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PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY AND SEQUENCE STRATIGRAPHY OF THE CARBONATE-FLYSH SEQUENCE AT PROSSILION IN THE PARNASSUS-GIONA ZONE, CENTRAL GREECE

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ABSTRACT

The analysis of the planktonic foraminiferal assemblages recorded in the carbonate-flysch sequence at Prossilion in the Parnassus-Ghiona Zone combined with the results of sequence stratigraphy indicated that (a) the pelagic limestone was deposited during the Campanian-Maastrichtian interval (the main "Lowstand" System Tract: LST2) (b) the stromatolitic bed was deposited during the upper Lower-Middle Paleocene (the base of the "Lowstand": LST1 (c) the red shales were deposited during the Lower Eocene (the Transgressive System Tract: TST) while (d) the flysch deposits during the Lower Eocene-Upper Paleocene (Highstand System Tract: HST). At the Cretaceous Tertiary boundary and through the lowermost Paleocene the deposition was interrupted and has given rise to a hardground on the top of the pelagic limestone (Sequence Boundary: SB). The planktonic foraminiferal fauna were used to distinguish biozones in the sequence except in the hardground-stromatolitic unit. They are (a) the *Globotruncanita elevata* and *Globotruncanita calcarata*. Zones of the Campanian and the *Globotruncana falsostuarti*, *Gansserina gansseri* and *Abathomphalus mayaroensis-Kassabiana falsocalcarata* Zones of the Maastrichtian which are distinguished in the pelagic limestone, and (b) the *Planorotalites pseudomenardii*, *Morozovella velascoensis* Zones of the Upper Paleocene and the *Morozovella subbotinae*, *Morozovella formosa formosa* and *Morozovella aragonensis* Zones of the Lower Eocene recognized in the flysch. The above biozones have been classified in terms of sequence stratigraphy, resulting in relative sea-level changes curve. The stratigraphical and sequence stratigraphy interpretation shows that the changes in the facies that appeared in the Prossilion section during the above interval, are the result of sea level changes, which are believed to have been caused by local movements which started in the zone during Late Cretaceous probably in combination with eustatism.

Key words: Planktonic Foraminifera, Cretaceous-Tertiary biostratigraphy, Sequence Stratigraphy, Parnassus - Ghiona Zone, Hellenides, Greece.

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INTRODUCTION

At Prossilion 10 N of the town of Amfissa in the Parnassus-Ghiona Zone, Central Greece (Fig.1), is a carbonate-flysch sequence consisting of pelagic limestone beds overlain by the clastic deposits of the flysch. At the boundary between the limestone and the basal shales of the flysch complex, is a phosphatic hardground-stromatolitic bed (Kalpakis, 1979). The pelagic limestone beds in turn overlie thick-bedded limestones with rudist fragments.

This sequence is of significance for the Cretaceous-Paleogene stratigraphy of the zone since it is composed of rocks deposited during two important events that affected the zone, the deposition of pelagic sediments in the Late Cretaceous which is considered to have been connected with the horst and graben tectonism (Richter & Mariolakos, 1974) and the deposition of the flysch in the Early Tertiary.

For most of the Mesozoic the Prossilion area was situated in shallow waters. In the middle Late Cretaceous the area began to subside while during the Late Maastrichtian-earlier Paleocene it emerged to form a paleotopographic high (Pomoni-Papaioannou & Solakius, 1991). During this interval deposition was interrupted and a hardground developed on top of the pelagic limestone (Solakius et al., in press). In the later Early Paleocene and the Middle Paleocene stromatolites were developed above the hardground showing that the sea was very shallow; in the Late Paleocene the sea floor subsided further and the clastic sediments of the flysch have been deposited.

The changes in the facies in the Prossilion sequence are the result of the changes in the sea level caused either by local movements or because of eustatic changes in sea level. These changes in sea level will be demonstrated below on the basis of a sequence stratigraphy model. The time at which the changes took place and the duration of the deposition that followed, is revealed by the foraminiferal assemblages found in the beds. A biostratigraphic zonation based on the planktonic foraminiferal fauna identified, will be presented. This is the first zonation in the Upper Cretaceous - Lower Tertiary beds of the zone to be presented and which will be of significance for the interzonal correlation of the Upper Cretaceous - Lower Tertiary sedimentary beds in Greece.

