-parallel veins - related to the early orogenic, compressional tectonic inversion - to thin, planar and thick complex, discordant veins, related to the late orogenic, extensional tectonic inversion. We aim at refining and testing this model by a study of inter- and intracrystalline microstructures, using optical microscopy, hot cathodoluminescence microscopy (CL), electron backscatter diffraction (EBSD) and scanning electron microscope cathodoluminescence (SEM-CL).

The evolution of the stress states during formation and deformation of the quartz veins is reconstructed by studying (1) intracrystalline deformation features, e.g. extinction patterns, deformation lamellae, deformation bands, shear bands, twins; and (2) intercrystalline deformation structures, e.g. stylolites. Indications for the syn- to post-veining nature of these microstructures are discussed. The microstructures are studied in perpendicular thin sections implying that the maximum shortening direction is only approximated in a two dimensional view. Therefore, the shortening direction measured with optical microscopy is termed the 'shortening bisector' (cf. Van Baelen, 2010). Preliminary findings indicate that compression bisectors of shear bands and stylolites show a similar orientation with respect to vein walls. Hence, the compression bisectors have an orientation approximately parallel and perpendicular to the vein walls of bedding normal and bedding parallel veins, respectively.

By means of EBSD, the rotation axis between the crystallographic orientation of shear bands and their host grain can be determined. The application of this rotation axis to deduce the real, three dimensional maximum shortening axis, is assessed. The amount of misorientation between the microstructures and their host grain and the activated slip systems are also evaluated. As such, the deformation inferred from the microstructures is partly quantified. The formation mechanism of shear bands is further elaborated with SEM-CL in order to discriminate a primary brittle or ductile process. In addition, the relationship between deformation lamellae, deformation bands and shear bands is addressed.

Van Baelen H., (2010). *Dynamics of a progressive vein development during the late-orogenic mixed brittle-ductile destabilization of a slate belt, examples of the High-Ardenne slate belt (Herbeumont, Belgium)*. Aardkundige Mededelingen 24, 221.

Paramagnetic metamorphic mineral assemblages controlling AMS in low-grade deformed metasediments and the implications with respect to the use of AMS as a strain marker

Haerinck T.[1], Adriaens R.[1], Debacker T.N.[2], Hirt A.M.[3], Sintubin M.[1]

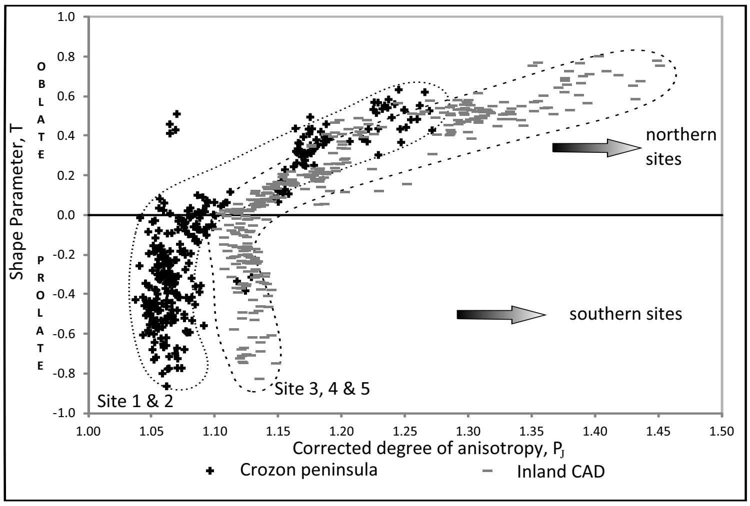
→ tom.haerinck@ees.kuleuven.be

1 Department of Earth and Environmental Sciences, Katholieke Universiteit Leuven, Belgium

2 F.W.O.-Vlaanderen, Belgium

3 Institute of Geophysics, ETH Zürich, Zwitserland

A regional, integrated analysis of the low-field and high-field anisotropy of magnetic susceptibility (AMS), of the (magnetic) mineralogy and of the geochemistry has been performed on low-grade metamorphic, deformed homogeneous siltstone beds (HSBs) of the Lower Palaeozoic Plougastel Formation in the Central Armorican Domain (CAD), Brittany, France. Despite the fact that we sampled a single bed type, different paramagnetic metamorphic mineral assemblages are controlling the AMS in the anchizonal metamorphic, Crozon peninsula sites (white mica and chlorite) and in the epizonal metamorphic, inland sites of the CAD (white mica, chloritoid and chlorite).



Plot of T versus PJ, showing a hockey-stick shaped pattern both for Crozon peninsula sites (anchizonal mineral assemblage) and for inland sites (epizonal mineral assemblage).

We show that the AMS of the HSBs reflects a composite magnetic fabric, resulting from the progressive superposition of a cleavage-parallel fabric on a pre-existing bedding-parallel compaction fabric. Both the Crozon peninsula and the inland datasets show a hockey-stick shaped pattern on a Jelinek graph, in which the shape parameter T is plotted against the corrected degree of anisotropy P_J, although the whole pattern is shifted to higher P_J values for the inland dataset (Fig. 1). We tentatively attribute this shift to the intrinsic AMS of chloritoid which we have proven to be significantly higher than the intrinsic AMS of white mica and chlorite. For both Crozon and inland datasets, the southern sites show relatively low P_J and T values compared to the northern sites. This suggests a northward-increasing strain gradient for the CAD, in line with the overall geodynamic model of the "Bretonian" convergence of the CAD with the Léon Domain, situated to the northwest of the CAD (cf. Sintubin *et al.* 2008, Ballèvre *et al.* 2009).

However, the different investigated sites also show an internal spread in P_J and T values that seems to be linked to the observed quartz/white mica ratio. We attribute this relationship to non-platy quartz that disrupts the petrofabric intensity. Also, high-field torque magnetometry indicates that the (low-field) P_J and T values in two inland sites (i.e. in site 3 and partly in site 5, see figure) are enhanced by a small ferromagnetic (*s.l.*) contribution.

Our findings show that the P_J and T values of the HSBs are strongly influenced by (small) compositional variations and do not merely indicate tectonic strain, even in very similar tectonostratigraphical settings. Therefore, the observed differences in AMS parameters cannot be compared quantitatively in terms of tectonic strain.

Ballèvre M., Bosse V., Ducassou C., Pitra P. (2009). *Palaeozoic history of the Armorican Massif: models for the tectonic evolution of the suture zones*. Comptes Rendus Geosciences, n°341, pp 174-201.

Sintubin M., van Noorden M., Berwouts I. (2008). *Late Devonian-early Carboniferous contraction-dominated deformation in Central Armorica (Monts d'Arrée, Brittany, France) and its relationship with the closure of the Rheic Ocean*. Tectonophysics, n°461, pp 343-355.

The Cambrian to Devonian odyssey of the Brabant Massif within Avalonia

Herbosch A.[1], Liégeois J.-P.[2], Pin C.[3], Gärtner A.[4], Hofmann M.[4], Linnemann U.[4]

→ Herbosch@ulb.ac.be

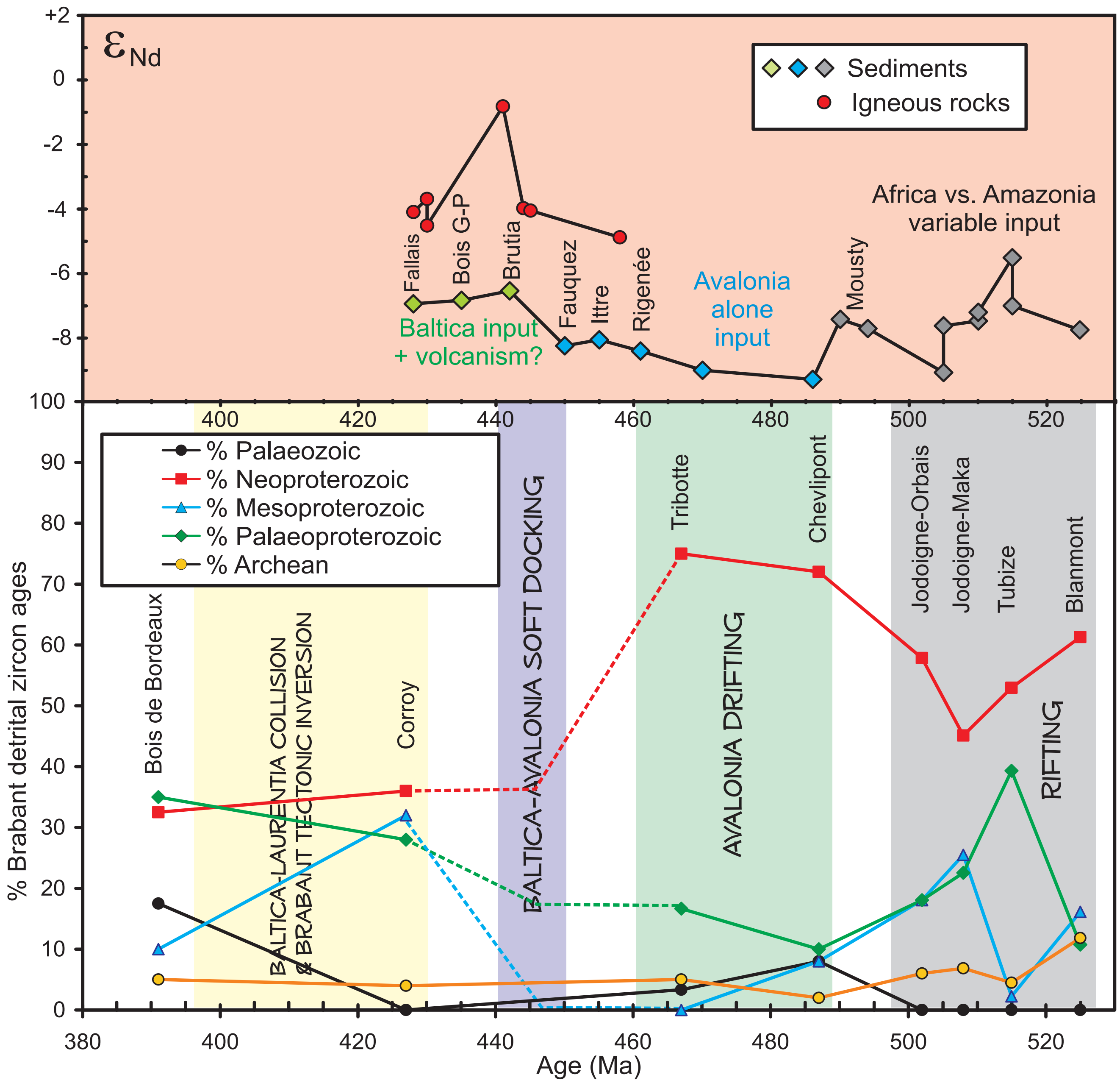
1 Université Libre de Bruxelles, 1050 Brussel, Belgium;

2 Royal Museum for Central Africa, 3080 Tervuren, Belgium;

3 Université Blaise Pascal, 63038 Clermont-Ferrand Cedex, France;

4 Senckenberg Naturhistorische Sammlungen Dresden, Museum für Mineralogie und Geologie, 01109 Dresden, Germany.

The Brabant Massif, belonging to the Anglo-Brabant Deformation Belt, is situated at the southeastern side of Avalonia microplate and constitutes the only well-known part of the northern passive margin of the Rheic Ocean. The Cambrian-Silurian sedimentary pile is >13 km thick, with >9 km for the Cambrian only. The unraveling of this continuous registration reflects the successive rifting and drifting of Avalonia from Gondwana mainland, followed by soft-collisional processes with Baltica and finally the formation of Laurussia. Based on recently established detailed stratigraphy, sedimentology and basin development, on U-Pb LA-ICP-MS analyses of igneous and detrital zircon grains along with geochemical data including Sm-Nd isotopes, a new geodynamic and palaeogeographic evolution is proposed. Brabant Megasequence 1 (lower Cambrian to lowermost Ordovician, >9 km thick) represents an embayment of the peri-Gondwanan rift from which the Rheic Ocean has evolved. Detrital zircon ages demonstrate that the Brabant is a typical peri-Gondwanan terrane with a major Pan-African (Neoproterozoic age) and a mixed West African and Amazonian source (Palaeoproterozoic, Archaean and some Mesoproterozoic age). The transition towards the Avalonia drifting is marked by an unconformity and a short volcanic episode. The northward drift of Avalonia towards Baltica is recorded by the Megasequence 2 (Middle to Upper Ordovician, 1.3 km thick). The source for Mesoproterozoic zircons vanished, as the result of the Rheic Ocean opening and the isolation from Amazonian sources. The transition to Megasequence 3 is marked by a drastic change in palaeobathymetry and an important (sub)volcanic episode during a tectonic instability period (460-430 Ma), reflecting the Avalonia-Baltica soft docking as also shown by the reappearence of Mesoproterozoic detrital zircons, typical of Baltica. Unradiogenic Nd isotope signature (ε_{Nd} -4/-5) and T_{DM} model ages (1.3-1.7 Ga) for Brabant magmatic rocks indicate an old recycled component. Megasequence 3 (uppermost Ordovician to lowermost Devonian; >3.5 km thick) includes the onset of a Silurian foreland basin that reflects the tectonic inversion of the core of the massif (Brabantian orogeny) in response to the Baltica/Avalonia - Laurentia collision. Finally, the comparison with the strikingly similar Cambrian successions of the Harlech Dome (Wales, Avalonia) and the Meguma terrane (Nova Scotia, peri-Gondwana) allows the construction of a new Early Cambrian palaeogeographic model for the whole Avalonia microplate, in which the Meguma terrane is included.



Below: variation through time of the proportions of Brabant detrital zircon ages regrouped in five classes.
Above: variation through time of the εNd signatures of the Brabant sediments and magmatic rocks and the deduced signature of main sources.

Synorogenic vein kinematics at the northwestern margin of the High-Ardenne slate belt (Redu-Daverdisse, Belgium)

GB 2012 Contestant for Best Oral Presentation

Jacques D., Muchez P., Sintubin M.

→ dominique.jacques@student.kuleuven.be

Geodynamics and Geofluids Research Group, KU Leuven, Belgium.

Fluid flow related to tectonic inversions has extensively been studied in the High-Ardenne slate belt (Germany, Belgium, France), as evidenced by the widespread occurrence of quartz veins. Veining linked to the main Variscan orogenic stage is far less abundant and strictly related to localized folding and faulting.

In the northwestern part of the High-Ardenne slate belt (Redu-Daverisse, Belgium) several (early- to) synorogenic quartz vein types were recognized during a structural mapping in the well-exposed Lesse river valley. Assessing the kinematics of the different vein types in the Lower-Devonian Saint-Hubert Formation, fluid flow has been related to brittle-ductile deformation, with a strong component of simple shear. Local fluid flow was influenced by lithology, with veins concentrated within the competent metaquartzitic rocks or at their interfaces, but also by specific sedimentological characteristics (e.g. lenticular competent layers, point bars, trough cross-bedded bars). Veining has been produced by several kinematic processes, such as fold-related deformation (e.g. saddle reef, tension gashes in the fold hinges, bedding-parallel slickenfibres, stockwork veining), shear reactivation of cross-bedding and truncation surfaces in a trough cross-bedded bar (e.g. bedding-parallel veins and slickenfibres, conjugate discordant shear veins), faulting (e.g. chaotic fault-parallel veins) and folding along sedimentological or tectonic wedges (e.g. blocky quartz geodes).

Because of the localized nature of the quartz veins and lack of evidence for large-scale tapping via fault-fracture meshes, the quartz most likely originated from local dissolution of the host rock. It is inferred from (micro)structural analysis that several veins formed as open voids/fractures, resulting from structural deformation along wedges or as saddle reefs. The lack of collapse and the free polycrystal growth in the cavities, suggest the presence of high fluid pressures during the filling of the mechanically induced cavities. Other vein observations concur this statement. We therefore conclude that in compressional orogenic settings, high fluid pressures can be sustained without hydraulic fracturing because of the large differential stresses characterizing the compressional regime.

Lufilian Arc: long record of brittle tectonics in relation to moving plates

GB 2012 Contestant for Best Oral Presentation

Kipata M.L.[1,2], Delvaux D.[3], Sebagenzi M.N.[1], Cailteux J.-J.[4], Sintubin M.[1]

→ kipatalouis@gmail.com; damien.delvaux@africamuseum.be

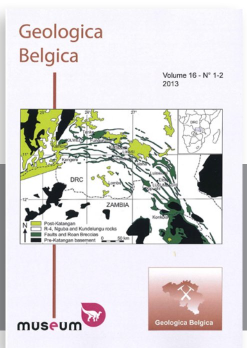
1 Department of Geology, University of Lubumbashi, Katanga, DRC

2 Geodynamics and Geofluids Research Group, K.U.Leuven, Leuven, Belgium

3 Royal Museum for Central Africa, Tervuren, Belgium

4 Groupe Forrest International, 22 Av. Kigoma, Lubumbashi, DRC

The Lufilian Arc of Katanga (DRC) and northern Zambia formed in response to the interaction between the Kalahari and the Congo-Tanzania cratonic plates during the late stages of the Pan-African amalgamation of Gondwana. If the general structure and stratigraphy are relatively well known, the deformation history during the long period spanning the peak of fold and thrust emplacement and the present-day extensional context related to the development of the east African rift system remains poorly known. We present new fault-kinematic field observations and paleostress inversion results from 21 important mines, quarries and outcrops spread over the Lufilian arc, its Kundelundu foreland and Kibarian margin. The results allow to propose a brittle evolution model with successively compressional to transpressional stages related to the Lufilian orogeny, transtensional to extensional stages related to late orogenic relaxation and extensional collapse, post-orogenic transpressional inversion and rift-related extension. These brittle deformations contributed significantly to the remobilization of mineral elements and their concentration into economic deposits.



Full paper in Geologica Belgica, Volume 16, n°1-2

Brittle tectonic and stress field evolution in the Pan-African Lufilian arc and its foreland (Katanga, DRC): from orogenic compression to extensional collapse, transpressional inversion and transition to rifting

by Kipata M.L., Delvaux D., Sebagenzi M.N., Cailteux J.-J., Sintubin M.

Metacraton nature, genesis and behavior: the Tuareg Shield (Sahara) case study

Liégeois J.-P.[1], Abdelsalam M.G.[2], Ennih N.[3], Ouabadi A.[4]

→ Jean-paul.liegeois@africamuseum.be

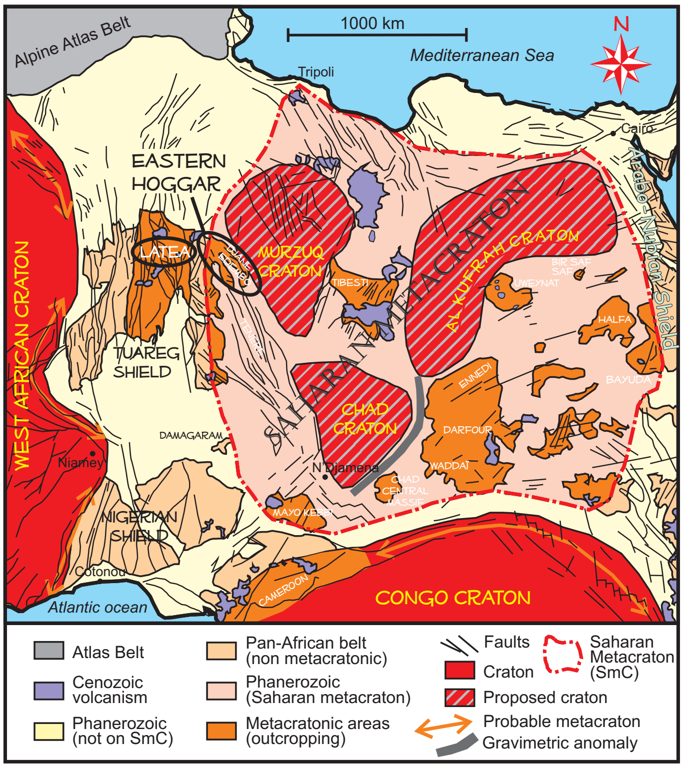
1 Isotope Geology, Royal Museum for Central Africa, B-3080 Tervuren, Belgium

2 Missouri University of Science and Technology, Dept Geological Sciences & Engineering, 1400 N. Bishop, Rolla, MO 65401, USA

3 Équipe de Géodynamique, Géo-éducation et Patrimoine Géologique, Dept Géologie, Faculté des Sciences, Université Chouaïb Doukkali, BP. 20, 24000 El Jadida, Morocco

4 Laboratoire LGGIP/USTHB, Faculté des Sciences de la Terre, de la Géographie et de l'Aménagement du Territoire, BP 32, El Alia Bab Ezzouar 16 111 Algiers, Algeria

We highlight that cratons involved in intercontinental collisions in a lower plate position are often affected by orogenic events, leading to the transformation of their margins. In some cases, craton interiors can also be shaped by the intense collisional processes, leading to the generation of intracratonic orogenic belts. We propose to call these events "metacratonization" and the resulting lithospheric tract "metacraton". Metacratons can appear similar to typical orogenic belts (i.e. active margin transformed by collisional processes) but are actually sharply different. Their main distinctive characteristics (not all are present in each metacraton) are: (1) absence of pre-collisional events; (2) absence of lithospheric thickening, high-pressure metamorphism generated by subduction, leading to high strain gradient and metamorphic intensity; (3) preservation of allochthonous pre-collisional oceanic terranes; (4) abundant post-collisional magmatism associated with shear zones but not with lithospheric thickening; (5) presence of high-temperature–low-pressure metamorphism associated with post-collisional magmatism; (6) intracontinental orogenic belts unrelated to subduction and oceanic basin closures. Reactivation of the rigid but fractured metacratonic lithosphere will cause doming, asthenospheric volcanism emplacement, and mineralizations due to repetitive mineral enrichments. In Sahara, the Pan-African orogeny, which led to the formation of Gondwana through the convergence of at least West Africa, Congo and Saharan cratons, has also led to the metacratonization of the latter (now the Saharan metacraton, 5,000,000 km2) as well as smaller tracts such as the LATEA metacraton in Central Hoggar. Here, we focus on the metacratonization of LATEA during continental subduction and transpressive escape tectonics (630-580 Ma) and on the metacratonization of eastern Hoggar (western Saharan metacraton) in an intracratonic setting (575-545 Ma) as a result of the impingement of the Murzuk craton (a relict craton within the Saharan metacraton), implying a possible role of the Siberian craton.



Main rheological domain of Saharan Africa centered on the Saharan metacraton. From Liégeois *et al.* (2012)

Liégeois J.P., Abdelsalam M.G., Ennih N., Ouabadi A. (2012). *Metacraton: Nature, genesis and behavior.* Gondwana Research, Volume 23, Issue 1, pp 220-237.

Petrology of the Sabalan volcanoclastic, implications for the initiation of Sabalan volcano, Meshkinshahr, Iran

Mousavi S.Z.[1], Darvishzadeh A.[2], Ghalamghash J.[3], VosooughiAbedini M.[4], Panahi Khiavi K.[1]

→ zahedmousavi@gmail.com

1 Department of basic science, Meshkinshahr Branch, Islamic Azad University (I.A.U.), Meshkinshahr, Iran, E-mail: zahedmousavi@gmail.com

2 Department of basic science, Lahijan Branch, Islamic Azad University (I.A.U), Lahijan, Iran, E-mail: Drdarvishzadeh@yahoo.com

3 Geological Survey of Iran,P.O.Box131851494,Tehran,Iran, E-mail: ghalamghash@gsi.org.ir

4 Department of basic science, Science & Research Branch, Islamic Azad University (I.A.U), Tehran, Iran, E-mail: drvosooughi@yahoo.com

The study area is located in the South- East part Meshkinshahr city, North West of Iran. Recent studies have shown that the Sabalan volcano, as a distinctive geologic province. The Sabalan volcanoclastic represents an important rock record to unravel the early of Sabalan volcano. Here, this formation is presented based on detailed field observation together with petrological and geochoronological data. The Sabalan volcanoclastic consists predominantly of deposits from pyroclastic density currents and breccias, originating from fluvial and mass flow processes. The clastic material is almost exclusively of volcanic origin, ranging in composition from andesite to rhyodacite. We made the first attempt to establish a stratigraphical framework for the volcanoclastic dividing the formation into three different units based on the dominating depositional processes: a volcanic-laharic unit, a fluvial-laharic unit and a laharic-volcanic unit. In the context of ongoing discussion on the initial activity of the Sabalan volcano, the volcanoclastic represents one of the most important formations to decipher the evolution of this subduction magmatic. K-Ar dating suggests that this section represent the time 2.8 ± 0.4 M.a. The fragment volcanoclastic rocks examined in thin section are predominately fine grained clasts, rich feldspar and subordinate mafic crystal fragment. The combined results are used to provide an interpretation of the depositional regimes of the Sabalan volcanoclastic.

Deformation history and micro structural assemblage of Gorveh metamorphic zone, Iran

Sheikhzakariayi J.[1], Mousavi, S.Z.[2]

→ jzr1346@yahoo.com

1. Department of basic science, Science & Research Branch, Islamic Azad University (I.A.U), Tehran, Iran, E-mail: jzr1346@yahoo.com

2. Department of basic science, Meshkinshahr Branch, Islamic Azad University (I.A.U.), Meshkinshahr, Iran, E-mail: zahedmousavi@gmail.com

The present contribution summarizes the first results of a study focusing on microstructures from Ghorveh area, Sanandaj – Sirjan belt, west of Iran. Its aim is both an analysis of the evolution of the metamorphic complex recorded in schistes, amphibolites, marbles and the supply of basic material for process-oriented studies on microstructures due to natural deformation. Quantitative analyses of the variations of statically recrystallized microstructures suggest a relationship with the peak metamorphic temperatures. Previously unrecognized post-thermal peak shear zones, showing overprint microstructures typical of grain-boundary migration and dynamicre crystallization, are described. The survey of cataclastic metamorphism role by using petro graphic and microstructure studing are indicated a tectonically pressure system have formed the kind of mylonite, crenulations, myrmikite, ribbon quartz and mica-fish microstructures.They document the natural deformation of Gorveh metamorphic zone.

Electron Backscatter Diffraction Analysis of Quartz in Early and Late Orogenic Veins in the High-Ardenne Slate Belt (Germany, Belgium)

Sintubin M.[1], Wenk H.-R.[2]

→ manuel.sintubin@ees.kuleuven.be

1 Geodynamics and Geofluids Research Group, Katholieke Universiteit Leuven, Belgium

2 Department of Earth and Planetary Science, University of California, Berkeley, USA

On a selection of early and late orogenic quartz veins in the High-Ardenne slate belt (Germany, Belgium) an electron backscatter diffraction (EBSD) analysis has been performed to obtain detailed crystallographic information on the vein quartz.

On the one hand, we selected early orogenic, bedding-perpendicular fibrous veins from the Rursee area (Eifel, Germany) and complex, hydrid extensional-shear, bedding-parallel veins, both predating the main Variscan deformation stage. On the other hand, we sampled late orogenic, discordant veins in the Herbeumont area (Belgium), part of an extensional brittle-ductile detachment. Both veining events are assumed to have occurred in periods of tectonic inversion, characterized by high pore fluid pressures (up to supralithostatic) and low differential stresses.

The microfabric of the vein quartz shows a wide range of deformation features, from undulatory extinction, deformation lamellae, to a wide range of recrystallisation features, typical for the deformation in low-grade metamorphic conditions (~250-450°C) in a brittle-ductile transitional environment at the base of the seismogenic crust (~10-15 km depth).

The EBSD analysis reveals the ubiquitous presence of Dauphiné twins in both the early and late orogenic vein quartz. It appears, though, that the twins do not to occur uniformly. Twinning is clearly confined to crystals with a particular crystallographical orientation, while neighbouring crystals with a different orientation are completely twin free. This relationship between twinning and crystallographic orientation suggests that the observed Dauphiné twins are a mechanically induced, stress-dependent feature.

Commonly, twins occur as ‘patchy’ intracrystalline domains, in the case of both large, equant quartz crystals in a blocky vein fill, and elongated quartz crystals in a fibrous vein fill. In a number of particular cases, twin boundaries are aligned and mark the boundaries of optically observed deformation lamellae. In other cases, deformation lamellae are unrelated to Dauphiné twinning and occur indiscriminately in both the twinned and untwinned domains within a single quartz crystal.

In this contribution we will further reflect on the observed relationships between Dauphiné twins and the intracrystalline deformation features in the different types of vein quartz, as well as on their significance with respect to the kinematics of the veining. The possible relationship between Dauphiné twinning and the stress-state evolution in both early and late orogenic veins will be discussed.

From Wegener until now

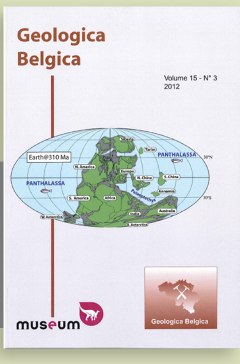
Torsvik T.H.

→ t.h.torsvik@geo.uio.no

Center for Physics of Geological Processes (PGP), University of Oslo, Norway

One hundred years ago, Alfred Wegener proposed that all the continents once formed a single supercontinent, which he named Pangaea, and that was surrounded by a vast marine area termed the Panthalassa Ocean. Wegener's Pangaea reconstruction was principally based on the similarity between coastlines on opposite sides of the Atlantic, but he also pointed out that Permian and Carboniferous plant and animal fossils from a number of continents, now separated by the Atlantic and Indian Oceans, were largely identical. From the distribution of glacial deposits, he was also convinced that a continental ice cap must have covered those contiguous southern parts of Pangaea in the Late Carboniferous. If we compare Wegener's Pangaea with modern reconstructions, which are based on a much larger database and more disciplines, there are many similarities, but the most striking difference is that we are now able to position Pangaea and other continents at their original latitude and longitude at the end of the Palaeozoic (and at other times). That is in addition to being able to define each of those old continents, and their margins which made up Pangaea and other now-vanished continental and oceanic units, much more objectively, as well as charting their histories.

Many substantial books and papers have described and analysed the history of the origin of Wegener's continental drift theory, its variable (and largely hostile) reception by different scientists, and its subsequent replacement in the 1960s by plate tectonics, and it is not our purpose to repeat that story here more than briefly. The chief aim is to review our understanding of Earth's evolution as it has developed and progressed since Wegener's work a hundred years ago, and to outline where we now are on this topic, which is of central relevance to Earth scientists.



Full paper in Geologica Belgica, Volume 15, n°3

From Wegener until now: the development of our understanding of Earth's Phanerozoic evolution

by Torsvik T.H., Cocks R.M.

Panafrican obduction, crushing & shearing of the Neoproterozoic Khzama ophiolite (Anti-Atlas, Morocco)

Triantafyllou A.[1], Berger J.[2], Plissart G.[3], Diot H.[4], Ennih N.[5]

→ Antoine.Triantafyllou@umons.ac.be

1 Université de Mons, Research assistant, Belgium.

2 Université Libre de Bruxelles, FRS-FNRS, Belgium

3 Université Libre de Bruxelles, FRIA - FRS-FNRS, Belgium

4 LPGN, UMR CNRS 6112, Université de Nantes, France

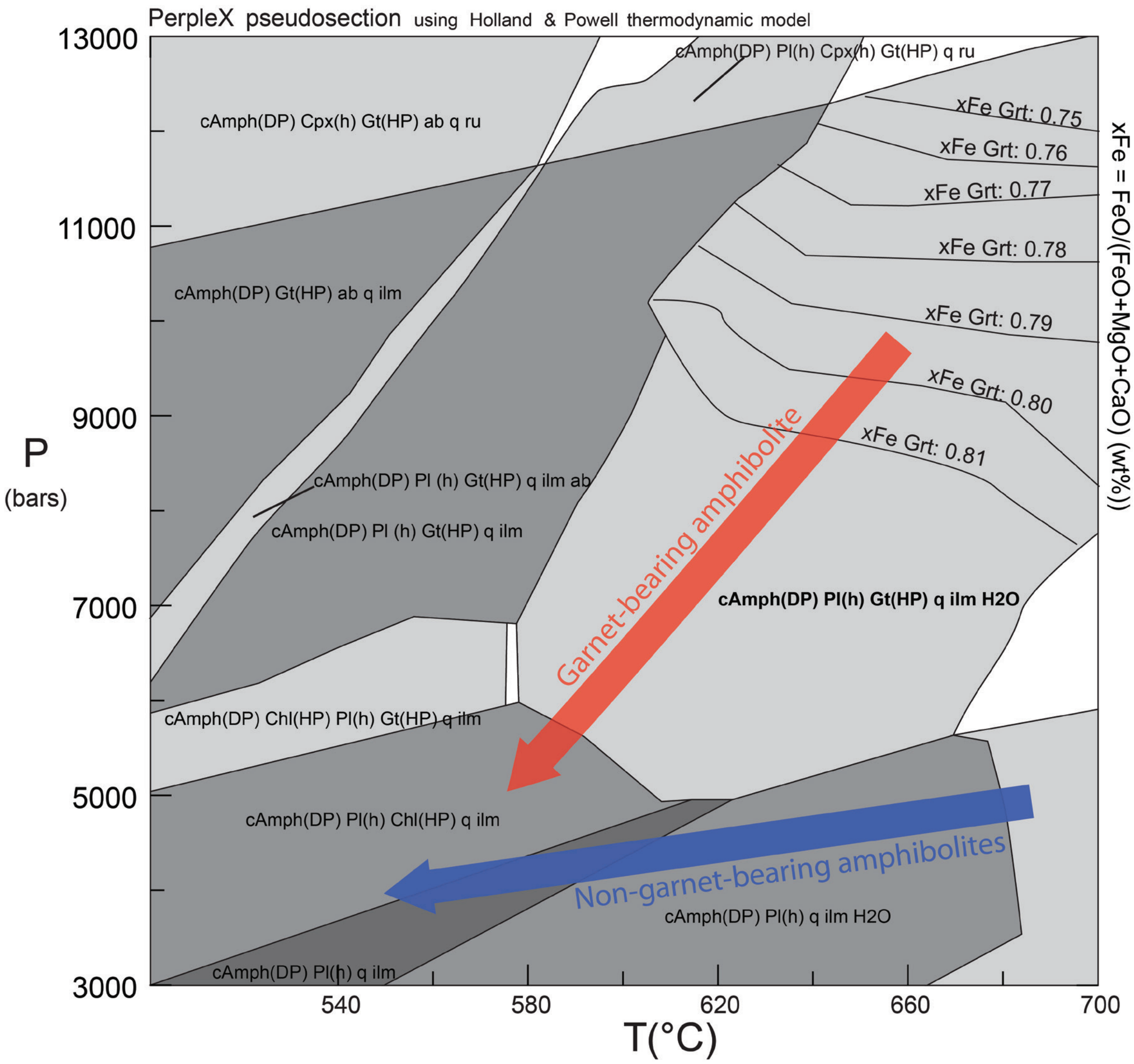
5 Université Chouaib Doukkali, El Jadida, Morocco

We present the results of a field, structural, petrographical study of the c. 740 Ma[1] Neoproterozoic ophiolite of Khzama, situated to the East side of the Sirwa Window of the Anti-Atlas Orogen of Morocco. The ophiolitic sequence is composed successively of serpentinites, talc-serpentine schists (metaharzburgites), pegmatitic amphibolites (metapyroxenites), porphyroclastic to mylonitic amphibolites (metagabbros), meta-dolerites, intrusive plagiogranites and few metabasalts. Associated tectonic framework is characterized by nappes thrusted southward on underlying remnants of magmatic arc (Iriri migmatites and Tachoukacht schists) and limited to the North by the discordant volcano-sedimentary formations of the Ouarzazate Supergroup.

The entire ophiolitic complex was affected by an important retro-metamorphism, from amphibolite to greenschists facies. Equilibrium temperatures of hornblende-plagioclases assemblages, range from 430° to 730°C (± 40°C) and from 350° to 600°C for chlorites, at low-pressure conditions (~2-3 kbar). Thermodynamic modeling of specific almandine-amphibole-plagioclase paragenesis located within the remnants of the oceanic rocks, argue for localised metamorphism acquired under low geothermal gradient (660°C, 9 kbar). This medium pressure conditions are also constrained by garnet xFe (wt%) isocomposition curves on PerpleX pseudosection, ranging from 0.77 and 0.81 wt% (see figure).

Foliation azimuths trend from N80° to N140° and two main populations of stretching lineations are observed. We distinct a first southward movement marked by foliated structures, recumbent folds and down-dip lineations (D1a). Contraction of the nappe stack leads to the formation of upright tight folds with horizontal axis and a generalised verticalization of the structures (D1b). Late stage deformation is marked by asymmetric upright isoclinal folds with vertical axis, horizontal to moderately dipping lineations (D2), asymmetric porphyroclasts and C-S shear bands formed in a globally sinistral transpressive regime.

These important observations allow us to propose a tectonic evolution of the Khzama ophiolite. We consider that the ophiolitic complex has thus accommodated pre- to syn-collision crustal stacking and obduction by horizontal displacement of thrust sheets toward the SW (D1a); syn-collision crushing (D1b) marked by upright structures. The continuation of the post-collision convergence and the geometrical constraint of continental paleoboundary lead to a sinistral transpressional regime. This late event probably due to the sliding of the northern Avalonia-related blocks along the northern margin of the West African craton is thus responsible for the formation of intense shear bands[3], and an intense reorganization of the structures. Calculated PT conditions and pseudosection modeling show that the ophiolite has registered both low-P metamorphism (oceanic or orogenic) and LT-MP recrystallisation. The latter is an evidence for partial subduction and tectonic extrusion of some oceanic thrust slices, which are essential actors in the tectonic evolution of this Neoproterozoic oceanic lithosphere and on a more global scale, in reconstructing the oceanic paleosutures dynamic of the Nothern West African Craton boundary.



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Geometrical analysis of kink bands in the Lower Devonian of the High-Ardennes Slate Belt in Herbeumont (Semois Valley, Belgium)

Vanermen L., Derez T., Van Baelen H., Sintubin M.

→ lisa.vanermen@student.kuleuven.be

Geodynamics and Geofluids Research Group, Katholieke Universiteit Leuven, Belgium

In the Herbeumont area, situated in the core of the High-Ardennes Slate Belt, Lower Devonian, Pragian, slates are well exposed. Folding during the Visean to early Namurian, Sudetic stage of the Variscan orogeny was associated with the development of a pervasive south-dipping slaty cleavage. In the study area the average cleavage attitude is 192/57 (dip direction/dip). The slates in the study area are characterized by an intense development of kink bands.

The studied Linglé outcrop is a well-exposed road cut, located 3 km north of Herbeumont. The foliations associated with the kink bands have been drawn on four overview slides (75cm x 1m; technique proposed by Timothy Debacker during a personal communication in August 2007) and 47 kink bands have been measured directly in the field. The characteristic kink band angles (ϕ, ϕ_k, ψ) were calculated from the orientation measurements in the field and measured on the overview slides. A detailed geometric and kinematic analysis by means of the kink band triangle of Srivastava *et al.* (1998) allows to deduce their formation mechanism and the related paleostress state by evaluating the angle (α) between the original anisotropy and the maximum compressive stress during formation. A dip isogon analysis has been performed on the kink bands. However, because of the angular shape of the hinges, the method is not straightforward.

In the Linglé outcrop, three types of kink bands can be recognized; (1) kink bands with kink band boundaries steeply dipping to the north and top-to-the-north kinematics, (2) kink bands with kink band boundaries weakly dipping to the north and top-to-the-south kinematics and (3) chevron-type kink bands. The kink bands have an overall contractional geometry. They represent a shortening of 2% and an angular shear strain of 8.5 and 6.4 deduced from the calculated and measured angles, respectively. In the kink band triangle most of the kink bands plot right of the central line, indicating an apparent internal extension of the kink bands, and α varies between 0° and 10°. Further, the kink bands likely formed by flexural slip. The evolution pad of the kink bands is defined by the rotation and/or the simple shear model; for the chevron-type kink bands the fixed hinge model of Van Baelen (2010) is proposed.

The kink bands give an insight into the deformation history of the Linglé outcrop, which can be different from the regional history. The kink bands are formed through an overall south-facing compression, oriented at a low angle to the south-dipping cleavage.

