

Definition of a Global Boundary Stratotype Section and Point for the Campanian/ Maastrichtian boundary

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Abstract

The Maastrichtian Working Group of the Subcommittee of Cretaceous Stratigraphy looked for a section which could contain the Global Boundary Stratotype Section and Point in the Campanian/ Maastrichtian transition. Over the last three years new data have been collected from a section situated in the Tethyan Realm, but connected with the Temperate Realm.

During the meeting in Brussels, the working group considered the markers which could be used for the localisation of this boundary. Various sections in which this boundary is well exposed, were compared. The characteristics of these sections were discussed in respect of the requirements recommended by the Commission on Stratigraphy for the Boundary stratotype point.

As a result, the Campanian/ Maastrichtian boundary will be proposed at a precise point in the disused quarry at Tercis (Landes, France) at the immediate proximity of the level where the oldest *Pachydiscus neubergicus* (von HAUER, 1858) has been found. At this site, that level has been directly related with the appearance or disappearance of taxa of different groups, including a very diverse and rich echinoid fauna, various inoceramids, ammonites of which the replacement allows a zonation. Furthermore, the sediments contain sufficient material which permits the fundamental characterisation by benthic and planktonic foraminifera, dinocysts and pollens and calcareous nannofossils. Other faunal groups are also present, such as the brachiopods, crinoids, asteroids, ophiuroids which can be used as biostratigraphical tools amongst others for the necessary connection between the historical stratotypes and the succession at Tercis. Also for the characterisation and correlation, lithostratigraphical, chemostratigraphical and magnetostratigraphical tools are also being studied in detail.

The strata of the Tercis quarry are already well studied, but their richness means that one can envisage other important developments in the future.

Key-words:

Maastrichtian, Upper Cretaceous, stratotypes, GSSP proposal, biostratigraphy, ammonites, belemnites, foraminifera, coccoliths.

Résumé

Le Groupe de Travail Maastrichtien de la Sous-commission de Stratigraphie du Crétacé a cherché une section qui pourrait contenir le "Global Boundary Stratotype Section and Point" pour la transition Campanien/ Maastrichtien. Ces trois dernières années, des données nouvelles ont été récoltées dans une section appartenant au domaine téthysien, tout en étant reliée au domaine tempéré.

Pendant la réunion de Bruxelles, le groupe de travail a considéré les marqueurs qui pourraient permettre la localisation de cette limite. Plusieurs sections où cette limite est bien exposée, ont été comparées. Les caractéristiques de ces sections ont été discutées en considérant les

règlements présentés pour la désignation du "Boundary stratotype point" par la Commission de Stratigraphie.

A la suite de ces discussions, la limite Campanien/ Maastrichtien proposée se trouve à un point précis dans la carrière abandonnée de Tercis (Landes, France) à proximité immédiate de l'endroit où a été trouvé le plus ancien *Pachydiscus neubergicus* (von HAUER, 1858). Dans cette carrière, ce niveau a été mis en relation directe avec l'apparition et la disparition de taxa appartenant à différents groupes, dont une faune diverse et riche d'échinoides, de nombreux inoceramides, des ammonites dont le renouvellement permet une zonation. En outre, les sédiments ont livré des témoins suffisants pour la fondamentale caractérisation à l'aide des foraminifères benthiques et planctoniques, des dinocystes, des pollens et des nannofossiles calcaires. Plusieurs groupes fauniques présents entre autres les brachiopodes, les crinoïdes, les astérides ou les ophiuroides, peuvent servir d'outils de corrélation biostratigraphiques notamment vis à vis de la nécessaire connexion entre les stratotypes historiques et la succession de Tercis.

Pour la caractérisation et la corrélation détaillées, les outils lithostratigraphiques, chemostratigraphiques et magnétostratigraphiques sont aussi étudiés.

Les strates de la carrière de Tercis ont déjà été beaucoup étudiées, mais leur richesse laisse envisager d'autres développements importants dans l'avenir.

Mots-clefs: Maastrichtien, Crétacé supérieur, stratotypes, proposition du GSSP, biostratigraphie, ammonites, bélemnites, foraminifères, coccolites.

Определение «Global Boundary Stratotype Section and Point» для Кампанско-Маастрихтской границы.

Резюме.