GEOLOGICAL SETTING AND LITHOLOGY

The limestone-flysch sequence is exposed at Prossilion which lies 10 km north of the town of Amfissa in Central Greece (Fig.1). The sequence belongs to the Parnassus-Ghiona Zone, one of the many geotectonic units that form the mainland Greece and the islands. It is bordered by the Subpelagonian Zone to the east and the Pindus Zone to the west. The zone was originally identified by Renz (1940). Subsequently, Papastamatiou (1960) and Celet (1960, 1962) who have investigated the zone in detail, confirmed Renz's definition of the zone. Two types of sediments can be recognized: the carbonate formations below and the overlying clastic sediments of the flysch. From the Triassic until the early Late Cretaceous the carbonate deposition was neritic. However, the presence of three main bauxite horizons shows that the platform was emerged for three short periods during this time.

In the Late Cretaceous there was a change in the neritic environment, the platform being affected by horst and graben tectonism (Richter & Mariolakos,1974),combined with eustatic sea level fall. Extensive areas emerged, while in some parts the neritic environment continued to exist. In the grabens, on the other hand, sedimentation was pelagic. During the Paleocene the whole platform became submerged and was covered by the clastic sediments of the flysch.

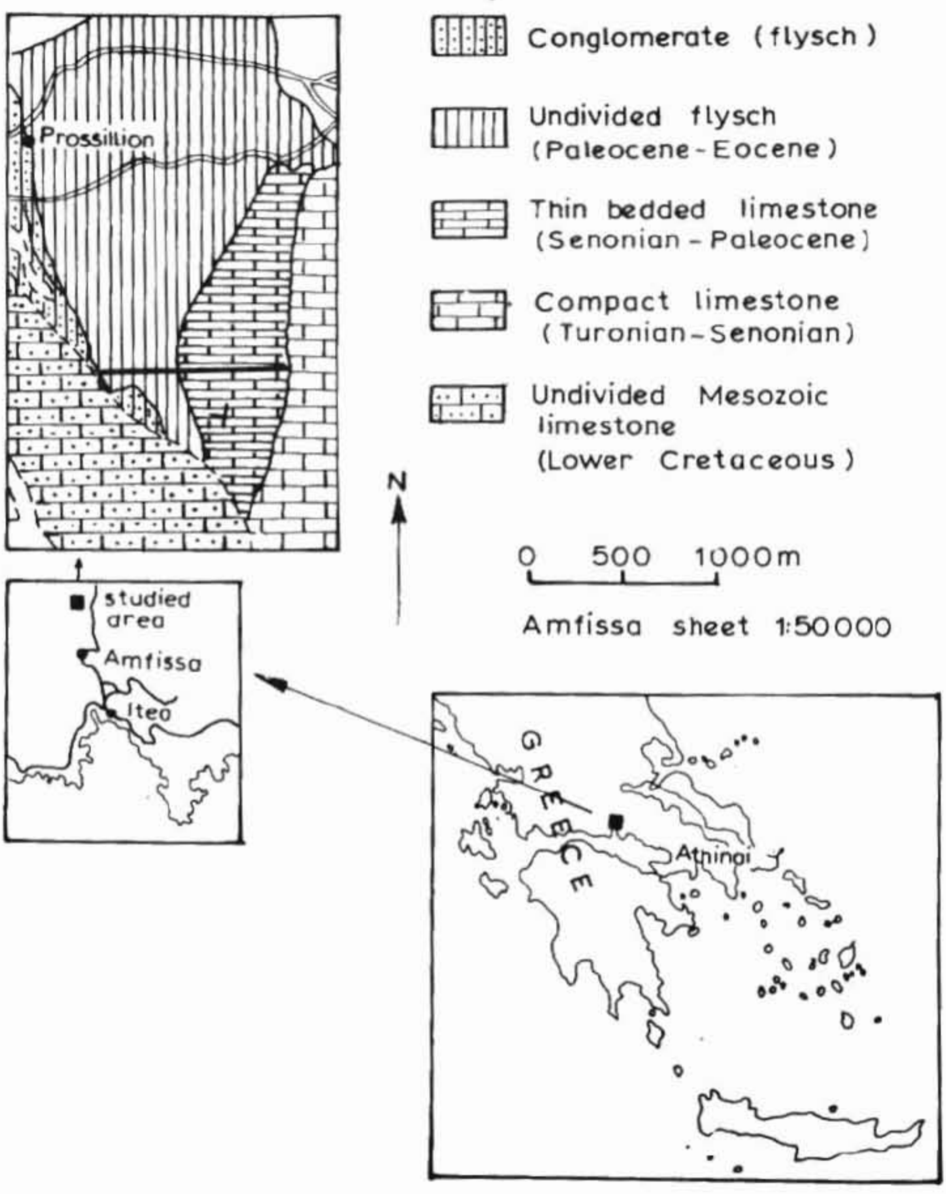

Fig.1: Geological map of the Prossilion area showing the location of the sequence studied.