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Session 12

The Brittle-Ductile record of earthquakes

Chairmen: Kris Vanneste & Damien Delvaux

Deformation pattern at the western tip of the Corinth Rift

Beckers A.[1,2], Hubert-Ferrari A.[1], Beck C.[3], Bodeux S.[1], De Batist M.[4]

→ abeckers@ulg.ac.be

1 Géomorphologie, Université de Liège, Liège, Belgium

2 Fonds pour la formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA), Bruxelles, Belgium

3 Laboratoire de Géodynamique des Chaînes Alpines, U.M.R. C.N.R.S., Université de Savoie, France

4 Renard Centrum of Marine Geology, Universiteit Gent, Belgium

The Gulf of Corinth in Greece is an active continental rift propagating westward toward the Aegean subduction zone. GPS data shows that deformation rate reaches a maximum of 15 mm/yr at its western tip. The style of extension and strain distribution is well documented offshore in the eastern and central parts of the rift (Bell, 2009). At its most active western extremity, published offshore data is not sufficient to characterize the deformation pattern. High resolution seismic profiles were thus acquired in that region within the framework of the SISCOR project to improve our understanding of fault evolution, seismicity and to be able to construct mechanical models of deformation. Here we investigate the spatio-temporal pattern of the basin subsidence and deposition with sparker data acquired in November 2011.

Active faults and correlative time horizons were first mapped. The stratigraphy was then correlated with the eustatic sea-level curve. This sequence stratigraphic interpretation is possible because there are strong glacial-interglacial variations in the depositional environment. In fact lacustrine conditions prevail within the gulf during glacio-eustatic lowstands and are characterized by low amplitudes seismic facies. So synrift sediment isopachs over the last 12 000 and 130 000 yrs could be produced. The interpreted data allow us to: (1) compare deformation pattern at the western tip of the Gulf with the more mature central and eastern part of the Rift; (2) constrain the pattern and the timing of deformation as well as rates of faulting.

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The recent activity of the Marqueffles fault (Artois)

Camelbeeck T.[1], Verbeeck K.[1], Lecocq T.[1], Vanneste K.[1], Sebrier M.[2], Bergerat F.[2], Jomard H.[3], Baize S.[3], Colbeaux J.-P.[4], Vandycke S.[5]

→ thierry.camelbeeck@oma.be

1 Royal Observatory of Belgium, Seismology, Avenue Circulaire 3, BE-1180 Uccle, Belgium;

2 ISTeP, UMR 7193 CNRS-UPMC, Université Pierre et Marie Curie, Paris, France

3 IRSN – Institut de Radioprotection et de Sûreté Nucléaire, Paris, France

4 Université des Sciences et Techniques de Lille, Lille, France

5 Géologie Fondamentale et Appliquée, Faculté Polytechnique, Université de Mons, Belgium

The Strait of Dover and southern North Sea area limited by south-east England, northern France and the Belgian coast suffered from three M≥5.5 earthquakes on 21 May 1382, 23 April 1449 and 6 April 1580 (Melville *et al.*, 1996). At the exception of the M = 4.6 September 2, 1896 earthquake (Kusman *et al.*, 2010) that occurred in the North of France, near the city of Arras, the most recent earthquake activity of the Artois region is characterized by few earthquakes with small magnitude. This is a typical example of the episodic character of the earthquake activity in plate interiors and of the difficulty to characterize it. To evaluate this episodic character, it is important to analyze if the structures that generated large historical earthquakes with M≥5.5 are active in a geological sense. The lack of geological activity would suggest an absence of the persistence at long term of the large earthquake activity on those structures, meaning that the activity migrated or will migrate on other structures.

We are investigating the region including the Strait of Dover and the North of France to find tectonic activity that could be related to these large earthquakes. Here, we present the results on our investigation of the northern part of the Artois anticline that limit the Flemish plain to the south. This structure is a small anticlinal flexure cut by faults reactivated with a reverse sense during the early Tertiary tectonic inversion (Auffret and Colbeaux, 1977) and named Artois fault system. Those faults have slightly different orientations in the Boulonnais (WNW-ESE) and in the Artois (NW-SE). This fault system appears as the only well-identified regional geologic structure capable to produce M=6.0 earthquakes as the one of 1580 in the Strait of Dover, corresponding to a ruptured fault surface of approximately 100 km^2 with a fault length around 10 km.

The faults have influenced the river development, independently of lithological contacts, suggesting possible Quaternary tectonic activity. Quaternary activity of the Marqueffles fault has also been suggested in the archaeological site of Biache-Saint-Vaast (Colbeaux *et al.*, 1981). We identified the precise location of the Marqueffles fault between the localities of Vimy and Fampoux by conducting geomorphological, geological and geophysical investigations. So far, we have surveyed 12 electrical resistivity profiles, 69 ambient seismic noise and 40 relative gravimetric measurements. We identify contrasts in the physical properties of the subsurface at depths varying from 1 to 60 m. Up to now, it has not be possible to identify definitively Quaternary activity that could be related to earthquake activity.

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Morphotectonics and paleostress of an active normal fault system in the Ufipa plateau in western Tanzania: deep-to shallow brittle record of repeated reactivations

Delvaux D.[1], Kervyn F.[1], Macheyeki A.S.[2], Temu E.B.[3]

→ damien.delvaux@africamuseum.be; ebtemu@yahoo.co.uk; asmacheyeki@yahoo.com

1 Royal Museum for Central Africa, Tervuren, Belgium,

2 Mineral Resources Institute, Ministry of Energy and Minerals, P.O.Box 1696, Dodoma-Tanzania

3 Geological Survey of Tanzania, O.O. Box 903, Dodoma, Tanzania

Active fault systems are often controlled by the reactivation of pre-existing zones of weaknesses, especially in tectonic zones that remained weak during a long geological period. The active normal fault systems that affect the Ufipa plateau between the Rukwa and Tanganyika rift basins in Western Tanzania illustrates this concept particularly well. This area was hit by a Ms 7.3 earthquake a century ago near Sumbawanga Town and this event remains the strongest known earthquake that affected the East African rift system to date. The Ufipa plateau is affected by a series of morphologically well expressed normal fault systems, of which the Kanda fault is the most prominent one. Morphotectonic investigations has shown that these fault systems are composed of / originated as isolated fault segments that interact each other / progressively merged together. Earthquake geology from outcrops along the trace of the Kanda fault shows a complex fault-rock structure that evidence several tectonic stages and allowed to reconstruct the stress field evolution in progressively shallower conditions trough time. The Kanda fault appears to reactivate an old mylonitic fabric of probable Pan-African age. It initiated as thrust faulting during the late stages of the Pan-African deformation, was reactivated as a strike-slip fault during a Triassic inversion, and turned into a normal fault during the development of the East African rift system. Recognition of this multistage history has important implications for the understanding of the opening dynamics of the East African rift system.

Dating uplift events by a composite metric of fluvial landscapes

Demoulin A.[1,2]

→ ademoulin@ulg.ac.be

1 FRS-FNRS Belgium

2 Dept of Physical Geography and Quaternary, University of Liège, Belgium

Geomorphometry may be a powerful tool to describe the landscape's response to tectonic signals, but the meaning of morphometric indices is often obscured by the interplay between the many variables controlling the geomorphological evolution. Moreover, although the hypsometric integral refers to the basin scale, most indices are generally derived from river long profiles and thus focus mainly on the short-term (<10^5 years) response of a drainage network to base level change. Here, I present a metric aimed at providing a comprehensive view of the response stage attained by different hierarchical levels of the landscape. This R metric is a ratio of two-by-two differences between the three normalized integrals linked respectively to the classical basin's hypsometric curve, to the main river's long profile, and, at the intermediate level, to a 'drainage network's hypsometric curve'. It is also corrected for the influence of branching level of the drainage network. The influence of uplift rate is largely cancelled by taking advantage of the observed relation between altitude and uplift rate and normalizing R. By contrast, the metric is strongly correlated with basin size A, reflecting the way an erosion wave propagates from the outlet of a basin toward its headwaters. Therefore, it cannot be used directly to extract a time signal from the landscape's shape. However, the logarithmic function linking the metric to drainage area is typical of each particular region, and it may be shown that the derivative S_R of the function $R = f(\ln A)$ is theoretically expected to evolve continuously with time during the transient response phase after a region has been uplifted, following a temporal pattern of slow and regular decrease after a rapid initial increase. S_R appears thus as a time indicator free of most external influences. Application of the R/S_R morphometric approach to regions worldwide where the age of the last perturbing uplift signal is more or less well constrained has pointed to an empirical scaling law between S_R and time. Based on 210 basin data from 9 uplifted regions, the best, physically meaningful fit takes the form of a power law (t in million years)

$$t = 0.009\ S$$

This expression tends to a steady state value of ~0.20 for S_R after a landscape response time of ~5 My. In conclusion, beyond their dating potential, the multi-scale R metric and the derived S_R index reveal that, as long as a landscape has not recovered from a perturbation, it possesses an inherent memory of the event. In other words, there exists a quantitative law of fluvial landscape evolution with time, largely independent of external factors (as far as one sticks to the actual content of the R metric).

Seeking the source of the 1580 dover-strait/Pas-de-Calais earthquake

GB 2012 Contestant for Best Oral Presentation

García Moreno D.[1,2], Vanneste K.[1], Verbeeck K.[1], Jomard H.[3], Versteeg W.[2]

→ David.GarciaMoreno@oma.be

1 Royal Observatory of Belgium. Av. Circulaire 3, 1180-Bussels, Belgium.

2 Renard Center of Marine Geology, Ghent University. Krijgslaan 281, Ghent, Belgium

3 Institut de Radioprotection et de Sûreté Nucléaire. Av. de la Division Leclerc 31, Fontenay-aux-Roses, France

Northern France, England and Belgium are characterized (apart from the Roer Valley Graben) by moderate and diffuse instrumental seismicity. Nonetheless, destructive earthquakes have occurred in historical times, such as the magnitude ~6.0 event that happened in the Dover Strait (Pas de Calais) on November 28th, 1580. This earthquake was widely felt and caused significant damage in many cities, reaching intensities of VIII (MSK). The epicenter of this earthquake has been located near the offshore extension of the Artois Shear zone, a major Variscan tectonic structure that traverses the Dover Strait, suggesting that this structure, or some of its fault segments, may be presently active.

Two campaigns have been organized by the Royal Observatory of Belgium and the Renard Center of Marine Geology in 2010 and 2012 with the objective of finding evidence of recent tectonic activity in the epicentral area of the 1580 earthquake. During these campaigns multibeam bathymetry and high-resolution seismic-reflection profiles were collected between the coasts of Sangatte (Northeastern France) and Folkestone (Southeastern England). The analysis of these data shows indeed some faults located in the western part of our study area deforming lower Cretaceous sediments. However, none of these faults seem to offset the sediments infilling the basins and paleo-channels located in this region. The most prominent feature revealed by the seismic reflection survey is a broad monoclinal structure that can be traced from southeast to northwest along the seismic grid. On the sea-floor, the crest of the monocline coincides in the southeastern half of the study area with a prominent NW-SE ridge, which corresponds to an outcropping seismic unit with higher reflectivity than under- and overlying layers, and probably formed by differential erosion. The characteristics and continuity of this monocline structure suggest that it may be the surface expression of a blind fault at depth. However, we have not been able to verify this hypothesis yet due to the low penetration of the seismic survey. So far, we could not find any clear evidence of recent deformation recorded in the sea-floor morphology or in Quaternary deposits, but this is severely hampered by the strong erosion and sediment-starved conditions in this area.

The possible use of landslides as paleoseismic markers

Havenith H.-B.[1], Lamair L.[1], Strom A.[2]

→ HB.Havenith@ulg.ac.be

1 Georisks and Environment group, Department of Geology, University of Liege. B18. 4000 Liege. BELGIUM. Email: HB.Havenith@ulg.ac.be

2 Geodynamic Research Center – Branch of Hydroproject Institute, Moscow, Russia

Landslides can be considered as indirect effects of earthquakes; therefore, they are much less commonly used as paleoseismic markers than (even hidden) fault scarps. There are only a few studies on this subject and those consider mainly the spatial distribution of landslides triggered by earthquakes. Here, we will present a new (and at this stage preliminary) approach to use landslides as paleoseismic markers, based on examples from the Tien Shan and the Lesser Caucasus. The studied periods range from 100 to 300 years for the Tien-Shan and more than 2000 years for the Lesser Caucasus, considering that the seismic history of Armenia is well-documented over a longer period than in the Tien Shan. Case histories presented here include ancient rockslides and related dams as well as landslides triggered by the M=8 Kemin earthquake in 1911, the Khait earthquake in 1949 (see Fig. 1) and some more recent events in 1989 (Gissar, Tajikistan) and 1992 (Suusamyr, Kyrgyz Republic). For Armenia, we will present a review on earthquake-triggered landslide events, including natural dams that can still be identified in the landscape as markers of past earthquakes, even more than 1000 years after triggering.

It is well known that in many mountain regions most of the landslides are induced by hydro-meteorological factors, such as in the Alps. The Tien Shan and Lesser Caucaus have been chosen because of their topography, their semi-arid climate and their high seismicity. Therefore, in those regions hydro-meteorological factors are less important as triggers of slope instability; especially, giant mass movements are generally triggered by major earthquakes.

However, it's essential to be able to distinguish seismic landslides from non-seismic landslides. This can be done through spatial analysis, especially on the basis of size-frequency distributions and through geomorphological studies. Paleoseismic interpretation further requires establishing the age of the paleoearthquake(s). Therefore, dating of landslide occurrences is required. Several methods for dating landslide movements will be reviewed, such as dendrochronology, lichenometry, radiometric and cosmogenic dating. The final purpose of our studies is to assess the impact of the earthquakes on mountain morphology in the Tien Shan and in the Lesser Caucasus.

Khait rock avalanche triggered by the 1949 Khait earthquake, Tajikistan; view towards the East from Yasman valley (unpublished photograph of 2005 provided by A. Ischuk). The length of the scarp is about 1 km.

Paleoseismic record of a sag-pond along the North Anatolian Fault (Turkey)

Hubert-Ferrari A.[1], Avsar U.[2], El Ouahbi M.[1], Lepoint G.[1], Fagel N.[1]

→ aurelia.ferrari@ulg.ac.be

1 Unit of Physical and Quaternary Geography, University of Liege, Sart Tilman, B- 4000 Liège Belgium

2 Ghent University, Renard Centre of Marine Geology, Department of Geology and Soil Science, Krijgslaan 281 s.8, Gent 9000, Belgium

Shallow lakes along minor structural bends or discontinuities of strike-slip fault are not usually paleoseismological target sites. In the present study we show that a 2m deep, 700m long lake crosscut by the North Anatolian Fault contain a reliable paleoseimological record obtain through coring. The North Anatolian Fault, a major strike-slip fault in Turkey last ruptured across the Asacipetecik Lake in 1939 with a slip of about 6 m. Seismic lines still shows remains of the fault ruptures forming minor 10 cm high scarps across the lake. Collected short cores show a set of sedimentary sequences composed of three different units. The lower unit, dark and fibrous, is similar to the present sedimentation at the top of the core. The strongly disturbed and whitish top unit 1 has anomalous organic matter content, grain size and mineralogy. The unit 2 is intermediate in between unit 1 and 3. The present stratigraphy is related to earthquake shaking inducing (1) sediment resuspension; (2) reworking of sediments coming from co-seismic scarps and lake margins; (3) increase in sedimentary runoff into the lake. The 2.5 m long core comprises 4 sequences, and thus 4 sedimentary events. Cesium and Lead data obtained in Boes *et al.* (2009) imply that the first sedimentary event was triggered by the 1939 M=7.9 Erzincan Earthquake. Radiocarbon age dating suggest that the last sedimentary event are initiated by the 1254 historical earthquake. The second sedimentary event may correspond to the 1668 earthquake documented in paleoseimological trenches a few kilometers to the east. The third sedimentary event does not correspond to a major known historical earthquake.

Paleostress analysis of brittle deformation in the Kinsevere Copper Deposit, DRC

Kazadi B.S.-B.[1,2], Bumby A.J.[1], Delvaux D.[3], Cailteux J.H.L.[4]

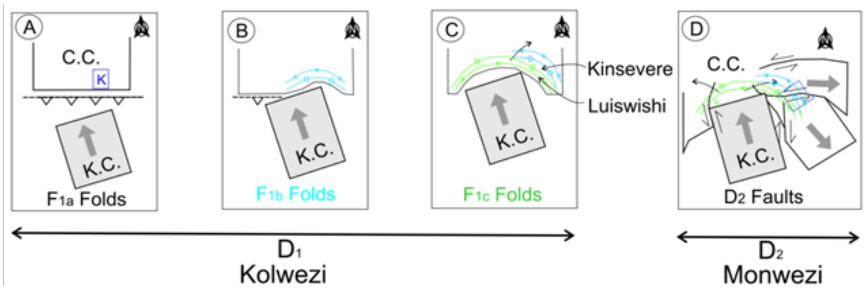
→ barryk@ivanplats.com

1 Department of Geology, University of Pretoria, Pretoria 0002, South Africa

2 African Minerals Barbados Limited, Ivanplats Group, Lubumbashi, DRC

3 Royal Museum for Central Africa, Department of Geology-Mineralogy, B-3080, Tervuren, Belgium

4 Département Recherche et Développement, EGMF, Groupe G. Forrest International, Lubumbashi, DRC



Indentor model of the Lufilian arc showing the indentation of the Kalahari craton into the Congo craton (modified from Kampunzu and Cailteux, 1999).

The Kinsevere mine is a copper deposit located in the Democratic Republic of Congo (DRC), within the Central African Copperbelt. This area is situated in the Katangan basin within the SE portion of the Lufilian Arc, which is a large, arcuate structure that extends from SE Angola, across the DRC, and into NW Zambia. The purpose of this study is to characterize the brittle deformation observed around the Kinsevere copper deposit, to help understand the deformation history of the area. This was accomplished by analyzing fault-slip and fold data to help understand the relationship between regional palaeostress, faulting and folding present in the mine vicinity. This study also attempts to characterize fracture-controlled copper mineralization within the interpreted geodynamic context of the area. The larger objective of this study is to relate the structural observations from Kinsevere to the deformation history of the Lufilian Arc.

This study uses the Right Dihedral method (Angelier and Mechler, 1977) to analyze slickensided faults, mineralized joints, and unmineralized joints and shear fractures. The data indicate that the paleostress associated with formation of brittle structures in the Kinsevere area occurred during three deformation events. The first event is characterized by a compressional stress regime which occurred during the early stage of the Kolwezian phase (D_1) (Regional, generally north-verging folds associated with the collision of the Kalahari and Congo cratons between 850-690 Ma: Kampunzu and Cailteux, 1999). The second event is characterized by a strike-slip stress regime that formed as the result of clockwise rotation of structures formed during the earlier (D_1) compressional regime. Two fault-slip vectors were observed on the strike-slip fault planes, indicating that a reactivation occurred during the Monwezian phase (D_2) (Regional sinistral strike-slip faulting between 690 and 540 Ma: Kampunzu and Cailteux, 1999).

The final structural event was characterized by the development of an extensional stress regime. This was associated with north – south oriented extension and it is related to the East African Rift System (D_3). The clockwise rotation recorded in the Kinsevere area supports previous studies undertaken by Unrug (1983), and Kampunzu and Cailteux (1999). These studies show that clockwise rotation of the eastern parts of the Lufilian Arc and Southeast tectonic escape by sinistral strike-slip faulting characterizes the eastern arc during progressive phases of collision between the Kalahari craton into the Congo craton (see figure). These interpreted events correlate well with the geodynamic context related to the Lufilian orogeny.

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Fracture networks and strike-slip deformation along reactivated normal faults in Quaternary travertine deposits, Denizli Basin, Western Turkey

Van Noten K.[1,2], Claes H.[1], Soete J.[1], Özkul M.[3], Swennen R.[1]

→ koen.vannoten@oma.be

1 Katholieke Universiteit Leuven, Department of Earth and Environmental Sciences, Geodynamics and Geofluids Research Group, Belgium

2 Royal Observatory of Belgium, Department of Geodynamics, Seismology Section, Belgium

3 Pamukkale University, Department of Geological Engineering, Denizli, Turkey

The Denizli Basin, situated in the Aegean extensional province in western Turkey, is known for its numerous Quaternary travertine occurrences amongst which the famous UNESCO world heritage site at Pamukkale. In tectonic active regions, such as the Aegean region, the morphology of travertine deposits is strongly related to the relative position of travertine precipitation with respect to nearby faults. Travertines have been described to develop in the hanging-wall of basin-bounding normal faults, in tensional fractures in shear zones, at the ends of fault segments or in extensional step -over zones (e.g. Pamukkale). Large-scale travertine masses formed at the complex intersection of several graben structures, however, are barely investigated, despite the fact that high permeabilities along fault-fracture networks in the subsurface are often demonstrated. In this study we examine the structural characteristics of a kilometre-scale travertine body in western Turkey situated at the intersection of the locally E-W oriented Denizli Graben and the adjacent NE-SW oriented Baklan Graben in the NE. Based on an extensive field campaign and LIDAR scanning of five quarries, in which this world-class travertine deposition is excavated, several high-resolution fault/fracture maps are constructed. A structural analysis is performed in order to determine the tectonic overprinting and to derive the different stress states in the basin after travertine deposition.

Based on an extensive orientation analysis in the different quarries three dominant fracture sets, i.e. E-W, NE-SW and NW-SE, are recognised. The mostly open, non-stratabound fractures are several tens of metres high and bifurcate along their height, creating a dense, irregular fracture network. Minor fluid flow along the fractures resulted in the development of complex travertine veins. It is concluded that these fracture sets are developed due to extensional fracturing caused by earthquake activity along local E-W and NW-SE faults in the Denizli Basin and NE-SW faults in the adjacent Baklan Graben. Several high angle, metre-wide, E-W to WNW-ESE faults cross-cut the quarries. These faults are either unfilled or filled with travertine debris and clastic infill of above lying sedimentary layers, indicative of the current open nature of the faults. They cross-cut the whole travertine mass and younger sediments, and can be traced along several hundreds of metres. The specific E-W to WNW-ESE orientation of the faults indicates that they probably initiated as normal faults during N-S extension in the locally E-W trending Denizli Basin. A palaeostress inversion analysis performed on kinematic indicators such as striations on the clayey infill of the faults and sinistral displacement of several palaeosols further shows that these normal faults were reactivated causing oblique-slip and strike-slip deformation. The stress field responsible from this reactivation can be related to strike-slip faulting along the NE-SW basin-bounding faults in the adjacent Baklan Graben in the NE. Focal mechanisms calculated from recent earthquakes in the eastern part of the Denizli Basin, however, show a dominant normal fault activity on similar E-W and WNW-ESE faults. It can therefore be concluded that both extensional and strike-slip tectonic regimes have interchanged numerously during the Quaternary.

Modelling the palaeotopography of the Brabant Massif: a necessity to understand the site effects of the 2008-2011 seismic activity in the Brabant Walloon

Van Noten K., Lecocq T., Verbeeck K., Vanneste K., Camelbeeck T.

→ koen.vannoten@oma.be

Royal Observatory of Belgium, Department of Geodynamics, Seismology Section, Belgium

In the region of Ottignies and Court-Saint-Etienne a seismic earthquake swarm took place between July 2008 and January 2011. The sequence started on the 12th of July 2008 with a M_L = 2.2 event and was followed the day after on the 13th of July 2008 by the largest event in the sequence which had a calculated magnitude of M_L = 3.2. The permanently installed seismic stations in Belgium did only record these moderate events. However, thanks to a locally installed temporary seismic monitoring system, more than 300 low magnitude events, with events as low as M_L = -0.7, have been detected. Preliminary results of the relocation of the different hypocenters and analysis of the focal mechanisms show that all these earthquakes took place along a (possibly blind) NW-SE fault (zone) at several km's depth (4 to 7 km) situated a few kilometer south of Court-Saint-Etienne.

Surprisingly, also the very low magnitude earthquakes were felt/heard by the local population. This was for instance deduced by analysing the macroseismic inquiries on the seismology website (e.g. 15 responses for a M_L = 0.7 event). Apart from the seismological research, also all geological and geomorphological information of the Brabant Massif and overlying Cretaceous, Cenozoic and Quaternary deposits have to be investigated in order to estimate and calculate the local site effects. To evaluate the attenuation of seismic waves through the Brabant Massif and to estimate the impact of the earthquakes at the surface, i.e. the seismic hazard, the thickness of the cover is calculated and the palaeotopography of the Brabant Massif in the Court-Saint-Etienne - Ottignies region is reconstructed. Such a reconstruction is primarily based on the availability and interpretation of outcrops and boreholes (DOV, BGS) in the region. Preliminary modelling results show that the Dyle/Thyle river valleys and their tributaries have cut into the Brabant Massif and dominate the model. Below the valley sides and tops, the top of the Brabant Massif gently dips to the NNW, however with the presence of several anomalies. The significance of these anomalies is currently unclear and needs to be evaluated with respect to the geological structure of the Brabant Massif. Due to a lack of drillholes in the direct environment of the fault, refinement of the model will be done by future geophysical surveying (e.g. H/V measurements, electrical resistivity tomography) allowing to determine the thickness of the cover accurately. Our results may furthermore also be compared to the palaeotopography of the Brabant Massif modelled in the Halle - Brussels region (Matthijs *et al.* 2005).

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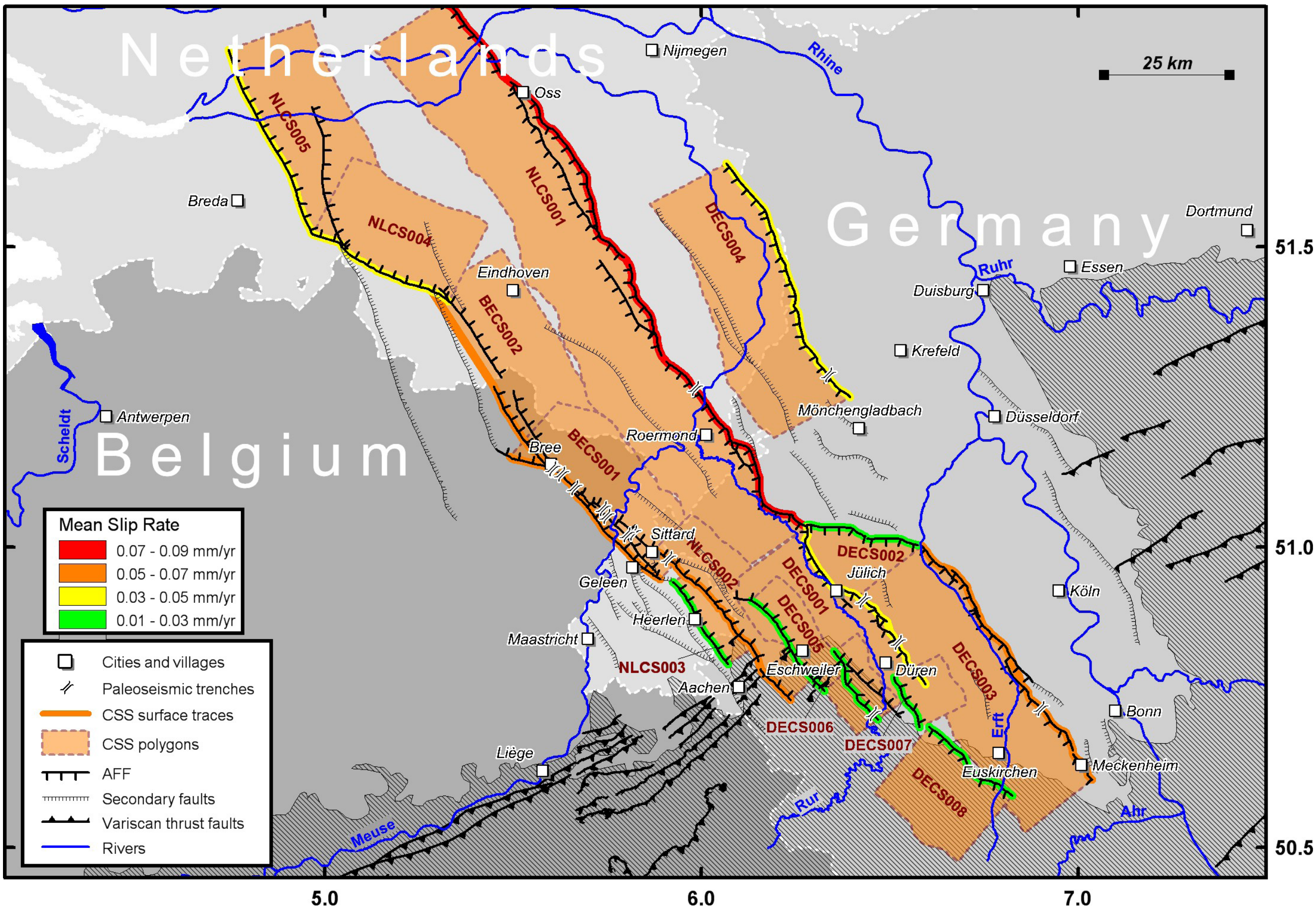
A model of composite seismic sources for the Roer Valley Rift System

Vanneste K., Verbeeck K., Camelbeeck T.

→ kris.vanneste@oma.be

Royal Observatory of Belgium

The Roer Valley Rift System (RVRS), straddling the border zone of Belgium, the Netherlands, and Germany, is an active tectonic structure in continental NW Europe. It is characterized by NW-SE oriented normal faults, and moderate but rather continuous seismic activity. Many faults have been mapped in the RVRS, but so far a model of fault hierarchy or fault segmentation was lacking. In the frame of a European database of seismogenic sources, we have devised a seismic-source model for the RVRS, consisting of so-called composite seismic sources. Each composite seismic source may encompass one or more fault segments, but it is unlikely that a rupture segment would extend across more than one source. We distinguish 15 seismic sources based on major stepovers, bifurcations, gaps, and important changes in strike, dip direction or slip rate. The sources are further subdivided into one or more informal fault sections, each with an associated surface trace. We have compiled all relevant data concerning the seismic-source parameters required for the database, putting lower and upper bounds on strike, dip, rake, slip rate, and depth, and an upper bound on earthquake magnitude. Combination of literature and seismological data indicates that fault dips in the RVRS likely range between 50° and 65°. Minimum and maximum strike has been determined for each source based on the one-sigma variation of their mapped surface-trace orientations. We determined the variation in rake by resolving the shear-stress direction on planes with the aforementioned ranges in strike and dip from a published regional stress tensor. The primary data for slip rates are vertical displacements recorded by fluvial terraces intersecting faults in the RVRS. We compiled an extensive set of vertical displacement rates, allowing us to assign minimum and maximum rates to each source. These vertical displacement rates range mostly between 0.01 and 0.07 mm/yr, and corresponding slip rates between 0.01 and 0.09 mm/yr. The Peelrand and Erft/Swist faults appear to be the fastest slipping faults. Earthquake hypocenters indicate a maximum depth of ~25 km. The minimum depth is set at 0 km, as all faults display offset of late Quaternary deposits, and paleoseismic studies have shown the occurrence of surface-rupturing earthquakes in the recent geologic past. The length of the Eft/Swist fault is considered to represent the longest credible rupture length, corresponding to a maximum magnitude M_w=7.1. Both paleoseismic studies and source-length considerations suggest that Mmax of the different sources ranges between 6.3 and 7.1. This composite source model should provide a new basis for modelling seismic hazard, as well as to guide further paleoseismic studies in the RVRS.



Map showing model of composite seismic sources for the Roer Valley Rift System, color-coded by mean slip rate determined from vertical displacements of fluvial terraces

Site selection for a new trench on the Rauw Fault

Verbeeck K.[1], Wouters L.[2], Camelbeeck T.[1], Vanneste K.[1], Demecheleer P.[3]

→ koen.verbeeck@oma.be

1 Royal Observatory of Belgium, Seismology section, Belgium

2 ONDRAF/NIRAS – Belgian agency for radioactive waste and enriched fissile materials, Belgium

3 S.C.R. - SIBELCO n.v., geological department, Belgium

The Rauw Fault is the closest fault to the nuclear zone of Mol-Dessel that has the potential to be investigated by paleoseismic trenches since its quaternary displacement is indicated by the Lommel sands being only deposited east of it. The topographical expression is the inverse of the supposed movement of the fault, explained by relief inversion due to differential erosion of the gravely Lommel sand in the east versus the pure sand of Mol in the west. This suggests that the most recent fault movement is relatively old and the deformation rate low. ROB conducted a topographic study and a geophysical survey consisting of electrical resistivity tomography, ground penetrating radar, electromagnetic resistivity, cone penetration tests, hand augering and two 10 m deep cored boreholes. The fault was sufficiently precisely localized to open a trench on one of the investigated sites in 2003. This trench was not successful in finding the expected recent deformations reaching almost to the surface. Instead the trench revealed intensely cryoturbated Pleistocene sediments in contact with Pliocene white Mol sand. The anomalies in the CPT's suggest a 6 m displacement within the ± 2 to 3 million years old Mol sands at the trench site. The average base of the cryoturbated Pleistocene sediments (dated younger than 26 kyr) does not show displacement. There is thus a quite large time hiatus in the sediments which makes a precise dating of the fault movement impossible in this trench.

Several questions remained after the trench. The observed 6 m displacement of the Mol Sands below the trench site are only a fraction of the 15 m which were reported as displacement of a peat layer within the Mol Sands between a nearby quarry and borehole. Recent boreholes by SCR-Sibelco, and new electrical resistivity tomography profiles and H/V ambient noise measurements by ROB in a larger area around the previous trench site indicate two other possible fault branches several hundreds of meters east and west of the present trench site. Especially the eastern possible fault branch looks promising in terms of better stratigraphic resolution because the electrical resistivity tomography profile shows a near-surface higher resistivity package that is bound by the position of the supposed fault. We plan to excavate a new trench at this location to try to: (1) get a better age constraint on the fault movements, (2) discriminate between co-seismic or a-seismic nature of displacements and (3) determine the amount of offset in each event as indicator of paleomagnitude.

This new site on another branch of the apparently distributed fault zone has more potential to resolve these questions. Probably the new trench will also suffer from a rather long erosional hiatus but this will be the same everywhere along this fault. The importance of the Rauw fault in terms of hazard to the nearby nuclear zone makes it worthwhile to conduct a further trench study of this fault, even if we may expect only partial answers to the questions at hand.

Session 13

Ore geology: new advances and interdisciplinarity

Chairmen: Philippe Muchez & Michael Meyer

Cathodoluminescence, rare-earth-element geochemistry and dating of Belgian fluorites

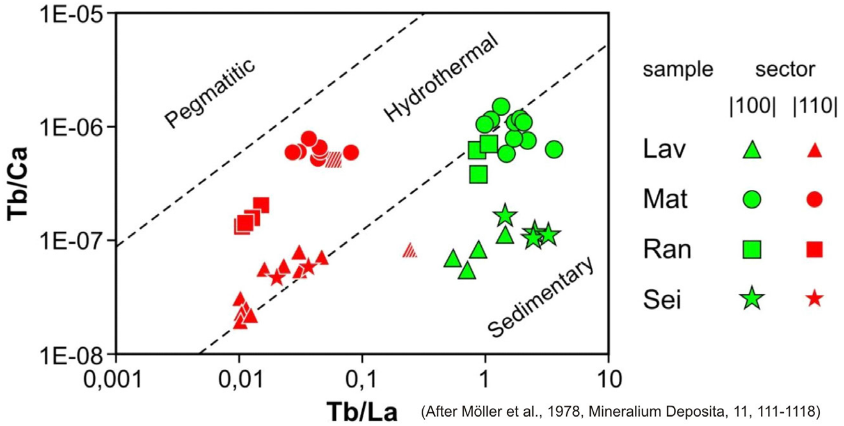
Baele J.M.[1], André L.[2], Debaille V.[3], Matielli N.[3]

→ Jean-marc.baele@umons.ac.be

1 Department of Geology, University of Mons, 20 place du Parc, 7000 Mons, Belgium. E-mail: jean-marc.baele@umons.ac.be

2 Royal Museum for Central Africa, Dept. of Earth Sciences, Division Mineralogy-petrography-geochemistry, 13 Leuvensesteenweg, 3080 Tervuren, Belgium

3 G-Time (Geochemistry: Tracing by Isotopes, Minerals and Elements), DSTE, Université Libre de Bruxelles, CP 160/02, 50., Av. FD Roosevelt, 1050 Brussels, Belgium



Tb/Ca-Tb/La diagram showing the effect of sectoral zoning on the interpretation of the formation environment based on REE in fluorites from four localities in Belgium

Fluorite is a common gangue mineral in many ore deposits and is widely used as a petrogenetic indicator, mainly based on REE geochemistry. A lot of data can now be acquired due to recent developments of micro-analyzing techniques such as Laser Ablation-Inductively Coupled Mass-Spectrometry (LA-ICP-MS) and micro-X-Ray Fluorescence (μ-XRF). However, these spot-based methods are very sensitive to compositional heterogeneities that result from crystal growth processes and variations in the fluid composition. Cathodoluminescence (CL) is often used to reveal these heterogeneities since $REE^{2+/3+}$ substituting for Ca^{2+} in the crystal lattice of fluorite are common CL activators. Hence CL can be considered as a guide for fluorite microanalysis but the strong blue emission due to Eu^{2+} may mask the weaker, but more informative, REE^{3+} lines. A systematic REE partitioning due to sector zoning was observed using spectral CL at UMONS and LA-ICP-MS at MRAC (Tervuren), in a survey of fluorite samples from several occurrences in Belgium (Baele *et al.*, 2011). Additionally, in term of CL signal and REE abundance, fluorite heterogeneities are often larger in a single crystal than between crystals collected from different deposits. CL and REE geochemistry should therefore be used with extreme caution for provenance analysis. Another significant result of our investigation is that the purest fluorite samples were not translucent and colorless crystals but the darkest purple. This is in contrast with previous studies and supports the lack of relationship between fluorite color and its REE content. Of particular importance is the sector zoning that induces large variations between the light- and heavy-REE abundances in growth sectors from the cubic |100| and the dodecahedronal |110| faces. In our study, a similar, but stronger effect was also noticed in the octahedral sector |111|, which has been observed at the center of the so-called “Mercedes stars” in the fluorite from Andenne. The identification of sector zoning is important as it allows Sm/Nd dating on single crystals, i.e. without the need of analyzing different minerals while assuming they formed concomitantly. This technique was not frequently applied to fluorite. Preliminary results obtained on the Andenne fluorite by isotopic analyses performed with a Nu Plasma MC-ICP-MS (ULB) yield an age of 215±18 Ma (Upper Triassic), which is consistent with the previous age estimation for South Belgium fluorite (Baele, 1998).

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REE characteristics of carbonates within the sediment-hosted Luiswishi Cu-Co deposit, Katanga Copperbelt (DRC)

Debruyne D.[1], Balcaen L.[2], Vassilieva E.[1], Vanhaecke F.[2], Muchez Ph.[1]

→ David.Debruyne@ees.kuleuven.be

1 KU Leuven, Department of Earth and Environmental Sciences, Belgium

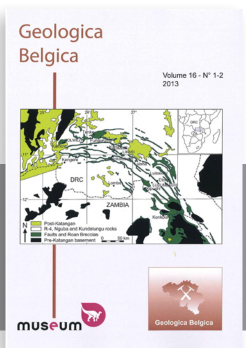
2 Ghent University, Department of Analytical Chemistry, Belgium

The Neoproterozoic Central African Copperbelt is a world-class metallogenic province characterized by sediment-hosted stratiform Cu-Co ore deposits and polymetallic vein-type deposits. The metals are generally thought to be derived from leaching of continental basement rocks by hot, saline fluids migrating upwards through the Precambrian basement along permeable, fractured zones. The resulting metalliferous brines subsequently interacted with reduced sedimentary units, rich in sulphides and organic material higher up in the section, thereby generating stratiform metal-sulfide deposits. Generally, two main hypogene mineralization phases are recognized in the stratiform ore deposits, the last of which is followed by variable extents of supergene remobilization of the ores. Recent studies (Van Wilderode *et al.*, 2012) revealed similarities between the Nd- and Sr-isotopic composition of the synorogenic gangue carbonates and their host rocks, suggesting sources with an isotopic signature similar to that of the host rock or host rock buffering.

The aim of this study is to determine the extent of host rock buffering in the synorogenic gangue carbonates at the Luiswishi deposit, based on their Rare Earth Element (REE) signature. The REE concentrations were determined with ICP-MS and compared to those in their respective host rocks in Upper Continental Crust-normalized plots.

