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THE LANDEN FORMATION

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1. GENERAL DESCRIPTION

The Landen Formation was defined and named as a formal lithostratigraphic unit by KAASSCHIETER (1961). It corresponds with the deposits formerly referred to as "Landenian", excluding the former "Heersian". The unit consists of marine sediments ("Lower Landenian", L1 of the geological map) mostly covered by coastal-plain and fluviatile sediments ("Upper Landenian", L2 of the geological map).

The Formation extends over the whole northern part of Belgium and over the Mons Basin. The outcrops are mainly situated in the Hesbaye and in the Hainaut. In northern Belgium, the deposits generally dip to the North, in the Mons Basin they lie in a broad syncline. Along the W.-E. axis of the Mons Basin, several cup-shaped depressions occur where the Formation reaches a maximum thickness of 75 m. In the western part of North Belgium, the thickness mainly varies between 30 m and 40 m, but in the Campine a maximum thickness of some 120 m can be found.

In the N.W. and in the Hainaut the Landen Formation generally covers Cretaceous deposits and in the N.E. it mainly rests on the Heers Formation. In a central area between Tielt and Halle the Formation covers Paleozoic rocks, due to the presence of a N.W.-S.E. oriented opwelling of the Brabant Massif, and further to the East (South of Wavre and Hoegaarden) Cambrian rocks are locally overlain. It rests on Carboniferous rocks and local Wealdian deposits in the northern part of the Hainaut (between Tournai and Soignies), and in the Mons Basin the Landen Formation locally covers the Bertaimont Formation (the former "Heersian of the Mons Basin") and Lower Paleocene (Dano-Montian) deposits.

The Formation is mainly overlain by the Ieper Formation. Only in the East it is covered by Middle Eocene ("Brussels Formation") or Lower Oligocene (Tongeren Formation) deposits.

The Landen Formation can be divided into several lithological units, with the rank of "member" (table 1). In case of insufficient information, informal terms (without capitalization) are used. Only the units of the type area (Hesbaye) will be discussed in the next sections.

2. THE LINCENT MEMBER

The basal unit in the type area is known as "Tuffeau de Lincent" (D'OMALIUS D'HALLOY, 1839). In accordance with the recommendations of the International Subcommission on Stratigraphic Classification (ISSC), the poorly defined and local lithological term "tuffeau" is abandoned. As the *Lincent Member* is no longer exposed at the type locality, a new type section has been defined at Wansin by MOORKENS (1972). This neostratotype is situated on the valley flank of the Wansin brook (topogr. map of Belgium 1/25.000 n° 41/1-2, co-ordinates : X=196155 Y=151850) and is easily accessible. The Lincent Member consists of pale, porous siliceous (opaline) limestone with intercalations of horizontally stratified hard chert layers and thin marl laminae. The carbonate content of the "tuffeau" s.s. varies between 30 and 50 weight % (fig. 1, samples W2, W3, W4, W7) but at the base of the section higher values can be found. The top part of the type section is decalcified. At Wansin the "tuffeau" rocks rest on Maastrichtian deposits with a well developed flint bed at the base (not be to seen in the neostratotype) but locally (Folx-les-Caves, Orp-le-Grand) a thin (max. 1 m) clay layer occurs at the base of the Landen Formation. The maximum thickness in the type area is about 20 m and upward there is a gradual transition to the Sands of Grandglise.

In the "tuffeau" s.s. the amount of detrital quartz is restricted (less than 10 vol. %), calcareous remains of foraminiferids, molluscs and echinids are abundant and the rock contains many regular cavities (up to 25 vol. %), resulting from the dissolution of siliceous sponges. Glauconite is always

Table 1. Members of the Landen Formation.

HAINAUT	*N.W. BELGIUM*	*N.E. BELGIUM*	*HESBAYE*
Erquelinnes	Oostende-ter-Streep	Loksbergen	Dormaal
Grandglise	Grandglise	Grandglise	Grandglise
Chercq	clayey sand and sandy clay	Halen Waterschei	Lincent