The lithology of the rocks of the sequence is briefly as follows (Fig.3): foraminiferal wackestones-packstones (87,5m thick) overlie the rudist-bearing limestone beds; they were deposited on the outer part of the inner shelf and include platform components (rudist and echinoderm fragments) periodically transported to the muddy pelagic sediments. The hardground-stromatolitic unit is composed of a bored surface impregnated by iron oxides below, overlain by ferrophosphatized stromatolitic crusts. This unit varies in thickness from 5 to 20cm. The hardground-stromatolitic horizon passes upwards to the calcareous shales of the flysch complex which are 77m thick grey-green in colour in the lower part and red in the upper part. They pass upwards to 35m thick grey shales intercalated with sandstone beds which in their turn are overlain by 10m thick sandstone beds (Fig.3).

SEQUENCE STRATIGRAPHY

The depositional model represents a carbonate platform that gradually became submerged owing to a eustatic rise in sea-level, beginning during the Campanian. However, a study of the sedimentary facies revealed several intermittent events that permitted a reconstruction of the relative sea level curve. In these terms every unit corresponds to the relative sea level trend (rise or fall) differing from that of the underlying or overlying units (van Steenwinkel, 1990). A eustatic rise in sea level inducing the landward shift of a nutrient-rich Tethyan current-system seems to have caused the subsidence of the platform in combination with the local movements (horst and graben tectonism, Richter & Mariolakos, 1974).

In terms of the sequence stratigraphy concept recently recognized (Brett et al., 1990; van Steenwinkel, 1990), the Prossilion section from base to top corresponds to the following systems tracts (Fig.2):

(a) a shallow-water, gradually deepening, main "Lowstand" System Tract (LST2), where the Campanian-Maastrichtian foraminiferal wackestones-packstones were deposited (pelagic sedimentation).

(b) a condensed section (CD), reflecting very low sedimentation rates and progradation due to a rapid fall in sea-level, (Upper Maastrichtian)

(c) a non-deposition interval during which hardgrounds developed, the sea floor being periodically exposed (SB: Sequence Boundary),

(d) a shallow-water retrogradation corresponding to the base of the "Lowstand" System Tract (LST1) during which stromatolites developed (Early-Middle Paleocene).

(e) a slow deepening (condensed sedimentation) during which the first sediments of the clastic series were deposited (Late Paleocene),

(f) a gradually deepening corresponding to the Transgressive System Tract (TST), where the red marls were deposited (Early Eocene) and

(g) a deeper water retrogradational, aggradational or periodically slightly progradational, Highstand System Tract (HST), during which a shale-siltstone-sandstone system related to turbidite current action, was deposited (flysch).

The lower part of the section corresponds to a lowstand transgressive system tract (RLS: relative lowstands) and consists at the base of rudist-bearing limestones (LST 1) overlain by pelagic facies (LST 2), while the upper part corresponds to a highstand system tract (RHS: relative highstands) during which flysch sedimentation took place.

Several small discontinuities recorded in the lower pelagic interval represent sea level drop surfaces (SDS) in a generally shallow-retrogradational-transgressive system tract. The red marine shales included in the flysch complex correspond to an early relative highstand (TST) that grades upwards into interbedded siltstones and sandstones, (late highstand), during which deep-water conditions were