The gangue carbonates at Luiswishi exhibit a large REE-variability between the different samples (over two orders of magnitude), generally with large negative Ce- and Eu-anomalies. In many cases, the MREE-HREE-signature of the Luiswishi carbonates shows similarities with the signature of their respective host rocks. However, such a relation is not evident with respect to the host rocks' LREE-content.

The large REE-variability at Luiswishi could have been caused by differences in fluid-rock ratios or physicochemical properties of the mineralizing fluid (pH, salinity, T). While this is certainly an important factor contributing to the variability, similarities between the REE-patterns in the gangue carbonates and their respective host rocks suggest that host-rock buffered remobilization of earlier mineralization phases also contributes to the REE-variability at this site. The observed negative Eu-anomalies most likely relate to mineralogical fractionation in reducing conditions at the mineralization site, as divalent Eu is incompatible in carbonate compared to trivalent Eu (Lakshtanov & Stipp, 2004). The large negative Ce-anomalies are likely acquired through interaction with their host rocks under oxidizing conditions. The strong LREE depletion observed in many cases could be related to fractionation of LREE-compatible phases in the mineralizing brine prior to mineralization. However, no evidence for precipitation of LREE-compatible minerals has been found yet at Luiswishi. Alternatively, the observed LREE-depletions can be explained by LREE-depleted sources and/or fractionation of the HREE by Cl-complexes in the brine.



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Full paper in Geologica Belgica, Volume 16, n°1-2

Rare earth element and yttrium characteristics of carbonates within the sediment-hosted Luiswishi and Kamoto Cu-Co deposits, Katanga Copperbelt (Democratic Republic of Congo - DRC)

by Debruyne D., Balcaen L., Vanhaecke F., Muchez P.

Origin of high-salinity syn-orogenic Cu-Co mineralizing fluids in the Katanga Copperbelt, Democratic Republic of Congo

El Desouky H.A.[1,2], Banks D.[3], De Clercq F.[1], Dewaele, S.[4], Cailteux J.[5], Muchez Ph.[1]

→ HamdyAhmed.ElDesouky@ees.kuleuven.be; Geohamdy@yahoo.com

1 Geodynamics & Geofluids, K.U.Leuven, Celestijnenlaan 200E, B-3001 Leuven, Belgium

2 Geology Department, Faculty of Science, Menoufyia University, Shebin El-Kom, Egypt

3 School of Earth and Environment, University of Leeds, Woodhouse Lane, Leeds LS2 9JT, UK

4 Department of Geology and Mineralogy, Royal Museum for Central Africa, Leuvensesteenweg 13, B-3080 Tervuren, Belgium

5 E.G.M.F., Groupe Forrest International, Lubumbashi, D.R.Congo

The Katanga Copperbelt (KCB) is the Congolese part of the well-known Central African Copperbelt, the largest and richest sediment-hosted stratiform Cu-Co province on Earth. Two main hypogene Cu-Co phases with early diagenetic (~816 Ma) and multistage syn-orogenic (peak = ~530 Ma) mineralization were distinguished in the KCB (Muchez *et al.*, 2008; El Desouky *et al.*, 2009). The syn-orogenic mineralization is related to a fluid with high temperature (270 to 385 °C) and salinity (35 to 45.5 wt.% NaCl equiv.). The origin of this fluid was investigated by quantitative fluid inclusion analyses. Laser ablation ICP-MS and bulk crush-leach analyses were performed on primary fluid inclusions in coarse-grained quartz intimately associated with the syn-orogenic Cu-Co sulphides at the giant Luiswishi deposit.

The molar Cl/Br ratios of the leachate solutions (1333 to 26230) are significantly variable and generally higher than the Cl/Br molar ratio of seawater (~660) indicating that the fluid obtained its salinity by halite dissolution. The variable molar Cl/Br ratios are likely related to the mixing with a Br-rich evaporated seawater trapped in the rock sequence. Fluid mixing likely occurred before the mineralization causing the rather uniform high salinity of the fluid inclusions (cf. El Desouky *et al.*, 2009). The fluids show significant coupled Ca-excess and Na-deficit, which is typical for albitization of Ca-rich feldspars (1 Ca for 2 Na exchange reaction). Indeed, intense albitization is commonly observed along zones of fracture-induced permeability, which are considered the main pathways for the syn-orogenic Cu-Co mineralizing fluids (cf. El Desouky *et al.*, 2009). The evidence for albitization of Ca-rich feldspars indicates that the mineralizing fluid has interacted with mafic igneous rocks or with siliciclastic rocks with at least partly a mafic origin.

The LA-ICP-MS analyses indicate high Ba, Sr and Li concentrations, which are likely related to fluid-rock interaction during the albitization process. High concentrations of Fe, Mn, Cu, Co, Zn and Pb were also reported and are in agreement with the expected high metal carrying capacity of such a high salinity, high temperature fluid. The metals were carried as chloride complexes. The syn-orogenic mineralizing fluid at Luiswishi could have obtained its high Cu and Co contents (av. = 1870 ppm Cu and 720 ppm Co) by remobilization of the diagenetic sulfides of the first Cu-Co phase, interaction with mafic igneous bodies or siliciclastic rocks with a mafic origin during the albitization, or by both processes.

High salinity mineralizing fluids were observed in several syn-orogenic and post-orogenic ore deposits in the KCB. The high metal carrying capacity of these fluids, as chloride complexes, and their large spatial and temporal (≥140 Ma) distributions indicate that they are important ore-forming fluids in the KCB. They were likely able to form base-metal ore deposits at any stratigraphic level whenever a suitable precipitation mechanism was present. Exploration of such important ore deposits should focus on the structural and metal traps that occur close to fracture-induced permeability zones, eg., faults, fractures and breccia zones.

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Geometallurgical approach and quantitative mineralogy of the ore deposit of Chelopech (Bulgaria)

GB 2012 Contestant for Best Poster Presentation

Evrard M., Pirard E.

Université de Liège (Belgium). GeMMe – Minerals Engineering, Materials & Environment.

The Chelopech deposit is localized in the northern part of the Panagyurishte metallogenic district (Bulgaria). The Chelopech ore deposit is an epithermal high-sulfidation ore deposit with high grade of copper (1.28%) and gold (4g/tons). The mineralizations have been set up in Cretaceous time (91.45Ma) and are composed of typical epithermal high-sulfidation sulfides as pyrite, enargite, tennantite, bornite, covellite, chalcopyrite, (galena, sphalerite) and gold. Exotic elements such as germanium, gallium, telluride, selenium and tin are also present in very low grade in the ore. The most of extracted copper come from arsenides and sulfosalts minerals such as enargite, luzonite and tennantite which is a big issue for the tailings management and treatment of copper concentrate.

A picture processing method has been realized on polished sections of plant processing products (ore after milling, tailings and concentrate) to quantify the minerals present in each stage of the plant processing. 55 pictures of each polished sections have been taken with 3 different wavelengths (438, 592 and 692 nm) in order to distinguish the minerals. Then, these pictures have been classified thanks to the software “Multispec” and treated with the software “Aphelion”. Several operations have been used to treat these classified pictures: Thresholding, Erosion, Geodesic Reconstruct, Closing, Hole-fill and Logical Difference in order to delete mixels and fill the surface scuffing and tearing inside the minerals caused by the polishing of polished section.

The aim of this quantitative analysis is to know the percentage and the nature of the minerals present at each stage of the ore processing. In our case, it is allowed to know in which form the copper and arsenic are present in the plant processing products and to trace them, which is relevant information in order to improve the ore processing and tailings management.

Characterisation and genesis of the Ouenza iron ore (Algeria)

Fontaine F., Pirard E.

→ F.Fontaine@ulg.ac.be

GeMMe (Génie Minéral, matériaux et environnement), University of Liege, Belgium

The Ouenza iron deposit is located in the north-east of Algeria. This deposit belongs to the "carbonate hosted" or "Bilbao Type" iron ore deposits. It was formed in two steps. Firstly, iron-rich hydrothermal fluids allowed the recrystallization of Aptian limestone into siderite and ankerite by metasomatic processes. Secondly, as a result of supergene alteration, these iron carbonates were oxidized to iron oxide and hydroxide which are respectively present as hematite and goethite. Nowadays, only the oxidized part of the deposit is mined and these reserves are estimated to be 40 Mt. In this mine, the ore is differentiated into three types, based on their black, red or brown color. This study aims to differentiate those three categories using electron and optical microscope combined with image analysis. Results show that all types of ore are mainly composed of black "dividing wall" of hematite, formed by the oxidation of siderite crystals into hematite. This transformation has been developed along the joints of siderite crystals, now missing, giving the hematite its "dividing wall" appearance and its important porosity. The ore color is related firstly to the composition of the carbonate ore and secondly to the intensity of weathering. The black and red ore differ by their proportion of siderite and ankerite in the carbonate ore. Indeed, more the carbonate ore contains ankerite, more the oxide ore will be colored red, as a result of oxidation of ankerite giving dolomite in which hematite microcrystals are dispersed. These hematite crystals have the effect of coloring the dolomite red. The brown color is mainly due to the presence of goethite microcrystals dispersed in the carbonates.

Structural setting of syn- to late orogenic Variscan hydrothermal mineralization, Siegerland district, Rhenish Massif (European Variscides, NW Germany)

Hellmann A.[1], Wagner T.[2], Meyer F.M.[1]

→ andre.hellmann@rwth-aachen.de

1 Institute of Mineralogy and Economic Geology, RWTH Aachen, Germany

2 Institute of Geochemistry and Petrology, ETH Zurich, Switzerland

The Siegerland district, which hosts diverse syn-orogenic mineralization styles, is located in the fold-and-thrust-belt of the Rhenish Massif. Peak-metamorphism and deformation occurred at 312-316±10 Ma (Ahrendt *et al.*, 1978) at temperature-pressure conditions of 280-320 °C and 0.7-1.4 kbar (Hein, 1993). The timing and structural relations of different syn-late orogenic mineralization is not well understood, and will be addressed here (table 1).

Siderite-quartz veins form the earliest type of syn-orogenic ore mineralization. The siderite-quartz veins are arranged in N-S, E-W and NE-SW trending, linear arrays. The vein systems are closely related to fold and reverse fault geometries (i.e. Adler et al, 1960). At least four syn-late orogenic mineralization stages are identified, which are Co-Cu-Au, Pb-Zn-Cu, Sb-Au, and hematite-digenite-bornite mineralization. Co-Cu-Au mineralization is closely related to the formation of NE-ENE trending reverse faults (i.e. the first-order Siegen Main thrust system) and associated imbrication zones, crosscutting and reactivating the older siderite-quartz veins (Hellmann *et al.*, 2011a). Co-Cu-Au mineralization is best developed in intersection zones of reverse faults and older fault and vein systems. Pb-Zn-Cu mineralization postdates both the Co-Cu-Au mineralization and the siderite-quartz veins (Hellmann *et al.*, 2011b). The mineralization is mainly hosted by E-W trending vein systems and NE-ENE trending reverse faults, related to the progressive development of the imbrication zones. N-S trending Pb-Zn-Cu veins are almost absent. Sb-Au mineralization postdates the Pb-Zn-Cu mineralization (Wagner and Cook, 2000) and is possibly associated with the final stage of late orogenic oblique reverse shear-folding. Sb-Au mineralization is spatially associated with reactivated, NW-SE, NE-SW and E-W trending vein systems. Veins are locally folded by small scale F3-shear folds. Hematite-bornite-digenite mineralization postdates siderite-quartz, Co-Cu-Au and Pb-Zn-Cu mineralization. Hematite-bornite-digenite mineralization is associated with oblique reverse- and strike slip-reactivation of former reverse faults, as well as pre-existing NW-SE and E-W trending vein systems (Quiring, 1931; Philipp, 1955; Stadler, 1959). The relative age of the mineralization with respect to Sb-Au mineralization could not established so far, although field observations and fluid inclusion data indicate a similar structural and temperature regime (Erlinghagen, 1989; Wagner, 2000) for both the mineralization styles.

The data suggest a close temporal and structural link between Co-Cu-Au and Pb-Zn-Cu mineralization, related to the formation of imbrication zones during reverse faulting associated with late synorogenic compression. Similarly, Sb-Au and hematite-bornite-digenite mineralization are associated with oblique reverse- to strike slip- and possibly normal- faults in a late oblique reverse to strike slip orogenic regime.

Deformation Stage	Structures	Veins	Mineralization	Main mineral associations	P-T conditions	Fluid Salinity (mass-% NaCl eq.)
D_1	NE-SW trending folds, F_1, S_1 reverse faults	diagonal-shear vein systems (E-W and N-S), fault fill veins	siderite-quartz	quartz, siderite, pyrrhotite, pyrite, ullmannite, gersdorffite	T_t =220-320°C), p = 0.7 -1. 4 kbar (T_h =180°-250°C)	≤5 (Erling-hagen, 1993, Hein, 1993)
D_2 (early)	F_2-folds, S_2, reverse faults, minor thrusts	reactivation of diagonal-shear vein systems, fault fill veins, NW-SE tren-ding veins	Co-Cu-Au	marcasite, arsenopyrite alloclasite-cobaltite-gersdorffite s.s./siegenite pyrite, chalcopyrite	?	?
D_2 (late)	S_2, reverse faults	E-W trending vein systems, fault fill veins	Pb-Zn-Cu	sphalerite chalcopyrite fahlore, galena	T_h= 150-250°C, 0.5-0.8 kbar	5-14 (Erling-hagen, 1989)
D_3	F_3-folds, S_3 kink-bands, oblique reverse faults, strike slip faults	E-W and NW-SE trending veins, fault fill veins	Sb-Au	meneghinite, bournonite, boulangerite antimonite	Tt=390-440°C,p = 0.6-1 kbar, (T_h= 160°–390°C)	1-11 (Wagner and Cook, 2000)
		E-W and NW-SE trending veins	hematite-digenite-bornite	hematite, bornite, chalcocite, digenite, chalcopyrite, carrolite, djurleite, wittichenite	T_t = 320°-340°C (T_h = 250-335)	3-7 (Erling-hagen, 1989)

Summary of syn-late orogenic structures and related mineralization

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Chemical fractionation of the Nb-Ta-Sn mineralised pegmatites of the Gatumba Area (Rwanda)

GB 2012 Contestant for Best Oral Presentation

Hulsbosch N.[1], Hertogen J.[1], André L.[2], Dewaele S.[2] and Muchez Ph.[1]

→ niels.hulsbosch@student.kuleuven.be

1 Geodynamics and Geofluids Research Group, Dept. of Earth and Environmental Sciences, KU Leuven, Celestijnenlaan 200E, B-3001 Leuven, Belgium

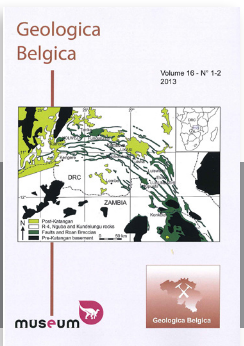
2 Dept. of Geology and Mineralogy, Royal Museum for Central Africa, Leuvensesteenweg 13, B-3080 Tervuren, Belgium

The Gatumba area is situated in western Rwanda in the Mesoproterozoic Karagwe-Ankole Belt. This area is characterised by numerous rare metal mineralised pegmatites that are presumably related to the barren G4-granites of early Neoproterozoic age. The pegmatites are affected by intense hydrothermal alteration resulting in albitisation and greisenisation. A regional mineralogical zonation within the pegmatite field has been documented by Varlamoff (1954). It comprises 7 distinct phases: (1) biotite, (2) biotite-tourmaline, (3) biotite-tourmaline-muscovite, (4) muscovite-tourmaline, (5) muscovite and phases (6) and (7) characterised by Nb–Ta–Sn mineralisation.

This study aims to determine the origin and evolution of the pegmatites and the mineralising fluids, and to model the mineralogical zonation in terms of geochemical fractionation. Mineral separates of feldspar, biotite, muscovite and tourmaline representing the whole gamut of regional pegmatite zonation and alteration have been analysed for major, minor and trace elements, in particular the rare earth elements (REE).

Tourmaline from different pegmatite phases shows significant compositional variation. The black schorl variant, with FeO ranging from 15.02 to 11.34 wt% and MgO ranging from 4.31 to 0.09, occurs in the first 5 pegmatite phases. The crystallization of schorl consumes Fe and Mg to the extent that the mafic components of the pegmatitic melt drop to trace levels. This hampers the biotite stability and promotes the growth of muscovite. The green elbaite variant of tourmaline is restricted to the highly evolved pegmatitic quartz cores of phase 6 and 7. The evolution from schorl to elbaite is paragenetically separated by a transient cessation of tourmaline crystallisation which allowed for an increase of the B-content of the melt due to fractionation. Fractionation also raised the Li-content to the level needed to stabilise the formation of elbaite. The observed compositional variation of tourmaline implies that the 7-phases zonation of Varlamoff (1954) can be simplified to one involving only 4 phases: a biotite, a two mica, a muscovite and a mineralised phase.

Alkali element variations (K-Rb-Cs) in muscovite and K-feldspar indicate that the origin of the different pegmatite phases can be explained by a single path of fractional crystallization of a granitic melt. Trace element variations show an evolutionary path from the granite to the pegmatite and alteration assemblages. It reflects the increasingly more fractionated melt composition and the systematic enrichment of the incompatible trace elements Li, Rb, Cs, Be and Ta, according to the newly redefined zonation sequence. The REE patterns of the separates are in agreement with the bulk fractionation model. Moreover, the V-shaped REE patterns of the mineralised pegmatites point to the important impact of monazite crystallisation on REE fractionation.



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Petrographic and mineralogical characterisation of fractionated pegmatites culminating in the Nb-Ta-Sn pegmatites of the Gatumba area (western Rwanda)

by Hulsbosch N., Hertogen J., Dewaele S., André L., Muchez P.

Alteration of VMS deposits and its impact on the behavior of critical elements

Koppelberg M.[1], Meyer F.M.[1], Sindern S.[1], Kramm U.[1], Hoffmann G.[2], Willis R.[3]

→ koppelberg@iml.rwth-aachen.de

1 Institute of Mineralogy and Economic Geology, RWTH Aachen University, D-52056 Germany

2 Department of Applied Geosciences, German University of Technology in Oman, Muscat, Sultanate of Oman

3 MAWARID Mining, Sohar, Sultanate of Oman

This project is planned as a study to investigate the alteration processes of eight different confirmed and potential massive sulphide deposits in the Semail ophiolite belt in northern Oman. The probed lenses of massive sulphides are at the contact between pillow basalts and massive basalts of the Ally, Lasail and Geotimes Units. The massive sulphides consist of mainly pyrite, chalcopyrite and smaller amounts of sphalerite and chalcocite. Some samples contain traces of carrollite. The silica-rich stockwork zones underneath have variable extensions, structures and mineralogy. Locally, the feeder zones contain significant enrichments of pyrite and chalcopyrite. Marine (sub seafloor) alteration of the massive sulphides is preserved under non-mineralized basalts. This alteration is characterized by the occurrence of hematite replacing sulphides. Oxidation events are also preserved in the stockwork zones. Textural evidence of alteration due to reducing and oxidizing hydrothermal events is a possible indication of fluctuation of dimension and position of hydrothermal systems.

While exposed to the surface, massive sulphides and stringer zone sulphides are affected by sub aerial gossan formation. Supergene processes, such as circulation of meteoric water and chemical weathering, produce pronounced mineral zonation. The typical structure of a gossan in the investigated area is a leached zone with oxides clays, followed by a Gossan Zone with Fe- and Mn-oxides and underneath a supergene zone with oxides and sulphides. The investigated gossans can reach vertical extensions of 10 to 20 m.

The poster will give an outline of the distribution of critical elements such as Indium, Selenium, Tellurium and Tin in primary, hydrothermal sulphides as well as in products of hydrothermal sub seafloor and sub aerial alteration. This gives information of the behaviour of critical elements during different steps of alteration of massive sulphides.

Gold-Bismuth-Telluride Mineral Association in Ores from the Serebryanoe Deposit (Eastern Transbaikalia)

Redin Yu., Dultsev V.[1]

→ baddulliano@gmail.com

V.S. Sobolev Institute of Geology and Mineralogy Siberian Branch of Russian Academy of Science, Russia

Two mineral associations with native gold are distinguished in the ores of the Serebryanoe deposit: 1) Gold-bismuth-telluride; 2) Gold-polysulphide. The gold-bismuth-telluride mineral association of the Serebryanoe deposit is superimposed on calcic skarn represented mainly by magnetite, hornblendite almost completely substituted by epidote, calcite and calcareous garnet. Native gold of the first paragenic association occurs as inclusions in arsenopyrite (I), as well as splices with bismuthine, tellurobismuthine, joseite B, marcasite, lellengite and chalropyrite (I). The size of gold grains in arsenopyrite (I) varies from 300 nm to 70 µm. In general, the composition of gold of the first generation is rather homogeneous, in addition to silver it contains mercury as admixture, with its maximal content about 0,6%. Measurements of gold assay in the central and edge parts of grains did not reveal variations within separate gold grains. This may point to the single ore deposition and the absence of subsequent processes of the chemical transformation of gold. The gold-bismuth-telluride type is characterized by the presence of early generations of high-arsenic (up to 50 mass % As) arsenopyrite I. In low-sulphide deposits, high-arsenic arsenopyrite coexists mainly with Ni-containing minerals, in particular with lellengite. Bismuthic mineralization was discovered in subalkaline monzonites where it is represented by jaskulskyite and native bismuth. An interesting finding is the presence of rarely occurring mineral jaskulskyite (Bi 30%, Pb 46%, Sb 7%, Ag 2%, Cu 1%, S 15%); it is associated with gersdorffite, ullmannite, chalcopyrite (I) and native bismuth. Isolated grains of native gold (I) were observed in chalcopyrite (I) as inclusions >1 µm. Native bismuth is likely to be formed as a result of the decomposition of jaskulskyite, P. Ramdor considered native bismuth to be formed in decomposition of bismuth compounds, mainly lead-bismuth sulfosalts, due to a decrease in temperature. The positive correlation between gold and bismuth was established with the help of LA-ICP-MS, at the Bi/Au ratio equal to 3. The highest gold concentrations (1700 g/t) were confined with the sites with high bismuth content (up to 5000 g/t). The isotopic composition of sulphur in ore minerals of all the three deposits of the Serebryanoe field corresponds to the narrow range from +3,9 to +5,8‰. Such an insignificant weighting of sulphur with respect to the meteorite standard is a convincing evidence of the deep-seated (mantle-crust) source of sulphur in ore minerals. A genetic affinity of gold-bismuth deposits with granitoids over a number of signs was established in the investigations carried out by G.N. Gamyanin, N.A. Goryachev *et al.*, 1998, 2006. The gold-bismuth association of the deposit is spatially and genetically connected with the dykes of subalkaline quartz monzonites related to the Shakhtamine complex of the middle and upper Jurassic age.

Critical electronic metals in sphalerite – evaluation of LA-ICP-MS methods and application to Pb-Zn deposits and ore processing wastes in the districts of Aachen and Kelmis (Germany and Belgium)

Sindern S.[1], Meyer F.M.[1], Gronen L.[1], Bohle S.[1], Lehmacher M.[2], Roth G.[3], Peters L.[3], Burchard M.[4], Schneider J.[5]
→ sindern@rwth-aachen.de

1 RWTH Aachen, Institut für Mineralogie und Lagerstättenlehre, Wüllnerstr. 2, D-52056-Aachen

2 RWTH Aachen, Institut für Anorganische Chemie, Landoltweg 1, D-52056 Aachen

3 RWTH Aachen, Institut für Kristallographie, Jägerstr. 17-19, D-52066 Aachen

4 Ruprecht-Karls Universität Heidelberg, Institut für Geowissenschaften, Im Neuenheimer Feld 236, D-69120 Heidelberg

5 Institut für Mineralogie, TU Bergakademie Freiberg, Brennhausgasse 14, 09596 Freiberg

The sphalerite structure allows incorporation of critical electronic metals, such as Ge, In or Te, due to various substitution mechanisms. Sphalerite, as well as its processing products, can thus play an important role as a source for these critical elements. The investigation of their geochemical behaviour during ore formation, as well as during ore processing and metallurgical operation requires accurate and precise trace element analysis with high spatial resolution. An appropriate matrix-matched standard, accounting for interferences and characterised by similar ablation behaviour with respect to sphalerite, is essential for the successful application of LA-ICP-MS.

In this presentation commercial standard materials relevant for sphalerite analysis (e.g. natural sphalerite, pressed powder pellets, lithium borate, soda-lime silicate or chalcogenide glass disks, welded natural sulfide) are discussed and evaluated. Most standard materials are characterised by ablation behaviours significantly different from sphalerite. In these cases correction factors accounting for difference in ablation sensitivity ratio of analyte element and internal standard element between sample and standard have a major impact on the quality of the analysis. Furthermore, some standard materials are not sufficiently homogeneous at the scale of instrumental resolution or they contain compounds, such as H_2O or Na_2O on a per cent level, which is inappropriate for sphalerite analysis.

Requirements for a LA-ICP-MS standard material with respect to homogeneity, spectrum and (certified) concentration of trace elements, physical and chemical characteristics of the matrix as well as ablation behaviour are best met by carefully sintered synthetic sphalerite doped with trace elements. A new method to precipitate such trace element doped sphalerite and to produce a homogeneous sintered aggregate is examined.

New LA-ICP-MS trace element analyses in sphalerite from the occurrences of Altenberg, Diepenlinchen, Bleiberg, Albertsgrube, Thermae 2002 and Hastenrath as well as in slags from smelters in Stolberg and Kelmis are presented. Sphalerite formed in post-variscan carbonate-sulfide veins, which are hosted by Upper Devonian to Upper Carboniferous shales and carbonates. It is characterised by collomorphous textures with alternating bands varying in colour between dark brown and light brown/yellow ("Schalenblende"). Dark bands show elevated Fe concentrations. The concentrations of Pb and Tl in sphalerite vary between 24 – 7143 ppm and < 1- 1983 ppm, respectively. Silver and Sb covary within a range of < 1 – 274 ppm (Ag) and < 1- 558 ppm (Sb). Germanium reaches values as high as 976 ppm and appears to be uncorrelated with respect to Fe. While Te is always < 5 ppm, In can be detected in altered sphalerite, which is also characterised by slight enrichment of Ga, Cu, Ag and Sb.

Economic Potential of Rare Earth Elements in Apatite of the Khibina Alkaline Complex, Kola Peninsula, Russia

Stoltz N.B., Meyer F.M.

→ stoltz@iml.rwth-aachen.de

Institute of Mineralogy and Economic Geology, RWTH Aachen University, D-52056 Germany

The typical deposits of rare earth elements (REE) are situated in carbonatites and laterite related ion-adsorption clays, whereas mining of placer deposits has been banned in several countries due to a high radioactive exposure (uranium and thorium). The countries with a major potential are China, Australia and Brazil. However, the carbonatite complexes on the Kola Peninsula, Russia, contain 25 different rare earth minerals[1]. Mining of phosphorus from apatite ores exists since the early 20th century. The largest magmatic apatite deposits in the world are connected with the Khibina agpaitic complex[2]. Since the demand for rare earth elements (REE) is increasing in the past few years, these huge apatite reserves might be also a source for high technology metals, extracted as byproducts a priori for Neodymium (Nd).

Apatite from the 370-380 Ma old Khibina alkaline complex is mainly fluorapatite $Ca_5(PO_4)F$, with enrichment of light rare earth elements (LREE, La, Ce, Pr, Nd, Sm, Eu) and almost no radioactivity (U, Th). The investigated LREE + Y contents range from 4268 to 4464 ppm with an average of 656 ppm for Nd. The more valuable heavy rare earth elements (HREE, Gd, Dy, Er, Yb, whereas Sc and Hf are absent) inventory is minor (∑HREE = 405 ppm). Analytical measurements were carried out by LA-ICP-MS and EMPA.

At first glance, this data seems not indicating economical enrichment. However, since the REE could be beneficiated as byproducts and taking into consideration the development of the REE prizes and extraction techniques, apatite from the Kola Peninsula and especially the Khibina massif may soon turn into a reliable supplier of LREE outside China.

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Tourmaline-turquoise geochemistry and genesis in the Kuh-Zar Copper, gold hydrothermal alteration deposit, South of Semnan, Iran

Taghipour B.[1], Mackizadeh M.A.[2], Taghipour S.[3]

→ taghipour@shirazu.ac.ir

1 Department of Earth Sciences, Faculty of Sciences, Shiraz University, Shiraz, Iran

2 Department of Geology, Faculty of Sciences, Isfahan University, Isfahan, Iran

3 Department of Geology, Faculty of Sciences, Tehran University, Tehran, Iran

Torud-Chah Shirine magmatic arc is located in south of Semnan. This arc is composed of Cenozoic volcanic, pyroclastic and intrusive rocks. The Kuh-Zar in manning province of Bagho is outstanding with Cu-Au mineralization. Mining is restricted to hydrothermal alteration zones in the area. Alteration zones includes: propylitic, argilic, phyllic, advanced argillic and silicic. The rare association of tourmaline as veinlets and dissemination spots with turquoise is visible in phyllic and advance argillic zones. EPMA data for mineral chemistry is indicated that tourmaline is from schorlite-dravite group. It is probable that tourmaline is generated from B-bearing fluids librated from metamorphic rocks in expense of muscovite in leached alteration zones.

Turquoise is formed in relation to oxidation reactions of Cu-bearing sulphide minerals. Then hydrolysis of alumino-silicates is taken place in acid environment and finally in corporation with P from leached fluids, the formation of turquoise is occurred in expense of Al-rich mineral phases (alunite). So the overprinting of two distinct alterations (early tourmalinization and late turquoise formation) is occurred.

Monazite-xenotime thermometer of the Kiruna-type magnetite-apatite ore deposits, Bafq area, Central Iran

Taghipour S.[1], Kananian A.[1], Harlov D.[2], Oberhansli R.[3], Taghipour B.[4]

→ taghipour.sedigheh@gmail.com

1 Department of Geology, College of Sciences, University of Tehran, Tehran, Iran, Tel.

2 GeoForschungsZentrum Telegrafenberg, D-14473 Potsdam Germany

3 Institute of Earth and Environmental Science, University of Potsdam, PO Box 601553, Potsdam 14415, Germany

4 Department of Earth Sciences, Faculty of Sciences, Shiraz University, Shiraz, Iran

The Central Iran micro-plate is a triangular shape area, which is located in the broad segment between two syntaxes of the Alpine-Himalayan system; the Turkish syntax to the west and the Pamir syntax to the east. The Bafq metalogenic district is a part of the Central Iran micro-plate and located in the Kashmar-Kerman tectonic zone, it is an area of iron ore deposits extending from Bafq to Robat-Poshte-Badam which is surrounded by the Kuh Banan and Kuh Daviran fractures respectively in the east and west. The Bafq's deposits typically take the form of magnetite-fluorapatite ore bodies of the Kiruna-type. They are hosted by a lower Cambrian sequence of lavas, pyroclastic rocks, epiclastic rocks, intercalated carbonates, and subvolcanic granites, which make up the Cambrian Volcanic-Sedimentary Unit (CVSU) (cf. Ramezani and Tuker, 2003). The CVSU is composed of an inter-layered sequence of largely unmetamorphosed, intermediate to felsic volcanic rocks, bimodal volcanic rocks, with minor gypsum beds, dolomite, limestone, sandstone, and shale. This sequence includes both the Saghand Formation and the Rizu-Dezu Series. Kiruna-type apatite-magnetite ore deposits are found in the Middle of the Saghand Formation in the Bafq region. The ores occur as tabular, metasomatically, vein, and massive bodies in the vicinity of a volcanic and subvolcanic sequence dominated by acid pyroclastic rocks, rhyolitic tuffs, rhyolites, trachite and diorites, and granodiorites with minor dolomite, limestone, shale, and sandstone. Hydrothermal alteration of the volcanic sequence is commonly extensive and is characterized by albitization and pervasive actinolitization. Primary and secondary fluorapatite occurs as massive, vein and veinlet, patchy shapes as well as intergrown with the magnetite and sometime as euhedral crystals between the mineralization zones. Primary fluorapatite occurs as cm-size, euhedral to subhedral crystals. Under BSE imaging bright areas are enriched in LREE, Cl, Na, Si and S, whereas dark areas are depleted in these elements. Both primary and secondary monazite and xenotime are found. Primary monazite-xenotime pairs yield temperatures of around 430 °C whereas secondary monazite-xenotime pairs yield temperatures of around 130 °C. This would suggest that primary monazite and xenotime were formed after emplacement and crystallization of the fluorapatite whereas the secondary monazite and xenotime formed during further lower grade alteration at 130-260 °C.

Assessing the orebody reserves by means of geological modelling

Tshibangu K. J.-P.[1], Ngoy Biyuka B.[2]

→ Jean-Pierre.Tshibangu@umons.ac.be

1 Université de Mons – FPMs, Belgium

2 Université de Lubumbashi, D.R. Congo

Geological resources occur in nature in different shapes and dimensions. Depending on the resource to be mined out and processed, different characteristics can be addressed: ore grades with respect to main components, physical and mechanical properties, etc. One knows that in geological formations, these parameters can vary spatially, and those variations can be emphasized by geological features like faults. To get a good evaluation of reserves one needs to manage data coming from different sources and of different format (essays from cores or cutting, densities, mechanical properties…). Some software packages have been developed worldwide to manage such data, and we present in this paper some typical applications. When the deposit is of sedimentary origin in a tectonically calm area, the geological model can be built using Laplace's grids, this is a case for instance when addressing limestone outcrops in the Tournai's region, Belgium. Depending on the quantity and quality of data used to define the lithology, the grids can give a good description of interfaces between different geological formations. On the other side, when dealing with a more complicated geometry because of tectonic disturbances for example, one needs to use three dimensions rings to assess the shape of the orebody. Copper deposits in the Katanga Province (D.R. Congo) are typical cases of complex geometry, and we give an example of what approach can be used to build such geological models.

Petrographic and mineralogical study of the Kambove-West ore deposit in the central part of the Katanga Copperbelt (DRC)

GB 2012 Contestant for Best Poster Presentation

Van Langendonck S.[1], Muchez Ph.[1], Dewaele S.[2], Kaputo Kalubi A.[3], Cailteux J.L.H.[4]

→ sander.vl@student.kuleuven.be

1 Geodynamics and Geofluids Research Group, K.U. Leuven, Leuven, Belgium.

2 Department of Geology and Mineralogy, Royal Museum for Central Africa (RMCA), Tervuren, Belgium.

3 Département Géologique, Gécamines, Likasi, D.R. Congo.

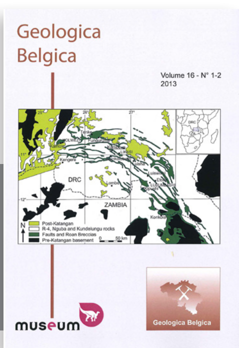
4 Département Recherche et Développement, E.G.M.F., Groupe Forrest International, Lubumbashi, D.R. Congo.

Kambove-West is a sediment-hosted Cu-Co deposit in the Kamoya-Kambove region in the central part of the Katanga Copperbelt (DRC). This deposit is hosted by rocks belonging to the Neoproterozoic Mines Subgroup.

Based on core logging, petrography on thin- and polished sections and cold cathodoluminescence microscopy a detailed paragenesis was established. Multiple phases of mineralization and remobilization were identified. In a first phase, a fine-grained dolomite, anhydrite nodules and pyrite precipitated. During early diagenesis the host rock is brecciated and a fine-grained silica and a second dolomite phase was formed. This dolomite is replacive, forms a cement and occurs in layers and irregular bedding-normal veins. Together with this dolomite generation, an important amount of pyrite, chalcopyrite, bornite, carrollite, digenite and chalcocite precipitated. During later diagenesis or low-grade metamorphism, a second phase of coarse quartz formed prior to a third phase of very coarse, sub- to euhedral dolomite which is present as a replacive and cementation phase but also in bedding-normal veins. Major chalcocite and minor carrollite and digenite precipitated together with this dolomite generation. A fourth generation of dolomite has been identified by cold cathodoluminescence. It overgrows earlier dolomite generations and forms irregular veins.

During an important supergene phase major remobilization took place. A fifth (fine-grained) dolomite phase was formed together with a fine-grained quartz phase, associated with large spots, irregular veins and massive replacements of chalcocite. Finally, together with important dissolution, spherocobaltite, native copper, hematite, goethite, malachite, pseudomalachite, heterogenite and manganese oxides precipitated.

Since chalcocite is the dominant copper-containing mineral present at Kambove-West and since it is formed during different stages of our paragenesis, it is of interest to make a distinction between the hypogene and supergene chalcocite. A differentiation can be made based on the two polymorphs of chalcocite. The transition between these polymorphs occurs at 103°C. The occurrence of the low (orthorhombic) and high (hexagonal) polymorph of chalcocite was recognized by X-ray diffraction. However, due to high reaction rates (on geological time scale) only limited amounts of high temperature chalcocite are detected. The chalcocite polymorphs can also be studied by detailed microscopy based on microtextures and crystal forms. However, none of the techniques were conclusive in this study. A microstructure that indicates supergene remobilization of copper is the close association of late chalcocite and goethite. Cobalt remobilization is indicated by the major occurrence of late cobaltoan dolomite and spherocobaltite. Quantification of the remobilization processes remains, however, speculative.



Full paper in Geologica Belgica, Volume 16, n°1-2

Petrographic and mineralogical study of the sediment-hosted Cu-Co ore deposit at Kambove West in the central part of the Katanga Copperbelt (DRC)

by Van Langendonck S., Muchez P., Dewaele S., Kaputo Kalubi A., Cailteux J.L.H.

Origin of metals in the stratiform Cu-Co deposits of the Central African Copperbelt: a Sr and Nd isotope approach

Van Wilderode J.[1], El Desouky H.A.[1], Muchez Ph.[1], Elburg M.A.[2], Vanhaecke F.[3]
→ jorik.vanwilderode@ees.kuleuven.be

1 KU Leuven, Department of Earth and Environmental Sciences, Belgium

2 University of KwaZulu-Natal, School of Geological Sciences, South-Africa

3 UGent, Department of Analytical Chemistry, Belgium

The Central African Copperbelt is a metallogenic province of exceptional economic value extending from the southernmost part of the Democratic Republic of Congo (DRC) into Zambia. Stratiform Cu-Co deposits are hosted by sediments of the Neoproterozoic Katanga Supergroup, which were deformed during the Lufilian Orogeny (~580 to 520 Ma). Recent research in the Copperbelt lead to a multiphase metallogenic model for the mineralisation (e.g. El Desouky *et al.*, 2010; Haest & Muchez, 2011), comprising an early diagenetic (816 Ma) and a multistage syn-orogenic (~530 Ma) mineralisation phase. However, comparatively few studies have addressed the origin of the ore metals. Radiogenic Sr and Nd isotopic compositions of carbonate gangue minerals are therefore compared with typical isotopic signatures of felsic and mafic basement rocks. The ore deposits of Kamoto, Luiswishi (DRC) and Nkana (Zambia) are examined as case studies.

The isotopic signature of gangue minerals from the first Cu-Co mineralisation, corrected to 816 Ma, are plotted in a εNd vs $^{87}Sr/^{86}Sr$ diagram. They fall in the range of felsic basement rocks and have more negative εNd signatures than their Mines Subgroup host rocks. A felsic source may explain the leaching and enrichment of Cu. The presence of a small overlap with the field of mafic rocks, however, could indicate a mafic contribution. This hypothesis is supported by the presence of Co and Ni, regarding their typical mafic association.

The gangue carbonates of the syn-orogenic Cu-Co mineralisation at Kamoto and Luiswishi plot near the isotopic composition of the dolomitic host rocks and within the field of mafic basement rocks. In addition, they overlap with the range of diagenetic gangue minerals at this point in time. This suggests possible interaction with mafic basement rocks, host rock buffering and remobilisation of the diagenetic sulphides, or a combination of both processes. Other arguments, based on S isotopes and ore mineral assemblies, indicate that the metals at least partly originate from remobilisation (El Desouky *et al.*, 2010).

At Nkana, however, the syn-orogenic gangue minerals fall in the felsic range, indicating a felsic source. Alternatively, this may be due to remobilisation of an unrecognised diagenetic phase at Nkana. Rock buffering by the siliciclastic host rocks could than explain the felsic signature. In addition, the relatively high metamorphic grade in this part of the Copperbelt supports such an intense water-rock interaction.