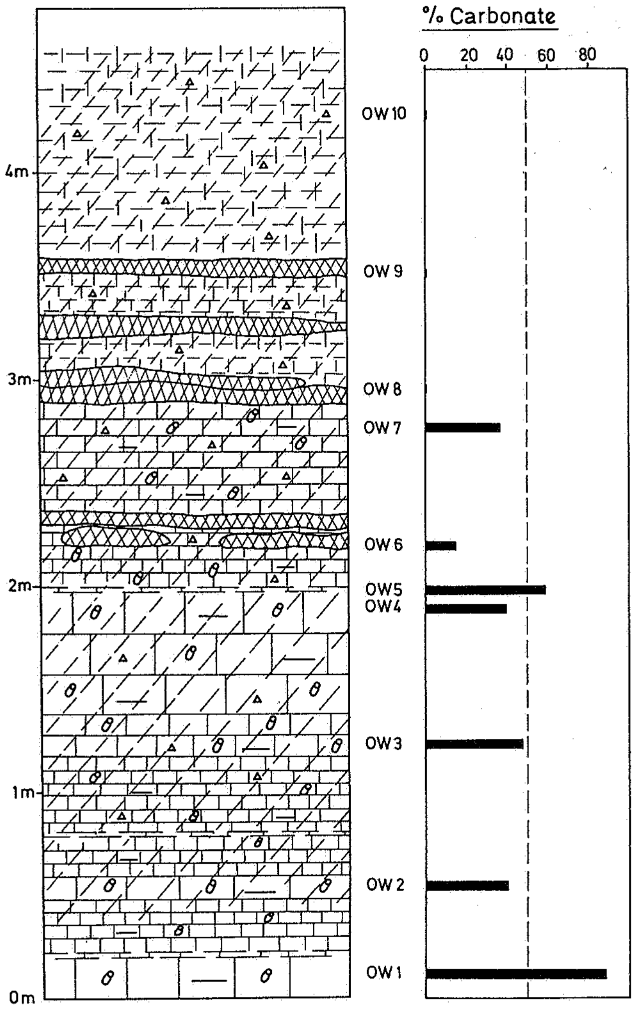

Fig. 1 : Type section of the Lincent Member at Wansin.

present ; especially fossil casts and internal molds are noteworthy. The cement consists of opal-CT with minute calcite grains and clay flakes scattered throughout the siliceous mass (DE GEYTER, 1981). The large amount of opal-CT, combined with the high porosity explain the characteristic small density. In most of the rock samples, particles with the same shape and dimensions as the cavities but made up of fibrous chalcedony occur. The axial canal of the sponge spicules, filled with opal or glauconite has sometimes been preserved ; in other cases, only the central part of the opaline skeleton is filled with chalcedony. In association with the chalcedony, aggregates of opaque crystallites are frequently found. The fine-grained cubic crystals and bar-shaped aggregates are lodged in the lower part of the chalcedonic particles and thus interpreted as geopetal iron sulphides.

In the hard interlayered cherts chalcedony is the predominant component of the cement. Detrital grains are scarce and restricted to the area with opal cement. The calcareous skeletons are sometimes preserved (sample W6) but mostly the shell fragments are silicified. When replaced by opal, the detailed organic structures sometimes remain visible but in the non calcareous chert samples only diffuse ghosts of skeletons, replaced by chalcedonic quartz, can be observed. The opaline skeleton of sponges is usually not preserved. In the area with opal cement the outer walls of the spicules, composed of chalcedony, are frequently sharply outlined ; in the chalcedonic zone the walls of the spicules have been lost in the groundmass but usually the axial canals have been preserved so that the original character of the spicules can still be distinguished.

The original sediment was deposited in a low-energy shallow marine environment. After the death of the organisms the opaline skeletons readily dissolved because the sea water was undersatured with respect to amorphous silica. Since it is generally agreed that glauconite is most readily formed at the sediment-water interface, the enlargement of the axial canals of siliceous spicules, - preceding the filling with glauconite -, must have occurred in a very early stage. After burial, the rate of opal-A (siliceous tests) dissolution probably exceeded the rate of silica diffusion, thereby increasing the silica concentration in the interstitial waters. Finally, the equilibrium solubility value of opal-CT may have been reached, leading to the cementation of the porous calcareous sediment or the replacement of the fine-grained calcareous matrix preserving minute calcite crystals in the siliceous groundmass. The occurrence of numerous regular cavities evidently indicates that dissolution of opaline skeletons must have taken place after the formation of the siliceous cement. Locally the filling of the axial canal by glauconite is preserved and thus the glauconite must have attained a certain consistency at the time of dissolution of the surrounding skeleton. Sometimes the regular cavities have been filled with fibrous chalcedony. This filling may have taken place after the complete dissolution of the opaline skeleton, but the association of opal and chalcedony in one particle may also be explained by the direct conversion of opal to quartz. However, the presence of geopetal iron sulphides indicates that this transformation proceeded by a dissolution-precipitation mechanism.

In the interlayered hard cherts, the occurrence of biogenic ghost structures and the patchy distribution of irregular opal islands in the chalcedonic groundmass suggest a replacement origin. In general, chert formation probably proceeded from an early diagenetic opal-CT cemented "tuffeau" rock with numerous unfilled opaline fossils to a later diagenetic quartzose chert with chalcedony-replaced and -filled fossils. The final stage of chertification involved the transformation from opal-CT to chalcedony, spreading from many nuclei throughout the rock.

3. THE SANDS OF GRANDGLISE

The term "Grès de Grandglise" was introduced by D'OMALIUS D'HALLOY (1842), but as the sandstone only locally occurs and laterally grades into glauconiferous fine sands , the term "Sands of Grandglise" was used by KAASSCHIETER (1961) for the sandy marine top unit of the Landen Formation in the Hainaut. MOORKENS (1972) introduced the term "Sands of Racour" for the L1d of the geological map in the Hesbaye. As all these sands have nearly the same lithological characteristics, the oldest lithostratigraphic term is preferred for this unit. The type sections are situated in the Hainaut and the abandoned sand pit of Rommersom (Hoegaarden) is proposed as the auxiliary reference section in the Hesbaye.