Рабочая Группа Маастрихтского яруса Подкомиссии Меловой Стратиграфии занимается поиском разреза, способного стать Global Boundary Stratotype Section and Point для Кампанско-Маастрихтской границы. В течение трёх последних лет, были собраны новые данные по разрезу, принадлежащему к области Тетис, но связанному тем не менее с бореальной палеобиогеографической областью.

В течение брюссельского заседания, Рабочая Группа установила указатели, которые смогли бы локализовать вышеупомянутую границу. Учёные сравнили несколько разрезов, в которых эта граница была ярко выраженной и обсудили характеристики этих разрезов, учитывая представленные Стратиграфической Комиссией положения для определения «Global Stratotype Point».

В результате этих дискуссий, предложенная Кампанско-Маастрихтская граница находится в конкретном пункте нерабочего карьера Tercis (Landes, Франция), в непосредственной близости того уровня, где был найден древнейший *Pachydiscus neubergicus* (von HAUER, 1858). Этот уровень карьера был прямо связан с появлением и исчезновением таксонов, принадлежащих различным группам, включающим разнообразную и

обильную фауну: морских ежев, многочисленных иноцерамов и аммонитов. Благодаря обновлению последних осуществляется распределение по зонам. К тому же, отложения содержат достаточное количество остатков, благодаря чему становится возможной, при помощи бентических и планктонических фораминифер, диноцист, пыльцы и известковых нанофоссилий, фундаментальная характеристика. Несколько присутствующих, относящихся к фауне групп, между прочим брахинопов, морских лилий и морских звёзд (*Asteroida* и *Ophiuroida*), могут играть роль биостратиграфических орудий корреляции, в частности, по отношению к необходимой связи между историческими стратотипами и наследием Tercis.

Для детальных корреляции и характеристики также изучаются литостратиграфические, хемостратиграфические и магнитостратиграфические технологии.

Страты карьера Tercis уже были изучены в деталях; тем не менее, их богатство предполагает другие важные открытия в будущем.

Ключевые слова: Маастрихтский ярус, верхний мел, стратотипы, предложение GSSP, биостратиграфия, аммониты, фораминиферы, кокколиты.

The Campanian/ Maastrichtian boundary

At the meeting in Brussels, presentations and discussions connected with the definition of a Global Boundary Stratotype Section and Point (later on GSSP) for a precise definition of the position of the Campanian/ Maastrich-

tian boundary, considered two points:

1. the level at which this boundary must be placed;
2. the choice of the most appropriate section for the concrete localisation of this level.

After the presentations and discussions in Brussels, the working group members reviewed the situation and gave an indicative vote on the various possibilities presented. The results of this vote are presented herein (Table 1). Since an obvious majority resulted from this consultation, a formal vote was attempted in October 1995 among the 40 members of the working group, entrusted with the consensus on this boundary. The working group largely expressed the same opinion as that previously expressed by the indicative vote in Brussels.

We summarise here,

- 1) the discussion elements considered for establishing the GSSP of the Campanian/ Maastrichtian boundary, and
- 2) the characteristics already known from the Tercis site.

For this site, it should be noted that whereas some results are already available, complementary studies are still being undertaken. Thus the chosen site will be a good reference point which can be presented to the Sub-commission as GSSP for the Campanian/Maastrichtian boundary.

Table 1.

Markers quoted for location of the Campanian/ Maastrichtian boundary and votes for them.

1st vote: all present were invited to vote for several primary markers amongst all those quoted in the discussion. No vote was given for: LO *Nostoceras hyatti*, LO *Globotruncanita elevata*, FO *G. aegyptiaca*, FO *Lithraphidites praequadratus*.

2nd vote: the four most quoted markers (underlined> were selected and each person present had to vote for one marker only.

3rd vote: in the last vote those present could vote for or against the most favoured marker.