In conclusion, these data suggest an important role of felsic basement units as ultimate metal source for the stratiform deposits. Furthermore, extensive remobilisation of diagenetic ore sulphides occurred during the syn-orogenic mineralisation phase, although a mafic contribution cannot be excluded and would explain the high Co concentrations of the ore.

Haest M., Muchez P. (2011). *Stratiform and vein-type deposits in the Pan-African orogen in Central andSouthern Africa: evidence for multiphase mineralisation.* Geologica Belgica, Volume 14, n°1-2, pp 23-44.

El Desouky H.A., Muchez P., Boyce A., Schneider J., Cailteux J.L.H., Dewaele S., Von Quadt A. (2010). *Genesis of sediment-hosted stratiform copper-cobalt mineralization at Luiswishi and Kamoto, Katanga Copperbelt (DRC)*. Mineralium Deposita, n°45, pp 735-763.

Characteristics of the pegmatite-hosted Sn and Nb-Ta mineralisation of the Gatumba area, Rwanda: Preliminary results

GB 2012 Contestant for Best Poster Presentation

Vandaele J.[1], Muchez P.[1], Dewaele S.[2], Piessens K.[3]

→ johan.vandaele@student.kuleuven.be

1 Geodynamics and Geofluids Research Group, KU Leuven, Belgium

2 Department of Geology and Mineralogy, Royal Museum for Central Africa, Belgium

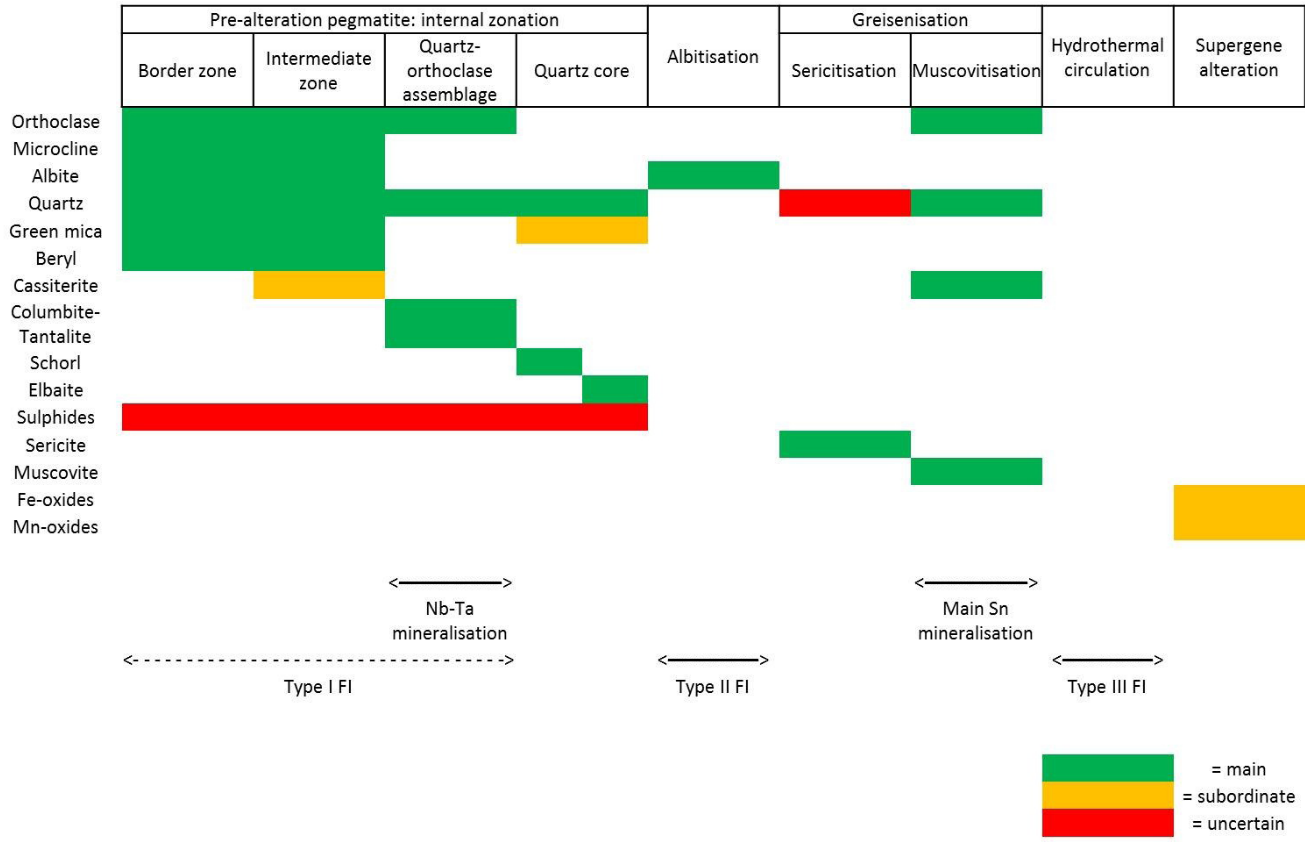
3 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

The Gatumba mining district, part of the larger Central African Karagwe-Ankole belt, contains numerous granite-related ore deposits with a Sn-W-Nb-Ta metal association. Until now the district has mainly seen (semi-)artisanal exploitation of its secondary alluvial or eluvial deposits and of near-surface -and thus deeply weathered- primary deposits under the form of quartz veins and pegmatites. With an estimated value for the whole metallogenic belt of 6.5 billion USD, the economic potential of well-regulated tin-tantalum mining could play an important role in the development of the Western Rift-Congo region. However, scientific and technical knowledge to realise this are largely missing. This work presents a detailed petrographic and a preliminary fluid and melt inclusion study of pegmatites from the Gatumba area in order to reconstruct the paragenesis and to determine the composition of fluids involved in the mineralising processes.

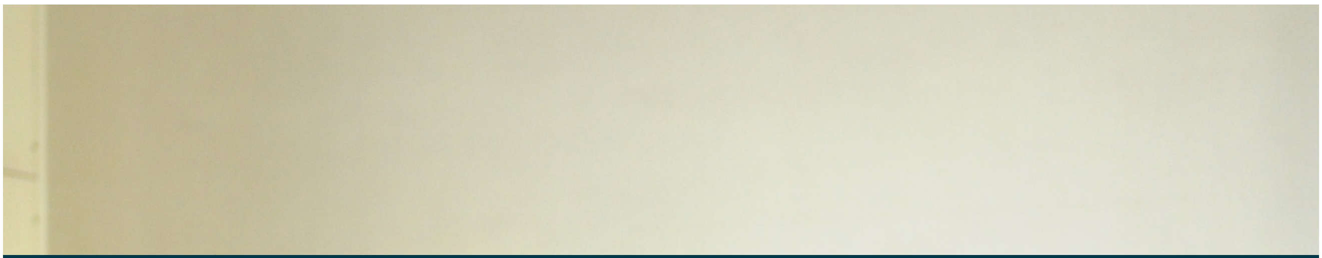
Based on core logging, petrography and hot cathodoluminescence microscopy a detailed paragenesis was established (see figure). The pegmatites show an internal zonation due to fractional crystallisation from the border zone to the quartz core which partially reflects the regional zonation of the field. Primary mineralisation

-related to pegmatite crystallisation- was found in the intermediate zone and the quartz-orthoclase assemblage under the form of cassiterite (Sn) and columbite-tantalite (Nb-Ta) respectively. Near the end of the crystallisation of the pegmatites an albitising fluid exsolved leading to patchy but profound albitisation. The major part of the Sn mineralisation is secondary in nature as it is related to late greisenisation of pre-existing pegmatites. Recent weathering of the pegmatites resulted in the alteration of primary sulphides with the formation of Fe-and Mn-oxides.

Of each zone and major alteration phase a wafer was studied for its inclusions through microthermometry and Raman microspectrometry. Fluid inclusions in the primary pegmatite (Type III in Fig. 1) occur in trails and enclose two-phase (L+V) mixtures of H_2O-NaCl-KCl-CO_2-N_2-CH_4 with total homogenisation temperatures ranging from 170 to 341 °C. Final clathrate melting temperatures show quite a large range from -6.4 to +6.0 °C. Primary inclusions from fully albitised patches (Type II in figure) represent the albitising fluid. These have somewhat higher total homogenisation temperatures (between 267 and 426 °C) and contain less CO_2. Final clathrate melting temperatures range from -0.4 to +4.6 °C. Primary and pseudosecondary inclusions in quartz and orthoclase from the greisen (Type I in figure) are two- or three-phase (L+V or L+V+S), enclose a H_2O-$MgCl_2$-CO_2-N_2 fluid and show total homogenisation temperatures ranging from 337 to 437 °C. Final clathrate melting temperatures show quite a large range from -9.7 to +2.0 °C with the lower end of the range represented by the three-phase (L+V+S) inclusions. Melt inclusions were found throughout the pegmatite (except in the quartz core) as well as in quartz and orthoclase from the greisen. High-temperature (> 400 °C) Type I fluid and melt inclusions in the greisen are interpreted to be relicts of the magmatic phase. The low-temperature (< 400 °C) Type III fluid inclusions in the primary pegmatite were likely formed during late hydrothermal circulation.



Paragenesis of the Gatumba mineralisation.



Session 13a

Ore geology and geodynamics of Central Africa (GECO Project)

Chairmen: Thierry De Putter & François Lubala
Key-note speaker: Anne-Sylvie André-Mayer

Insights of geochronological constraints in the understanding of gold and uranium mineralizations in African Proterozoic orogen and their relation with continental crust formation and evolution

André-Mayer A.-S.[1], Reisberg L.[2], Vanderhaeghe O.[1], Le Mignot E.[1-2], Eglinger A.[1], Fontaine A.[1], Ramiandrisoa N.[3]
→ anne-sylvie.andre@univ-lorraine.fr

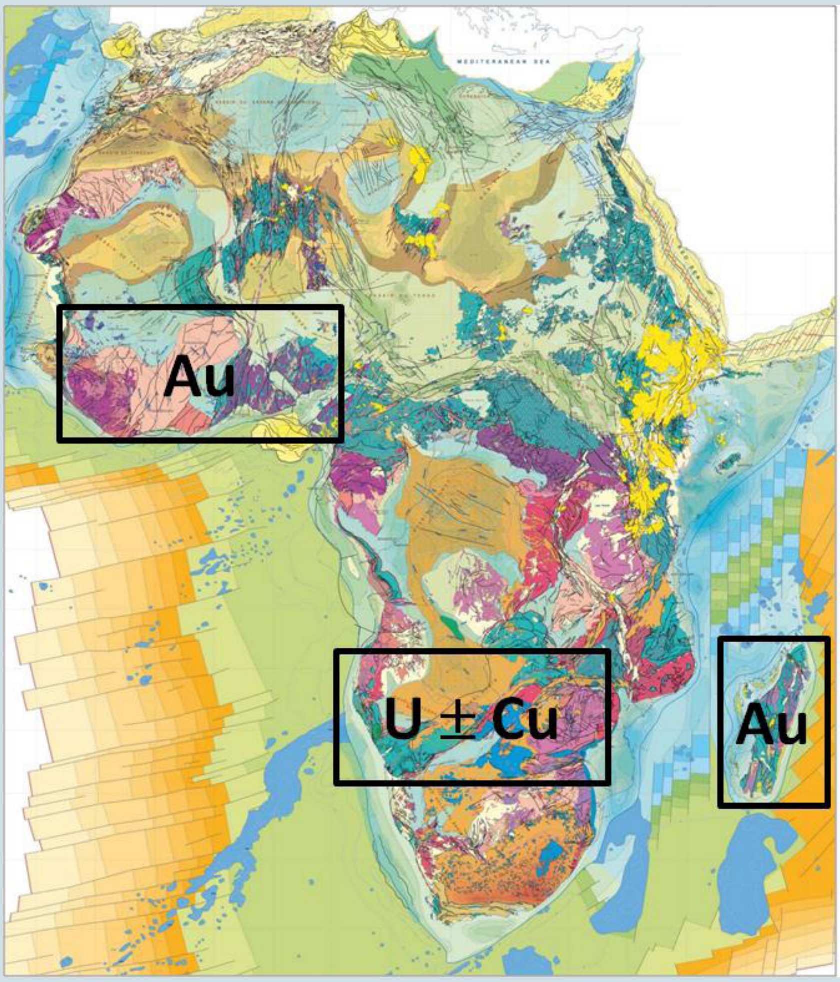
1 Université de Lorraine – G2R – France

2 CNRS – CRPG – France

3 Université d'Antananarivo

Through three geographical zones in Africa, examples of datation of ore minerals (uraninite, pyrite, chalcocite and gold by Re-Os and U-Pb) will illustrate the input of geochronological constraints in the understanding of metallogenic processes and their relation with the geodynamic evolution of Proterozoic crust.

- In western Madagascar, the age of Precambrian formations of Dabolava-Miandrivazo are currently in discussion. They are considered to be Mesoproterozoic by Tucker *et al.* (2011). Re-Os geochronological constraints, obtained on some gold occurrences in Dabolava, indicate that the sulphides transposed in the metasedimentary formations are Paleoproterozoic and we may have to consider these formations as a western lateral facies of the Itremo domain.
- In West Africa, Madagascar, Re-Os geochronological constraints on numerous orogenic gold deposits help to discuss about the (i) the timing of major gold event(s) in the eburnean orogeny and (ii) the timing relation of the gold metallogenic event(s) with the metamorphic evolution of the crust.
- In Zambia and R.D. Congo, the Lufilian orogenic belt hosts world-class Cu-Co deposits and uranium occurrences within deformed Neoproterozoic Katanga metasedimentary rocks. Compilation of geochronological constraints on these deposits is of good interest to decipher the geodynamic evolution of the crust from basin formations to collisional events during the Panafrican orogeny.



Localisation of the Proterozoic areas hosting uranium and gold mineralizations which will illustrate this presentation. Modified from tectonic map of Africa (Milesi *et al.* 2010)

Heterogenite ($HCoO_2$) morphologies, cristallinity degree and geochemical properties across the Katangan copperbelt

Burlet C., Decrée S., Thys T.

→ Christian.burlet@naturalsciences.be

Royal Belgian Institute for Natural Sciences, Geological Survey of Belgium, Belgium

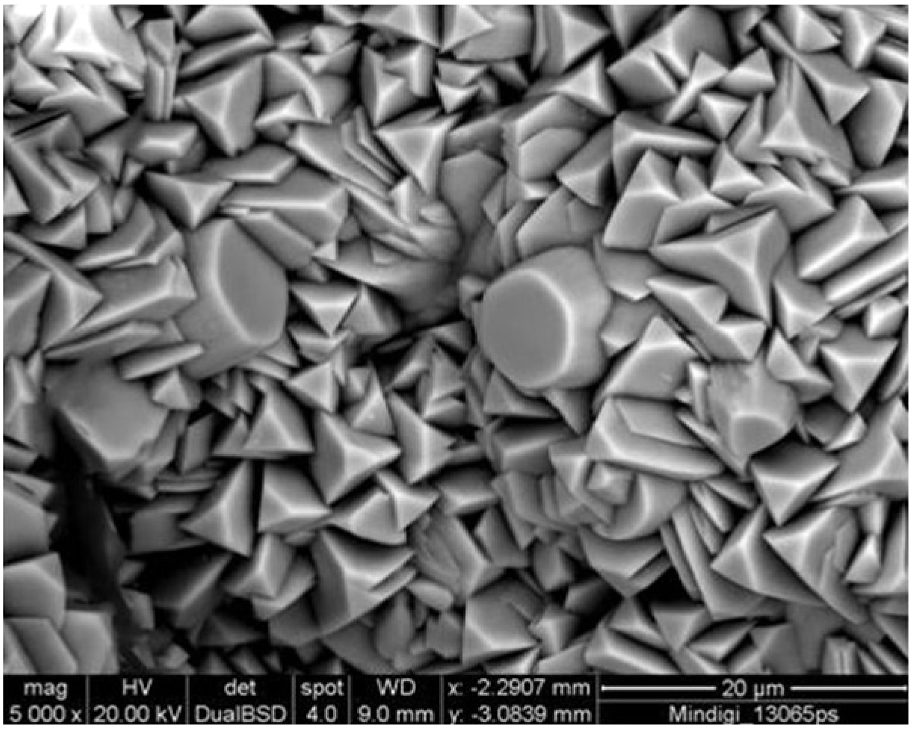
Heterogenite ($HCoO_2$: ideal composition) is a major economical mineral for the Cobalt extractive industry of the Katanga province (Democratic Republic of Congo). It is found in the superficial altered zone (secondary deposits) above primary Cu-Co sulfide ore deposits. The physical conditions of growth of heterogenite are very low temperature and low pressure with maximum temperature of 200-300°C. Heterogenite above these conditions transforms irreversibly into a Co-spinel form (Co_3O_4). Other indications of these environmental conditions are the strong relationship of heterogenite with open cavities leading to the growth of botryoidal texture or even into the shape of speleothems.

The literature review indicates that an important part of the common samples collected around mining sites in Katanga show an amorphous texture under X-Ray diffraction, as a result of contaminations by other cations, mainly Cu and Ni, which disrupt the mineral structure. Nevertheless crystallized fibers with chemical composition close to the ideal one were also found into fractures (ex: Mukondo Deposit). In addition, heterogenite can crystallize according two different polytypes, namely a hexagonal form: $P6_3/mmc$, also named Heterogenite-2H or a trigonal form R-3m or heterogenite 3R.

In this context, this study presents an extensive review of the morphological, petrological and spectroscopic (Raman signature) and chemical characteristics of a representative group of Heterogenite samples collected along the Copperbelt in Katanga. Most of the studied samples present botryoidal, nodular masses of banded heterogenite, from several mm-sized coatings to decimetric-thick concretions.

The aim of this study was also to define a general classification scheme that embodies the main parameters affecting the variability observed in the heterogenite samples collected along the Copperbelt. In this regard, a classification based on the crystallization state of the mineral was defined and 3 types of heterogenite have been recognized:

- **Amorphous heterogenites**, no crystallites. These samples, that are relatively scarce (but locally abundant, as in the Etoile mine), present various forms at macroscopic scale, generally with a dull or earthlike aspect. Some of the samples can present choncoidal fractures. They bear generally a significant amount of other cations than Co (Cu, Ni, Mn, Fe).
- **Micro-cristalline heterogenites**, shows small crystallites (up to 50 micrometers) when crosscutting a banding of heterogenite. Crystallites are present as a poorly organized needles network or as small prisms. This type of heterogenite is the most abundant and occurs in most of the Copperbelt mines. Those samples frequently bear some amount of Cu or Mn in the range of a few % in mass.
- **Crystalline**, Heterogenite occurs as pluri-mm fine crystallites radiating and forming nodules, with surfaces covered in tetrahedral or hexagonal "barrels" crystallites (figure 1). This type of heterogenite is not abundant and have been generally found in fractures (Kalabi, Mindigi, Mukondo). The X-Ray, EBSD (electronic back-scattered diffraction) and Raman analysis performed on those samples revealed the prevalence of the 2H polytype, forming the largest cristals in the samples. Those heterogenites represents the most pure samples, bearing less than 1-2% of other cations like Cu.



Clusters of heterogenite crystals on a cavity wall showing tetrahedra (cut-off on 001 plane) and rounded hexagonal "barrel" prisms (BSED image)

Mineral resources, Environmental issues and Sustainable development of the Democratic Republic of Congo: a review

Chabu M., Lubala F.T.

→ flubala66@gmail.com

Département de Géologie, Université de Lubumbashi, LUBUMBASHI (R. D. Congo)

D. R. Congo mineral extractive industry is supported by an extensive and diversified resource base and has been for almost a century, the cornerstone of the national economy. Apart for copper and cobalt, there are many other mineral commodities some of them being produced and for which D. R. Congo is the leading holder of reserves.

For many decades, mining activities in the D. R. Congo were conducted and focused on profit making with no regard to the environment issues. Consequently, soil, surface water, ground water and air were yet polluted. Taking the example of the Copperbelt, up to 1 billion cubic meters of mine tailings can be found around old mining and hydrometallurgical sites. The assessment of those previously mining areas is of great interest in setting up a more comprehensive programme for site depollution based on the one hand on the retreatment of the tailings and on the other hand on the phytoremediation techniques.

D.R. Congo infrastructure remains one of the poorest of the continent. Most of its abundant mineral resources are located far from ports and existing infrastructure. Also, many mineral resources are largely landlocked and distant from the existing infrastructure and few of these mineral resources are likely to become viable mines without improved infrastructure.

A Sustainable Management of Mineral Resources Project for D. R. Congo possibly to lead to a relevant integration of mineral potential, environmental issues, infrastructure development and the corresponding impacts of the two on the integrated development of the country is proposed. This dynamic mineral resources management system approach is based on this triple objective:(1) strengthen the Government’s capacity to manage both large and small- scale mining mineral sector with respect to the environmental norms; (2) enhance private local and foreign investment; (3 improve the socioeconomic impacts of this activity on Congolese.

Geometallurgy of hétérogénite from Katanga Copperbelt, Democratic Republic of Congo

Decamp X.

→ x.decamp@ulg.ac.be

Université de Liège

Owing to today's economy, an optimization of mineral processing is constantly sought. Heterogenite (CoO.OH) is a cobalt mineral abundantly present in supergene rocks of Central African Copperbelt (especially in the Congolese part). This area is the largest sediment-hosted stratiform Cu-Co ore deposit worldwide and contains more than 50% of cobalt's world reserves. The study of heterogenite is therefore interesting because it can be described as strategic in the economy of cobalt.

In order to obtain the best characterization of heterogenite, this study is based on four areas: 1)mineralogy (macroscopic and microscopic description, X-ray diffraction and EDX mapping with Environmental Scanning Electron Microscope), 2)chemistry (chemical analysis of the heterogenite, differential thermal analysis, thermogravimetry and analysis of specific surfaces by the BET method), 3)granulometry (laser granulometry) and 4) metallurgy (flotation and leaching).

Optic microscopy shows that crystalline and cryptocrystalline mineral phases closely coexist in the same heterogenite. X-ray diffraction was used to calculate a degree of crystallinity and thermal analysis were used to measure a degree of hydration. As for the BET method, it enabled to determine the size and shape of the micropores of the heterogenites, as well as their specific surface (it can range from 60 to 120 m^2/g).

Finally, from these various tests, it emerges that it is not only the specific surface that influences the consumptions of acid and the reaction speed for leaching and sulfidation (preliminary step in the flotation process) tests but rather the size and shape of the micropores. Analyses with ESEM also highlight different sulfidations according to the type of heterogenite.

Refined stratigraphy of the Nefza-Sejnane mining district (Tunisia): implications for the formation of ore deposits (Fe, REE, Pb-Zn, Mn) and raw materials

Decrée S.[1], Ben Abdallah R.[2], Moussi B.[3], Medhioub M.[2], Antoine P.-O.[4], Baele J.-M.[5], Chaftar H.[6], Dupuis C.[5], Hatira N.[7], Jamoussi F.[3], Yans J.[8]

→ Johan.yans@fundp.ac.be

1 Royal Museum for Central Africa, 13 Leuvensesteenweg, 3080 Tervuren, Belgique

2 Faculty of Science Sfax, CNRSM, Soukra Road km 3,5 – BP n°802, 3018 Sfax, Tunisia.

3 CNRSM, Technopôle de Borj Cedria BP 273, 8020 Soliman, Tunisia

4 University Montpellier II, UMR 5554, Pl. Bataillon, F-34095 Montpellier Cedex 5, France

5 UMons, Faculty of Engineering, 9 rue de Houdain, 7000 Mons, Belgium

6 Office national des Mines, 24 rue 8601 ZI La Charguia, Tunis, Tunisia

7 Faculté des Sciences de Gabes, Sciences de la Terre, Cité Erriadh 6072 Zrig, Gabes, Tunisia

8 FUNDP, University of Namur, Geology, 11 rue de Bruxelles, 5000 Namur, Belgique

The mining district of Nefza-Sejnane encloses numerous ore deposits and raw materials, the formation of which would be related to Middle-Late Miocene magmatism, associated to regional extension[1,2,3,4,5]. During the last decade, pluridisciplinary research refined the regional stratigraphical framework, in order to better constrain the formation of these deposits.

The ore deposits overlay a substratum comprising folded marls **Albian-late Priabonian** in age, and **Chattian-Burdigalian** “Numidian” sandstones, present as thrust sheets[6]. The regional felsic sub-volcanic rocks emplaced between 12.9±0.5 Ma and 8.2±0.4 Ma (**Serravallian to Tortonian**)[7], while basaltic flows were dated between 8.4±0.4 Ma and 6.4±0.15 Ma[8]. The first notable mineralization event in the area was associated to a major brecciation episode and led to the formation of the ring-shaped Oued Belif REE-hematite breccia. The ages of 9.4-9.1 Ma (**Tortonian**) obtained onto adularia from this breccia (dated by K-Ar method) confirm that these events are coeval with the neighboring felsic magmatism. The *Sedex-type* Pb-Zn ore of Sidi-Driss and Douahria, related to thermally-driven fluid circulations, would be stratigraphically correlated with the stratified Fe-ore of Douaria which contains the rhinocerotid *Diceros douariensis,* the large sivatheriine giraffid *Helladotherium duvernoyi,* and the anthrocotheriid *Libycosaurus* cf. *anisae*[9]. The three latter species are usually found in the circum-Mediterranean uppermost Miocene sediments (« Turolian »: ~ 8,7-5,33 Ma)[10,11] but are not mentioned in earlier rocks (« Vallesian » rocks: ~ 11,1-8,7 Ma). Therefore, this fauna is rather considered as Messinian in age. The Tamra iron mine sediments are overlying the Sidi Driss basin. It comprises Fe and Mn oxides, together with halloysite lenses. Fe and Mn oxides are the result of mixed hydrothermal fluid circulations and weathering processes. The deposition of the Mn oxides constitutes a late milestone for the Tamra Fe-Mn mineralization. Dating on hollandite $[Ba(Mn^{4+},Mn^{2+})_8O_{16}]$ and coronadite $[Pb(Mn^{4+},Mn^{2+})_8O_{16}]$ yielded ages of 4.7±0.1 and 3.35±0.07 Ma (**Zanclean**)[3,12]. Finally, recent mineralizations (**post 3.35±0.07 Ma**) of galena, pyrite and siderite in sub-vertical fractures cut the whole rocks and are associated with a new hydrothermal event. Together all these new ages provide an essential stratigraphic framework to discuss the formation of materials (phyllosilicates including halloysite and nontronite, Pb, Zn, Fe, As, Mn, …) of the Nefza-Sejnane district.

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SIMS U-Pb dating of uranium associated with cobalt in the Katanga (D.R. Congo) and geodynamic implications

Decrée S.[1], Deloule E.[2], De Putter Th.[1], Dewaele S.[1], Mees F.[1], Marignac Ch.[3]

1 Royal Museum for Central Africa, B-3080 Tervuren, Belgium

2 CRPG/CNRS, F-54501 Nancy, France

3 UMR-G2R CREGU & Ecole des Mines de Nancy, Nancy, France

In uranium ore deposits of Katanga (DR Congo), part of the uranium is closely associated with heterogenite (CoOOH), which is the most abundant mineral in oxidized Co ores of the region. Although heterogenite formation is generally related to a regional Mio-Pliocene weathering episode (Ngongo, 1975; De Putter *et al.*, 2010; Decrée *et al.*, 2010), an age of 632 ± 20 Ma has been reported for U-rich heterogenite from Shinkolobwe (U-Pb ages; Deliens, 1974). Heterogenite dating by using SIMS U-Pb analysis (Decrée *et al.*, 2010) could therefore be an appropriate, although unusual, method for further investigation of U cycling and U deposit development in the Katanga Copperbelt.

New SIMS U-Pb analyses of U-rich heterogenite yield two distinct Neoproterozoic ages, at ~820 Ma and ~680 Ma. At the present state of knowledge, the geological context prevailing in the time frame suggested by these ages was not favourable for heterogenite formation and/or its long-term preservation. We therefore propose that the dated heterogenite has inherited the U-Pb signature of a U-rich mineral, most likely uraninite, that formed at ~ 820 Ma and ~ 680 Ma respectively. This implies that uraninite occurred associated with Co-sulphides before Mio-Pliocene weathering/oxidation event, which resulted in the formation of the U-rich heterogenites that have been dated.

The 820 Ma age in this study could confirm early syn-diagenetic concentration of uranium in the Katanga Copperbelt, which has already been suggested by several authors (François, 1974; Ngongo, 1975; Meneghel, 1981; Cailteux, 1983; Loris, 1996; Cailteux, 1997). This age, together with new geodynamic concepts and geological data relating to the study area, allows an improved assessment of potential U sources in Katanga.

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Geology of the Sn-W (and Nb-Ta) mineralisation of the Kalima area (Maniema, Democratic Republic of Congo): current state of knowledge

Dewaele S.[1], Fernandez M.A. [1], Boyce A.J.[2], Burgess, R.[3]

→ Stijn.dewaele@africamuseum.be

1 Department of Geology and Mineralogy, Royal Museum for Central Africa, Leuvensesteenweg 13, B-3080 Tervuren, Belgium

2 Scottish Universities Environmental Research Centre, Rankine Avenue, East Kilbride G75 0QF, Scotland, UK

3 University of Manchester, School of Earth, Atmospheric and Environmental Sciences, Oxford Road, Manchester M13 9PL, UK

The Karagwe – Ankole fold belt (KAB) is situated in the eastern part of the Democratic Republic of Congo (DRC), Rwanda, Burundi and the eastern parts of Uganda and Tanzania forms an extraordinary metallogenic province that hosts a variety of granite-related mineralisation. Numerous ores have been exploited since the beginning of the previous century, including, cassiterite, columbite-tantalite (Nb-Ta ore historically called coltan), wolframite, amblygonite, beryl. In this study, we focus on the Sn, Nb-Ta and W mineralisation in the Kalima area (DRC), since this area has historically been the main centre of mineral exploitation in the Maniema province, and since the deposits are well documented in the mining archives and rock collections of the Royal Museum for Central Africa (RMCA).

The Kalima area consists of Palaeo- and Mesoproterozoic metasedimentary rocks that have been intruded by several generations of granite and dolerite intrusions. The granites observed in the Kalima area are associated with numerous mineralised quartz veins and, to a lesser extent, pegmatites, and have been dated at 989±28 Ma (Cahen et Ledent, 1979). The quartz veins are mineralised with cassiterite and wolframite, but no columbite-tantalite. These veins occur either as massive veins along foliation or fractures planes in the metasediments surrounding the granite bodies, or as stockwork mineralization in the exterior zone of the granites. The mineralised quartz veins are associated with an intense host-rock alteration: silicification, tourmalinisation, sericitisation and muscovitisation. The cassiterite and wolframite occurs in fractures and at the margin of the veins, associated with muscovite. The Sn-W mineralization is followed by the precipitation of sulphides (e.g. pyrite, chalcopyrite and galena). Intense weathering resulted in the formation of different oxides, hydroxides, etc. The Nb-Ta mineralisation is limited to relatively small pegmatite bodies that occur inside the granites.

Petrographic investigation of fluid inclusions of quartz and cassiterite samples from different locations indicates the predominance of secondary inclusions. Stable isotope ($\delta^{18}O$ – δD) values of cassiterite and quartz samples are very uniform and fall in the field of magmatic fluids. The δD values of the quartz samples are slightly higher, which can be explained the presence of the secondary fluid inclusions that represent younger fluids that have interacted with the surrounding metasedimentary rocks. Muscovites associated with cassiterite mineralisation (1015 ± 10 Ma; 1021 ± 11 Ma) and from a non-mineralised pegmatite (1025 ± 11 Ma) have been dated by ^{40}Ar-^{39}Ar.

Overlap between the ages of the granites, pegmatite and cassiterite mineralisation, the isotopic composition and the geological context favour a direct magmatic origin for the Sn-Nb-Ta-W mineralisation in the Kalima area.

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Geology of the world-class Sn, Nb-Ta and Li mineralisation of Manono-Kitotolo (Katanga, Democratic Republic of Congo): current state of knowledge

Dewaele S.[1], Fernandez M.A.[1], Boyce A.J.[2], Burgess R.[3]

→ Stijn.dewaele@africamuseum.be

1 Department of Geology and Mineralogy, Royal Museum for Central Africa, Leuvensesteenweg 13, B-3080 Tervuren, Belgium

2 Scottish Universities Environmental Research Centre, Rankine Avenue, East Kilbride G75 0QF, Scotland, UK

3 University of Manchester, School of Earth, Atmospheric and Environmental Sciences, Oxford Road, Manchester M13 9PL, UK

The Mesoproterozoic Kibara fold belt (KIB) is located in the Katanga province in the Democratic Republic of Congo. The KIB consists of a succession of metasedimentary rocks that have been intruded by different generations of granitic and mafic rocks. This has resulted in an exciting metallogenic province that hosts a variety of granite-related mineralization containing, for example, cassiterite, columbite-tantalite (Nb-Ta ores historically called coltan), wolframite, amblygonite, beryl.

In this study, we focus on the Sn, Nb-Ta and Li mineralization of Manono-Kitotolo, situated in the northern part of Katanga at ~500 km NW of Lubumbashi. The deposit consists of different sub-parallel pegmatite lenses that occur largely in 2 pegmatite fields that together cover ~10-12 km long and ~500-1000m wide, oriented N50E. These pegmatites have been linked to the youngest, ”E-granite”, generation of intrusions, which have been dated at 977 ± 18 Ma (Cahen and Ledent, 1979).

In the western pegmatite field, the pegmatite lenses are intruded in metasedimentary rocks, while the lenses of the eastern field crosscut doleritic rocks. Intrusion of the pegmatites resulted in an intense alteration of the host-rocks, with the formation of staurolite, biotite, muscovite, tourmaline and quartz. The pegmatite lenses show a weak zonal development, but also important metasomatic/hydrothermal overprinting. The zonal development is greatly obscured by superficial weathering. The margin of the pegmatites is formed by a relatively fine-grained mixture of K-feldspar, (green) mica and minor quartz. Further into the pegmatite, the same minerals occur with addition of albite, but they have a larger crystal size and occur in varying ratios. Typical for Manono-Kitotolo is the development of large spodumene crystals. Coltan mineralisation can be identified in these zones and has been dated at 940.2 ± 5.1 Ma and 947.3 ± 2.3 Ma (Melcher *et al.* submitted). Locally, the original pegmatite composition has been completely altered by metasomatic processes, mainly albitisation and phyllic alteration. Concentrations of cassiterite mineralisation, associated with muscovite, can be found in such zones that seem to occur dominantly at the contact between the pegmatites lenses and the host-rocks.

Stable isotope ($\delta^{18}O$ – δD) values of cassiterite and quartz samples are very uniform and fall in the field of magmatic fluids. The δD values of the quartz samples are slightly higher, which can be explained by invoking the influence the secondary fluid inclusions representing younger fluids which have interacted with the surrounding metasedimentary rocks. Muscovites associated with cassiterite mineralisation have been dated by ^{40}Ar-^{39}Ar at 923.3 ± 8.3 Ma.

Overlap between the ages of the coltan (and therefore) pegmatite formation and cassiterite mineralisation, the isotopic composition and the geological context favour a direct magmatic origin for the Sn mineralisation.

Cahen L., Ledent D. (1979). *Précisions sur l’age, la pétrogénèse et la position stratigraphique des “granites à étain” de l’est de l’Afrique Centrale*. Bulletin de la Société belge de Géologie, n°88, pp 33-49.

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From unconformity to syn-metamorphic uranium type deposits in the Copperbelt: Contribution of uraninites geochemical signatures

Eglinger A.[1], André-Mayer A.-S.[1], Vanderhaeghe O.[1], Mercadier J.[1], Decrée S.[2], Cuney M.l.[1], Feybesse J.-L.[3], Milesi J.-P.[3]

→ aurelien.eglinger@univ-lorraine.fr

1 UMR G2R CNRS-CREGU, Université de Lorraine, France;

2 Royal Museum of Central Africa, Tervuren, Belgium,

3 AREVA BU Mines Paris, France

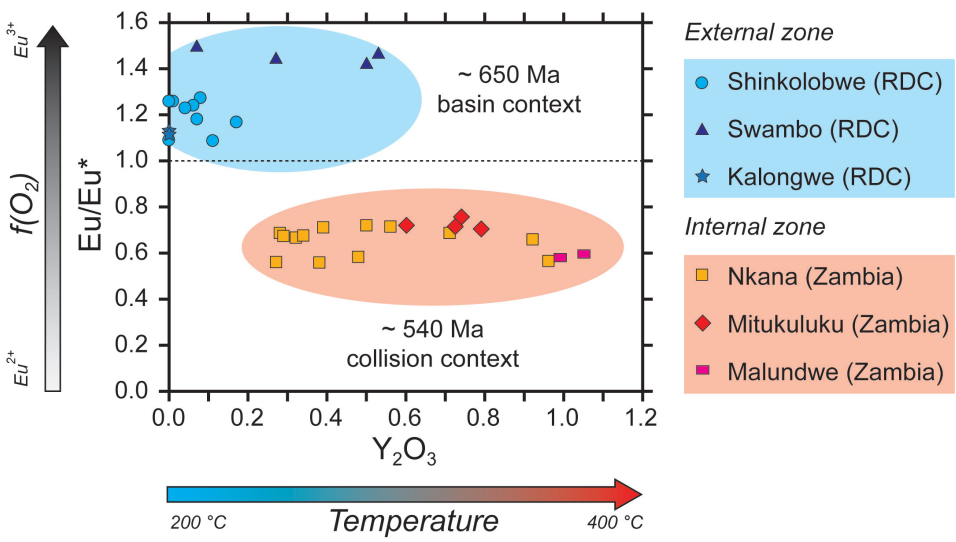
The Lufilian belt formed between the Congo and Kalahari cratons with the evolution of the Gondwana supercontinent during the Panafrican orogeny[1]. This orogenic belt hosts (i) world-class Cu-Co deposits and (ii) uranium occurrences within deformed Neoproterozoic Katanga metasedimentary rocks[2]. To decipher the geochemical (REE and Y) signatures in uraninite from the external to internal zones of the Lufilian belt, we used an Ablation Laser Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS, G2R, Nancy) on sixteen uranium oxides samples from seven uranium showings in D. R. of Congo and Zambia.

The Lufilian belt is subdivided in two major lithotectonic units: (i) the external zone characterized by folded and trusted sedimentary sequence in lower greenschist grade and (ii) the internal zone with exhumed gneissic and migmatitic domes coring in a metasedimentary sequence in upper amphibolites grade[3]. In the external zone, uranium showings occurred as scattered uraninite (UO_2) or concentrated in fracture within dolomitic shales, named the Roan formation. In the internal zone, the ore mineralogy is characterized by uraninite and brannerite $(U, Ca)(Ti, Fe)_2O_6$ hosted by a siliciclastic and carboneous rocks, probably within the same Roan formation[4].

For the external zones, the uraninite REE patterns draw a “bell shape” centered on Tb. This may be in relation with the ionic radius size which is similar for uranium (U^{4+}), terbium and its neighbors and then, the REE fractionation observed might be due to crystallographic control of the uraninite structure at low crystallization temperature (< 350 °C). For the internal zone, the uraninite REE patterns are smoother, without major fractionation between LREE and HREE and the REE contents are higher than those from the external zone. At high temperature (> 350 °C), the dilatational nature of the uraninite structure allows the incorporation of large amounts of REEs.

When plotting the europium anomaly (Eu/Eu*) versus the yttrium content, we obtain two clusters: the uraninites from the external zone are characterized by low Y content and positive Eu anomaly which can be related respectively to low crystallization temperature (no Y incorporation) and oxidizing conditions (trivalent europium state) during the precipitation of the uranium oxides and vice-versa for high crystallization temperature (cf fig.). These geochemical signatures follow previous geochronological studies (Decree *et al.*, 2011) with two mineralized events already described, at 652.3 ± 7.3 Ma in the external zone and the second at 530.1 ± 5.9 Ma in the internal zone.

We proposed that the first event, at ~650 Ma, is due to the late diagenetic to hydrothermal processes before the Lufilian compressive event that took place ~120 Ma later. The uraninite REE patterns, from the external zone, are similar to those observed in the Athabasca basin described as an uranium unconformity-type deposit[6]. The second mineralization event, at ~540 to ~520 Ma, appears to be synchronous to the Lufilian collision, in relation to hydrothermal-metamorphic processes and the uraninite REE patterns appear very similar to the Mistamisk synmetamorphic deposit with a negative Eu anomaly and high REEs content controlled by the dilatational uraninite structure.