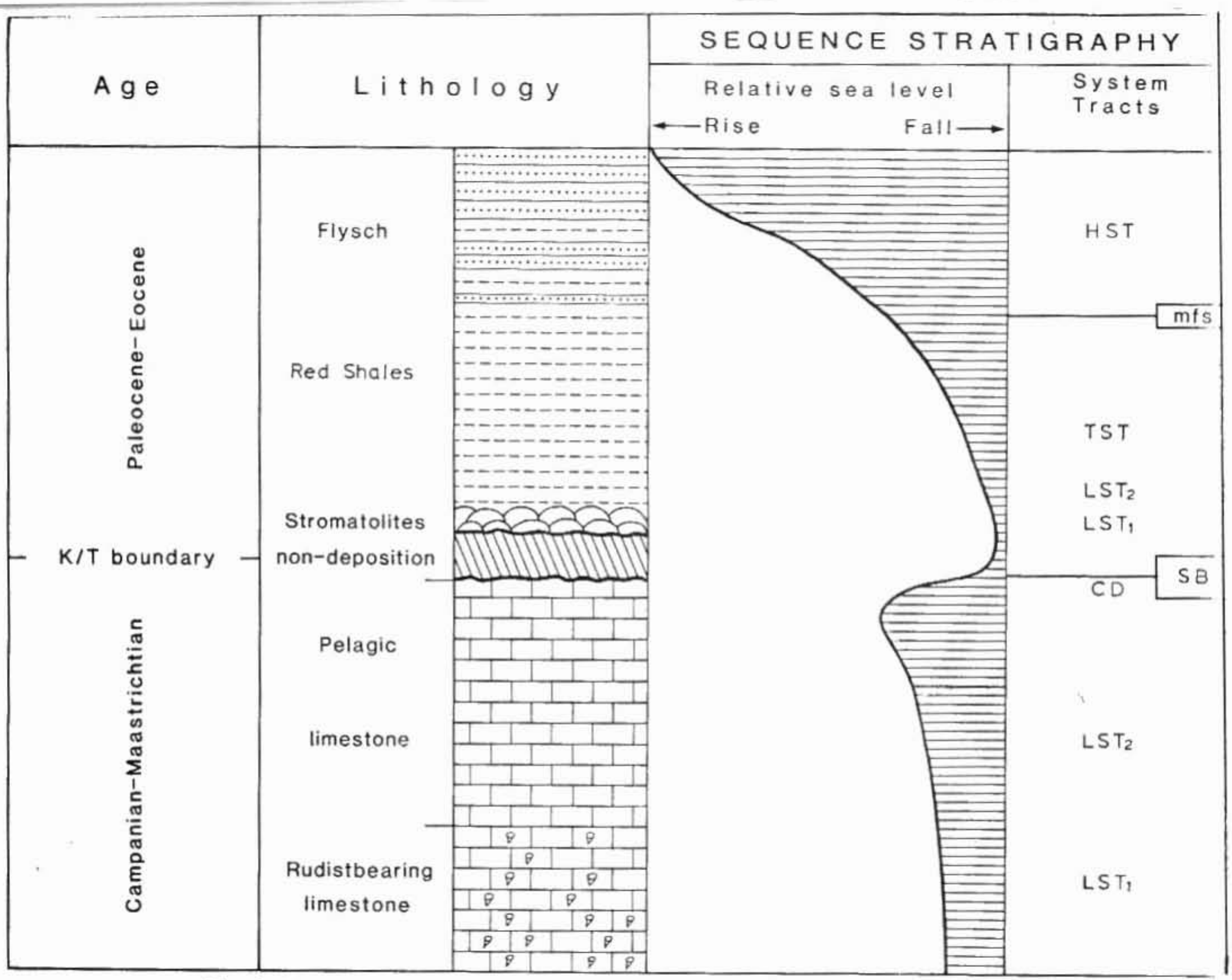

Fig.2: Sequence stratigraphy of the Campanian-Lower Eocene sedimentary beds at P[illegible]ransgressive System Tract. LST1: The base of the "Lowstand" System Tract. LST2: The main "Lowstand" System Tract. SB: Sequence boundary. CD: condensed section, mfs: maximum flooding surface.