FO = First Occurrence; LO = Last Occurrence.

boundary marker	1st vote	2nd vote	3rd vote
Ammonites			
FO <i>Pachydiscus neubergicus</i>	25	20	28 for; 8 against.
FO <i>Hoploscaphites constrictus</i>	5	—	
FO <i>Nostoceras hyatti</i>	2	—	
FO <i>Pseudokossmaticeras brandti</i>	1	—	
Belemnites			
FO <i>Belemnella lanceolata</i>	12	5	
FO <i>Belemn. licharevi</i>	2	—	
Planktonic foraminifera			
FO <i>Gansserina gansseri</i>	4	—	
LO <i>Globotruncanita calcarata</i>	3	—	
FO <i>Archaeoglobigerina kefi</i>	1	—	
Benthic foraminifera			
<i>Bolivina decurrens</i>	3	—	
<i>Neoflabellina reticulata</i>	3	—	
<i>Orbitoides mammillata</i>	1	—	
Coccoliths			
LO <i>Aspidolithus parvus constrictus</i>	11	10	
LO <i>Reinhardtites anthophorus</i>	5	—	
Physico-chemical			
Magnetic reversal marker	17	2	
Chemical marker (87Sr/86Sr)	1	—	

Discussion on the Campanian/ Maastrichtian boundary

The potential markers for placing the boundary

In 1984, the conclusions on the proposals for the position of the Campanian/ Maastrichtian boundary (BIRKELUND *et al.*, 1984) mentioned six taxa which had ranges useful for defining this boundary.

appearance:

- of the ammonites
- 1. *Hoploscaphites constrictus* (J. SOWERBY) type specimen at the Natural History Museum, London
- 2. *Pachydiscus neubergicus* (VON HAUER) type specimen at the Geologische Bundesanstalt, Vienna, Austria - it has been re-figured by KENNEDY & SUMMESBERGER, 1986, pl. 3, figs. 1-3; WARD & KENNEDY, 1993, fig. 28.
- of the belemnite
- 3. *Belemnella lanceolata* (SCHLOTHEIM)
- of the foraminifer
- 4. *Globotruncana falsostuarti* (SIGAL)

extinction:

- of the foraminifer
- 5. *Globotruncanita calcarata* (CUSHMAN)
- of the calcareous nannofossil
- 6. *Quadrum trifidum*. (STRADNER) sensu PRINS & PERCH-NIELSEN

Since the 1984 restatement, other biomarkers have been cited, recommended, discussed or used: appearance or extinction of *Nostoceras hyatti* (STEPHENSON), extinction of the calcareous nannofossil *Broinsonia parca constricta* (STRADNER) BUKRY HATTNER. Geochemical and geomagnetic markers have also been considered.

Some specialists consider the first criterion of a marker should be its practical use: it should be recognisable at the precise level in the reference section and if possible, throughout the globe. From this point of view, candidates for locating the boundary are limited to macrofossils (if they are sufficiently frequent and easy to identify) or eventually to lithological criteria (but these can rarely be recognised beyond a single basin).

Other specialists argue that macrofossils are generally too rare (or even too long lived) to allow the easy and precise location of a boundary: they prefer to recommend a microfaunal, geochemical or magnetic marker. Table 1 lists all the markers proposed in Brussels.

Sections useful for the definition of the boundary.

The two regions used for the definition of the historical stage stratotypes (around Maastricht in Limburg, The Netherlands, for the Maastrichtian; and the Charentes, SW France, for the Campanian) do not contain sufficiently continuous sections at the Campanian/ Maastrichtian boundary.

Five regions contain possible type section candidates. One is in the cold temperate realm (N. Germany) and four are in the tethyan realm [Basque region (France-Spain), Tunisia, Apennines (Italy), Landes (France)].

The Krons Moor section (N. Germany) is well known through many publications as indicated by KENNEDY *et al.*, 1995. Furthermore, it is the only section which can be considered if the belemnites have to be the marker of the boundary. In principle, regions further eastwards, in the ex-USSR, could also be considered, but our information on these regions is less complete. Less favourable is that the Krons Moor quarry is still being worked, and that the loose nature of the sediment makes it difficult to indicate a constant reference point.

In the Basque Region (Pais Vasco) the Zumaya section (Spain) is well studied. The section at Bidart (France) has been fairly well studied. Those sections are easily accessible and especially well exposed. They would be favourable if microfossils were considered as markers. Macrofauna is however rare near the Campanian/ Maastrichtian boundary.

In Tunisia the sediments contain a good microfauna; macrofauna is present but relatively rare. The studies on this region are not sufficiently diversified so far, but, as with the Basque region, Tunisia could be used for comparison when combining different correlative tools to obtain better precision on their relative stratigraphic positions.