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Mineralogical, petrographical and geochemical characterization of the weathered ores in Luiswishi (Katanga, D.R. Congo)

Fontaine L.[1], Bernard A.[2], Decrée S.[3], De Putter T.[3], Cailteux J.[4], Yans J.[5]

→ Johan.yans@fundp.ac.be

1 Royal Institute for Cultural Heritage, Parc du Cinquantenaire 1, B-1000 Bruxelles, Belgium

2 Department of Earth and Environmental Sciences, CP 160/02, Université Libre de Bruxelles, 50 Av. F. Roosevelt, 1050 Brussels, Belgium

3 Department of Geology and Mineralogy, Royal Museum for Central Africa (RMCA), Leuvensesteenweg 13, 3080 Tervuren, Belgium

4 Département Recherche et Développement, E.G.M.F, Groupe Forrest International, Lubumbashi, D.R. Congo

5 Department of Geology, FUNDP, UCL-Namur, Rue de Bruxelles 61, 5000 Namur, Belgium

The Neoproterozoic Luiswishi Cu-Co quarry (Katanga, D.R. Congo) belongs to the Central Africa Copperbelt, a world-class Cu-Co ore deposits. The primary orebodies consist of stratiform disseminated/veined sulfides hosted in fine-grained siliciclastic and carbonate sedimentary rocks of the Mines Subgroup. Formed from the Mio-Pliocene onwards, the derived secondary weathered ores are still poorly documented, though most of them are strongly enriched in both copper and cobalt. By using XRD, optical microscopy, SEM-EDX and ICP-Ms, mineralogical, petrographical and geochemical investigations were performed on three types of ores occurring in the Luiswishi quarry: sulfides, partially oxidized sulfides (“mixed” ores), and fully oxidized ores. The results suggest that the formation of the oxidized ores proceeded into three steps: (1) oxidation of the primary sulfides (mainly chalcopyrite, carrollite, pyrite) by downward percolating surface oxidizing water, (2) rapid neutralization of the resulting acidity by host-rock carbonate minerals and Mg-chlorite, and (3) concomitant precipitation of weathered mineral phases (limonite, malachite, heterogenite, pseudomalachite, amorphous Cu-silicate). Complex geometry and various mineralogical parageneses are highlighted in the weathering profile, emphasizing the variability typically encountered in recent, supergene, oxidized Cu-(Co) deposits. The oxidized ores commonly occurs between 20 and 60 m in depth. As expected, a downward leaching of the LREE also takes place, with a residual enrichment in less mobile HREEs. The leached LREE are accumulated in the mixed zone of the weathering profile, where both secondary chalcocite-type sulfides and Fe-rich residues and flames developed by oxidation from the rims and cracks in chalcopyrite. This mixed oxidized-sulfide zone extends down to about 100m deep, in the study area. Deriving from a particular protolith, the oxidized B.O.M.Z. (Black Ore Mineralized Zone) shows a specific geochemical response to weathering, with enrichment in both LREE and HREE and a positive Ce-anomaly in the oxidized part of the profile.

Uniform GIS-Compilation (1: 750.000) of a geological map of the Kibara fold belt, Katanga, Democratic Republic of Congo (DRC)

Laghmouch M., Fernandez M.A., Dewaele S.

→ Mohamed.laghmouch@africamuseum.be

Department of Geology and Mineralogy, Royal Museum for Central Africa, Leuvensesteenweg 13, B-3080 Tervuren, Belgium

The Mesoproterozoic Kibara fold belt (KIB) is located in the Katanga province in the Democratic Republic of Congo. The KIB consists of a succession of Palaeo- and Mesoproterozoic metasedimentary rocks that have been intruded by different generations of granitic and mafic rocks, which are covered by younger Phanerozoic sedimentary rocks. The KIB forms a metallogenic province that hosts a variety of granite-related mineralization containing, for example, cassiterite, columbite-tantalite (Nb-Ta ores historically called coltan), wolframite, amblygonite, beryl.

Although the KIB has been intensively prospected since the beginning of the last century for its mineral resources, no detailed geological map with indication of the lithostratigraphy is available. This mapping exercise reports the results of a compilation of the available unpublished geological information from the mining and geological archives of the RMCA that has been compiled, re-interpreted and combined in a geological map of scale 1: 750.000. The geological information has been mainly recovered from two sources: the Comité Spécial du Katanga (C.S.K.) and an E.R.T.S. satellite-photo interpretation study.

Geologists of the C.S.K. have carried out geological mapping during colonial times for the different square degrees of the southern part of the KIB (south of 8°S). Drafts of geological maps and stratigraphic columns exist for each square degree. A first attempt to compile and combine this information was carried out by Cahen & Lepersonne (1967). According to these authors, no Palaeoproterozoic rocks can be found in this part of the KIB. The Mesoproterozoic stratigraphy of the KIB can be subdivided into 4 lithostratigraphic units. They are from oldest to youngest: the Kiaora Group, the Lufira (formerly Nzilo) Group, the Mount Hakansson Group and the Lubudi Group (Cahen *et al.*, 1984). The Kiaora Group is dominantly consisted of (quartzo-) phyllites and schists, with quartzitic horizons and with rhyolites at the top. The Nzilo group is dominantly quartzitic, with locally (quartzo-)phyllitic levels. The Mount Hakanssson Group consists of dark-coloured slates and quartzites, with conglomerates at the base. The Lubudi Group consists of dark-coloured arkoses and conglomerate lenses, black graphitic shale with some sandstone levels and an upper part consisting of limestones and dolomites, often silicified with stromatolites.

The second source of information comes from a remote sensing study that has been carried out for the northern part of Katanga (between 8°S and 5°S) (Programme E.R.T.S. 1981, Unpublished data RMCA). This study resulted in 4 maps with indication of only the larger geological units: i.e. zones with the occurrence of Palaeoproterozoic Ruzizian, Mesoproteroic Kibaran, Neoproterozoic Bushimayian and Phanerozoic rocks. The Ruzizian rocks consist mainly of gneisses, micaschists, amphibolites, migmatites with large quartzite lenses and smaller crystalline limestones. The Kibaran rocks consist of (conglomeratic) quartzites, (mica-)schists, limestone lenses and some amphibolite intrusions. The Bushimay rocks consist dominantly of (dolomitic) limestones and limestones with stromatolites.

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Croisettes histories II: Characterization and provenance ancient copper currencies from the Katanga (D.R. Congo) using LA-ICP-MS

Nikis N.[1], Gnat D.[1], Livingstone Smith A.[1,2],[3], De Putter T.[2], André L.[2]

→ nicolasnikis@gmail.com;

1 Université Libre de Bruxelles

2 Royal Museum of Central Africa, Geology Dept, Geodynamics and Natural Resources (ThDP)

3 University of Witwatersrand

Croisettes (cruciform copper ingots) are found in the graves of the Upemba Depression as in other parts of the Katanga Province (D.R. Congo) and in Zambia. These ingots have probably been used as currency units in the but archaeological and historical data are scarce on either the origin of the copper ore used, or on the circulation patterns of these artefacts. The aim of this study was first to look at the chemical composition of the copper used for the *croisettes* in a spatial, diachronic and synchronic level and, second, to see whether it is possible to link the metal of the artefacts with a known copper ore deposit, using discriminant tracers. In this perspective, we have selected a representative range of croisettes from the collection of the section of Prehistory and Archaeology in the Royal Museum for Central Africa (RMCA). The croisettes belong to Final Classic Kisalian (13^{th} century AD), Kabambian A and Kambambian B (14^{th} to 17^{th} century AD) archaeological contexts. After a preliminary archaeological study assessing critical information such as the typology and relative dating of the artefacts, forty eight *croisettes* were analysed using LA-ICP-MS at the department of Geology of the RMCA. The results show significant correlation between the elementary composition of the artefacts and their age or geographical origin. Probable links between the artefact groups and copper ore source areas are established using the malachite ore reference collection of the geological section of the RMCA. The results show that there are “shifts” in the ore sourcing through time, opening new avenues of research on large scale economic systems of pre-colonial central Africa.

Processes of crystal fibers growth of Heterogenite ($HCoO_2$) minerals

Vanbrabant Y., Burlet C.

→ Yves.vanbrabant@naturalsciences.be

Royal Belgian Institute for Natural Sciences, Geological Survey of Belgium, Belgium

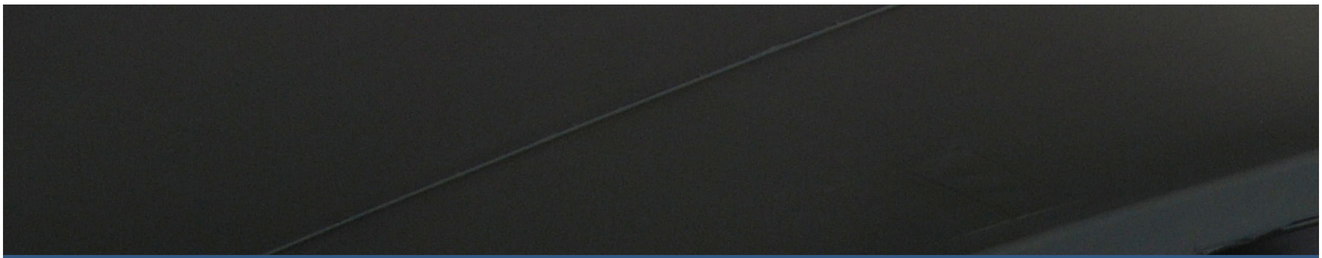
Heterogenite ($HCoO_2$: ideal composition) is a major economical mineral for the Cobalt extractive industry of the Katanga province (Democratic Republic of Congo). It is found in the superficial altered zone (secondary deposits) above primary Cu-Co sulfide ore deposits. The physical conditions of growth of Heterogenite are very low temperature and low pressure with maximum temperature of 200-300°C. Above these conditions Heterogenite transforms irreversibly into a Co-spinel form (Co_3O_4). Other indications of these environmental conditions are the strong relationship of Heterogenite with open cavities leading to the growth of botryodal texture or even into the shape of speleothems.

The literature review indicates that the bulk of samples show an amorphous texture under X-ray diffraction conditions as a result of contaminations by other cations, mainly Cu and Ni, which disrupt the mineral structure. Nevertheless crystallized fibers with chemical composition close to the ideal one were also found into fractures. In addition, Heterogenite can crystallize according two different polytypes, namely a hexagonal form: $P6_3/mmc$, also named Heterogenite-2H or a trigonal form: R-3m, also named Heterogenite-3R.

In this study, we analyze the crystallized forms of Heterogenite using microcrystallographic information provided by Electron Backscattered Diffraction (EBSD) technique coupled with (semi-) and quantitative geochemical data of EDS and WDS detectors. The results indicate that Heterogenite crystalline fibers growth according to a complex process even within a single botryodal element. The Heterogenite-2H fibers are observed at high angle with respect to the botryodal layering. The latter is marked by variation within the crystal texture and/or corresponds in some cases to small chemical Cu contaminations. Nano- to micro-fibers can be observed near the structure centre in a very pure area, but remarkably the crystal c-axes are orthogonal to the fiber elongation. The first minor Cu-contamination (~ 1 %Wt) coincides with a major modification in the crystal growth process, since crystal c-axes become parallel to the Heterogenite-2H fiber elongation. In addition, the size of single crystal increases significantly to a thickness of 20-30µm. Heterogenite-2H keeps in very Cu-poor area the heritage of the first Cu-contamination through an epitaxial growth with crystal c-axis remaining at high-angle to the botryodal layering. Nevertheless the fibers start to grow into diverging direction resulting into a fan structure. The apparition of a new Cu-contamination horizon is associated with a sharp interruption in the fibers growth and seeds a new cycle of "broad" diverging crystal fibers growth.

The presence of minor Cu-contaminations is therefore not antagonistic with the development of well-developed Heterogenite-2H fibers. This observation contrasts with the existing model of impure (amorphous) Heterogenite where more significant Cu and Ni contaminations hindered the crystallizing process.

Our results are also compared with observations conducted during the synthesis of semiconductor materials, especially Delafossite-type minerals, which share strong affinities with Heterogenite. The synthesis of Delafossite-type minerals is the subject of intense researches especially for thedevelopment of transparent conducting oxides (TCO).



Session 14

A future with geo-energy

Chairmen: Jean-Marc Baele & Andreas Busch

ThermoMap Project– Very shallow geothermal energy resources mapping in europe using WebGIS for information distribution

Bertermann D.[1], Klug H.[2], Morper-Busch L.[2], Bialas C.[1], Rohn J.[1], Petitclerc E.[3], Declercq P.-Y.[3]

→ pierre-yves.declercq@naturalsciences.be

1 Department Of Geoscience, University Of Erlangen-Nuremberg, Schlossgarten 5, D-91054 Erlangen, Germany. DAVID.BERTERMANN@GZN.UNI-ERLANGEN.DE

2 Centre For Geoinformatics, University Of Salzburg, Schillerstraße 30, A-5020 Salzburg, Austria. FIRSTNAME.LASTNAME@SBG.AC.AT

3 Royal Belgian Institute Of Natural Sciences, Dpt Vii: Geological Survey Of Belgium, Rue Jenner, 3 - B-1000 Brussels, Belgium. PIERRE-YVES.DECLERCQ@NATURALSCIENCES.BE

In addition to the already implemented solar, wind, and hydro power domain, less research has been conducted in the analysis of very shallow geothermal energy resources in Europe. However, industrial partners from the EU funded project ThermoMap argue for an efficient and inexpensive exploitation of this geothermal resource. Based on existing geodata the authors together with the ThermoMap consortium developed an approach to estimate very shallow geothermal potentials for the first ten meters below surface according to the Kersten formula (Kersten 1949). Pedological, climatological, topographical, geological, administrative, and groundwater data sets have been used to calculate both the pan-European geothermal energy potential on a small-scale (1:250.000) and selected case study areas on the local (site level) to medium (regional level) scale. In Belgium for instance, two test sites have been selected, one of 1600 km² in Gent and the second of 600 km² in Liège. These test areas have been selected in order to apprehend a part of the geological complexity of the country. In this talk we will also demonstrate the methodological framework for the pan-European approach and its extension to the processing methods developed for the geoscientific data sets in different test areas. Processing methods are unified across Europe and standards developed for the spatial analysis in order to allow a unified geovisualisation approach. For visualisation, a WebGIS interface was developed to facilitate the access to the different data sets. The results show variations of air temperature and heat flow in depths which are predominantly controlled by soil parameters like grain size according to US soil classification (USDA 2012) and soil type according to World Reference Base for Soil Resources (WRB 2006), bulk density, pore size distribution and characteristic air- and water balance within the soil matrix. Thus, the modelling approach and the WebGIS toolbox provide target groups such as planners, governments and non-governmental organisations with a common interactive information tool for instance on heat conductivity in W/m*K and heat capacity in MJ/m3*K. This is running on a platform independent web browser (see figure). Private users may check the potential of their residential district, community planning and administration authorities may test the geothermal potential of their entire administrative unit. This tool is intended for multi-purpose use in a transdisciplinary working environment

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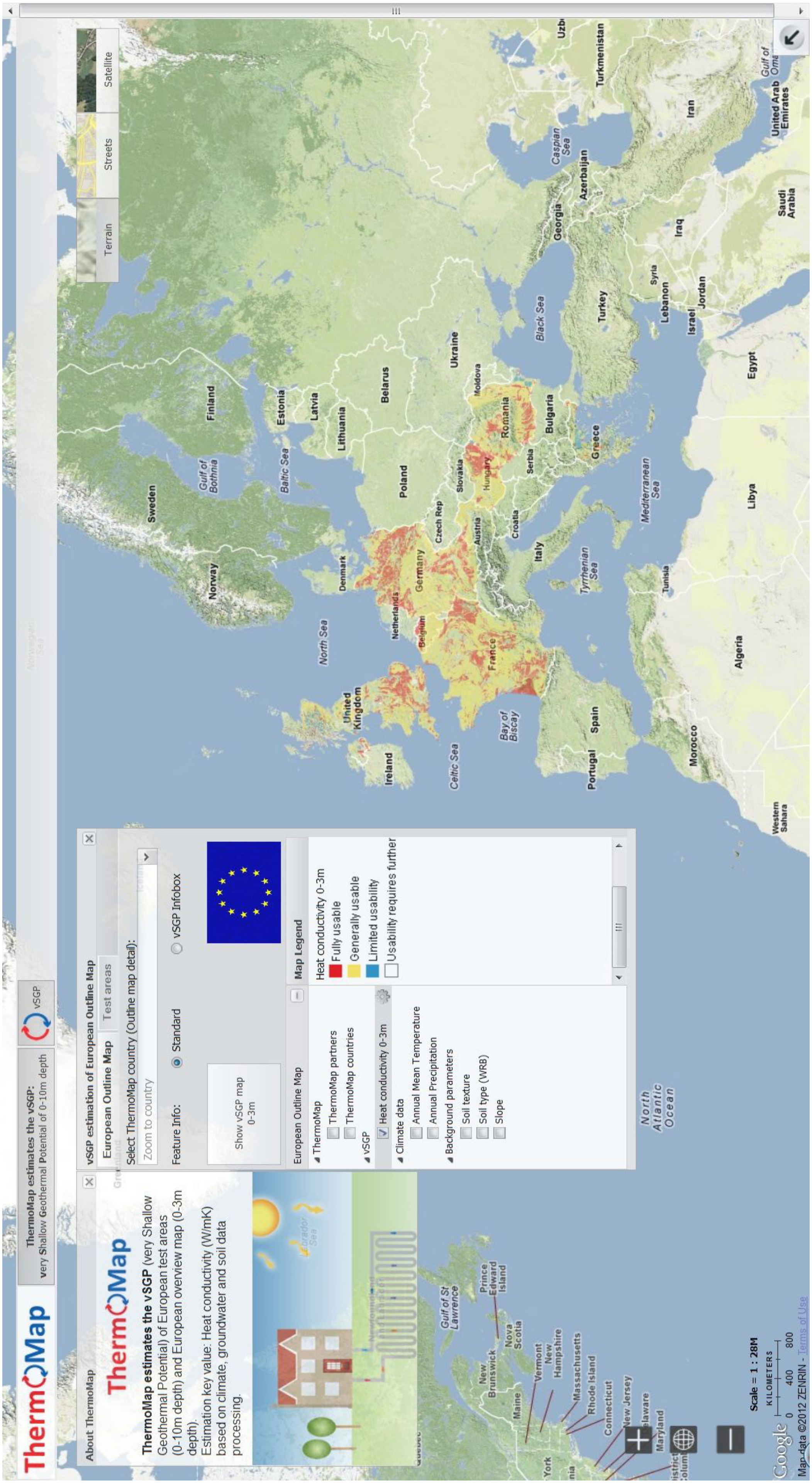

WEBGIS application.

The Werkendam natural CO_2-accumulation: An analogue for geological storage of CO_2

Bertier P.[1], Nover G.[2], Busch A.[3], Hangx S.[3]

→ Pieter.Bertier@emr.rwth-aachen.de

1 Clay and Interface Mineralogy, RWTH Aachen University, Germany

2 Steinmann Institut, University of Bonn, Germany

3 Shell Global Solutions, Rijswijk, The Netherlands

This presentation will report on the preliminary results of a study into the effects of natural CO_2 charging on the reservoir properties and cap rock sealing integrity of the Werkendam CO_2 field.

In 1965, a hydrocarbon exploration well (Werkendam 2) was drilled by NAM into the Mesozoic sequence of the south-eastern part of the West Netherlands Basin, about 30 km east of Rotterdam (Netherlands). No exploitable accumulations were found, but a section through the Upper and Middle Bunter Sandstone was cored (down to 3516 m). In 1991 a new well, Werkendam 3, was deviated several 100s of metres northeastward from the Werkendam 2 borehole, into a gas-charged fault bound structure. The reservoir contained about 70% of CO_2 and is situated in the top Bunter Sandstone/Röt Formation. The sediments are so-called Basin Fringe deposits, i.e. intercalated sand-silstone and mudstone intervals, deposited by a dryland fluvial system.

The Werkendam wells offer a unique opportunity to compare natural CO_2-exposed reservoir- and cap rocks to their unexposed counterparts. A comprehensive study was set up to assess the impact of the CO_2-charging on the reservoir properties and seal integrity of this natural analogue for geological carbon storage. A detailed reconstruction of the diagenetic history of both wells, based on petrography, mineral quantification and geochemical analyses, allows identification of the CO_2-induced mineral alterations. Petrophysical measurements on plugs from all lithofacies recognised in the CO_2-charged core section are compared to their unexposed counterparts, to assess the impact of the identified alterations on porosity and permeability. In addition a set of plugs from the uncharged interval is exposed to CO_2 at reservoir pressure and temperature, in batch and flow experiments. These will allow comparing experimentally induced CO_2 alterations to those observed in natural accumulations.

On the use of multiple lines of geoscientific evidence in support of a Safety Case for geological disposal of high-level and/or long-lived radioactive waste in plastic clays – the Boom Clay case

Brassinnes S.[1], Wouters L.[1], De Craen M.[2], Van Baelen H.[1,3], Berckmans A.[1], Van Geet M.[1]

→ s.brassinnes@nirond.be

1 Belgian Agency for Radioactive Waste and Enriched Fissile materials (ONDRAF/NIRAS), Kunstlaan 14, 1210 Brussels, Belgium.

2 Institute of Environment, Health and Safety, Belgian Nuclear Research Centre (SCK•CEN), Boeretang 200, 2400 Mol, Belgium.

3 KU Leuven, Applied Geology and Mineralogy Group, Celestijnenlaan 200E, 3001 Leuven, Belgium

At present and at an international level, geological disposal of high-level and/or long-lived radioactive waste is considered from a technical point of view as the safest and the most sustainable final solution in the long-term management of these potentially hazardous substances (2011/70/EURATOM). In such an approach, the host-rock aims at providing long-term isolation and confinement of the waste at timeframes on the order of several 100 ka. The Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS), as proposed in its Waste Plan (NIROND-2011-02), suggests using plastic clays, such as the Boom Clay or the Ypresian clays, as a potential host-rock.

In order to guarantee that the considered host rock will fulfil these two key functions (isolation and confinement), a lot of efforts were done during the last 30 years to gather multiple lines of geoscientific evidence supporting, on the one hand, the predictable nature and long-term "stability" and integrity of the host rock and its geological coverage and, on the other hand, the favourable properties of the system to delay and attenuate the release of the radiotoxic compounds with time.

The so-called "Geosynthesis project" integrates the results obtained from many geoscientific studies performed both at specific sites for the Research, Development and Demonstration (i.e., Mol and Doel for the Boom Clay and the Ypresian clays respectively) and at a regional scale.

In the framework of the site-specific investigations, an Underground Research Facility (i.e., HADES) has been built in Boom Clay at a depth of 225 m under the nuclear site at Mol where numerous in situ experiments are running for decades, ranging from radionuclide migration tests to heating tests. The outcomes obtained from these large-scale investigations aims at supporting the demonstration that a geological repository for high-level and/or long-lived radioactive waste in plastic clays is feasible and safe.

Additionally, the studies performed at a regional scale aim at evaluating the future long-term evolution of the considered area so that possible forthcoming processes can be identified. The magnitude and the impact of these processes (e.g., geomorphologic, tectonic, climatic …) on the disposal system will be used to define the evolving conditions that have to be considered in the frame of the safety analysis.

Moreover, considering that several processes relevant for geological disposal cannot be captured over decades due to their very low rate, natural analogues are used to get insights on these processes. For instance, in the frame of the NEA Claytrac project, the use of natural tracer profiles allowed to improve the understanding of radionuclide migration over such long timescale and of the evolution of the reference sites for geological disposal.

The present paper will give an overview on how several geoscientific studies performed, in terms of long-term isolation and confinement abilities, will be integrated to provide a sound scientific basis of the past, present and future conditions that needs to be considered in the assessment of the long-term safety of geological disposal of high-level and/or long-lived radioactive waste in the Boom Clay.

Carbolab: improving the knowledge of carbon storage and coal bed methane production by “in-situ” underground tests

Canto N.[1], Fuentes-Cantillana J.L.[2], Leynet A.[3], Lafortune S.[4], Skiba J.[5], Vidal-Gilbert S.[6], *et al.*

→ a.leynet@brgm.fr

1 HUNOSA, Spain
2 AITEMIN, Spain
3 BRGM, France
4 INERIS, France
5 GIG, Poland
6 TOTAL, France

Amongst the various CO2 geological storage options for reducing greenhouse gas emissions, storage in unmineable coal seams represents an economic potential for middle-term spreading but also reflects uncommon technical difficulties. Indeed, the profit from methane recovery should lessen the costs, but low and changing injectivity is to be expected, at least in European coal deposits. However, these coals have to date received little testing for this technique: in Europe, only one on-site project has been undertaken to give better assessments far from the laboratory benches. Such uncertainties make it difficult to demonstrate the feasibility of injecting CO2 into coal seams and create a major drawback in terms of identifying the reliability and safety of this geological storage option.

Therefore, the CARBOLAB project is working at an intermediate scale between laboratory and industrial pilot, studying an in-situ injection to test and upscale laboratory experiments (for example the CHARCO project) before further pilot-size injections. Our aim is to inject a significant, though not pilot-related, quantity of CO2 into a coal seam lying at the bottom of the Monsacro mine in Asturias, Spain.

Putting devices in the near vicinity of the CO2 plume, only a few metres away, will allow data of much higher quality and density to be collected, and to adapt the injection and monitoring protocols accordingly. Data acquisition includes geophysics (both active and passive seismic and electrical methods) and geochemistry (chemical and isotopic measurements). These and other methods also provide an initial characterization of the coal seam and its surroundings.

The injection and acquisition phase is to occur this summer. The in-situ work will be complemented by parallel laboratory experiments to provide intrinsic properties and characterisation of relationships between water, gases and coal. Afterwards, the data will be compared with results from simulations using existing analytical means as well as new developed ones.

Until now, common reservoir simulators did not represent the adsorption process, which is a key point for explaining the gas storage and migration through coal seams. CO2 sorption onto coal and the exchange with sorbed CH4 are associated with mechanical processes like swelling/shrinkage. Two models are developed, a coupling between TOUGH2/EOS7C and ASTER_CODE (by BRGM), and a COMSOL-based tool (by INERIS). Their intercomparison and their validation with in-situ data have yet to be realised; they will give opportunities for long-term behaviour simulations, in order to provide a basis for the definition of safety criteria for undertaking enhanced coal bed methane projects associated with CO2 injection. The overall aim is to make the impact on Man and the environment close to zero in the short, medium and long terms. However, site selection, risk analysis, storage security management, implementation and eventual remediation need to be studied.

The CARBOLAB project is supported by the European Fund for Coal and Steel, involving partners from three European states: the leader Hunosa, owner of the mine, and Aitemin from Spain, BRGM and Ineris from France, GIG from Poland, and the company Total. It started in 2009 and will end in 2013.

Strain development in smectite clays due to exposure to CO_2

de Jong S.M.[1], Spiers C.J.[1], Busch A.[2]

→ sandermdejong@gmail.com

1 HPT-Laboratory, Faculty of Geosciences, Utrecht University, The Netherlands

2 Shell Global Solutions International, Rijswijk, The Netherlands

Smectites (or swelling clays) are common constituents of claystones, mudstones and shales and are often present in the caprocks and faults sealing potential CO_2 storage reservoirs. To investigate possible effects of CO_2 on their characteristic swelling properties, we performed unconfined volumetric strain measurements on compacted pellets of montmorillonite (SWy-1), which is a common type of smectite, and on smectite-bearing shale. This was done using an optical cell. We probed the macroscopic response of the pressed samples to assess the overall strain response to exposure to CO_2 at typical P-T conditions expected in carbon dioxide storage sites, i.e. at a temperature of 45°C and CO_2 pressures up to 15MPa. Samples were heat-treated prior to exposure to CO_2 to obtain a defined hydration state (d_{001}-spacing). This was determined independently using X-ray diffraction methods. In addition to these unconfined strain measurements, we performed uniaxial compression experiments (T = 45°C/CO_2 pressures up to 10MPa) on the same material to investigate the influence of normal stress on possible sorption reactions. This was carried out by measuring the swelling pressure from interactions with (supercritical) CO_2, for different states of initial effective stress or simulated burial depth.

Our results show that montmorillonite SWy-1 swells almost instantaneously (in a few seconds) to an equilibrium state, when placed in contact with (supercritical) CO_2 for the conditions $P_{CO2} \leq 8$ MPa, T = 45°C. Maximum swelling is observed for an initial d_{001} spacing of 11Å, reaching 2.4 ± 0.45% at a CO_2 pressure of 15MPa. Only minor swelling (0.55 ± 0.46% at 10MPa CO_2 pressure) is found for clay with an initial d_{001} spacing equivalent to 9.8Å. For an initial spacing of 9.8Å ≤ d_{001} ≤ 11Å, swelling decreases systematically with decreasing d-spacing at all pressures investigated. The strain effect is already observed at low CO_2 pressure (1MPa) and expansion appears to be completed at P_{CO2} ~ 8MPa. Shale/claystone samples containing 53% smectite display a volume increase of ~1.0%, at T=45°C and P_{CO2} = 10MPa. The uniaxial compression experiments show clearly the development of swelling pressure for different simulated crustal burial depths. The swelling pressure of SWy-1 decreases from ~11 to 7MPa, for depths corresponding to ~1.3 and ~2km respectively. In addition, smectite-bearing shale also exhibits a swelling pressure up to 9.3MPa for burial conditions corresponding to approximately 2km.

Our results demonstrate that montmorillonite can swell unconfined up to a few percent due to uptake of CO_2, and that sorption would also take place at stress conditions for typical CSS injection sites. Whether the CO_2 actually penetrates the interlayer region, or is adsorbed at clay crystallite surfaces remains unclear. For smectite-bearing caprocks above carbon sequestration reservoirs, our results suggest that a minor swelling can be expected if CO_2 migrates into caprocks and faults, probably closing any open fractures or joints and thus reducing bulk permeability.

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Contribution of terrigenous rocks of South Belgian coal deposits in geological storage of CO_2: new opportunities

Dupont N.[1], Baele J-M.[1], Chenoy L.[2], De Weireld G.[2]

→ nicolas.dupont@umons.ac.be

1 Mons University, Fundamental and Applied Geology Department, Belgium

2 Mons University, Thermodynamics Department, Belgium

Sequestration of CO_2 in unmined coal seams is one of the different options for storing CO_2 in geological reservoirs. In the case of South Belgian coal measures, both weak permeability of the coal and frequent faulting/folding of the seams are likely to decrease the efficiency of this technique.

Westphalian A and B sediments from South Belgium are containing only about 2.5% vol. of coal; the other rocks consisting of shales (~80%) and sandstones (~20%). For all these lithologies, the main processes of CO_2 sequestration are adsorption in coal and clay minerals that are partly forming shales, and within rock porosity in the case of sandstones and, to a lesser extent, in the shales/siltstone porosity. In a previous assessment of the sequestration potential in Westphalian coal measures of South Belgium, Baele *et al.* (2006) showed that coal and shales each account for 25% of the total sequestration potential, and the rest, i.e. 50%, is related to sandstones on a basis of 2% porosity.

The aim of this study is to refine the contribution of the westphalian South Belgium terrigenous rocks (sandstones and shales) to the geological storage of CO_2. Measurements were performed on about forty rock samples in order to determine their mineral compositions and petrophysical properties. The results for the sandstones where introduced in Dupont *et al.* (2009). This paper includes results for the shales.

Effective porosities measured in studied rocks is ranging are about 60% on average higher than the value taken in the previous capacity evaluation, which conduct to increase the sequestration potential in the porosity. Moreover, new estimations of sequestration by adsorption on coal grains and clays minerals of the terrigenous rocks shows that this process could contribute in the same order than porosity sequestration.

Finally, the contribution of each lithologies (coal, sandstones, and shales) in the total sequestration potential is roughly identical to their proportions in the Westphalian (A-B) strata.

Results from this study show other promising insights for the sequestration of CO_2 within Westphalian terrigenous rocks of South Belgium, despite their low permeabilities (few milli-Darcies at best). Carbonate minerals, which occur with 2% in average, could significantly increase the porosity and especially the permeability, due to their dissolution by water acidification caused by CO_2 injection. Adsorption onto coal fragments and clay minerals in the terrigenous rocks has an estimated sequestration potential similar to that of storage in rock porosity. Finally, for reservoir safety purpose, a preliminary assessment of the mineral trapping potential shows that the whole sequestrated CO_2 (within the porosity and by adsorption) could react with CO_2-sensitive minerals such as chlorite and feldspars in the long term.

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The added value of CO_2 geological storage in developing countries: a case study for Kazakhstan

Janssens R., Welkenhuysen K., Piessens K.

→ Rindert.Janssens@naturalsciences.be

Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

New industrialised and some developing countries experience a fast growing economy coupled with increased energy demands. This is also the case for Kazakhstan, a leading economy in Central-Asia with important fossil fuel reserves. Electricity here is mainly produced by coal-fired power plants dating back to the USSR time (World Energy Council, 2007). Several solutions exist and are needed for reducing the CO_2 emissions in order to reduce global emissions of CO_2.

Amongst the possible mitigation options, CO_2 capture and geological storage (CCS) is an important and likely necessary solution for countries which uses fossil fuels as a main source of electricity. The occurrence of sedimentary basins and fossil fuels in Kazakhstan, as well as in other developing countries, suggests that there is an important CO_2 geological storage potential. However, within the ACCESS-project (Assistance in Clean Coal and Environmental Sound Storage Solutions) in Kazakhstan it was observed that the Kazakh government and industry were reluctant towards CCS since this technology gives no direct economic profit but will instead increase energy prices. Other CO_2 reduction options such as energy efficiency and renewable energy production provide a more economic prospect in the short term. Wind energy has significant potential and solar boilers could provide additional capacity during summer. Renewing the inefficient old power installations will significantly increase energy efficiency and reduce emissions per GWh produced. It is however likely that these measures alone will not suffice in reducing CO_2 emissions.

A case study for Kazakhstan is carried out to investigate the possible investments options and compare the reduction potential and costs of CO_2 capture and geological storage and renewable energy technologies. The techno-economic PSS III simulator, which was specially developed to assess geological reservoir capacities and the economic potential of CCS, was extended to handle renewable energy sources. Simulations are performed with a set of country-specific parameters such as the existing energy production portfolio, future energy demand projections, possible geological reservoir locations and their storage potential, availability and amount of wind and insolation. Existing uncertainties on the data are dealt with in a Monte-Carlo approach.

Based on the simulation results a marginal cost abatement curve for the period until 2050 is constructed. Kazakhstan has an important potential for wind energy and energy derived from solar boilers. However, fossil fuels will likely remain an important source of energy in Kazakhstan because of their large availability, and as a partly base, partly backup load to compensate renewable energy production fluctuations. CO_2 capture and storage might therefore become an important CO_2 emission reduction technology, but a sufficiently high price on CO_2 emissions, which reflects the global benefit of reducing greenhouse gas emissions, is needed to justify the additional costs. Wind and solar energy can additionally play an important role in remote areas for decentralized energy production avoiding energy loss during transportation on the electricity grid.

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Convective flow pattern in the geothermal reservoir of Hainaut: Thermal, hydrogeological, chemical and isotopic arguments. First steps in modeling flow and heat transfer.

Licour L.

→ luciane.licour@umons.ac.be

University of Mons, Belgium

The Hainaut geothermal reservoir lies under the Mons Basin in the Mississipian formations of the Namur Parautochton. The 1000 to 2500 m thick limestone and dolostone that compose the deep reservoir crop out a few kilometers north from the geothermal wells of Saint-Ghislain, Douvrain and Ghlin. The south extension of the reservoir has not been determined yet, but most probably exceeds 25 km, with depth increasing from 1400 m to more than 3500 m, according to seismic surveys. In the Saint-Ghislain region, Mississippian strata still include thick layers of anhydrite that have only been discovered in the Epinoy Borehole, in France, in the Overturned Thrust Sheets under the Allochton unit.

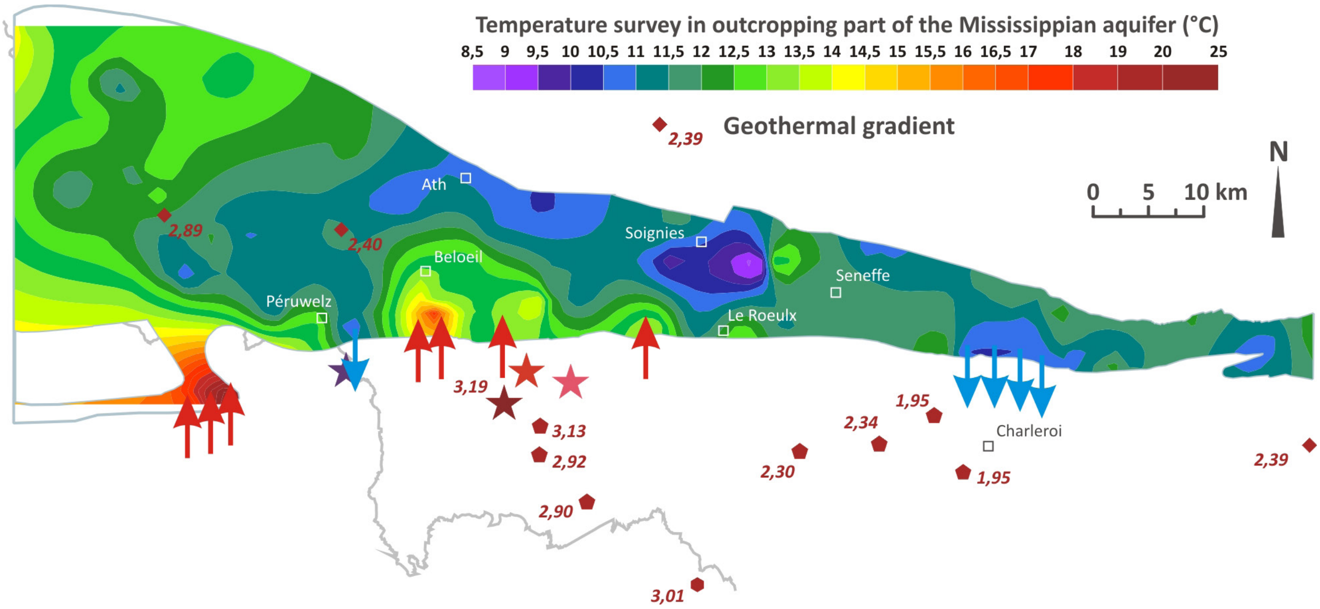
The hydraulic continuity between the outcropping part of the reservoir and its deep ends is indicated by the surface-mapped hydraulic heads matching those calculated from the well-head pressures measured in the three artesian geothermal wells. The hydrogen and oxygen isotopes in water prove its meteoric origin and consequentely confirm the recharge of the reservoir via its outcrop.

The thermal survey of the shallow part of the reservoir (see figure) enlightens a warmer area north and north-west from the geothermal wells. This anomaly is confirmed by the high sulfate content of water regarding that of the average sub-outcropping aquifer water. Isotopic ratios of sulfur and oxygen in dissolved sulfate indicate a strong contribution of evaporite leaching.

Temperature data from deep bore holes allow to estimate the geothermal gradient at the level of non-permeable terrains, where no thermal convection occurs. The estimated gradient in the Parautochton is 2.4 to 3.2 °C/100 m. The temperature data in the carboniferous formations overlying the reservoir allow to estimate the gradient from 1.9 (Charleroi area) to 3.1°C/100 m (south of Saint-Ghislain). Those variations could be due to water flow in the reservoir.

Those observations put together allow to state the hypothesis of large-scale convective circulations in the geothermal reservoir. The deep aquifer would be recharged via the northern and eastern parts of its outcrop and warmer water would flow upwards following the top of the aquifer and reach the outcrop in the thermal/chemical anomalies area.

The modeling of flow and heat transfer confirm the likelyhood of large convective flow patterns in the reservoir as well as the asymmetry in the recharge flow due to the head gradient in the sub-outcropping part of the aquifer. Modelized darcy velocities are under 1 m/yr and are consistent with residence times estimated with ^{14}C residual activity in geothermal water.