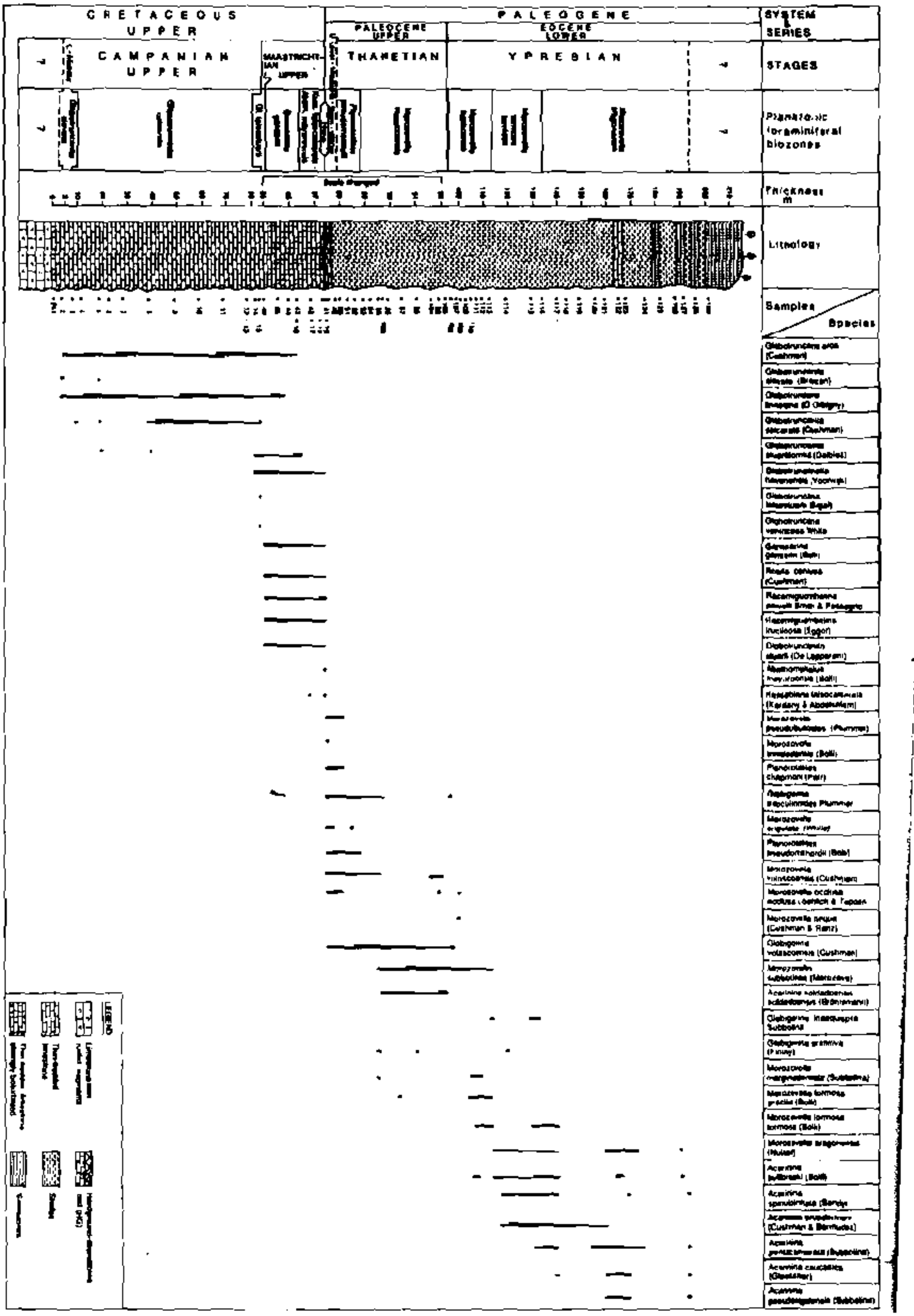

Fig.3: Biozonation and stratigraphical distribution of the most important planktonic foraminiferal species recorded in the sequence examined.

established (HST). The boundary between the shales and the flysch represents the maximum flooding surface (mfs) (Fig.2).

The boundary between the lower shallow-water transgressive system tract and the overlying highstand water facies of the shales and the flysch system is represented by a surface of non-deposition, caused a rapid fall in sea level, which resulted in a period of exposure.

BIOSTRATIGRAPHY

Both planktonic and benthic species of foraminifera are recorded in the sequence. The planktonic species only have been treated since they are of significance for biostratigraphic zonation (Fig.3). The zones distinguished are previously known biozones that are well-established in the Upper Cretaceous and Paleogene of the Tethyan realm. The biozones recognized in the carbonate part of the succession are thin-section biozones and are based on the first appearance of the index species for the zone which is not always present in all of the beds. The zones distinguished in the flysch are the total range and interval zones that are recognized for the Paleocene and Eocene (Toumarkine & Luterbacher, 1985).

The limestone beds

The foraminiferal assemblages in the limestone beds are sparse except in the upper part where they are abundant. The species are identified on the basis of two-dimensional views because they are examined in thin-sections and the zones presented here are thus thin-section biozones. They are as follows (from below upwards, Fig.3):

Campanian

The *Clobotruncanita elevata* Zone
Samples 2 and 3, Fig.3.
Author: Postuma (1971). Partial range zone extending through the Lower Campanian to the lower Upper Campanian.