The unit consists of fine glauconiferous sands that become somewhat more clayey downward. The glauconite content gradually diminishes upwards and in the top part the glauconite is concentrated in laminae revealing a very irregular stratification. These soft-sediment de formation structures, that also occur in the overlying fluvial sands, were studied by GULINCK (1948, 1963) and interpreted as due to sub-aquatic sliding ("glissement sous-aquatique"). Although downslope movement under gravity locally may have been important, it is suggested here that the deformation is primarily related to water escape processes. This is evident for the diapiric structures but the occurrence of recumbent-folded deformed cross-bedding can also be explained by the action of current drag on a sand bed liquefied as the result of either tectonic (earthquake shocks) or non-tectonic (perhaps storm-induced microseisms) trigger mechanisms (ALLEN & BANKS, 1972). The Sands of Grandglise are sometimes deeply eroded but at Hoegaarden the thickness may reach 15 m. Downward there is a gradual transition into the Lincent Member ; the contact with the overlying Sands of Dormaal is usually sharp.

4. THE DORMAAL MEMBER

The top unit (L2 of the geological map) of the Landen Formation is primarily made up of fine to medium white sands with intercalations of dark lignitic clays and pale marls. At the base, gravel beds are sometimes found underlying medium to coarse cross-bedded river channel sands. The erosion channels are locally deeply incised in the lower Members of the Landen Formation.

Lignitic sands have been described at Landen but the former terms "Sands or Lignites of Landen" are not in accordance with the ISSC recommandation, not to apply the same geographic name both to the unit as a whole and to a part of it. Therefore the other traditional name "Sands of Dormaal" (RUTOT, 1884) is preserved. A detailed description of the type section was given by de HEINZELIN (*in* CASIER, 1967). This locality is well-known for its rich mammal fauna but unfortunatily the stratotype is no longer visible.

Both the Grandglise Member and the Dormaal Member are exposed in an abandoned sand pit at Rommerson. A detailed description of this profile is given by GULLENTOPS (this excursion guide). Only the silicifications in these units will be considered in the next section.

5. NEAR-SURFACE SILICIFICATION IN THE TOP UNITS OF THE LANDEN FORMATION

In former times very hard siliceous rocks were quarried in the Hesbaye, in the Hainaut and in northern France. Huge blocks with mammillated surfaces, known as "grès mamelonnés", were found at the base of quarternary deposits, but only a few in situ occurrences have been described. The best known exposures were situated in Overlaar, a hamlet of Tienen. There, a hard horizon, about 1 m thick, was overlain by lignitic clays containing numerous silicified wood fragments and several tree trunks. Locally, about 1 m lower and separated by white fine sands, a second but less hard horizon was mentioned. In the abandoned sand pit of Rommerson highly siliceous nodules and mammillated blocks were found in a sandy mass above a lignite layer (DE GEYTER, 1980), but this section is no longer visible.

The major part of the siliceous rocks display a quartzitic texture. This type consists of closely packed quartz grains, 100 to 250 μm across, with secondary overgrowths, sometimes showing well defined crystal faces. In the siliceous rocks containing root structures, areas with equigranular quartzitic texture aside zones with microgranular quartz cement and many dark impurities can be observed. The silicified root structures are easily recognized for the cell walls are usually well preserved and the small cell lumina are filled with microcrystalline quartz, contrasting with the surrounding larger quartz grains. At the periphery of the roots a concentration of dark impurities can frequently be found and locally larger euhedral quartz crystallized in the remaining voids.

The occurrence of silicified wood and root traces, the position of the indurated layers, the petrographic characteristics together with the relation to the surrounding sediments, strongly suggest that the silicification has taken place in near-surface conditions. The siliceous rocks may thus be related to the extensive siliceous crusts and concretions of Australia and Southern Africa, best known under the term "silcrete" (LANGFORD-SMITH & DURY, 1965 ; STEPHENS, 1971). SMALE (1973) recognized five textural types, including a quartzitic type and the occurrence of mammillated surfaces and the incorporation of silicified wood has repeatedly been mentioned.

The full elucidation of the near-surface silicifications in the Landen Formation will clearly require a very detailed study of several good exposures, but these are no longer available for the moment. So, a tentative interpretation is merely based on the study of the Rommersom section, some ten years ago (DE GEYTER, 1980). The slight silicification of the top part of the lignitic clay suggests a concentration of siliceous solutions above the impermeable layer as a result of downward and lateral movement of silica bearing groundwater. The silica may have been derived from the weathering of almost pure quartz sands at higher elevations. The direct precipitation of quartz from siliceous solutions poor in other cations may then have occurred in areas of suitable low relief and restricted surface drainage. Such a process could have been favoured by an alternation of warm wet and dry periods. The common occurrence of well defined growth rings in coniferous wood appears to confirm seasonal variation and most palaeobotanists decide in favour of sub-tropical conditions. During the dry periods the precipitation of quartz may have been enhanced by intense evaporation, but probably the extensive near-surface silicification has been a process of long duration. Al this moment there is no comprehensive explanation for these silicifications in terms of detailed processes due to the paucity of areas in which sufficient geomorphic relationships are preserved for reconstruction of the early Eocene landscapes and environments.

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