Hypothetic large scale flow in the Mississippian aquifer using water temperature survey and geothermal gradient estimations

Structural discontinuities in the deep reservoirs of the Namur Parautochton: The importance of future geophysical investigations for exploring the geothermal resource in Hainaut

Licour L., Dupont N., Baele J.-M., Kaufmann O., Rorive A.

→ luciane.licour@umons.ac.be

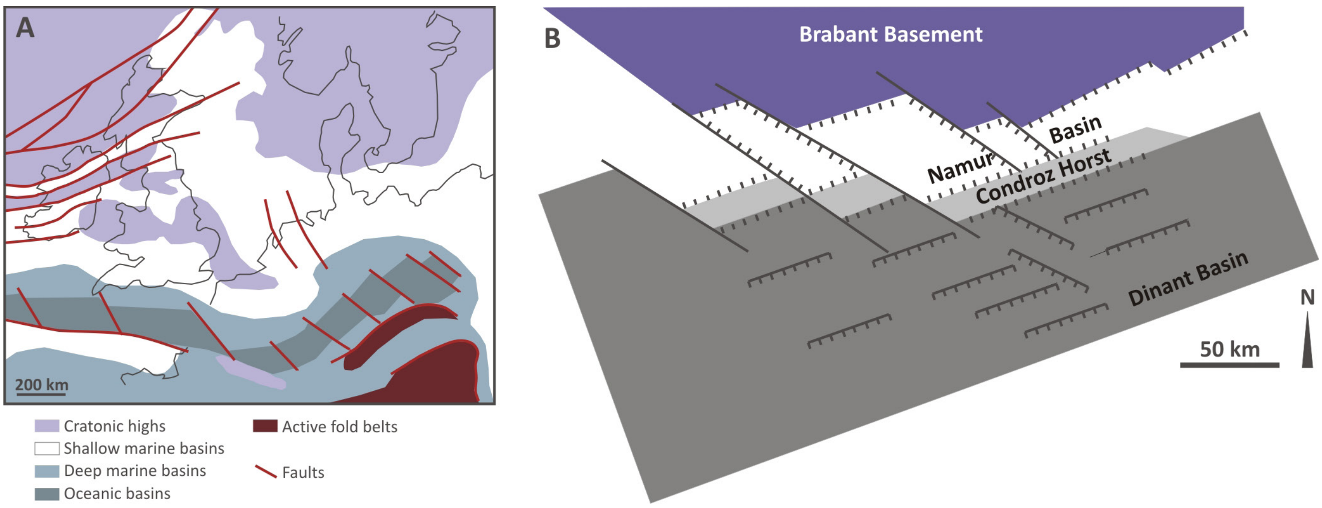
University of Mons, Belgium

Deep geothermal energy is exploited in the Hainaut area since 1986. The reservoir is hosted by Mississippian carbonate of the Namur Parautochton, which is part of the Palaeozoic bedrock of the Mons Basin. The whole Mississippian sequence was recognized in the Saint-Ghislain borehole while only its upper part was drilled in the Douvrain and Ghlin geothermal wells.

The Saint-Ghislain borehole revealed the important thickness of Devono-Carboniferous strata in this region. Mississippian formations outcropping North of Saint-Ghislain have a similar thickness and Visean series are affected by slumping. In the Jeumont borehole, 20 km Southeast of Saint-Ghislain, these formations are much thinner, which supports the hypothesis of tectonic discontinuities within the Palaeozoïc bedrock. These discontinuities could be linked to the eo-Variscan structural context that prevailed during the Devono-Carboniferous sedimentation (see figure). Moderate tectonic extension in the Rheno-Hercynian basin could have induced block faulting with variable subsidence rates. In this scenario, the Saint-Ghislain-Tournai area could have been part of a highly subsident block, whereas the Jeumont area would have been located atop a horst-type structure, where sedimentation is reduced.

Several development plans are currently in progress for geothermal exploitation of the Mississippian reservoir of Hainaut. The well which is going to be drilled next to the Mons station is not very distant from the current productive area. However, other projects led by IDEA, an intermunicipality which manages the local production of geothermal energy, are more distant. These projects will face larger geological uncertainties regarding the geothermal resource. The possible existence of deep discontinuities in the Parautochton is likely to impact key characteristics of the reservoirs such as its extension and compartmentalization.

Two NNE-SSW seismic profiles are planned in the short-term future for anticipating the lateral extension of geothermal production and the exploration of potential underlying reservoirs. With a length of ca. 20 km each, the profiles cross the reservoir formations from their outcrop North of the basin towards South where an important variation in reservoir thickness is observed. Offset and/or dip effects caused by hypothetic deep discontinuities are thus expected especially near the French border. The discontinuities would most probably be multiple and highly dipping. A seismic survey will not allow detecting them directly but the offset and dip effects they induced. Deep reflectors associated with lithological contrasts were already observed in the Palaeozoic series in the Hainaut (Dejonghe *et al.*, 1992). Vertical offset is expecting to increase with depth from a few hundreds of meters to two kilometers in the case of Palaeozoic synsedimentary faults. Preliminary results of these operations, if available, will be presented in session.



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Geothermal resources assessment methodology in Wallonia (Belgium)

Petitclerc E., Vanbrabant Y., Declercq P.-Y., Goemaere E.

→ estelle.petitclerc@naturalsciences.be

Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

The Geological Survey of Belgium (GSB) is involved in different geothermal projects from very shallow depth through the European project Thermomap (<10 m) to deep geothermal resource assessment with the EGEC project Geoelec and at a regional scale (Wallonia, southern Belgium). The latter project, entitled Geothermal Platform of Wallonia produced for the Walloon Region, aims to identify and to map the potential medium to high enthalpy reservoirs located at depths between 300 and 6000 m. The methodology followed for this work will be compared to international best practice.

In Belgium, previous thermal analyses of the subsurface were conducted by Legrand in 1975 and updated by Vandenberghe & Fock in 1989 based on temperature values from the coal and hydrocarbon exploration wells. The temperature measurements results show the low geothermal gradient of this area with values spreading between 20 to 40°C/km and reveal the strong influence of groundwater circulation. The intense deformation associated with the Variscan fold-and-thrust belt setting in Wallonia and the lack of deep information makes geothermal gradient interpretation, reservoir temperatures and reservoir volume difficult to assess as it is usually done in others countries.

The first step of Walloon Geothermal Platform project consisted mainly in preparing and collecting deep geological structure and geothermal resource data. Geophysical, geological, temperatures and hydrogeological data required also some up to date reinterpretation.

In a second step, a detailed study on Liege area produces a 3D geological model (Liège University) producing an accurate image of the contact between Carboniferous limestone (target reservoir) and the overlying Upper Carboniferous coal measures. In addition, chemical geothermometers analyses conducted by the GSB on existing groundwater composition data from the Walloon Region reveals the necessity of a new campaign of water sampling oriented towards a geothermal prospecting. In fact, the available data set is frequently unhomogenized or specific chemical elements (Mg, Li) are not yet quantified .

Finally based on all this data, two maps of geothermal energy interests were produced: one for low to medium depth (300-3000 m), and another one for great depth (3000-6000 m). For these two geothermal horizons the Devono-Carboniferous limestone formations and Lower Devonian quartzite horizons represent the most interesting potential geothermal reservoirs. The deep limestone formations were already identified as a significant geothermal target during the carrying out of Saint-Ghislain/Douvrain deep boreholes conducted by the Geological Survey of Belgium in 1978 and 1979, respectively. The natural permeability of fractured limestone associated with evaporate members represents the main interest for these reservoirs. By contrast, the Lower Devonian quartzites would be more appropriate for Enhanced Geothermal System (EGS) application in order to improve the porosity/permeability of these horizons. Simplified versions of the two maps destined to the public and policy makers were constructed according to the USGS geothermal resource and reserve terminology, illustrated in the Mc Kelvey diagram (1980).

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Converting abandoned coal mines into pumped-storage hydroelectric power stations

Piessens K.

→ Kris.Piessens@naturalsciences.be

Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

In spite of the clear intentions of Europe to reduce its CO_2 emissions by 2050 with 80 to 95%, it is becoming less likely that this goal will be reached. The current economic crisis and the lack of motivation in other parts of the world, seem to consolidate a consensus on a less ambitious strategy limited to two 'no-regret' options: increasing energy efficiency and renewable energy production.

This renewable energy portfolio will be dominated by wind and to some extent photovoltaic energy. The principal hurdle for deploying such technologies at a scale where they cover more than 20% of demand, is matching electricity production and consumption. This type of renewables produces power for only 15 to 40% of the time. As a result, there is a need for large scale storage of electric energy. One of the few efficient ways is to convert electricity into potential energy in pumped-storage hydroelectric power stations that currently have typical global cycle efficiencies above 80%. A good and well-known example in Belgium is the Coo-Trois-Ponts hydroelectric power station where about 8.5Mm³ water can be pumped/drained over an average height difference of 245m.

This type of 'rechargeable' power stations will be needed to buffer the renewable energy production. However, the construction requires a suited geographic setting, and similar to other hydroelectric power plants can have a significant impact on local communities. Alternatives that are considered include the storage of compressed air in salt caverns or aquifers, and the construction of dike surrounded basins near off-shore wind parks.

Mines are also cited as potential storage reservoirs, and several of the Belgian coal mines seem to be particularly interesting. The basic concept is to use the residual volume of the abandoned coal mines and their depth in schemes quite similar to that of the surface installations. The most straightforward opportunities are provided by deep mines which were relatively dry during exploitation. Such mines are found in the Walloon basins, as well as e.g. in the UK. The example used here is that of the relatively well studied Anderlues colliery in the Hainaut basin. The mining activity was historically limited to levels above an impermeable thrust fault at about 550m depth. The deeper levels of the mine were only mined later, be it intensively, using two shafts. Using the depth difference between the upper and lower, nearly perfectly isolated parts of the mine, potential energy can be stored by pumping water from the deep to the shallow reservoir when electricity is available, and reversing this flow path to for power production in times of need. Incidentally, the height difference between the two reservoirs and the total remaining volume of the mine are a near perfect match to those of the Coo-Trois-Pont facility, allowing it to store roughly 2/3rd of the energy produced by wind energy in Belgium on an average day in 2009. The construction of such an installation poses additional difficulties, but may in the near future be economic and required, and has very limited environmental impact.

Implications of increasing subsurface concentrations of CO_2 since 1966 as evidenced from measurements in caves on the monitoring programs for the detection of leakage from geological storage sites for CO_2

Piessens K.[1], Ek C.[2], Godissart J.[3], Welkenhuysen K.[1], Janssens R.[1]

→ Kris.Piessens@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

2 Université de Liège, Belgium

3 Union belge de Spéléologie, Belgium

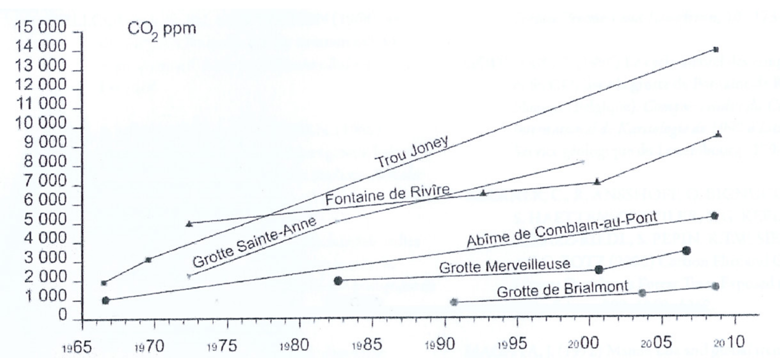
The geological storage of CO_2 in deep reservoirs forms an essential part of the CO_2 Capture and Storage concept that is a recognised climate mitigation option. An important element of concern is the integrity of the geological reservoir, and an EU-wide regulation is being implemented to foresee in sufficient monitoring to provide the guarantee that CO_2 does not migrate out of the anticipated reservoir.

Such a geological reservoir is a natural, and therefore difficult to predictable system. It is located at a depth of over 800m, which makes detailed mapping of the reservoir challenging. If leakage occurs, it will in most cases not be an abrupt or violent event, but a gradual and diffuse process that is more difficult to detect. Therefore several monitoring techniques will be foreseen, some following the behaviour of the CO_2 in the reservoir, others directly focussed on detecting leakage.

A final line of monitoring for especially onshore storage sites is the near surface detection of increased concentrations or changing gradients of CO_2. The importance of defining a proper natural baseline for these values has been demonstrated for the Weyburn project, where a lawsuit was filed against the operators based mainly on suspected increased soil concentrations of CO_2 (PTRC, 2011). Also from a pure scientific/operational point of view, it is important to understand the variability of the natural concentrations in order to discriminate leakage from natural fluctuations. These baseline monitoring campaigns will typically cover a record of 5 years, which seems sufficient to reliably determine seasonal variations, local anomalies, average concentrations, etc. However, few, if any, near soil records span sufficiently long periods to reliably identify trends at decadal scale, which is the time during which the monitoring system will be operational.

Such records do however exist for CO_2 concentrations in caves for six locations in Belgium dating back to 1966. Interestingly, all of these show a clear increase of the partial CO_2 pressure, up to a doubling of the concentrations over 50 years. Several potential causes have been evaluated, such as the increasing atmospheric concentration of CO_2 or the anthropogenic influence of tourists and other visitors, but the prime cause seems to be an increased activity of soil processes of the terrains overlying the caves. The direct reason for the increased biological activity and CO_2 generation would be the increased average temperature.

If this is correct, then this is an important parameter when setting up a long-term monitoring program to detect (or rule out) leakage of CO_2 from a storage site, since setting thresholds based on the average concentration alone will unavoidably lead to a false positive. Decadal time records, combined with additional field measurements, a better understanding of the migration of natural CO_2 and of the activity level of biological processes, should lead to a monitoring parameter that is more precise and reliable at longer time scales.



Changes in the CO_2 concentration in 6 caves in Belgium between 1966 and 2008 (after Ek & Godissart. 2009. Internat. Congress of Speleol., Kerrville, Texas).

PTRC. (2011). *Response to a soil gas study performed by Petro-Find Geochem.* 7 p. http://www.ptrc.ca/siteimages/WMP-Response-to-Petro-Find.pdf

Natural CO_2 releases of geogenic origin: Cross-border comparison (Belgium-Germany) for selected emission locations

GB 2012 2 Student Competition for Best Poster Presentation

Welkenhuysen K.[1], Schlömer S.[2], Möller I.[2], Janssens R.[1], Piessens K.[1]

→ Kris.Piessens@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

2 Federal Institute for Geosciences and Natural Resources, Hannover, Germany

Natural releases of CO_2 are of remarkable economic interest, e.g. in the context of bottling mineral waters. At some of the emitting sites, gas flow rates can be high enough to reach CO_2 concentrations in the soil column and even in the near-surface air layers that may pose risks to men and environment. These reasons have triggered research in the past, but recently a renewed scientific interest for these areas stems from the potential to study them as natural analogues of future CO_2 storage sites, where accidental leakage is rather unlike but cannot be completely excluded. Natural leakage sites allow studying in a practical context the effect and hazard levels of CO_2 to both the natural and agricultural vegetation, the flow path of CO_2 with respect to the local geological structures, and the testing of different measurement technologies in terms of efficiency and economy.

The German part of the Eifel area is characterised by migration of CO_2 to the surface and into the groundwater. The source of CO_2 is directly linked to the volcanic/magmatic activity in this area of which the most recent large scale expression dates back about 10000 years. CO_2 monitoring in this region has a long history. Several locations were recently used as test sites for the development and evaluation of monitoring tools and approaches for geological CO_2 storage sites (Jones *et al.*, 2009).

The deep plume structure causing the carbon dioxide emissions partly extents to the volcanic West Eifel of the Ardennes. Another area of interest in Belgium is located around Spa. Rain water infiltrating in the Haute Fagnes (located between the Ardennes and the Eifel) area gets saturated with CO_2 when migrating through dolomites, which increases the reactivity of the groundwater allowing it to become mineralised along its further trajectory. Isotope studies point to a mantle source for CO_2, quite similar to the findings in the Eifel area.

In spite of this common origin of the CO_2, there are significant differences in terms of the geological setting and overall concept, since the CO_2 reaches the surface by secondary mobilisation from the dolomite reservoir. This allows to study CO_2 migration in a probably partly fault dominated context using continuous monitoring of CO_2 and Rn-concentrations in the soil gas, including some basic meteorological and soil parameters (Furche *et al.*, 2010). The area under consideration for the cross border study has experienced an earthquake swarm in 1989-1990 which results to-date in lingering microseismic activity. This will allows studying CO_2 migration along intermittently active faults, comparable to studies in the NW Bohemian swarm quake region (Weinlich *et al.*, 2006).

Furche M., Schlömer S., Faber E., Dumke I. (2010). *One year continuous soil gas monitoring above an EGR test site*. Geophysical Research, Abstracts 12, pp 2010-3095.

Jones D.G., Barlow T., Beaubien S.E., Ciotoli G., Lister T.R., Lombardi S., May F., Möller I., Pearce J.M., Shaw R.A. (2009). *New and established techniques for surface gas monitoring at onshore CO_2 storage sites*. Energy Procedia, n°1, pp 2127-2134.

Weinlich F.H., Faber E., Boušková A., Horálek J., Teschner M., Poggenburg J.r. (2006). *Seismically induced variations in Mariánské Lázně fault gas composition in the NW Bohemian swarm quake region, Czech Republic — A continuous gas monitoring*. Tectonophysics, Volume 421, Issues 1-2, pp 89-110.

The Ypresian clays as potential host rock for radioactive waste disposal in Belgium. A transferability study.

Van Baelen H.[1], Wouters L.[2], Vandenberghe N.[1], Brassinnes S.[2], Van Geet M.[2]

→ herve.vanbaelen@ees.kuleuven.be

1 KU Leuven, Applied Geology and Mineralogy Group, Celestijnenlaan 200E, 3001 Leuven, Belgium

2 Belgian Agency for Radioactive Waste and Enriched Fissile materials (ONDRAF/NIRAS), Kunstlaan 14, 1210 Brussels, Belgium

For high-level and/or long-lived radioactive waste, ONDRAF/NIRAS advises deep geological repository in a plastic clay host rock. Since the seventies, Oligocene Boom Clay has been studied for this purpose and, because of an extensive local data set available, Mol is considered as the reference site for the RD&D. The Ypresian clays have been studied for their basic properties since the recommendations of SAFIR I and a first well has been drilled in Doel during the nineties and a second in Kallo during the last decade.

This study aims at determining to which extent methodologies, knowledge and know-how can be transferred from Boom Clay to the Ypresian clays, in order to enhance the knowledge of this potential host rock and define the priorities in the new research. It evaluates the present knowledge of the Ypresian clays and figures out which elements are sufficiently known and understood, which elements of the Boom Clay can be reused and which need additional research. The analysis examines to which extent a disposal system concept, as currently designed for Boom Clay would fulfil the safety functions of the safety concept in a Ypresian clay environment. The safety concept in non-indurated clays relies on (1) a temporal containment function fulfilled by an engineered barrier, (2) a confinement function fulfilled by the host rock and (3) an isolation function guaranteeing that no major changes in overall configuration will occur by internal or external processes. The analysis also sheds a first light on the feasibility of constructing a disposal system in the Ypresian clays.

As currently designed for Boom Clay, the containment function should be fulfilled by a thick carbon-steel overpack in a cementitious buffer. Major issues in the case of Ypresian clays, might be the corrosion of the steel and deterioration of cementitions phases, given the pore water composition of the clays and its potential evolution in the area of interest. An adaptation of the current design in function of the host rock and its environment might therefore be considered. Concerning the confinement function of the host rock with respect to radionuclides, no important differences are expected between both host clays, as indicated by similar transport properties and a mineralogy favouring retention. The isolation function of the disposal system, potentially endangered by internal and external processes, can be treated as similar, at least regarding geodynamic and climatologic processes. Perturbations caused by the presence of the disposal facility and waste might be somewhat different owing to differences in mechanical properties and pore water chemistry, but might, if jeopardising the isolation function, be avoided by adapting the design. For both the isolation and the retention function the Boom Clay currently overlying the Ypresian clays in a large part of the research area might, moreover, act as an additional barrier. The differences in mechanical properties between both host clays appear to be significant and might require a modification of the construction techniques and design.

Probabilistic parameters in risk analysis for the geothermal reuse of depleted oil- and gas fields in the Vienna Basin (Austria)

Wegerer E.[1], Hoffellner G.[2]

→ Eva.Wegerer@unileoben.ac.at

1 University of Leoben, Department of Applied Geosciences and Geophysics

2 Infinite Ltd., Energy & Environmental Engineering

The assessment of an economical deployment of geothermal energy under low enthalpy conditions depends on the analyses of a variety of geological, geophysical, geochemical and technical parameters, and parameters concerning the customer site. The Vienna Basin, a hydrocarbon reservoir, offers adequate structural, lithological and facial properties for the application of hydrothermal-, petrothermal- and in-situ-systems, and the possibility of a geothermal reuse of depleted hydrocarbon wells for geothermal utilization. A reservoir assessment incorporating the quantification of the energy gain and the profitability took place by a cooperation of geological disciplines, reservoir engineering, technical and economical disciplines with the focus on indirectly stretching of the energy generation of a hydrocarbon reservoir. The here discussed investigations target on the examination how the distribution range of geological parameters influence reservoir modelling and the inclusion of a probabilistic approach in geological risk analyses. Subsequently the output of the analyses should serve the decision making process for the implementation of a geothermal project.

The Neogene Vienna basin, an intramontane pull-apart basin between the Eastern Alps and the Western Carpathians, is structurally characterized by a complex synsedimentary fault system seperating high zones and depression zones with a synsedimentary offset of approximately 6 km (Wessely, 2006). The Neogene basin fill consists of transgressiv-regressive cycles corresponding to layers of terrigenous material; the substructure is formed by Alpine units and Autochthonous Mesozoic strata. A compilation of data of the hydrocarbon exploration and production delivered, that Triassic successions of the Calcareous Alpine Nappes cover aquifer structures (dolomitic formations) in depth below 2.500 m with appropriate thickness. A reservoir modelling and simulation took place focused on hydrothermal utilization based on input delivered by log-, seismic-, geochemical, geophysical and outcrop analyses (Straka *et al.*, 2011). The database enclosed measured petrophysical (e.g. thermal conductivity, thermal capacity, density, porosity), lithofacial and hydrologic parameters (e.g. fluid chemistry) and assumptions comprising fracture porosity and special structures for providing fluid pathways (e.g. overlapping normal faults, horse-tailing fault terminations, dilational fault intersections). As for the thermal regime, a simplified algorithm for predicting subsurface temperatures for different depths was used based on corrected bottom-hole temperatures and hydraulic drill stem test results. Based on statistical risk analyses of the oil exploration (Lerche, 1997) the geothermal risk analyses target on variables including input data, equation parameters and intrinsic assumptions which hold elements of uncertainty and influence the simulation results.

For the determination of geothermal key values on basis of the empirical data, probability distributions instead of deterministic values like the mean value were developed and inserted as function parameters in standard equations. The main factors for the probabilistic approach of the analyses include formation porosity, permeability, thickness as well as the time related heat flow and the time and depth related temperature profile. The model variables being probability distributions or random values around the mean value allow simulation runs and sensitivity analysis with the aim to get response functions that lead to the possibility of high quality risk estimations for geothermal energy projects in the examined area.

Storage as bottleneck for the commercial introduction of CCS

Welkenhuysen K., Piessens K.

→ Kris.welkenhuysen@naturalsciences.be

Royal Belgian Institute of Natural Sciences – Geological Survey of Belgium, Jennerstraat 13, 1000 Brussels, Belgium

CO_2 capture from large industrial installations and storage in geological reservoirs (CCS) is regarded to be a necessary technology to reduce global CO_2 emissions and mitigate climate change. A maximum global temperature rise of 2°C compared to pre-industrial levels is regarded to be the limit for avoiding large-scale climate change and natural disasters. This corresponds to a stabilisation of atmospheric CO_2 concentration at 450ppm. A stabilisation requires the accumulation of CO_2 in the atmosphere to decrease at a certain rate, determined by the historical accumulation: the longer high emissions continue, the steeper a decrease is needed. This means timing is critical in commercially deploying mitigation techniques, including CO_2 capture and geological storage. In the past, most R&D was focused on the capture part, as it is necessary to develop a highly efficient capture technique in order to keep the energy penalty as low as possible. Now however it is becoming apparent that the storage part is the bottleneck in the CCS chain. There also seems to be a general delay in the development and implementation of most mitigation technologies, including (IEA, 2012) and additional efforts will be needed to reach climate goals.

In order to meet the climate change mitigation target, a commercial deployment of CCS is deemed necessary by 2020. Because of the high investment costs, a CO_2 capture installation will not be built without the timely confirmation of sufficient storage capacity at an acceptable cost. Each potential storage reservoir is meanwhile unique and needs individual exploration. Capacity and containment need to be proven, and exploration, permitting and development take at least 5 to 8 years. In order to reach the 2020 target, planning of commercial projects should be started now.

The politic and economic environment is also not optimal for financing CCS projects, and companies indicate that they will only engage in economic CCS projects. The low CO_2 ETS price not only encourages private companies to postpone investment decisions on CCS, it also diminishes the amount of NER300 EU funding for renewable energy and CCS projects. In reaction to the current situation, the European Technology Platform for Zero Emission Fossil Fuel Power Plants has published a number of recommendations to the EU (ZEP, 2012) to additionally support the deployment of CCS.

A possible way forward is, instead of focussing on (very expensive) integrated demonstration projects, to commence several storage pilot projects for gaining expertise in different geological settings, using different materials etc. Although the 2020 deadline might be missed, vital experience will be gained enabling a faster maturation of CCS technology afterwards.

IEA (2012). *Tracking Clean Energy Progress – Energy Technology Perspectives 2012 excerpt as IEA input to the Clean Energy Ministerial*. International Energy Agency, 78 p.

ZEP (2012). *Securing the business case for CCS as a key enabler for the decarbonisation of Europe – ZEP Strategy Review 2012*. European Technology Platform for Zero Emission Fossil Fuel Power Plants, 19 p.

The Neeroeteren Formation as a viable CO_2 storage option in Belgium

GB 2012 Contestant for Best Oral Presentation

Welkenhuysen K.[1,2], Piessens K.[1], Swennen R.[2]

→ Kris.welkenhuysen@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences – Geological Survey of Belgium, Jennerstraat 13, 1000 Brussels, Belgium

2 Department Earth and Environmental Sciences, K.U.Leuven, Celestijnenlaan 200E, 3001 Heverlee, Belgium

The anthropogenic emission of CO_2 is widely accepted to be a main contributor to global climate change. There are several mitigation options that are likely all needed to keep costs within limits. One of the possible solutions is CO_2 capture and storage (CCS): CO_2 is captured at a large industrial facility, transported, and injected into a suitable deep reservoir for permanent and safe storage. Possible geological storage reservoirs in Belgium are relatively poorly explored. In order to assess these reservoirs' suitability for CO_2 storage with accurate capacity estimates, the existing uncertainties need to be reduced by additional exploration and reservoir modelling. It is however possible to partly circumvent this lack of data by approaching the uncertainties from a statistical and economic point of view. A techno-economic reservoir calculation scheme (PSS Explorer), and simulator (PSS II) are used to handle uncertainties and match CO_2 emitters and potential reservoirs over the next 40 years based on investment decisions. Potential reservoirs are not only regarded as geological entities, but also as part of investment opportunities which have a certain chance on development.

363 Monte-Carlo iterations were performed for Belgium, with the option of exporting CO_2 to neighbouring countries enabled. The results indicate that the Neeroeteren Formation is the most likely to be developed for CO_2 storage, preceding the Buntsandstein and Dinantian reservoirs. The probability that this potential reservoir is successfully developed for one or more CCS projects before 2050 is 15 %, considering a high CO_2 market price. The average total capacity of the Neeroeteren Formation is calculated to be 52 Mt (90% c.i. 4-106 Mt) and an average injectivity of 2.2 Mt/y (90% c.i. 2.2-5.3 Mt/y).

The Neeroeteren Formation has previously been studied because of its good reservoir characteristics. Having a Westphalian D age, it was deposited at the top of the Belgian Coal Measure Group, and it consists of medium grained to conglomeratic sandstones with an average porosity and permeability of 17 % and 140 mD respectively. The Neeroeteren Formation occurs in the deepest part of the Campine Basin, potentially having a lateral equivalent in the Roer Valley Graben, though this is not yet proven by any hard evidence. Sealing however might be problematic in the Campine Basin where in some cases the Neeroeteren Formation is directly overlain by sandy chalks, while in the Roer Valley Graben the Permian and Triassic sediments would provide adequate sealing.

The calculated capacity is sufficient for storing the lifelong emissions of a full-size gas-fired power plant or a demo-scale coal-fired power plant. Even at this moment, with the existing uncertainties, this formation is the first geo-economic choice. A confirmation of the occurrence of the Neeroeteren Formation in the Roer Valley Graben, together with its proven good reservoir qualities makes this a primary target for future CO_2 storage projects in Belgium.

Session 15

Sustainable use of natural resources

Chairmen: Eric Goemaere & Gilles Fronteau

Raw geomaterials exploitations in French Ardennes from XIXe to XXIe

Chalumeau L., Fronteau G., Lejeune O.

→ gilles.fronteau@univ-reims.fr

GEGENA², EA3795, University of Reims (URCA), France

The French administrative area called "Ardennes" is partly supported by the south of the geological Ardenne and partly by the various sedimentary layers of the Paris Basin. The large diversity of raw materials coming from Paleozoic, Meso, Ceno and Quaternary stratas was intensively used for building materials (building stones, raw stones, lime, slates), ornamental stones, pavements, ballasting, ceramics, bricks and tiles, iron ore,...

A SIG-Based cartographic approach, from XIXe datas linked to stratigraphical informations, allows organizing the huge amount of exploitation spots into "geological basin", "exploitation district" and quarries.

For building stones and cultural heritage conservation of the north of France and of the south of Belgium, this interpreted database gives a new lecture of the French Ardennes area and of its local raw natural resources.

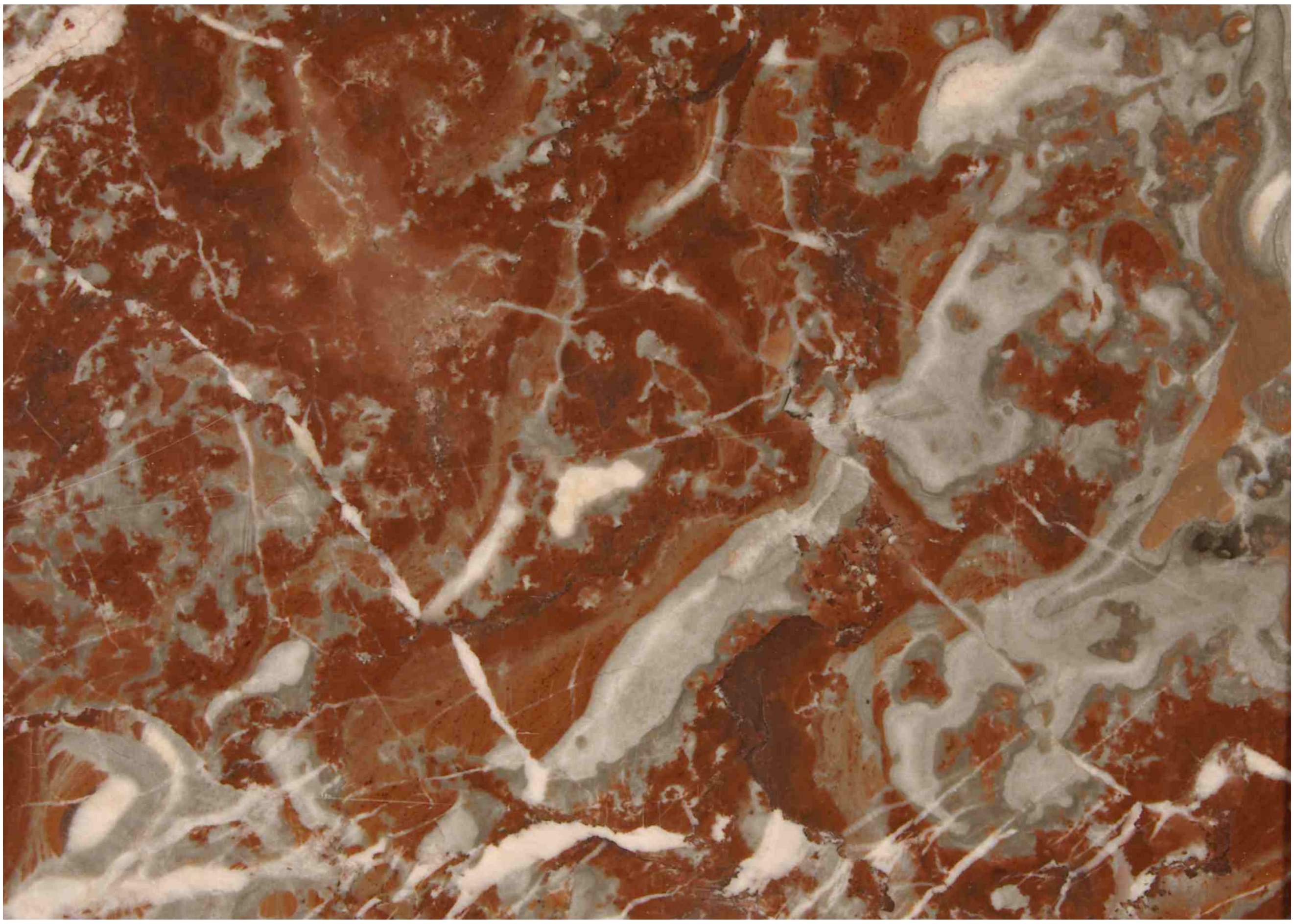
Belgian Marbles in the Royal Institute of Natural Sciences

De Ceukelaire M., Groessens E.

→ Marleen.deceukelaire@natuurwetenschappen.be

Royal Institute of Natural Sciences, Geological Survey of Belgium

Belgian marbles are very famous. They represent a variety of colors with different kinds of red, grey and black. Most of these marbles are represented in the collection of the GSB – RBINS as a heritage of the world exposition in 1897. Some of them are also used in the institute in floors and stairs and can be the reason of an interesting visit.



Red Marble – Griotte

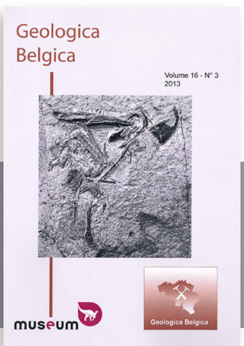
The red crinoidal limestone of Baelen (late Upper Devonian), a particular historical building stone with an unusual depositional setting, global geological importance and local use

Dreesen R.[1], Marion J.-M.[2], Mottequin B.[2]

1 Geological Survey of Belgium, Brussels

2 University of Liège, Liège

The "Marbre rouge à crinoïdes de Baelen" is a local ornamental stone from the Limbourg area (Vesdre valley, Eastern Belgium), quarried at least since the 16th century. Some of its varieties strongly resemble the Frasnian (Upper Devonian) Belgian red "marbles", whereas others are diagnostic for the Baelen Marble. It represents a local member of the Upper Famennian (late Upper Devonian) Souverain-Pré Formation and it is only known from the Vesdre Synclinorium, although time-equivalent small crinoidal limestone accumulations and possibly analogous facies have locally been reported from the Dinant Synclinorium (Hamoir area and Lesse Valley). This deposit is rather unique as it represents probably the only known carbonate mud mound complex worldwide at this particular stratigraphical level. Individual mounds reached a thickness of at least 100m and a width over 500m. They correspond to a worldwide transgressive pulse or highstand system tract during the Late *Palmatolepis marginifera* Chron: a remarkable carbonate episode interrupting the siliciclastic Condroz Sandstone Group. Detailed petrographical and micropaleontological analysis point to unusual sedimentary and paleo-ecological conditions. In contrast with Frasnian mounds, corals and stromatopores are totally absent here. Carbonate microfacies comprise (crypt)-algal bindstones, stromatactis-bearing spiculitic mudstones and microbialites, frequently interrupted by lenticular crinoidal-foraminiferal grainstones. Mixed carbonate-siliciclastics, strongly affected by pressure solution, mark the transition with underlying and overlying sandstones. Macrofaunas comprise crinoids, hexactinellid sponges, brachiopods (e.g. small-sized spiriferids and productids) and orthoceratids. Microfaunas include dasycladacean algae, problematics, plurilocular foraminifera and ostracodes. Transitional facies between the peri-mound nodular limestones and the mound-core facies have now been described for the first time. The location of the mounds most probably coincides with that of former deep-seated extensional faults. The carbonate production might well have been related to cold-water hydrocarbon seeps (still unproven). The earliest record of quarrying is from the 16th century (Limbourg). The last active quarry (Les Forges, Baelen) closed in 1940. It has been used for both building and ornamental purposes in historical buildings mostly within a short radius of the production sites. Two varieties exist: a massive grey-pink stromatactis-bearing fine-grained limestone (mound core = marble quality) and a grey to red-stained argillaceous crinoidal limestone with numerous crinoid ossicles. The latter frequently encloses pale-grey, densely packed coarse crinoidal limestone lenses. The best examples of its usage can still be admired in the medieval town of Limbourg. Nice examples of marble-type quality are kept within the Chapel of the Home Saint Joseph (Baelen-Les Forges). It became most popular at the beginning of the 20th century, mainly for decorating art nouveau houses. One of the most famous buildings where it has been used as an ornamental stone, is the Antwerp town hall. The oldest original underground quarry from which it has been quarried (1560-1563), is still preserved in the Hors-les-Portes area, just outside Limbourg.



Full paper in Geologica Belgica, Volume 16, n°3

The Red Marble of Baelen, a particular historical building stone with global geological importance and local use

by Dreesen R., Marion J.-M., Mottequin B.

Critical Thinking about Critical Resources

Heirman K., **Vandewijngaerde W.**, Piessens K.

→ Kris.Piessens@naturalsciences.be

Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

Natural resources underpin our economy and quality of life. As a consequence of the tight conditions overshadowing today's resource markets, concerns over access to raw materials have been rising again in recent years (e.g. Raw Material Initiative, Polinares). The worldwide demand for natural resources has grown rapidly. The surplus demand does no longer originate from Western countries alone, but is now largely located in developing countries such as China. This has led to new conflicts: access to reserves outside of the developed countries are increasingly being claimed by developing regions. Continuing our current patterns of resource use is not an option.

The general public is largely uninformed of the consequences if Europe were to be cut off of primary resources. A mobile phone contains today more than 40 different raw materials, such as cobalt, gallium, platinum and rare earths elements. Moreover, many applications rely on key raw materials that are currently very difficult, or even virtually impossible, to substitute due to their specific physical and chemical properties.

It is vital to create public and political awareness concerning this matter. Several strategies can help to reduce these risks. Those on the demand side include more efficient recycling and the research for and development of alternatives. Also securing and expanding the reserves within the European continent is crucial. An obvious, and at the same time controversial approach is to consider the renewed exploitation of known reserves of different commodities within Europe itself.

Before considering this re-exploitation, it is important to have a reliable, complete and sufficiently detailed overview of the current reserves of different commodities in Europe. Efforts to gather and organise this data have taken profit of the initiatives relating to the implementation of the Inspire directive. The biggest challenge is to harmonize the databases of the different European Geological Surveys in such a way that they can be compared in not only a qualitative, but also in a quantitative way. The level of detail also requires to look into the confidentiality of the different datasets. Subsequently, the network needs to be expanded with the aim to build a truly pan-European database, and to keep this system up-to-date. The EuroGeoSource group (www.eurogeosource.eu) has taken the lead in creating such an European natural resource database with an open-access dataportal.

If mining and quarrying activities receive media attention, it is often negative. Natural resources, however, cannot be grown, they can only be exploited at locations where they are available. This land is, however, not lost forever, especially in Europe many abandoned quarries are turned into nature reserves and become patches of green with a very high biodiversity in a densely populated and urbanized landscape.

Similar to initiatives in the agricultural industry where local crops are promoted, the use of local building materials should be encouraged. This will boost local economic opportunities and competitiveness.

Understanding how crucial the problems related to shortages of natural resources may become, is a first step, now understanding to what degree Europe can be self sustaining is next.