This zone is defined in the sequence by the first occurrence of *Globotruncanita elevata* (Brotzen) and the first occurrence of *Globotruncanita calcarata* (Cushman), *Bicarinella asymetrica* (Sigal) which by its disappearance marks the lower boundary of the zone (Caron, 1985), has not been found in the beds indicating that the planktonic foraminifera made their first appearance in the Prossilion area after the beginning of the Campanian; the lower boundary must therefore lie within the underlying limestone beds with rudist fragments. The *Globotruncana ventricosa* Zone, which is intermediate between the *Globotruncanita elevata* and *Globotruncanita calcarata* Zones (Robaszynski et al., 1984; Caron, 1985), could not be distinguished since the zone marker is absent in this part of the succesion. Other planktonic species identified in the *Globotruncanita elevata* Zone are *Globotruncana arca* (Cushman) and *Globotruncana linneiana* (D'Orbigny).

The *Globotruncanita calcarata* Zone
Samples 3 to 15, Fig.3.
Author: Herm (1962)

Total range zone restricted to the upper part of the Upper Campanian. This zone is defined on the total range of *Globotruncanita calcarata* (Cushman). The marker species is associated' with *Globotruncana arca*, *Globotruncanita elevata*, which occurs only in the lower part of the zone, *Globotruncana linneiana* and *Globotruncanita stuartiformis* (Dalbiez).

Maastrichtian

The *Globotruncana falsostuarti* Zone

Samples 15 and 46, Fig.3.
Authors: Zone equivalent to the *Globotruncana falsostuarti* Zone in the sense of Salaj & Samuel (1966) and Robaszynski et.al., (1984). Interval zone extending throughout the Lower Maastrichtian.

The *Globotruncana falsostuarti* Zone is the first zone in the Maastrichtian and represents the interval marked by the first occurrence of *Globotruncana falsostuarti* Sigal and the first occurrence of *Gansserina gansseri* (Bolli). Other important species found in this zone are *Globotruncanita stuartiformis, Globotruncana arca, Globotruncana ventricosa White* and *Globotruncanella havanensis* (Voorwijk).

The *Gansserina gansseri* Zone

Samples 46 and 43, Fig.3.
Author: Bronnimann (1952). Interval zone marking the lower part of the Upper Maastrichtian.

This zone is defined by the first occurrence of *Gansserina gansseri* (Bolli) and the first occurrence of *Abathomphalus mayaroensis* (Bolli). In the *Gansserina gansseri* zone planktonic foraminiferal species such as *Rosita contusa* (Cushman), *Racemiguembelina powelli* Smith & Pessagno, *Racemiguembelina fructicosa* (Egger), *Globotruncanella havanensis, Globotruncanita stuarti* (De Lapparent) and other significant species were identified.

The *Abathomphalus mayaroensis-Kassabiana falsocalcarata* Zones

Samples 43-41, Fig. 3.
Authors: For the *Abathomphalus mayaroensis* Zone Bronnimann (1952) and for *Kassabiana falsocalcarata* Zone Kassab (1976).

The *Abathomphalus mayaroensis* Zone was originally defined as a total range zone. However the presence of *Kassabiana falsocalcarata* throughout the upper part of the *Abathomphalus mayaroensis* Zone makes this an interval zone and the *Kassabiana falsocalcarata* Zone to a total range zone.

The two zones together form the last interval of the Maastrichtian at the top of the carbonate succesion since the zone markers appear together in the sediments; the upper part of the Prossilion sequence being characterized by a condensed sequence. The lower boundary of the zones is defined by the presence of *Abathomphalus mayaroensis* and *Kassabiana falsocalcarata* and the upper boundary by the discontinuity surface and the presence of upper Lower Paleocene species within the hardground-stromatolitic bed. Apart of the zone markers *Cansserina gansseri, Globotruncanella havanensis, Racemiguembelina powelli, Racemiguembelina fructicosa, Rosita contusa, Globotruncanita stuarti* also occur. The occurrence of upper Lower Paleocene species in the stromatolitic bed indicates the presence of a hiatus between the limestone and the stromatolitic bed (Fig.3).

The hardground-stromatolitic foraminiferal interval

Sample 41, Fig.3. Upper Lower-Middle Paleocene.