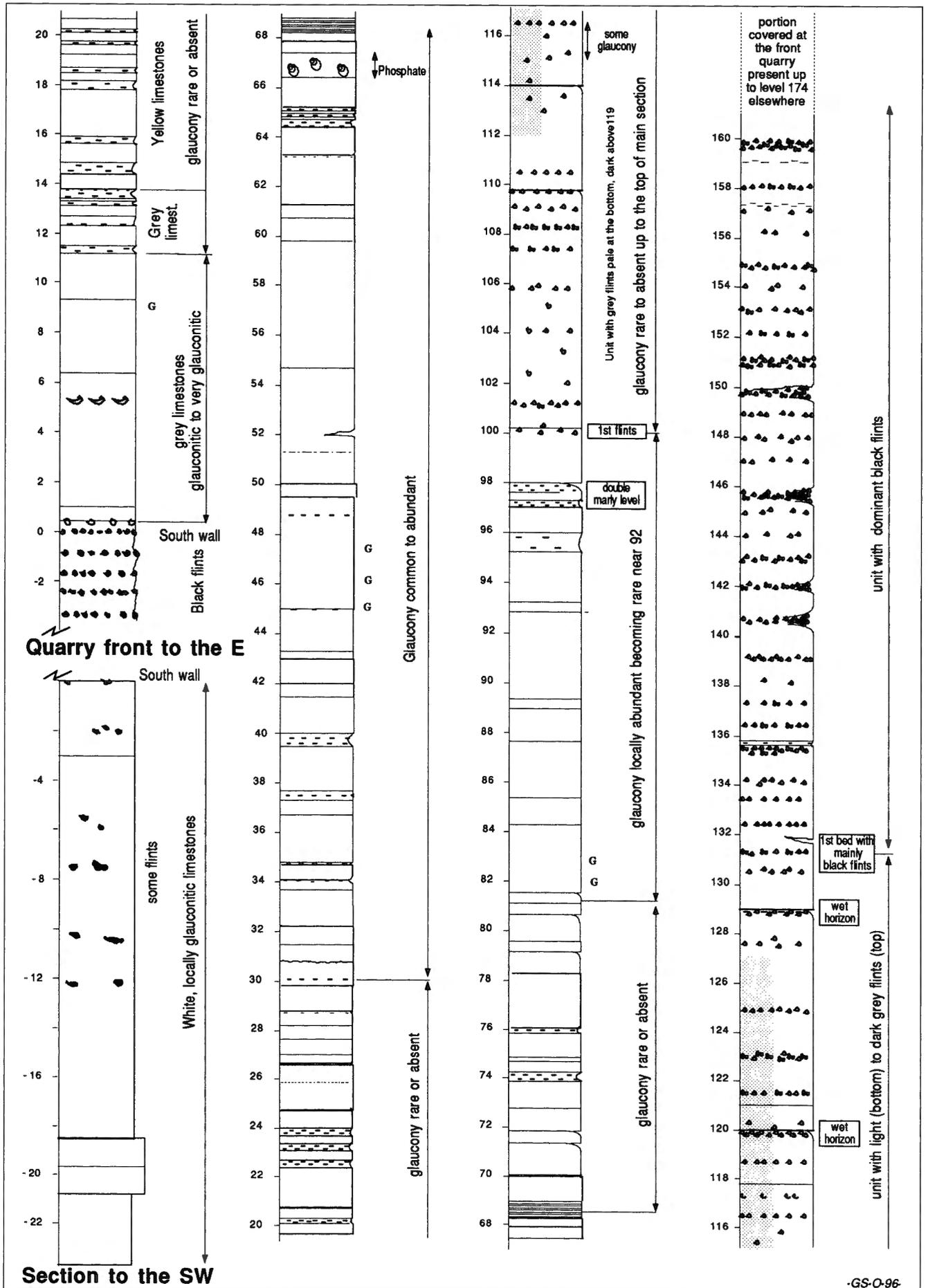
The section at Botaccione (Apennines, Italy) has been very thoroughly studied. Microfauna is present but can only be studied in thin sections.