Monitoring system for a sustainable surface mineral resources policy

Kok L.[1], De Groot C.[1], Schoofs R.[1], Vandecruys J.[2], Huygh K.[2], Nielsen P.[3], Lagrou D.[3], Smets T.[3]
→ chris.degroot@lne.vlaanderen.be

1 Department of Environment, Nature and Energy (LNE), Flemish Government,

2 Public FlemishWaste Agency (OVAM), Flemish Government,

3 Flemish Institute for Technologic Research (VITO).

The development of a sustainable mineral resources policy and by extent a sustainable materials management is depending on the availability of reliable basic data, such as the total needs for primary mineral resources in the different industrial and building processes, the import and export movements of the different mineral resources as well as the application and potential of possible alternatives as substitutes for primary minerals.

Therefore, the Flemish Government developed in 2010 a "monitoring system for a sustainable surface mineral resources policy" in cooperation with the Public Flemish Waste Agency (OVAM) and the Flemish Institute for Technologic Research (VITO).

At the beginning of 2011 producers, traders and consumers of mineral resources and alternatives were inquired for the first time after three elements that are required for the design of a sustainable mineral resources planning. These elements are:

- the total need of primary surface minerals
- the import and export flows of surface minerals
- the use of alternative materials.

The combination of the results of all these inquiries provide an overall picture of market developments on an annual basis. The collected results have been published in a publicly accessible annual report on www.vlaanderen.be/natuurlijke-rijkdommen. These results are also useful in the framework of sustainable materials management, which is an important subject in Flemish environmental policy. Sustainable materials management seeks to reduce the use of natural resources throughout the life-cycle of materials (independent of whether they are resources, finished products or waste).

The results of 2010 show a total need for raw materials in Flanders of 63 Mton. Approximately 31 Mton or 49% are primary raw materials and 51% or 32 Mton are substitutes for primary minerals. The demand for gravel and crushed stones is the highest of all primary raw materials, with respectively 12 Mton and 11 Mton.

Approximately 74% of the primary raw materials that are used in the Flemish region is imported and 26% is exploited in Flanders. Only for the clay, the amount of clay extracted in the Flemish region is larger than the amount of imported clay, respectively 69% against 31%.

The substitutes for primary raw materials, up to 21 Mton, can be divided into 2 groups: (1) the total use of construction and demolition waste in Flanders in 2010 is about 11 Mton and (2) other substitutes to primary minerals such as dredging sludge, excavated soil, .. take more than 21 Mton.

It is the objective of the Flemish Government to do these inquiries on a frequently base (possibly annually) so that a sustainable mineral resources planning can be designed.

Characterization and origin of the "Limestones of Lorraine" from the Saint-Paul Cathedral (Liège)

Lecuit M.-X.[1], Piavaux M.[2], Fronteau G.[3], Boulvain F.[4], Eyssautier S.[3], Morel D.[2], Finoulst L.-A.[2], Yans J.[1]

→ Johan.yans@fundp.ac.be

1 AcanthuM, Department of Geology, FUNDP, University of Namur, 61 rue de Bruxelles, 5000 Namur, Belgium

2 AcanthuM, Department of Art History and Archaeology / FNRS, FUNDP, University of Namur, 61 rue de Bruxelles, 5000 Namur, Belgium

3 Université de Reims Champagne-Ardenne, GEGENA², EA3795, France.

4 Pétrologie sédimentaire, B20, Université de Liège, Sart Tilman, B-4000 Liège.

Historical sources suggest that the "Calcaires Lorrains" stones which were used to build gothic churches in Liège come from the Donchery area, by the Meuse. Here we attempt to confirm this origin through several methods: thin section petrography, X-ray diffraction and geochemical analyses on both bulk rocks and decarbonated rocks. These methods have been tested on stones from Dom-le-Mesnil underground quarry (close to Donchery), Grandcourt and Tuffeau de Maastricht stones, as well as on Saint-Paul's cathedral itself.

Thin section petrography allows us to confirm the origin of Saint-Paul's cathedral building stones but it does not provide a distinction between different levels of Dom-le-Mesnil quarry.

Geochemical analyses, and more particularly Rare Earth Elements profiles, not only allow to confirm the origin of Saint-Paul's cathedral stones, but also give the possibility to refine the field of possible origin to some levels of the quarry. It implies that only hundreds of milligrams of rocks are necessary to have such suitable results. On the other hand, limestone decarbonatation with 25% HCl must be avoided as it modifies the profile of Rare Earth Elements and therefore makes the method most probably ineffective.

X-ray diffraction does not provide conclusive results for such similar stones as those that have been studied here.

Effective and sustainable use of Dolomitic materials in The Mbuji-Mayi region (DR Congo)

GB 2012 Contestant for Best Oral Presentation

Matamba Jibikila R.[1], Pirard E.[1], Dewaele S.[2]

→ r.matamba@doct.ulg.ac.be

1 University of Mbuji-Mayi, Department of mining, DR Congo.
University of Liège, PhD student, GeMMe, Belgium.

2 University of Liège, GeMMe, Belgium.

3 Royal Museum for Central Africa, Belgium.

Due to the scarcity of alluvial diamond deposits, intensive artisanal mining and crushing of building materials has grown in the Mbuji-Mayi region. This type of operation is performed without any selectivity of materials. Our study aims to characterize the different facies present in the subgroup BIIb - BIIc of Mbuji-Mayi Supergroup in order to define the appropriate applications fields for each facies. Drill cores samples were obtained from The S13B survey (316 m) performed at Kanshi in the city of Mbuji-Mayi and preserved in the Royal Museum for Central Africa (Tervuren). The XRF analysis results show a variability of CaO, MgO and SiO_2 in the upper and lower parts of the survey while the intermediate portion has a low variability of the same components as well as interesting grades. CaO (> 30%), MgO (> 20%). Optical microscopy and physical tests showed low porosity of materials of upper and lower zones whereas the mechanical strengths are ranged between 200 and 380 MPa. All these results were used to classify different types of materials. So for example, the intermediate layers must not be exploited for crushed aggregates purposes. They are better indicated for the production of decarbonated dolomite, raw ground dolomite, or magnesia. Decarbonated dolomite could eventually find applications in the metallurgy of nonferrous metals whose results of exploration in the region are very promising. While the raw ground dolomite could serve as an amendment in agriculture. The exploitation of aggregates may currently be restricted to upper and lower layers with the high content SiO_2. Thus this study has contributed to an effective and sustainable management of our reserves of dolomitic materials.

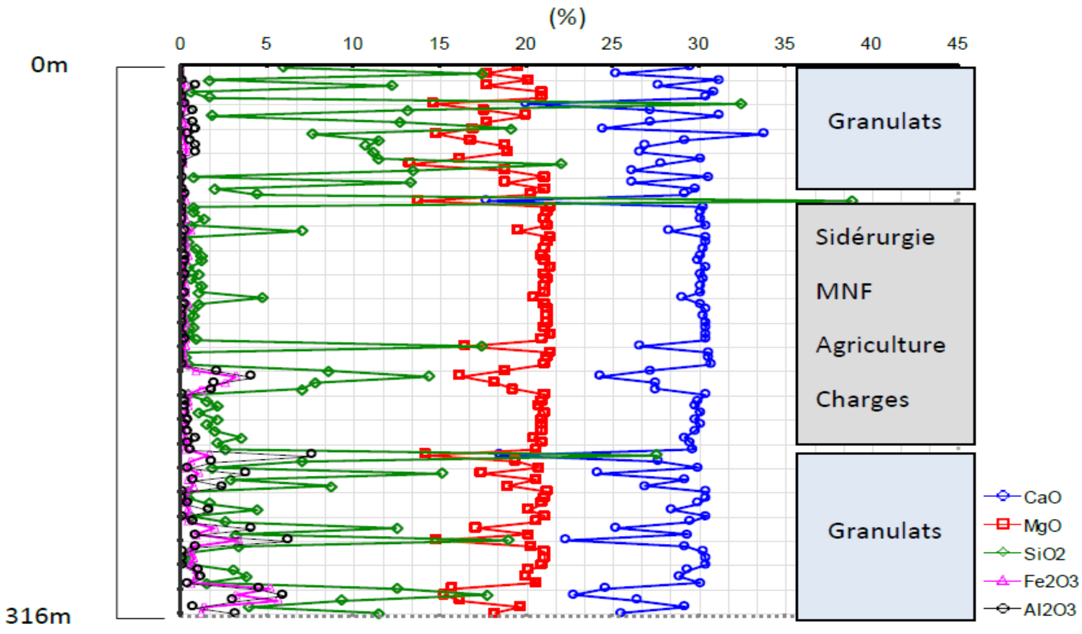


Fig. Analyses XRF des échantillons du sondage S13B.

XRF results show how different components vary from the beginning until to the end of the survey.

Roughouts of whetstones discovered in a Roman cellar in Buizingen (Flemish Brabant, Belgium): geological and geographical origins of raw material and making steps

GB 2012 Contestant for Best Poster Presentation

Thiébaux A.[1], Goemaere E.[2], Herbosch A.[3]
→ athiebaux@hotmail.com; eric.goemaere@naturalsciences.be; herbosch@ulb.ac.be

1 University of Liège, Belgium.

2 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium.

3 Free University of Brussels, Belgium.

During the construction of the motorway linking Brussels to Mons, a Roman cellar containing roughouts of whetstones was discovered in 1967 (Pierrard, 1970) in Buizingen (Halle, Provincie Vlaams Brabant, Belgium). This workshop was abandoned after a fire. Eighty-one pieces (raw material, roughouts, semi-finite products, manufacturing waste and polishers) were found in this cellar dating by pottery from the IInd to IIIth century AD.

The whetstones are made from the following raw materials: micaceous feldspathic sandstone, greywacke or coarse siltstone known as "arkose de Tubize" (Tubize Formation, Early Cambrian). These are characterized by a grey-green color (chloritic cement), the presence of minute crystals of magnetite lithic fragments and a relative freshness of the feldspar. The raw material was mined from open pits or outcrops in the vicinity of Buizingen along the Senne river (Brabant Massif).

In this study the way these whetstones were produced is reconstructed based on the characteristics of the roughouts found in the cellar. Some flat rectangular slabs of sandstone were split in several parallelepipeds. Secondly, these parallelepipeds were cut up to obtain cylinders with an elliptic or circular cross-section. Tool marks present on the whetstones suggest that the stones were made with a chisel, point and gradine. Finally, both fine grey-green sandstones and a recycled white-colored millstone (*catillus*) made in "Arkose of Haybes" (Fépin Formation, Lochkovian, north Eodevonian border of the Rocroi Inlier) were used to polish the final product.

The discovery of these whetstones is exceptional in Europe. The elaboration of a distribution map of whetstones in Belgium and surroundings countries is in progress. The whetstones are part of the collections of the "Musée du CPAS de la Ville de Bruxelles" and the "Zuidwestbrabants Museum" of Halle.

Pierrard J.-M. (1970). *Atelier de fabrication de pierres à aiguiser d'époque romaine à Buizingen*. Archéologie, n°2, pp 75-76.

Towards a more sustainable exploitation of human activities, Belgian part of the North Sea

Van Lancker V.[1], Baeye M.[2], Du Four I.[2], Janssens R.[1,2], Degraer S.[1], Fettweis M.[1], Francken F.[1], Houziaux J.S.[1], Luyten P.[1], Van den Eynde D.[1], Devolder M.[1], De Cauwer K.[1], Monbaliu J[3]., Toorman E.[3], Portilla J.[3], Ullman A.[3], Liste Muñoz M.[3], Fernandez L.[3], Komijani H.[3], Verwaest T.[4], Delgado R.[4], De Schutter J.[4], Janssens J.[4], Levy Y.[4], Vanlede J.[4], Vincx M.[5], Rabaut M.[5], Vandenberghe H.[5], Zeelmaekers E.[5], Goffin A.[5]

→ Vera.vanlancker@mumm.ac.be

1 Royal Belgian Institute of Natural Sciences. Management Unit of the North Sea Mathematical Models, Belgium

2 Ghent University, Renard Centre of Marine Geology, Belgium

3 KULeuven, Hydraulics Laboratory, Belgium

4 Flanders Hydraulics, Belgium

5 Ghent University, Marine Biology Section, Krijgslaan 281, S-8, B-9000 Gent, Belgium

6 Flanders Marine Institute (VLIZ), Belgium

Seabed, living and non-living resources are exploited increasingly: sand and gravel is needed for beach nourishment and for construction purposes, the accessibility of harbours requires regular dredging and disposal operations, offshore windmills contribute to our future energy supply and pipelines and cables transport gas and electricity to the mainland. The interaction of these activities with seabed and water column nature and processes needs careful consideration. A more sustainable ecosystem-based approach to management is needed, based on an overall marine environmental status. Setting-up environmental targets and well-balanced monitoring programs have become timely (Europe's Marine Strategy Framework Directive).

QUEST4D has anticipated through investigating the Belgian marine ecosystem over the past 100 years, addressing: (1) Natural variability of sediment processes; (2) Historic baselines, sediment and benthos; (3) Ecosystem changes, on the medium- to long-term; (4) Case studies, relating seabed and water column changes to both naturally- and anthropogenically-induced sediment dynamics; (5) Climate change scenarios and their effect on seabed processes; and (6) More sustainable exploitation strategies of non-living seabed resources. A combined suite of tools was used, comprising *in situ* measurements, seabed mapping and modelling, on the small to large-scale, and aiming at increasing both process and system knowledge of the Belgian part of the North Sea.

Van Lancker V., Baeye M., Du Four I., Janssens R., Degraer S., Fettweis M., Francken F., Houziaux J.S., Luyten P., Van den Eynde D., Devolder M., De Cauwer K., Monbaliu J., Toorman E., Portilla J., Ullman A., Liste Muñoz M., Fernandez L., Komijani H., Verwaest T., Delgado R., De Schutter J., Janssens J., Levy Y., Vanlede J., Vincx M., Rabaut M., Vandenberghe H, Zeelmaekers E, Goffin A. (2012). *Quantification of Erosion/Sedimentation patterns to Trace the natural versus anthropogenic sediment dynamics (QUEST4D). Final Report*. Science for Sustainable Development, Brussels: Belgian Science Policy, 97 p. + Annexes. (http://www.vliz.be/projects/quest4d/docs/BelspoSSD_QUEST4D_FinalReport2012.pdf)

Standardisation and Harmonisation of Geological and Geophysical data for improved Seabed Habitat Mapping

Van Lancker V.[1], Coggan R.[2], Dolan M.[3], Elvenes S.[3], Guinan J.[4], van Heteren S.[5], Kupschus S.[2], O'Leth J.[6], Mason C.[2], Monteys X.[4], Moussat E.[7], Schmitt T.[8], Thorsnes T.[3]

→ Vera.vanlancker@mumm.ac.be

1 Royal Belgian Institute of Natural Sciences. Management Unit of the North Sea Mathematical Models (MUMM), Belgium

2 Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Laboratory (CEFAS), United Kingdom

3 Geological Survey of Norway (NGU), Norway

4 Geological Survey of Ireland (GSI), Ireland

5 TNO Built Environment and Geosciences, Geological Survey of the Netherlands, The Netherlands

6 Geological Survey of Denmark and Greenland (GEUS), Denmark

7 IFREMER / IDM/SISMER, France

8 SHOM (Service Hydrographique Et Oceanographique De La Marine), France

Seabed habitat mapping is mostly based on the assumption that the ecological value of an area can be represented by its abiotic characteristics (substrate type, topography and energy regime). Within this realm geological and geophysical data are crucial, as are their derivatives. For end-users, the availability of data is not always clear, and when data are compiled from various sources, problems arise on how to harmonise the data. More standardised archiving of data is needed, as also more standardised approaches on how to deal with the data. Geo-Seas, an FP7 pan-European e-infrastructure for geological and geophysical data is addressing this need. Geo-Seas targeted 'Seabed Habitat Mapping' as a field where standardisation and harmonisation of geological data can lead to better mapping products. Sediment and terrain characterisation is focussed on, respecting applications on a regional (>500m), medium- (50m) to fine-scale (<5m).

A report is produced highlighting: (1) the importance of sediment/terrain characterisation within habitat mapping initiatives (soft vs hard bottom types / flat vs high relief areas); (2) a demonstration of main methodological approaches and classification; (3) an investigation on how different resolution of data affects the sediment/terrain characterisation; and (4) recommendations on parameters, resolution, formats, confidence, and data query tools to be used for habitat mapping. Results are framed within the context of major European Directives (e.g. Europe's Marine Strategy Framework Directive). Cross-fertilisation exists between Geo-Seas (http://www.geoseas.eu) and EMODNET-Geology (EU DG MARE, http://www.emodnet-geology.eu/).

Characterization and recovery of Kasangulu clayey materials (DR Congo)

Wetshondo D.[1], Pirard E.[2]

→ don_owdo@yahoo.fr; eric.pirard@ulg.ac.be

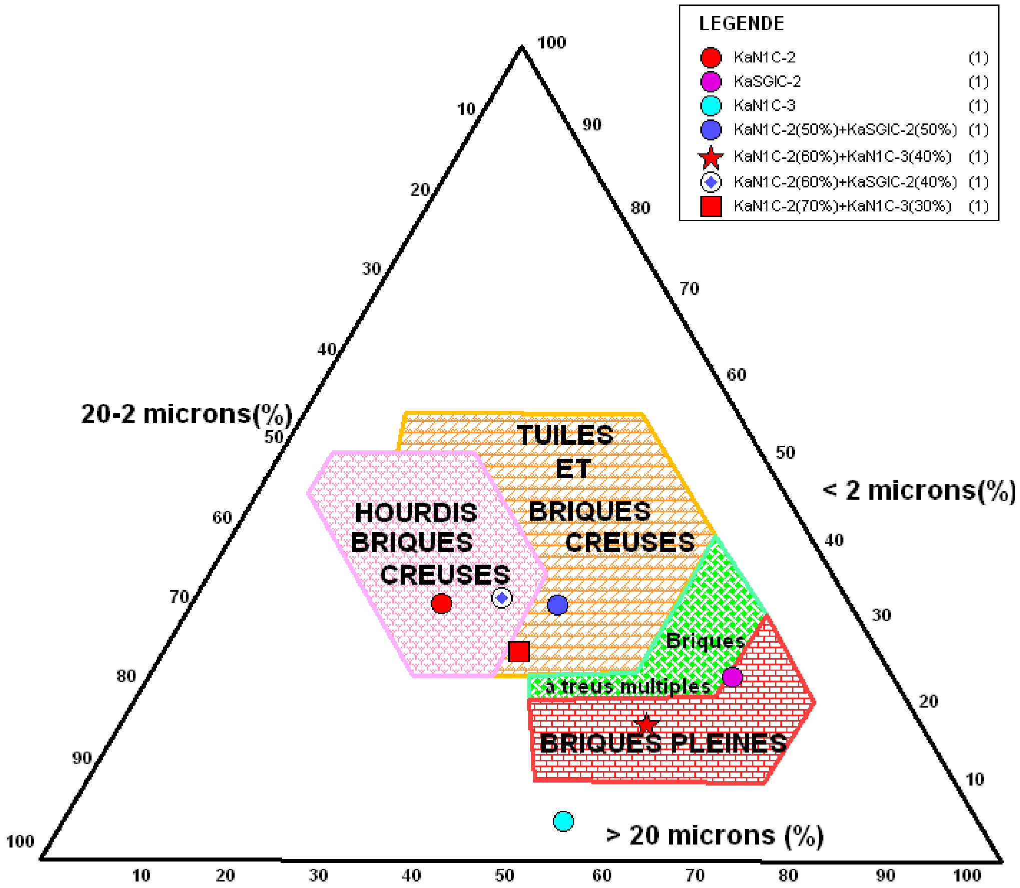
1 Senior assistant at the University of Kinshasa and PhD student in Engineering sciences (GeMMe) at the University of Liège (ULg).

2 Professor, GeMMe, ULg

Following the promulgation of the Mining Code in July 2002, almost all investments of the national or multinational mining companies working in DR Congo is directed to basic metals (Cu, Co, Sn, Mn) and precious minerals (gold, diamond). The sector of ceramic which is very promising and using industrial substances as raw materials is among the lowest developed sectors in the most of the country.

With a natural water content between 10 and 20 % , an equivalent of sand varying from 10 to 14 %, the grounds of Kasangulu are clayey materials (2 in 32 % of clays) plastics (IP: 16-27; WL < 50 %; WS: 14-21 %), inorganic (M.O < 1 %), very substantial (IC: 1,18-1,44), muddy (11 in 42 % of silt), sandy (14 in 32 % of fine sands and 24 in 35 % of unrefined sands) and lateritized. These materials consist of a mineralogical assembly dominated by the kaolinite, the quartz, the muscovite or the illite, the goethite, the gibbsite, the alkaline feldspars and the chlorite. Chemically, these materials are characterized by silica content (SiO_2) from 62 to 71 %; in alumina (Al_2O_3) from 10 to 22 %; oxide of titanium (TiO_2) and sesquioxide of iron (Fe_2O_3) from 2 to 7 %; in alkaline oxides ($Na_2O + K_2O$) and oxidize alcalino-earthy (CaO + MgO) lower than 3 %.

The resulting scientific knowledge can justify the use of clayey materials in the pilot site in the chain of Kasangulu coarse ceramic or ceramic construction. Indeed, materials and especially Kasangulu lithofacies layers 2 and 3 are sand-clay plastic which are industrial mineral resources of good quality for the manufacture of various products including baked or stabilized bricks (hollow, perforated, full and of facing), the slabs and tiles. The presence of goethite associated with titanium oxide in these natural products provides a significant added value in dyeing and reddish / yellowish or finished products. In all cases, the grading curves are continuous, which should help to obtain dense textures and therefore also to the manufacture of finished products resistant.



Ternary diagram of granules and their ability to manufacture finished products

Session 16

Open session

Chairmen: Michiel Dusar & Vera Van Lancker

Recognizing pedogenic features in Paleogene sandstones and silcretes in Belgium. A key-feature for paleoenvironmental and sourcing material studies.

Baele J.-M.[1], Cnudde V.[2], Dupuis C.[1], Quesnel F.[3], Ricordel-Prognon C.[3], Veldman I.[4]

1 UMons, Faculty of Engineering, Dept of Geology, Mons, Belgium

2 UGent, Faculty of Sciences, Dept. of Geology and Soil Science, Belgium

3 BRGM (French Geological Survey), Geology / Regolith and Reservoir, Orléans, France

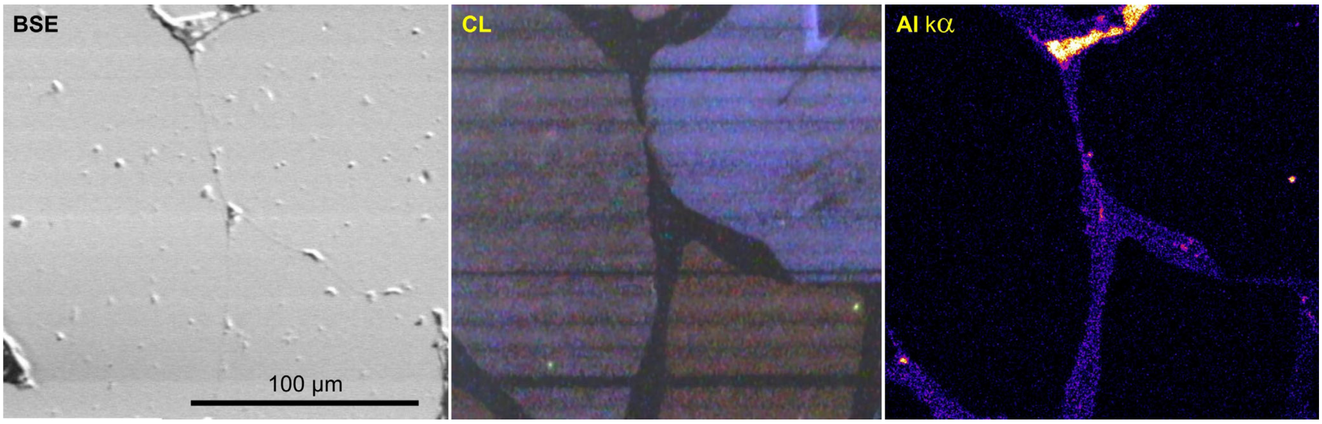
4 Kijnigstraat 1, 2250 Olen

Some quartzarenitic sandstones occurring in Belgium, especially those from Paleogene strata, share many common features with pedogenic and groundwater silcretes documented in the Paris Basin in France, in South Africa and in Australia (e.g. Thiry, 1999; Summerfield, 1983; Webb & Golding, 1998,). We review the criteria that may be used to assess the pedogenic or "groundwater" origin for sandstones and silcretes.

At field scale, pedogenic features in silcrete often result in the development of vertical (columnar) or nodular structures within layers (horizons) due to vertical percolation (illuviation) and transformation of materials in the profile's porosity and cracks. Groundwater silcrete often exhibits a typical mammilated surface (e.g. Nash & Ullyot, 2007). Root and rootlet casts, sometimes with silicified root or wood material, also indicate that the rock evolved at or near-surface.

At microscopic scale, illuviation of silt and clays in the vadose or water-table environment results in the formation of a series of finely-laminated coatings and infillings. These pedofeatures consist in "typic", "crescent", "capping", "pendent", "micropan" and "crust" coatings (Bullock et al., 1985). Irregular rounded structures or "glaebules" also develop as well as micro-columnar or prismatic textures. Many of them have been observed in pedogenic silcretes around the world (e.g. Thiry, 1999) but also in Paleogene silcrete in Belgium (e.g. Veldeman et al., in review). Of particular importance is the concentration of fine-grained titanium-oxides in pedogenic silcrete. These Ti-oxides most probably originated from the weathering of clay material and were concentrated via the same pedogenic processes which concentrated silica in the silcrete profile (Thiry, 1997).

In sandstones with a pure sand matrix, where no or few fine-grained material is available for illuviation, assessing the pedogenic origin for the silicification is much more difficult based solely on microtextural observations. New perspectives may arise from trace-element analysis in the quartz cement overgrowing the grains. For example, combining cathodoluminescence imaging (CL) and electron microprobe analysis (EPMA) allowed the detection of abnormally-high concentration of Al and K in the quartz cement relative to the quartz grains in the Grandglise sandstone of Thanetian age in the Mons Basin (figure). The following conclusions can be derived from this study: the weathering of glauconite, which is still present, is the likely source for silica and evidence of aluminum migration would indicate strongly acidic conditions in the pore fluids.



Back-scattered electron (BSE), cathodoluminescence (CL) and X-ray map of Al kα of quartz cement in the Grandglise sandstone (Thanetian).

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Characterisation and classification of weathered siliciclastic rocks in Wallonia

Barbier F., Yans J.

→ Francois.barbier@fundp.ac.be

University of Namur, Department of Geology, Namur, Belgium

Weathered heterogeneous siliciclastic rocks are quite ubiquitous in Wallonia. Here we characterise these rocks through three weathering profiles: the Ardenne Anticlinorium (Transinne), the Brabant Massif (Ottignies) and the Condroz (Morialmé).

Macroscopic observations of the weathered profiles in the three study areas allow us to propose four categories of rocks according to their weathering degree: fresh rocks, slightly weathered to weathered rocks, weathered rocks to strongly weathered rocks and very strongly weathered rocks. These categories are confirmed by mineralogical and geochemical criteria.

For each site, neoformed mineral parageneses, correlated with the weathering degree, have been identified, based on XRD analysis of the fraction $< 2\mu m$. The proportions of clay minerals are not correlated with sites; this is probably due to the difference of fresh rock lithology (protolite).

The mineralogical study of the three profiles confirmed that the main mineral phases providing kaolinite during the weathering in our regions are phyllosilicates (mostly chlorite) and not the feldspars as often stated in the literature.

The geochemical study is based on the weathering index. These indices reveal the evolution of the weathering degree of rocks, in response to changing concentrations of major element oxides. The weathering index which is the most sensitive to the weathering process in heterogeneous siliciclastic rocks of Wallonia is the Vogt index (Vogt, 1927). The mineralogy values for each category of weathered rocks of the Vogt index 1927 differ from one profile to another. Normalized to the fresh rocks, the evolution and the index values of Vogt are similar from a profile to another.

This characterisation study shows, through three profiles, that the use of the classification of rocks according to the weathering degree can be applied to all weathered siliciclastic rocks in the Walloon region. The study of the evolution of clay parageneses and the Vogt index normalized to the fresh rock confirms this classification, which can form the basis for a mapping of weathered rocks in the Walloon Region.

Patterns and estimates of post-Miocene (relative) uplift in Flanders: towards a synthesis

Beerten K.

→ kbeerten@sckcen.be

SCK•CEN, Institute Environment-Health-Safety, Boeretang 200, 2400 Mol, Belgium

At present, ONDRAF/NIRAS is developing a safety and feasibility case (SFC1) for the geological disposal of radioactive waste in the Boom Clay and Ieper Clay formations, northern Belgium (Flanders). An important requirement for such geological formations hosting a repository is sufficient depth to ensure isolation of the waste for a very long time period, up to several 100 ka and beyond. Over such long timescales, uplift and erosion may modify the thickness of the overburden significantly.

Assessing the long-term evolution of landscapes over very long timescales requires a thorough knowledge of patterns of uplift and subsidence during the geological past. These patterns are expected to vary in space and time and are likely to have left traces in the geological record. In this paper, a (semi-)quantitative evaluation and synthesis of the amount and distribution of (relative) uplift is presented after deposition of the Diest Formation in the northern part of Belgium. The area takes an intermediate position in between the rapidly subsiding North Sea basin, and the uplifting Ardennes.

Estimates of (relative) uplift are based on the altitude difference between reference levels for which age control could be found in the literature. Reference levels are either residual hills (e.g., Diest Formation), terrace fragments from the rivers Scheldt and Meuse, and cuestas. As such, a general view on the total amount of erosion since a given point in time (after deposition of the Diest Formation) in Flanders can be given.

In the southwest of Flanders, a residual landscape is present showing a total amount of at least 140 m of post-Miocene (relative) uplift. Further to the east, the amount of (relative) uplift is slightly less, ~ 80-100 m, and even decreases to ~ 60 m in the Haspengouw area. Here, a relatively fresh landscape is present with rather narrow valleys, indicative of a younger uplift phase.

In the northern Campine area, (relative) uplift only started gradually in the late Pliocene and Early Pleistocene, as witnessed by the Nete valley floor situated ~ 20-30 m below the reference levels. Further to the southwest (Ghent area), traces – if any – of uplift patterns have been removed by strong erosion during formation of the Flemish Valley, that probably started ca. 450 ka ago as a result of a sudden base level lowering.

In summary, (relative) cumulative uplift of ~ 150 m in the southwestern part of Flanders is spread out over at least the last 7 Ma, while ~ 60 m of uplift occurred during the last ~ 0.8 Ma in the southwestern part.

It stands beyond doubt that the presented framework needs further refinement, especially in view of the rather poor age control. New developments in dating techniques (ESR dating and cosmogenic nuclide dating) may help to improve the current knowledge on (relative) uplift rates in the northern part of Belgium during the Neogene and Quaternary.

Global sensitivity analysis of climate response to astronomical forcing variations

GB 2012
Contestant for Best Oral Presentation

Bounceur N., Crucifix M.

→ Nabila.bouonceur@uclouvain.be

Georges Lemaître Centre for Earth and Climate Research (TECLIM)
Earth and Life Institute (ELI)
Faculty of Sciences (SC)
Université catholique de Louvain

A Global Climate Model is a complex deterministic input-output computer program, called a simulator, where a mathematical representation of the physics of the climate system is implemented.

Our purpose is to use this simulator in paleoclimate, to estimate the global sensitivity of the climate response (temperature and precipitation) to astronomical forcing variations.

An approach to deal with a computationally expensive simulator for sensitivity study is the construction of a statistical surrogate, called an emulator. This emulator is calibrated on a moderate number of experiments (typically 10 times the number of input parameters), chosen using a space filling design to fully fill the input space optimally (here, a MaxiMinLatin hypercube design). The emulator provides both an estimate of the model at unknown, arbitrary inputs, and quantifies uncertainty associated with the fact this is an emulator instead of the full simulator. The emulator chosen here is a Gaussian process.

The emulator is expressed in a reduced output space made of the principal modes of the climate variability, extracted using a principal component analysis on seasonal mean surface temperature and seasonal mean precipitation. The methodology is applied to an Earth system model of intermediate complexity named LOVECLIM.

Multi-resolution CT for the quantification of reservoir properties in complex carbonate rocks

GB 2012 Contestant for Best Oral Presentation

Claes S.[1], De Boever W.[2], Bultreys T.[3], Brabant L.[3], Van Hoorbeke L.[3], Cnudde V.[2], Swennen R.[1]
→ Steven.Claes@ees.kuleuven.be

1 Geology, Earth and Environmental Sciences, KULeuven, Celestijnenlaan 200E 3001 Heverlee, Belgium
2 Department of Geology and Soil Science, Ghent University, Krijgslaan 281/S8, B-9000 Ghent, Belgium
3 Department of Physics and Astronomy, Ghent University, Proeftuinstraat 86, B-9000 Ghent, Belgium

Complex carbonates cause heterogeneity at many scales, which have an influence on reservoir properties (e.g. porosity). Recent developments in CT and image analysis research allow characterization of complex pore networks in three dimensions from sub-micron to centimetre scale.

Travertine rocks are selected in this study because of their large variety in pore types concerning their size and spatial distribution. Excavated blocks (dimensions: 2 by 3 by 2m) of different travertine lithologies are documented using high-resolution photographs of the front, side and top faces. Photographs of smaller areas are used in order to estimate the REA in function of porosity types. Based on these photographs porosity is estimated by point-counting. Out of these blocks large cores are drilled in three perpendicular directions (dimensions: 10cmØ and 15cm height). In these cores, small plugs (dimensions: 2cmØ and 4cm height) are drilled. In a last step micro-plugs (dimensions: 0.7cmØ and 1.5cm height) are drilled out. For each sample size different scanners are used, providing optimal resolutions (sample size/1000). This workflow allows quantifying porosity values of the same sample using datasets with different resolutions.

Special attention is paid to the segmentation of porosity in the resulting images. The indicator kriging segmentation algorithm is used, for which automatic parameter selection methods are explored.

Using 3D image analysis programs such as Morpho+ allows establishing a new 3D classification of pore shapes based on form ratio's I/L and S/I (Brabant et al, 2011). 5 shape classes are defined: rod, blade, cuboid, plate and cubic shapes. This approach allows separating different types of pore shapes as well as assessing the anisotropy of the porosity in the sample by using the orientation of the longest dimension. However computational limitations do not allow incorporating heterogeneities on small scales in full-field reservoir simulations. Hence a critical decision has to be made at which scale petrophysical measurements should be taken in order for them to be homogeneous and statistically stationary. The concept of the Representative Elementary Volume (REV), i.e. the smallest value that can be taken as a representation for the entire sample area/volume that does not respond to small changes in volume or location, was introduced by Bear in 1972.

To define the fluctuation of the porosity parameter the chi-square criterion is used. This parameter measures how much a single tested sample deviates from the mean value of all realizations.

The upscaling workflow demonstrates the importance of the resolution of the 3D datasets on the calculated porosity value. Porosity networks in large core samples and plug samples are clearly different. This study also illustrates that the size of the REV is dependent of the lithology of the analyzed rocks. Only by calculating the REV at different scales and resolutions, reservoir properties in complex carbonate rocks can be evaluated correctly.

Bear J. (1972). *Dynamics of fluids in porous media*. American Elsevier, New York.

Brabant L., Vlassenbroeck J., De Witte Y., Cnudde V., Boone M., Dewanckele J., Van Hoorebeke H. (2011). *Three-dimensional analysis of high-resolution X-ray computed tomography data with Morpho+*. Microscopy and Microanalysis,Volmue 17, n°2, pp 252-263.

20 years of ground movements in Brussels monitored by radar interferometry (PSI)

Declercq P.-Y.[1], Devleeschouwer X.[2]

→ pierre-yves.declercq@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences, Dpt VII: Geological Survey of Belgium, Rue Jenner, 3 - B-1000 Brussels, Belgium. pierre-yves.declercq@naturalsciences.be

2 Royal Belgian Institute of Natural Sciences, Dpt VII: Geological Survey of Belgium, Rue Jenner, 3 - B-1000 Brussels, Belgium. xavier.devleeschouwer@naturalsciences.be

The 19th century population increase of Brussels was accompanied by the industrialisation around the historic city centre. Water extraction by these industries from confined aquifers resulted in quantifiable ground motions. The Persistent Scatterer Interferometry (PSI) technique (Ferretti, Prati & Rocca 2000 & 2001) has been used on an area covering the city and its periphery. The PSI technique makes it possible to measure specific displacements of radar reflecting objects present on the ground named Persistent Scatterer (PS), from a stack of Synthetic Aperture Radar (SAR) image.

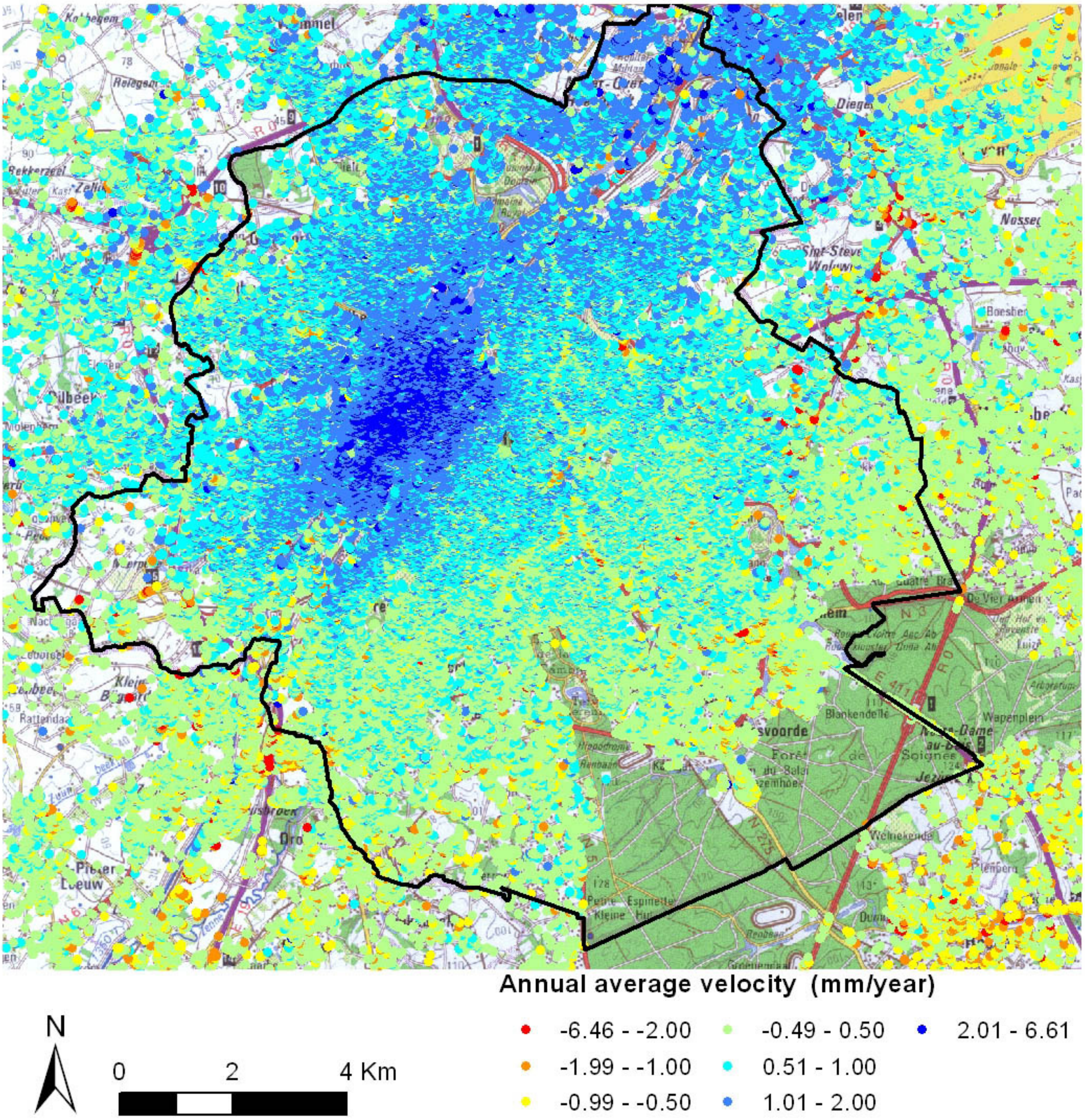
The first processing was carried out on ERS1/2 images covering the time span 1992-2003. A second phase starting in 1992 and finishing in 2010 including ERS1/2 and Envisat SAR images is currently processed and analysed. In the first stack of radar images 173,000 PS were identified. Working on these data in the GIS made it possible to highlight and relate movements of the ground with geological data. The density in the centre of Brussels varies from 800 PS/km² to a maximum of 1632 PS/km². Such high density of information provides the opportunity to study the data from small scale to high resolution. Figure 1 gives the location and a colour classification based on the annual average velocity of the PS. The red colour represents negative velocities while blue colour corresponds to positive values. It appears that the central part of Brussels is globally facing a positive vertical movement (uplift) at a velocity ranging from 1 to 6.61 mm/year maximum. Several yellowish lineaments with negative velocities (< -0.5 mm/year), probably corresponding to traffic arteries pop out of the blue colour SE of the centre of the city.