Previous studies made on the transition from the carbonate to the flysch facies of this sequence (Solakius et al., in press) indicated that the foraminiferal assemblages found within the hardground-stromatolitic bed belong to the upper Lower Paleocene and the Middle Paleocene and that there was an interruption in deposition beginning at the end of the Maastrichtian and extending throughout the earlier part of the Early Paleocene. This conclusion is based on the presence of biostratigraphically significant Paleocene species such as *Morozovella pseudobulloides* (Plummer), *Globigerina triloculinoides* Plummer, *Planorotalites chapmani* (Parr), *Morozovella angulata* (White) and *Planorotalites pussila pussila* (Bolli). Lower Paleocene species such as *Globigerina fringa* Subbotina, *Globigerina eugubina* Luterbacher & Premoli-Silva and *Globoconusa daubjergensis* (Bronnimann) have not been recorded in the bed indicating that there was no deposition in the area during this interval. The hardground-stromatolitic bed is c. 25cm thick which indicates that the stromatolitic bed developed slowly and the fauna found in the bed is of different ages.

The flysch deposits

The foraminiferal assemblages recorded in the clastic sediments of the sequence are abundant and diversified except in the uppermost part (sandstone beds) where the planktonic foraminifera are entirely lacking. The few agglutinated foraminifera found in these beds will be treated in a forthcoming paper. Only the most significant planktonic species were examined on the basis of which the following biostratigraphic zones were distinguished.

Upper Paleocene

The *Planorotalites pseudomenardii* Zone
Samples 49-53, Fig.3.
Author: Bolli (1957a). Total range Zone occurring in the lower part of the Upper Paleocene.

In our sequence the *Planorotalites pseudomenardii* zone is the interval defined by the total range of the species *Planorotalites pseudomenardii* (Bolli), *Globigerina triloculinoides, Morozovella angulata, Morozovella occlusa occlusa* Loeblich & Tappan, *Planorotalites champani,* and *Morozovella velascoensis* (Cushman) also occur.

The *Morozovella velascoensis* Zone
Samples 53-105, Fig.3.
Author: Bolli (1957a). Interval zone occurring in the uppermost Paleocene.

This zone is defined by the last occurrence of *Planorotalites pseudomenardii* (Bolli) and the last occurrence of *Morozovella velascoensis* (Cushman). Several planktonic species made their first appearance e.g. *Morozovella subbotinae* (Morozova), *Acarinina soldadoensis soldadoensis* (Bronnimann), *Morozovella formosa gracilis* (Bolli) and *Morozovella marginodentata* (Subbotina).

Lower Eocene

The *Morozovella subbotinae* Zone
Samples 106-113, Fig.3.
Authors: The name *Globorotalia subbotinae* Zone has been used by the Soviet authors (Anonymous, 1963); the zone was later defined by Luterbacher & Premoli Silva (in Caro et al.,1975). Interval zone marking the lower part of the Lower Eocene.

This zone is defined by the last occurrence of *Morozovella velascoensis* (Cushman) and the first occurrence of *Morozovella aragonensis* (Nuttall). However, the Lower Eocene *Morozovella edgari* Zone could not be distinguished since few specimens of *Morozovella aff. edgari* (Premoli-Silva & Bolli) have been identified are few and these are poorly preserved. The other species found in the *Morozovella subbotinae* Zone are *Morozovella marginodentata, Acarinina* *soldadoensis soldadoensis, Morozovella formosa gracilis* and *Morozovella formosa formosa* (Bolli).

The *Morozovella formosa formosa* Zone
Samples 113-116, Fig.3.
Authors: Beckman et al. (1969). Interval zone occurring in the Lower Eocene.

This interval zone is defined by the first occurrence of *Morozovella aragonensis* (Nuttall) and the first occurence of *Acarinina pentacamerata* (Subbotina). Apart from *Morozovella formosa formosa* (Bolli), also the species *Morozovella formosa gracilis, Globigerina inequispira Subbotina, Acarinina bullbrooki* (Bolli), *Acarinina spinuloinflata* (Bandy), *Acarinina broedermani* (Cushman & Bermudez) and *Morozovella aragonensis* are present.