Remarkable is that the Botaccione section offers the possibility to combine biostratigraphic and magnetostratigraphic data. However, it contains no macrofauna. Another problem which might arise with this road side section is that it could become inaccessible. The data accumulated on this section allow worldwide correlations, especially in the deep (bathyal) marine strata.

The Tercis section (Landes, France) is remarkable in the diversity of the macrofauna, except for the absence of belemnites. This section allows to correlate cool temperate macrofauna and tethyan microfauna. The microfauna and the nannofossils are partially less favourably preserved than in deeper-water deposits. Their study is more time consuming than in other basins, but a characterisation is possible. The data concerning this section are being studied in detail. The section's accessibility and permanency are as favourable as possible.

Among the possible sites for defining the Campanian/ Maastrichtian boundary stratotype, none completely covers the criteria summarised elsewhere (ODIN, 1992):

- 1) quality of the section with accessibility for study and for the preservation of a given point;
- 2) quality of the sedimentary record with fully marine facies, continuous deposition, good preservation of the "signals" without change of facies;
- 3) quality of the biostratigraphic record permitting especially a correlation between the cold temperate and tethyan biomarkers;



4) applicability of physico-chemical tools with magnetostratigraphy, chemostratigraphy and radioisotopic dating.

Using sections situated in different palaeogeographic and sedimentary environments, the boundary can be defined more completely by adding to the chosen site for the GSSP, auxiliary reference sections.

The proposals which were preferred during the votes

Table 1 (p. 112) summarises the opinion of the participants at the Brussels meeting.

Where the biomarkers are concerned, the macroscopic and the "hidden" criteria had the same number of supporters. When only one criterion had to be selected the macrofossil supporters were more numerous. The appearance of the ammonite *Pachydiscus neubergicus* seems to be the only criterion which obtained a consensus. This is due largely to the fact that this ammonite has a wide distribution outside the cold temperate realm. HANCOCK & KENNEDY (1993) and KENNEDY *et al.* (1995) cite the taxon from the Basque region to Denmark, from N. Germany, the Ukraine, Russia to Armenia and from Africa: Tunisia, Nigeria, South-Africa, Madagascar, and also from S. India.

After the Brussels meeting, a formal vote was taken on October 15, 1995 by all members of the working group: 40 persons including all those having actively cooperated with the studies of the group and those which had expressed an interest in its activities to the chairman of the subcommission and having actively participated in the discussions. This vote confirmed the conclusions reached in Brussels in which the members expressed the wish to obtain a concrete result and to emphasize Tercis as a reference section.

Substages of the Maastrichtian stage

Where needed the formal Maastrichtian Stage may be subdivided into substages. At the meeting in Brussels, the majority of those attending agreed by vote of 26 to 0, with 6 abstentions, that a subdivision into two substages should be recommended.



Fig. 1 — Present section in the quarry at Tercis (simplified from ODIN & ODIN, 1994). The whole succession is limestone with occasional argillaceous beds (10-15% clay: dashed beds). Major bedding planes are shown. Eight units are distinguished with sharp boundaries at levels 0, 11, 30, 68.5, 81, 100 and 131. The relative abundance of poorly evolved glaucony (maximum: 30%, usually in very small grains - 30 to 100 μm) is one of the few criteria for subdividing the homogeneous lithology. The Campanian/Maastrichtian boundary is within the 0.3 to 0.6 Ma long dotted interval; it will be constrained to 0.03 Ma when current research has been completed.

There was no agreement on the boundary-criterion for the base of the Upper Maastrichtian. Possible criteria mentioned included:

- the extinction of rudistid reefs,
- the extinction of the majority of the inoceramids,
- the lowest occurrence of a calcareous nannofossils species;
- the lowest occurrence of *Pachydiscus fresvillensis* Seunes.

It was agreed, without a vote being taken, that the section at Zumaya, northern Spain, should be better documented before any final decision is made on the base of the Upper Maastrichtian.

The site of Tercis

Geographically, the village of Tercis is situated in the Landes (S.W. France), in between the Basque Region (well known by numerous, recently undertaken studies) to the south, and the Charentes (with the historical stratotype of the Campanian) to the north. The palaeogeographic position of Tercis, in a small basin north of the Pyrenees, but belonging to the tethyan realm, is favourable for comparison between the cold temperate realm (Charentes, Limburg, N. Germany) and the tethyan realm of which the faunas are found in this Aturian basin.