The region affected by the strongest positive ground deformation corresponds to the area of water catchments and pumping from the concealed Cretaceous aquifer during the industrialisation period of Brussels (1880-1950). During the early production years, the archives of the Geological Survey of Belgium indicate that the aquifer drawdown for industrial purposes (breweries, dyeing, distillery, refinery, etc) was initially artesian. A superimposition of the water wells and the PS indicates that the uplift and the location of the former wells match completely. In more detail, the artesian wells occur in the downtown area along the Senne river. Now the industry has waned from Brussels and the aquifer is being recharged again. In the northern part (Vilvoorde), the piezometric level of the Cretaceous aquifer has risen 30 m since 1992. A cumulative effect of the recharge of the confined Cretaceous aquifer and the phreatic aquifer of the Senne river alluvium could explain the observed ground motion.

In conclusion, the PSInSAR technique combined with geological, hydrogeological and topographical data has permitted to highlight and understand the ground movements observed in the centre of Brussels. The groundwater extraction of past industrial activities correlates well with the present-day millimetric uplift zones and the recharge of the aquifer.

Ferreti A., Prati C., Rocca F. (2000). *Nonlinear subsidence rate estimation using permanent scatterers in differential SAR Interferometry.* IEEE Transactions on Geoscience and Remote Sensing, Volume 38, Issue 5, pp 2202-2212.

Ferreti A., Prati C., Rocca F. (2001). *Permanent scatterers in SAR Interferometry.* IEEE Transactions on Geoscience and Remote Sensing, Volume 39, Issue 1, pp 8-20.



Annual average velocity (mm/year) of the PS in Brussels

Negative $\delta^{13}C$ stable isotope geochemistry indicative of global glacial Marinoan events in western Central Africa (D.R. Congo and Gabon) ?

Delpomdor F., Préat A.

→ franck.delpomdor@ulb.ac.be; apreat@ulb.ac.be

Université Libre de Bruxelles, Biogeochemistry & Modeling of the Earth System, Belgium

The worldwide distribution of Neoproterozoic glacigenic deposits highligths three or four episodes of glaciation in the Neoproterozoic (Sturtian', 'Marionan', 'Gaskiers'), none of them before 750 Ma. The major Cryogenian glaciations are the mid-Cryogenian 'Sturtian' (ca. 720 – ca. 660 Ma), the end-Cryogenian 'Marinoan' (ca. 650–635 Ma) and the mid-Ediacaran glaciation(s) (e.g. Gaskiers Event ca. 580 Ma). The two first show evidence for low-latitude glaciers and are likely to have been of global extent. Only the end-Cryogenian ('Marinoan glacial events') displays overlying cap carbonates on a global scale. Glacigenic evidences are marked by a typically strongly negative $\delta^{13}C$ signature, in pre-glacial deposits and overlying cap carbonates.

The proposed explanations for the $\delta^{13}C$ negative shifts include -1) build-up of mantle-derived carbon in the atmosphere–ocean reservoir during a Snowball period of prolonged hydrological shutdown, -2) overturn of an anoxic deep ocean, -3) melting of large-scale methane clathrate reservoirs, -4) 'algal' blooms in a low salinity meltwater plume that separated the surface from deep ocean waters or -5) early meteoric and/or burial diagenesis.

Our study focuses on these negative $\delta^{13}C$ excursions, in relationship with new sedimentary data and their interpretations of the pre-marinoan (Haut-Shiloango Subgroup, Bas-Congo basin) and post-marinoan carbonates (Schisto-Calcaire Subgroup in Bas-Congo and Niari basins) from DR Congo and Gabon.

Mineralogy of Miocene lacustrine sequences associated to hominid sites from the East Africa; indicator of palaeoenvironmental conditions (Tugen Hills, Kenya)

Dericquebourg P.[1,2], Person A.[2], Ségalen L.[2], Fagel N.[1], Pickford M.[3], Senut B.[4]

→ Perrine.Dericquebourg@doct.ulg.ac.be

1 University of Liege, Laboratory Clays, geochemistry and sedimentary environments, Department of Geology, Belgium

2 University Pierre and Marie Curie, Laboratory Biomineralisations and sedimentary environments, ISTEP-UMR 7193, France

3 Chair of Palaeoanthropology and Prehistory, College of France, France

4 National Museum of Natural History, Department History of Earth, UMR 5143, France

Many previous studies showed the interest to use mineralogical associations, especially clay minerals, as indicators of palaeoclimatic and palaeoenvironmental conditions. This approach is applied to lacustrine sequences coming from the Lukeino Formation, which is dated to the upper Miocene. This Formation appears in the area of Tugen Hills (Kenyan part to the East African Rift) and has delivered fossils belonging to the first biped hominid, *Orrorin tugenensis.* The radiometric datings realised on volcanic lavas which enclosed the Lukeino Formation indicate an age between 6.0 – 5.5 Ma.

In this context of rift, the continental sedimentation is mainly represented by clays and sand deposits interrupted with many pyroclastic and diatomitic levels. Localised lacustrine carbonates and stromatolithes are also observed.

The sedimentological studies and the mineralogical analyses by X-Ray Diffraction have been realised on sedimentological samples coming from several cross sections in different sites, located at several levels along the Lukeino Formation. The aim is to research changes of environmental conditions between the base and the top of Formation.

First results reveal several palaeoenvironmental and palaeoclimatic aspects. XRD analyses indicate that clay neoformations record, from the alteration of pyroclastic deposits, periods more or less well drained, with fluctuations smectite / kaolinite. The smectites, very represented compared to kaolinite, suggest that lake was preferentially supplied by groundwater. Moreover, variations of mineralogical associations observed along cross sections, and on several sites, indicate a progressive evolution to a lake environment. This observation is confirmed by the presence of diatomitic levels and by the precipitation of carbonates.

Sediment dynamics as a proxy for soft substrata habitat distributions, Belgian part of the North Sea

Van Lancker V.[1], Baeye M.[2], Degraer S.[1], Fettweis M.[1], Francken F.[1], Houziaux J.-S.[1], Legrand S.[1], Rabaut M.[3], Van den Eynde D.[1]

→ Vera.vanlancker@mumm.ac.be

1 Royal Belgian Institute of Natural Sciences. Management Unit of the North Sea Mathematical Models. Gulledelle 100, B-1200 Brussels, Belgium

2 Ghent University, Renard Centre of Marine Geology. Krijgslaan 281, S-8, B-9000 Gent, Belgium

3 Ghent University, Marine Biology Section, Krijgslaan 281, S-8, B-9000 Gent, Belgium

Fine-scale seabed mapping (<5m resolution) (e.g. geology, surficial sediments, morphology and benthos) was conducted at several locations along the Belgian part of the North Sea. Together with modelling results on hydrographic conditions (e.g. residual currents; sedimentation due to tidal forcing; suspended particulate matter or SPM), and current measurements, the variability in sediment processes can be linked to variations in habitat distributions. Highest biodiversity is often found where finer sediments are naturally trapped (e.g. near sediment transport convergence zones). Sometimes, this process is enhanced by changes in morphology, due to e.g. long-term disposal of dredged material or marine aggregate extraction. Evidence will be presented on disposal activities that have induced permanent modifications of hydrographic conditions. Around these areas, where mostly transient fluxes of SPM prevail, high abundances of opportunistic and invasive species occur. In the framework of Europe's Marine Strategy Framework Directive discussion is on-going whether or not this causes adverse effects on the ecosystem. The adversity of effects links to issues on biodiversity, food webs and seafloor integrity.

Understanding natural sediment dynamics is crucial to predict the spatial scale of the effects of human activities on the habitats. In the case of disposal activities, fine-grained material may be dispersed over several kilometers, though the interplay of currents, in combination with availability of SPM, will determine the importance of smothering on the benthos. The severity of the impact on the benthos will then further be determined whether or not a habitat change occurs (e.g. difference in sediment nature between disposed material and substrate type). Around the disposal grounds, habitat creation or modification takes place. The extent depends on amount, frequency and duration of disposal activities, in combination with residual currents. In any case, increased system knowledge (incl. morphological setting, substrate characteristics, sediment processes, sediment dynamics, habitat sensitivities and recovery potential) is needed to estimate final impacts.

Results are valorized in the framework of the projects QUEST4D (Belgian Science Policy, http://www.vliz.be/projects/quest4D/), and Geo-Seas (EU FP7-I3; http://www.geoseas.eu), a pan-European Infrastructure for Management of Marine and Ocean Geological and Geophysical Data.

Van Lancker V., Baeye M., Du Four I., Janssens R., Degraer S., Fettweis M., Francken F., Houziaux J.S., Luyten P., Van den Eynde D., Devolder M., De Cauwer K., Monbaliu J., Toorman E., Portilla J., Ullman A., Liste Muñoz M., Fernandez L., Komijani H., Verwaest T., Delgado R., De Schutter J., Janssens J., Levy Y., Vanlede J., Vincx M., Rabaut M., Vandenberghe H, Zeelmaekers E, Goffin A. (2012). *Quantification of Erosion/Sedimentation patterns to Trace the natural versus anthropogenic sediment dynamics (QUEST4D). Final Report*. Science for Sustainable Development, Brussels: Belgian Science Policy, 97 p. + Annexes..

Petrography, geochemistry and stable isotope geochemistry of a banded columnar calcite deposit sampled at 1000 meters depth in the Wépion core drilling, Namur, Belgium; implications for the origin of the calcite

Verheyden S.[1,2], Hennebert M.[3], Gewelt M.[4], Groessens E.[1] , Van Rampelbergh M.[2], Keppens E.[2], Quinif Y.[3]
→ sophie.verheyden@naturalsciences.be

1 Royal Belgian Institute of Natural Sciences - Geological Survey of Belgium, Belgium
2 Departement Geologie - Vrije Universiteit Brussel, Pleinlaan2, 1050 Brussels, Belgium
3 Faculté Polytechnique - Université de Mons, Rue de Houdain9, B-7000 Mons, Belgium
4 Independent researcher, former at the Université de Liège and SCK/CEN Mol, Belgium

Between 1953 and 1956, a core drilling to a depth of 2310 meters was conducted for the Geological Survey of Belgium at 6 km south of Namur, Belgium, to get a better understanding of the tectonic structure of the Brabant Parautochthone (the former Namur Synclinorium). The drilling starts at 152.58 masl (meters above sea level) (0 meter depth) and cuts the Carboniferous, Devonian and Silurian rocks. Between 960 and 1015 meters depth, a series of voids containing massive calcite deposits were crossed. The calcite is crystallographically very similar to vadose flowstone speleothems encountered in nowadays caves. The origin and age of the cave formation as well as of the calcite deposits are controversial and different hypotheses exist. The caves could have been formed just after deposition of the Visean limestone, during the end of the Visean or the beginning of the Namurian, before the Variscan Orogeny. However, in this case, the caves and the speleothem calcite would most probably have been affected by the Variscan Orogeny. However no important alteration or drastic change is apparent. The caves could have been formed during the Permo-Triassic-Jurassic when the region was uplifted and cave formation could take place. However, vadose conditions and subsequent speleothem deposition at minimum 1000 meters depth, even in an uplifted region compared to the present situation, is unlikely. A third possibility is more recent cave formation, possibly by the removal or partial collapse of limestone ghost-rock formed during the Cretaceous period. However, vadose speleothem formation is not possible in this hypothesis and the calcite must be formed in an earlier stage or was not formed in vadose conditions but as a vein deposit in the aquifer. The studied calcite deposit was dated older than 350ka BP, the limit of the Th/U dating method and probably older than 1.5Ma as suggested by the equilibrium between ^{238}U and ^{234}U. Stable oxygen and carbon isotopic results, chemical composition of the calcite and ongoing U-Pb dating will bring additional indications on a possible origin and age of the deposits and consequently of the cave formation.

A piece of the Wépion calcite deposit crossed by the Wépion core drilling at ~1000m depth.

Characterisation of Ypresian clays in Belgium with reference to geophysical well logs

De Ceukelaire M.[1], Vancampenhout P.[1], Dusar M.[1], Lie S.F.[2], Wouters L.[3]

→ Marleen.deceukelaire@natuurwetenschappen.be

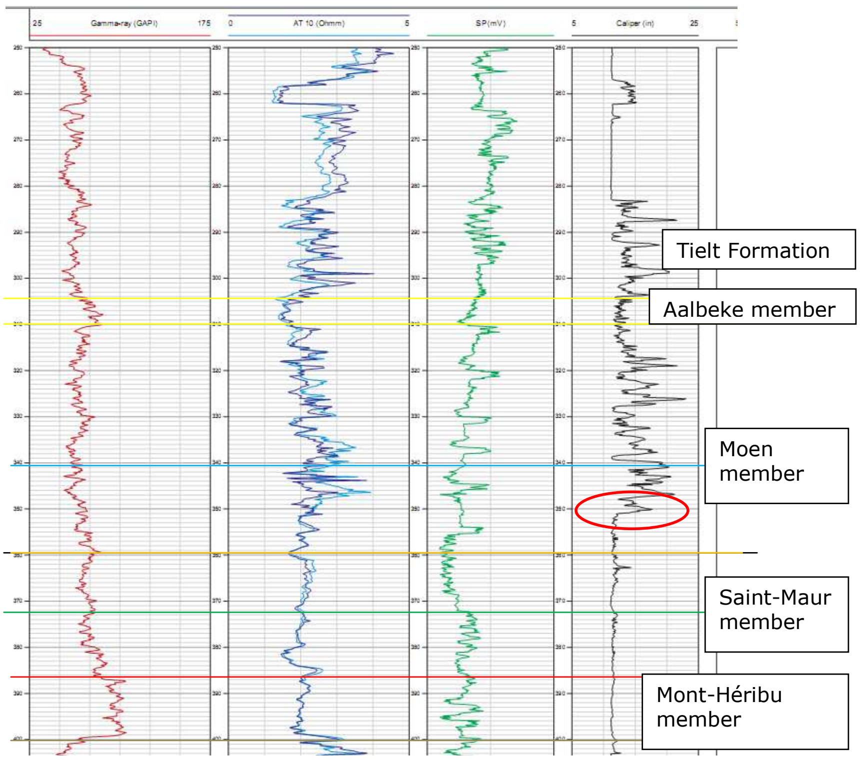
1 Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium

2 Faninbel

3 ONDRAF/NIRAS

For the long-term management of high-level and/or long-lived radioactive waste, the Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS) advises deep geological repository in a plastic clay host rock. Since the seventies, Oligocene Boom Clay has been extensively studied for this purpose and is, in the Belgian context, considered as the reference host rock with Mol as the reference site. The alternative host rock, the Ypresian clays, has been studied for their basic properties, from the late nineties onwards, with Doel as reference site. Two drilling campaigns, carried out in the framework of potential radioactive waste disposal at Doel and Kallo, allowed to collect new data and describe the Ypresian clays. Unexpected breakouts in the Ypresian clays were however noticed on caliper logs on both wells, registering changes in diameter of the borehole over restricted vertical intervals, mainly in the Roubaix/Moen Member. ONDRAF/NIRAS entrusted the GSB with a study in order to determine if this feature was restricted to a stratigraphic interval, related to a region, or mechanically induced and to find out about the cause.

Borehole breakouts represent changes in borehole geometry caused by a rotating and down cutting drill bit under normal operating conditions, hence linked to lithological - geotechnical characteristics and the stress regime of the geological formation. An overview of the geophysical well logs showed that breakouts were widespread but also quite different between the wells: not always observed, nor over the same stratigraphical interval nor over a comparable vertical section. They seem linked to the mixing of the different granulometrical and mineralogical components of the Ypresian clays. This unexpected phenomenon necessitated a revision of the electrical lithostratigraphy of the Ypresian clays.



A large increase of the diameter above the base of the transition silt - clay
Example: Kallo – 14E0355

Late-Maastrichtian to Paleocene seismic stratigraphy of the southwestern Roer Valley Graben

Deckers J., Broothaers M., Matthijs J.

→ jef.deckers@vito.be

Flemish Institute for Technological Research (VITO), Raw Materials, Boeretang 200, BE-2400 Mol, Belgium.

2D reflection seismic and stratigraphic data of the southwestern Roer Valley Graben (RVG) (northeastern Belgium) have been analyzed to determine its Late-Maastrichtian to Paleocene (LM-P) tectono-sedimentary evolution. The latter interval comprises Late-Maastrichtian to Danian shallow chalks abruptly overlain by continental to marine Paleocene siliciclastics. This sequence of less than 200 meter thickness unconformably overlies Lower Jurassic shales and is in turn unconformably overlain by Lower Oligocene sands.

From the Late-Oligocene on, the RVG experienced strong subsidence relatively to the surrounding basins. Because of the greater depth, few deep exploration wells were drilled in the RVG and only one well was drilled deep enough to penetrate the LM-P sequence: the Molenbeersel well (Belg. Geol. Survey file 49W226). This well, provided with VSP and well log data, was drilled in 1987 along a seismic line of the 2D Poppel-Lommel-Maaseik (PLM)-survey carried out in 1984. Seismic reflection data from this line was tied to the Molenbeersel well data by Demyttenaere & Laga (1988) to create isohyps maps of the region .

Regained interest in the region for gas storage triggered the reprocessing of PLM-lines and the acquisition of a new 2D seismic survey in the southern part of the Belgian RVG by VITO in 2007. When the interpretations of Demyttenaere & Laga (1988) were analyzed on the reprocessed data, it became clear that these had to be revised for the LM-P interval.

The LM-P interval is outlined on the new seismic sections by their easily identifiable over- and underlying unconformity surfaces. Where recognized in wells, unconformities act as reliable anchor points for well-to-seismic ties and can therefore partly compensate for the overall lack of well data in the study area. In between both unconformity surfaces, the seismic data were tied to the LM-P log signatures of the Molenbeersel well by both a synthetic seismogram and VSP data.

Paleocene siliciclastics were tied to continuous high-amplitude reflectors that either conformably overly or slightly truncate the top chalk reflector. The latter on its turn often conformably overlies high-amplitude intra-chalk reflector(s). At several locations however, the upper chalk interval thins and shows onlap terminations onto structural highs. On the flanks of these highs the top chalk reflector sometimes cuts underlying parallel intra-chalk reflectors. This deformation affected individual fault-bound blocks as indicated by abruptly changing thicknesses across faults. More gradually changing upper-chalk thicknesses occurred within small tilted fault-bound blocks.

These data provide first seismic evidence for severe vertical tectonic movements during and possibly still shortly after Early Paleocene chalk deposition within the Belgian RVG. This event broadly coincides in time with the Laramide inversion phase that affected all Dutch basins further to the north.

Demyttenaere R., Laga P. (1988). *Breuken en isohypsenkaarten van het Belgisch gedeelte van de Roerdalslenk*. Belgische Geologische Dienst, Professional Paper 1988/4, n°234, 20 p.

The island flank margin model as a new paradigm for the Carboniferous limestone aquifer of the Campine basin (NE Belgium)

Dusar M.

→ Michiel.dusar@natuurwetenschappen.be

1 Royal Belgian Institute of Natural Sciences- Geological Survey of Belgium

The deep saline aquifer of the Dinantian of the Campine Basin is linked to a regional unconformity separating the Dinantian platform carbonates from Silesian siliciclastics. The late Visean – early Namurian sea level fall led to a temporary emersion of young carbonate shelf deposits in the western Campine basin, prone to karstification. The carbonate sequence is sealed by a Namurian, predominantly clayey sequence. The platform carbonates of Visean age in the western Campine are tightly cemented but locally fractured and occasionally brecciated. These early diagenetic fractured intervals of the aquifer present high secondary porosity, have unsolubles at their base and collapse breccias above. The 3D-distribution of the fracture zones follows a consistent pattern, being most strongly developed towards the top of the carbonates. The stage-like development fracturation and brecciation is non-tectonic but related to standstills of the raising Namurian sea level at about 180 m (rarely observed), 120 m and 60 m below the top of the carbonate platforms, and of course the top 15 m, all corresponding to the most permeable, hence productive zones of the reservoir. The '*island flank margin model for dissolution cave development in carbonate platforms*' by Mylroie & Carew (1990) enables to accommodate for the observed anomalies. This Bahama-based model of rapid mixing zone karst development controlled by sea level in subrecent tropical carbonate islands allows to explain the location of the most productive paleokarst, even in the absence of proof of vadose zone karst features or isotopic signals of meteoric origin. Subsequent diagenesis under burial conditions compacted the open fabric in the poorly consolidated carbonates and has sealed all fractures. Coalification of organic matter from overlying shales and coals at time of maximal burial during the late Carboniferous expulsed fluids which migrated upward towards the shallow edge of the sedimentary-tectonic basin, where the karstified limestones were located. Dissolution preferentially occurred along pre-existing fracture planes. This latest phase of the diagenetic evolution partly reopened the fractures and voids network, without evidencing their karstic origin. The actual, secondary, porosity of the Dinantian limestone aquifer has recreated a fractured reservoir in this paleokarst. For reservoir engineering purposes, a simplified non-karstic model of a fractured reservoir is used with average thickness of 75 m and homogeneous porosity – permeability distribution, despite evidence of locally enhanced or suppressed reservoir properties. The island flank margin karst model is different from (sub)recent karst and Cretaceous (Wealden) paleokarst, affecting fully consolidated limestones and occurring in a continental environment. No allochtonous sediment is observed in the Dinantian karst of the Campine Basin. Strongest karstification, hence best reservoir properties, are observed on the northern seaward slopes of the platform, particularly on the tectono-sedimentary domes characterised by algal – microbial build-ups with early consolidation (e.g. the Heibaart and Poederlee domes). Use of this model would allow to differentiate reservoir properties in the Campine Basin, reducing its prospectivity over southward-bound areas but explaining the enhanced productivity around former paleogeographic highs.

Introduction of new formal lithostratigraphic units for the Dinantian in the Campine Basin

Lagrou D., Laenen B.

→ David.lagrou@vito.be

Flemish Institute for Technological Research (VITO), Boeretang 200, BE-2400, Belgium

During systematic lithostratigraphic description of the deep subsurface of the Campine basin (Northern Belgium) it was found that certain stratigraphic intervals in deep boreholes, already identified and described as separated units by different authors, are not yet formally named. As one of the goals of the detailed stratigraphic study was to put all data in the Flemish web-based 'Databank Ondergrond Vlaanderen' (DOV), codes for the different lithostratigraphic units were needed. To have an accordance between DOV and the Belgium official stratigraphy, the newly proposed lithostratigraphic units will be submitted to the National Commission of Stratigraphy.

The bio- and lithostratigraphy of the Dinantian of Belgium (including the Campine Basin) is synthesized by Paproth *et al.* (1983). In the Dinantian of the Campine Basin they introduced the 'Kempen Formation'. Here, we propose to upgrade and expand the 'Kempen Formation' into the 'Carboniferous Limestone Group' and subdivided the new Group in several Formations.

Above the 'Kempen Formation' of Paproth (1983) in borehole Turnhout 80m of partly karstified limestones (breccia) are present (old codes V3c-b), for which we propose the name Loenhout Formation and incorporated it in the 'Carboniferous Limestone Group'. This Formation is famous because the excellent reservoir properties (actually in use as underground gas storage). The underlying Velp Formation consists of compact bioclastic limestones and reach thicknesses of about 100m. The rocks of the Steentje-Turnhout Formation are mainly massive (light) gray limestones and dolomites, varying in thicknesses (10 m to 400m), probably due to paleotopography and block faulting. The Kessel Formation (about 80m thick) is only found in 2 boreholes. For sedimentological reasons it is assumed that the occurrence of the Kessel Formation is limited in between the paleo shoreline of the London-Brabant Massif in the west and the open marine limestones and reefs of the Steentje-Turnhout Formation to the east.

The research is financed by the Flemish government (ALBON).

Formation	Main lithology	Stratotype borehole	Depth interval (in m)	Old	Ref.*
Loenhout	Boundstones, black limestones (locally silicified, (micro)breccias)	007E178 (KB129-Loenhout-Heibaart))	1141-1320	V3	2
Velp	compact bioclastic limestones	076E243 (KB131 - Halen)	984 - 1082	V2a-b	1
Kessel	alternation of redbrown limestones, red sandstones, variegated red and black claystones	044W011 (KB38 – Kessel-bij-Lier)	622-703	V1b-V2a	1
Steentje-Turnhout	Massive (light) gray limestones and dolomites	017E225 (KB120 – Turnhout)	2306-2706	V1a	2

New lithostratigraphic units in the Dinantian in the Campine Basin. *1= Paproth *et al.* (1983); 2= Laenen (2003).

Laenen B. (2003). *Lithostratigrafie van het pre-Tertiair in Vlaanderen, Deel II: Dinantiaan & Devoon*. VITO-rapport 2003/SCT/R/095, 86 p.

Paproth *et al.* (1983). *Bio- and lithostratigraphic subdivision of the Dinantian in Belgium, a review*. Annales de la Société Géologique de Belgique. Volume 106, pp 185-239.

Geological 3D Model of the Tertiary subsurface of Flanders

Lanckacker T., Matthijs J., De Koninck R., Deckers J., Lagrou D.

→ timothy.lanckacker@vito.be

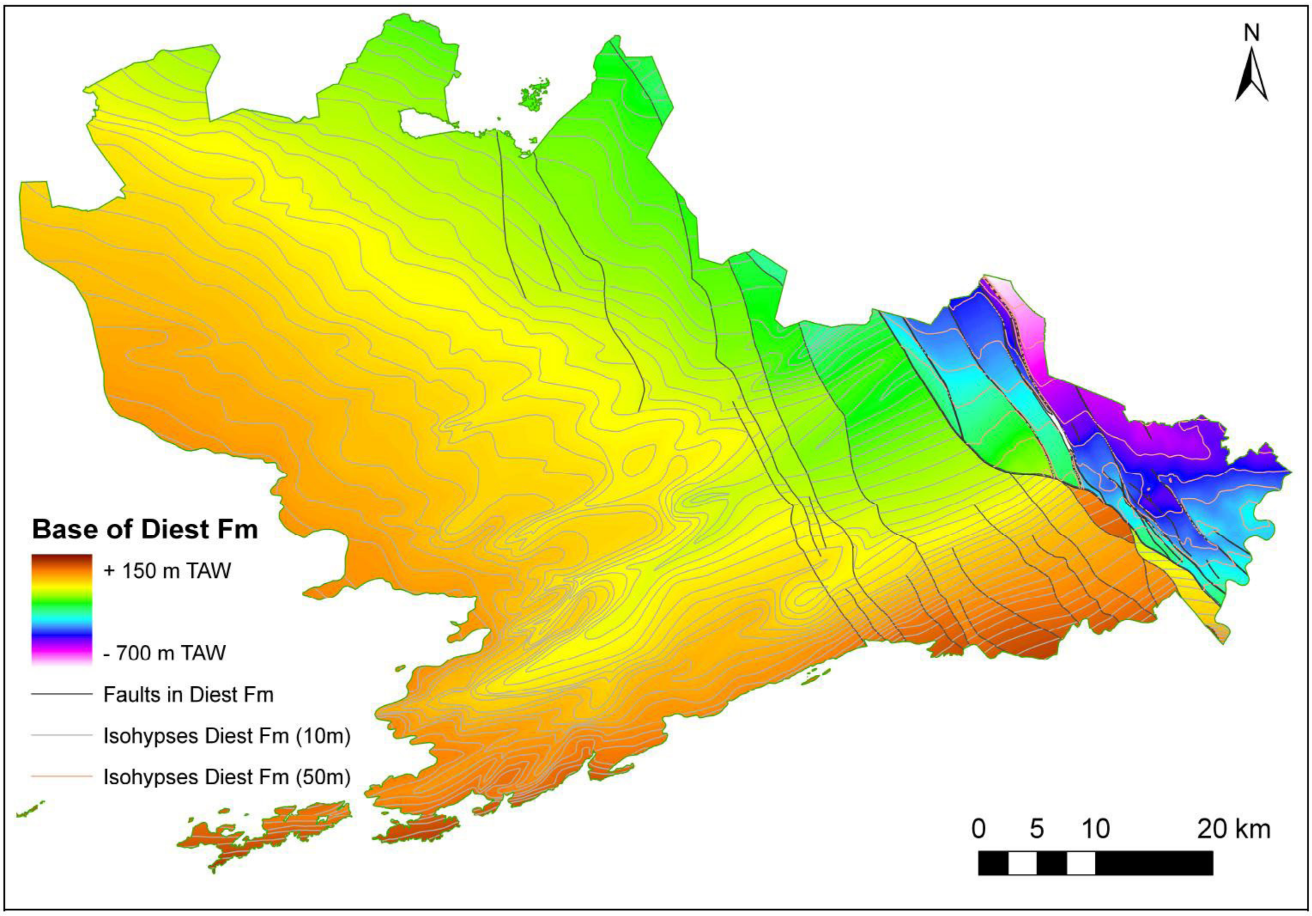
VITO, Flemish Institute for Technological Research, Belgium

On behalf of the Flemish government (ALBON), VITO has modelled the main surfaces within the Flemish Paleozoic, Mesozoic and Quaternary substrate in 3D. In addition, modelling of the Cenozoic subsurface is still in progress and is planned to be finished at the end of 2012. The Flemish Government will make it available through a free web application (available via http://dov.vlaanderen.be).

During the modelling of the Tertiary strata, the basal surfaces of 25 regionally defined lithostratigraphical units were generated. The modelling mainly combines outcrop and borehole data, both stored in an ArcGIS-database. This facilitates the correlation of the data-points and the subsequent generation of basal isohypses. During this process, the geologist is taking into account the specific type of basal surface that fits this unit (e.g. a planar surface, a gully-shaped surface, a faulted surface), according to the data, the present geological knowledge and the new insights found during the modeling process. By doing so, he is introducing geological concepts into the modeling process which will have a major influence on the resulting model. The geologist makes the difference between a mathematically or statistically 'correct' model and a geologically realistic model. The resulting isohypses are imported into an AutoCAD-environment and transformed into 3D-lines. Interpolation of those lines results in 3D-surfaces, stored as raster-files, that basically constitute the framework of the 3D model.

Due to a lack of borehole data, a different approach was used in the Roer Valley Graben (northeast of Flanders). Here seismic survey data were analyzed with WinPics software. Seismic reflectors were correlated to known geophysical contrasts. Subsequently, based on the few available borehole data, a time-depth conversion was executed. This way, 3D-depth-surfaces were created and again stored as raster files. Joining of those rasters with the previous, borehole-based rasters, finished the construction of the 3D model.

One of the modelled Tertiary lithostratigraphic boundaries is the base of the Miocene Diest Formation (figure 1). Unlike the majority of the Tertiary strata, the Diest Formation is not gently dipping to the north, instead it has a gully-shaped base and an overall dip to the east-north-east. Hence, the Diest Formation is crosscutting many underlying Tertiary strata. The Diest Formation was modelled by using a large number of outcrop and borehole observations (approximately 2 points per 10 km²). The geological concept of a gully-shaped basal surface, which is observed in the field and on the seismic cross-sections, was fitted onto these data points. The result is a 3D-surface which clearly crosscuts the basal surfaces of underlying Cenozoic units, like the Boom Clay. New subcrop areas for these older strata were generated through the numerical difference of their basal 3D-surfaces and the 3D-model of the Diest Formation. Hence, new information was generated for studies concerning hydrology, nuclear waste storage, sand extraction, etc. Precise examination of the Diest Formation 3D model could also provide new insights about the way the Diest Formation was deposited.



Colour map of the base of the Diest Formation, relative to sea level, TAW. The interval between the isohypses is 10m (gray) or 50m (orange).

Flanders' Subsurface in 3D

Matthijs J., De Koninck R., Lagrou D., **Lanckacker T.**

→ timothy.lanckacker@vito.be

Flemish Institute for Technological Research, VITO, Belgium

On behalf of the Flemish government, VITO has been working on a geological 3D model for the subsurface of Flanders since 2006. It will be available through the free web application http://dov.vlaanderen.be.

Dividing the subsoil by means of 3D surfaces into different lithostratigraphical units, each with a specific set of properties, is an important step in building a geological 3D model. These surfaces are stored as raster files, based on unit cells of 100 m by 100 m, characterized by the X-, Y- and Z-coordinates of their central node. Depending on the amount and type of data available and the type of 3D surface to be modeled, different methods are used to create the 3D surfaces. However, the geologist will have a major influence on the resulting model as he decides in which way the 3D surfaces are to be modeled. Indeed, he makes the difference between a mathematically or statistically 'correct' model and a geologically realistic model by introducing geological concepts into the modeling process.

Up to now, all major lithostratigraphic units of the Paleozoic and Mesozoic have been modeled.

The 3D surfaces of the Paleozoic strata are based on subcrop maps by Langenaeker (2000) and isochron maps by Dreesen *et al.* (1987). Thickness models were built for each unit by adding thicknesses, observed in boreholes, to the subcrop maps. Subsequently the 3D surfaces were constructed by adding the thickness models to the 3D surface for the base of the Mesozoic. The latter represents the subcrop surface for the Paleozoic strata. It was generated by using borehole and outcrop data and by adding the concept of block faulting in the Campine Basin and Roer Valley Graben area and the concept of a paleorelief, as a result of a pronounced differential erosion at the top of the Lower Paleozoic Brabant Massif.

The top of the Mesozoic strata was constructed in the same way, while the different lithostratigraphic units within the Cretaceous were modeled in a proportionate way, based on the percentage of the total thickness of the Cretaceous for each lithostratigraphic unit, observed in the boreholes.

The 3D surface for the base of the Quaternary is the result of the numerical difference between the topographic model and a thickness model for the Quaternary. This was generated not only by using the boreholes and outcrops, but also by applying concepts derived from the correlation between the thickness of the Quaternary cover on the one hand and the lithology, inferred permeability of the substrate; topographical position and slope on the other hand.

The modeling of Tertiary strata is still in progress.

Dreesen R., Bouckaert J., Dusar M., Soille P., Vandenberghe N. (1987). *Subsurface analysis of the Late-Dinantian carbonate shelf at the northern flank of the Brabant Massif (Campine Basin, N-Belgium).* Toelichtende verhandelingen bij de geologische kaart en de mijnkaart van België, Verhandeling n°21, 37 p.

Langenaeker V. (2000). *The Campine Basin, stratigraphy, structural geology, coalification and hydrocarbon potential for the Devonian to Jurassic.* Aardkundige Mededelingen, n°10, 142 p. KULeuven.

Contourite depositional systems in the southern Gulf of Cadiz: stratigraphy and palaeoceanography of the Pen Duick area

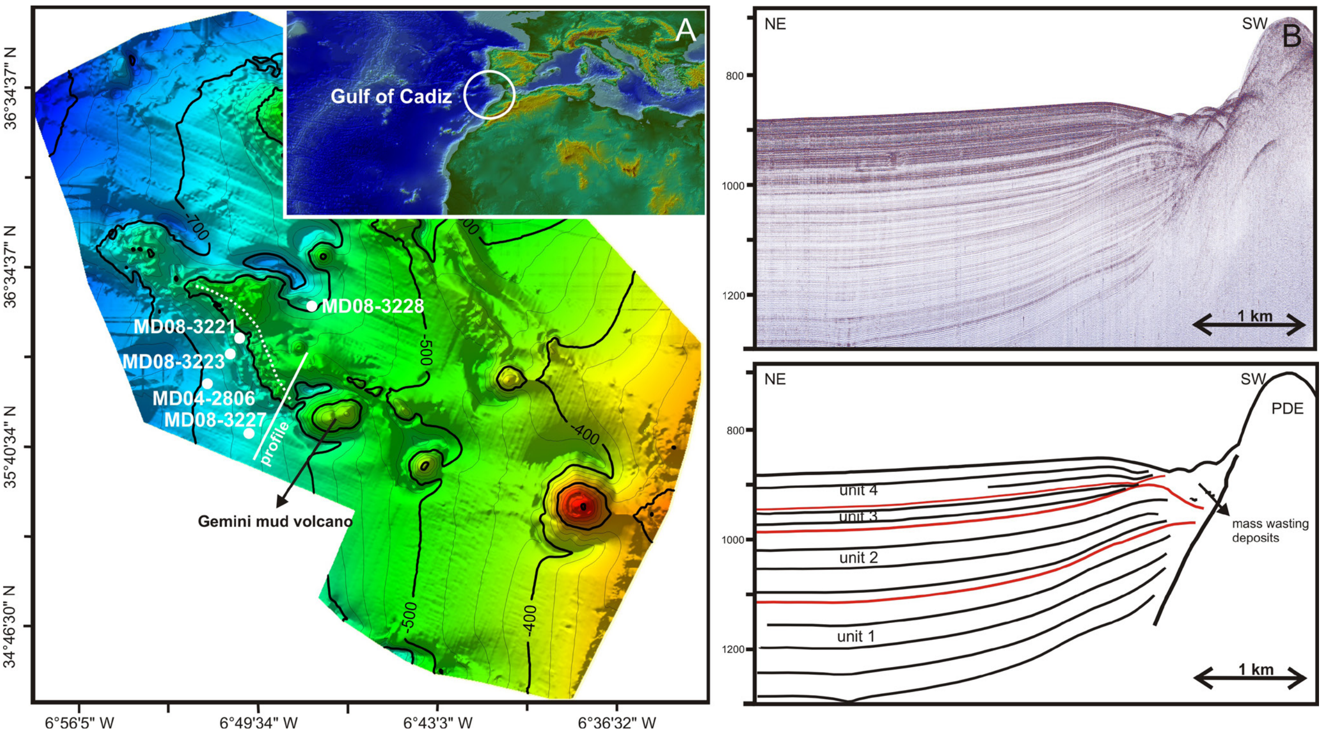
Vandorpe T.[1], Van Rooij D.[1], Vangampelaere E.[1], Ransschaert M.[1], Dejonghe C.[1,2], Blamart D.[3], Henriet J.-P.[1]
→ Thomas.vandorpe@ugent.be

1 Renard Centre of Marine Geology, Faculty of Geology and Soil Science, Ghent University 9000 Gent (Belgium). thomas.vandorpe@ugent.be

2 Department of Marine Biogeochemistry, Royal NIOZ, PKL. Box 59, NL-1790 AB Den Burg, The Netherlands.

3 Laboratoire des sciences du Climat et de l'Environment (LSCE), Laboratoire mixte CEA/CNRS/UVSQ, Avenue de la Terrasse, bâtiment 12, F-91198 Gif-sur-Yvette, France

Contourite depositional systems (CDS), as well as water masses in the northern Gulf of Cadiz (GoC) have been extensively studied and described, leading to the IODP expedition 339 from last November to February. On the contrary, the southern part of the GoC has received little attention so far, although the temporal and lateral variability of bottom currents may have strongly influenced the "health status" of cold-water coral ecosystems. The CDS along the Pen Duick Escarpment is one of these systems. High-resolution seismic data show a 350 meters thick sedimentary sequence partially or entirely shaped by bottom currents. The lower part, with a tentative late-Pliocene age, is affected by less intense bottom currents against an uplifting PDE. The upper part, containing higher amplitudes, is affected by stronger bottom currents and mass wasting deposits, originating from this escarpment (in the northwest) or the mud volcano (in the southeast). North Atlantic Central Water (NACW) plays an important role in the higher parts of the region (above 600 meters), while Antarctic Intermediate Water (AAIW) does in the lower regions, on the foot of the escarpment. Moreover, NACW and AAIW seem to be stronger during interglacial periods, leading to more coarse-grained sedimentation in the moat.



Location map of the area. White dots represent cores. B. Seismic profile across the PDE(vertical scale in ms TWT).

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