The *Morozovella aragonensis* Zone
Samples 116 and 117, Fig.3.
Author: Bolli (1957a). Interval zone, Lower Eocene. The interval distinguished by the first cooccurrence of *Acarinina pentacamerata* (Subbotina) and the first occurrence of *Turborotalia cerroazulensis frontosa* (Subbotina) or *Planorotalites palmerae* (Cushman & Bermudez). There is no upper boundary since the zone-markers *Turborotalia cerroazuinsis frontosa* or *Planorotalites palmerae* were not found. The most significant species are *Morozovella aragonensis, Morozovella caucasica* (Glaesner), *Acarinina pentacamerata* and *Acarinina pseudotopilensis* (Subbotina).

CONCLUDING REMARKS

Analysis has shown that the sediments of the Prossilion sequence were deposited during the Late Cretaceous and Early Tertiary. The deposition was, however, not continuous and the rate of sedimentation varied considerably because of changes in sea level.

The presence of the *Globotruncanita elevata* Zone in the lower part of the pelagic limestone shows that the change from the neritic to pelagic facies took place during the Campanian. The rate of sedimenation was low as seen by the 7m thick beds included in this zone (Fig.3). However, since the lower boundary of the zone has not been found and the *Globotruncanita elevata* Zone is extended here to include the Middle Campanian (the Middle Campanian *Globotruncana ventricosa* Zone culd not distinguished here because of the lack of the index species), it is difficult to determine whether sedimentation began in the Lower of Middle Campanian. During the Late Campanian the sea became deeper and a thick sequence was deposited.

This 75m thick carbonate sequence (included in the *Globotruncanita calcarata* Zone) may indicate a gradual increase of the relative sea-level rise rate In terms of sequence stratigraphy this unit corresponds to the main "Lowstand" System Tract (LST2). Thin beds (2,5m) marked by the Lower Maastrichtian *Globotruncana falsostuarti* Zone may indicate that during the slow deepening of the basin a short period intervened showing a shallow-upward tendency and resulting in condensed sedimentation. This assumption suggests that the Campanian transgression was followed by a regression in the Lower Maastrichtian.

The low rate of sedimentation appeared throughout the Lower Maastrichtian continued also in the Upper Maastrichtian, as it is shown by the thickness of the beds included in the Upper Maastrichtian *Gansserina gansseri* and *Abathomphalus mayaroensis - Kassabiana falsocalcarata* Zones which are no more than 2,5m thick. (condensed sedimentation).

At the end of the Maastrichtian, a sudden fall of sea-level occured, followed by an interruption of sedimentation and periodical local sub aerial exposure. The above event may be is attributed to the "horst and graben" type tectonism of the area probably combined with eustatism . The regression culminated in a break of deposition which extended through the lowermost Paleocene, since the area became exposed. A hardground was developed subsequently on top of the carbonate sequence (CD: Condensed Sequence).

During the upper Lower Paleocene stromatolites appeared above this discontinuity surface. This stromatolitic facies which followed after a long break, continued to exist until the Upper Paleocene where the first clastic beds were deposided. Thus, the development of the stromatolitic bed was formed during the upper Lower and Middle Paleocene. The stromatolitic horizon indicate a new cycle of sea-level rise and in terms of sequence stratigraphy the unit corresponds to the base of the "Lowstand" System Tract (LST1).

The first sediments of the clastic series were deposited during the Upper Paleocene as is shown by the presence of the Upper Paleocene index species *Planorotalites pseudomenardii* and other Upper Paleocene species (Fig. 3). However, the beds included in the Upper Paleoecene *Planorotalites pseudomenardii* and *Morozovella velascoensis* Zone are only 6m thick indicating that during the Paleocene transgression the rate of sedimentation was low (condensed sedimentation). This unit corresponds to the main "Lowstand" System Tract (LST2). The facies towards the top correspond to greater depths.

The deposition of the clastic sediments reached its maximum in the Lower Eocene, when a thick sequence consisting of red shales occurred. This is the main transgression of Lower Eocene and corresponds to the Transgressive System Tract (TST). Towards the top the depth and the rate of sea-level rise increase. The top of the unit marks the maximum flooding surface (mfs). The subsequent deposition of sandstone /shale alternation overlain by sandstone beds (last 10m), clearly indicate a gradual prograding towards the sequence top. Progradation may be is due to an increasing sedimentation rate, that overwhelmed the relative sea-level rise rate. In terms of sequence stratigraphy the last unit corresponds to the Highstand Systems Tract (HST). In this classic sequence, the Lower Eocene biozones recognized, included beds of considerable thickness (Fig.3).

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