The site is situated 8 km SE of the railway station at Dax, on the left bank of the Adour River. The outcrop is part of the east-west ridge of Tercis-Angoumé. In the northern flank of this anticline, which is partially of diapiric origin, Mesozoic strata outcrop subvertically; at their centre is Triassic of Germanic facies.

The outcrop is situated in a quarry with five formerly worked "platforms", each 5 to 6 m high, opening westwards between the south and north walls, about 100 m apart. These "levels" allow repeated observation of the series.

The major section of about 165 m thickness, is the old quarry face. A disused quarry just to the south shows 25 m of older strata. Another section, about 60 m thick, is visible around the north entrance of the quarry, which contains part of the uppermost strata of the main section. Younger strata are visible to the north of the quarry in small exposures as far as the "Mur de Bédât", at the Cretaceous/Palaeogene boundary. The whole 40 m just below the K/T boundary can be studied.

Access to the site and "permanence" of the section

Working of the quarry has stopped. In 1993, for security reasons, a considerable re-planning of the site was undertaken. It was aimed at preservation and improvement of the accessibility to its geology. The main section was measured and described (ODIN & ODIN, 1994). Markers have been placed every metre between - 4 and + 161 on at least one level.

About 15 years ago, the first advanced studies on the site were started and directed by J. M. Hancock (HAN-

COCK *et al.*, 1993) who demonstrated the importance of the site. In 1988 P. Ward also studied the site. Since the spring of 1992 a systematic study including the marking of the section and bed by bed collecting has been undertaken. Since 1994, all the results have been accumulated in the framework of the Maastrichtian Working group of the Cretaceous Subcommittee and they will be monographed in 1996.

The city of Dax is served by a good railway service from Paris and Spain and easily accessible by road. The road to the quarry is good.

At present the owner of the site is the "Ciments Français". This company readily gives access permits. Soon, as a result of the acceptance of the security planning of the site (18 October 1995) the city of Dax will take charge, in cooperation with the "Conservatoire des Sites d'Aquitaine". This latter institution is empowered by the national French environmental authorities to protect sites. These organisations have shown they are interested in recognising the Tercis site as a public site, accessible yet protected against destruction in the near as well as for the distant future.

Sediments

Depositional environment

The sediments have been deposited in an open marine environment represented by limestones with pithonellids and calcispheres. A depth of 50 to 200 m is probable – thus representing the top of the continental slope or the lower shelf.

Depositional history

The strata were placed in a vertical position by the Pyrenean orogeny. They are cut locally by small faults, mainly visible outside the main section. Their throw ranges from 20 to 30 cm to several m. Foraminifera and nannofossils are locally strongly recrystallised. There is some minor shearing.

Characteristic stratigraphic tools and their correlation potential

Lithostratigraphy

The major section contains generally 95% carbonates. More than 10 % clay is only found in some thin beds, a few cm to 30-40 cm thick.

The main lithological variations are related to the amount of glauconite (not very evolved and fine), and the development of chert (grey or black flints). These criteria have allowed a subdivision into 8 units (ODIN & ODIN, 1994). Specific marker beds provide precise correlations between the sections on different levels within the quarry at Tercis: two beds with *Pycnodonte vesicularis* (oysters), a double marly level, a bed with numerous inoceramids. The most important lithostratigraphic characteristic is the obvious rhythmicity of the concretions of chert. Similar rhythms have been interpreted as being of climatic origin in the Maastrichtian of Limburg (ZIJLSTRA, 1994). This should allow the evaluation of the depositional speed and its regularity. The regular

rhythms, especially clear at the Campanian/ Maastrichtian transition, are also a very useful tool for demonstrating the continuity of the deposition.

Biostratigraphy of the macrofauna

The section contains an abundant echinoid fauna, allowing a double zonation: one with *Echinocorys* species, another with *Micraster* species and closely allied taxa (being studied by D. Néraudeau). Inoceramids are present from the base to the top of the section (DHONDT, 1993, and further studies). Ammonites are sufficiently varied and numerous to allow far reaching correlations with the tethyan and cold temperate realms. Further progress has been made since the work by HANCOCK & KENNEDY, 1993: 250 specimens collected *in situ* by the WG chairman are available for study at the Université P. & M. Curie in Paris (contributions by W.A. Cobban, W.J. Kennedy, and P.D. Ward). Macrobrachiopods and microbrachiopods are quite common, but macrobrachiopods are limited to certain beds (under study by D. Gaspard). Asteroid, crinoid and ophiuroid remains have been collected by the WG chairman, and should allow interesting correlations with the Campanian and Maastrichtian historical stratotypes (studies by L. Villier and J. W.J. Jagt).

Biostratigraphy of the microfauna

Benthic (studied by J. Magné and J. Ion) and planktonic Foraminifera (studied by M. Caron and J. Ion); see also SIMMONS *et al.*, in press) are present in most levels. The preservation varies from very good to poor for planktonic foraminifera, and the marker taxa are sometimes only sporadically present. A zonation can be established and correlations can be proposed. The benthic forms are fairly well preserved and also allow a zonation and correlations. Noteworthy is that the beds with the most diverse and well preserved microfauna with the oceanic characteristics are situated very near to the appearance of fossil markers used for the boundary.

Ostracodes (studied by R. Damotte) are present and locally ornate forms permit correlations.

Coccoliths (BURNETT in HANCOCK *et al.*, 1993, and further work by M. Bonnemaison, K. von Salis-Perch-Nielsen, M. Melinte, and more recently by S. Gardin, S. Monechi, J. A. Bergen) are present in most samples. Preservation is average to poor, but zonations have been proposed by several specialists.

Dinocysts and pollens (studied by E. Antonescu, new studies foreseen by J. A. Bergen and G. J. Wilson) are present in many samples, and are well preserved. They should help considerably in correlations, even over long distances.

To summarise: even if the preservation is not perfect for all fossil groups, the sediments of the Tercis section are unique in that they allow a direct correlation potential for many fossil groups (except belemnites and radiolarians) and for a direct interregional correlation.

Physico-chemical stratigraphic tools

Geochemical analysis has been undertaken: trace ele-

ments, Sr isotopes. Trace elements present a potential for regional and global correlation. Sr isotopes have not yet given satisfactory results.

The magnetostratigraphic analysis has been undertaken in the laboratory of B. Galbrun. Only the lower half of the section gave a useful result.

Practical localisation of the GSSP

The actual status of the Tercis quarry allows to consider a GSSP which would be concretely developed and protected. Following an investment of 1000 kF (200.000 US \$) for the development of the site and for the safety of visitors to the quarry, negotiations are advancing towards its protection in the near and distant future. The precise location of the GSSP depends on different factors.

Theoretically the choice of the biological marker *Pachydiscus neubergicus* is fundamental. Already at least three scientists have found one or several specimens near the Campanian/ Maastrichtian boundary. These specimens have been identified by at least three specialists (W. A. Cobban, W. J. Kennedy, P. Ward). More recent collections are still being identified.

At the time of the meeting in Brussels, it was believed that the lowest occurrence of *Pachydiscus neubergicus* was somewhere in the range of the levels 112-127, in the limestones with pale grey flints, probably within a thickness of no more than 10 m (representing less than 0.4 Ma). Part of the problem of uncertainty is that the section-

measurements in HANCOCK *et al.* (1993), made whilst the quarry was still being worked, are not as accurate as the later measurements in ODIN & ODIN (1994). Nevertheless, it is expected that the placing of the boundary-criterion, i.e. the lowest *P. neubergicus* will shortly be possible to a definite bed, that is to a precision of about 0.03 Ma.

Practically there are three sections in which the GSSP can be fixed. This would allow the complete preservation of a section containing the GSSP, whereas samples and research could be undertaken in the two other stages of the quarry at the critical horizon of the boundary. Furthermore, if the GSSP were destroyed by mistake or otherwise, there still is a discrete sedimentological criterion, found in all three stages of the quarry and distinct within the whole exposure.

Acknowledgements

The results of the working group are largely due to the specialists who have collaborated before and at the meeting in Brussels, and to the results brought together on the sections. The work has been only possible with the access permission and the important development of the Tercis site, authorised and undertaken by the "Ciments Français", Calcia division.

Abbreviations:

GSSP: Global boundary stratotype and section point.

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