The "Cantera de Margas" section, Olazagutia, northern Spain. A candidate GSSP for the base of the Santonian Stage: its stratigraphy across the Coniacian–Santonian transition.

Marcos A. Lamolda (compiled) and the Santonian Working Group
Departamento de Estratigrafía y Paleontología, Universidad de Granada, Spain. mlamolda@ugr.es

with contributions from: Jaume Gallemí, Jana Ion, Gregori López, Ludmila F. Kopaevich, Ricard Martínez, Mihaela C. Melinte, Christopher R.C. Paul, Danuta Peryt, Jose Maria Pons, Seiichi Toshimitsu, and Elena Jagt-Yazykova.

The FO of the inoceramid *Platyceramus undulatoplicatus* in the eastern border of the "Cantera de Margas", Olazagutia, northern Spain, was selected by the Santonian Working Group as GSSP for the base of the Santonian Stage, in November 2007. As it was circulated on December 14th, 2007, the Olazagutia section was selected with 24 favorable votes (Ten Mile Creek got 6 votes; Abstain: 4 votes, and 1 negative vote for both candidates), in total 35 persons returned ballot-paper on time (2 votes where sent later that the dead-line). These 35 delivered valid votes are around 73% of all possible votes (48). The 24 favorable votes received by Olazagutia are around 68% of valid votes (35). In both cases these figures are more than 60% required for a quorum and a valid decision, respectively. Following the procedures of the International Commission on Stratigraphy, we have produced this proposal for the consideration of the International Subcommission on Cretaceous Stratigraphy.

1. Historical

The Santonian Stage was proposed by Coquand (1857), presumably named after the town of Saintes in south-west France. One of the localities which Coquand mentioned was Javrezac, a village on the north-west side of Cognac. The boundary there was drawn on a hardground between glauconitic, nodular limestone, with many *Exogyra* of the Coniacian below, and soft micaceous chalk of the Santonian above.

At the First Symposium on Cretaceous Stage Boundaries (Birkelund et al. 1984) the consensus was that the first appearance of *Texanites* (*Texanites*) and of *Cladoceramus* (=*Platyceramus*) *undulatoplicatus* (Roemer) are the two best boundary criteria. *Texanites* (*Texanites*) has been used over a wide area, although in classic regions of north-west Europe this subgenus is far too rare to be a practical marker (Hancock, 1991). *Platyceramus undulatoplicatus* is widespread, and owing to its characteristic form and sculpture is easy to determine. The appearance of *Platyceramus siccensis* (Pervinquière) is well known in N. Africa associated with *Texanites*, and it could be another possible marker for the base of the Santonian.

In the Santonian Working Group report to the IInd Symposium on Cretaceous Stage Boundaries other macro- and microfossils were mentioned as possible indices for the Coniacian-Santonian Boundary.

Thus, the lowest occurrence of the ammonite *Placenticeras polyopsis* (Dujardin) is relatively close to lower *Texanites* (*Texanites*). Similarly, the entry of the *Sphenoceramus pachti-cardissoides* group is a possible marker for this boundary, associated with *Texanites* and *Platyceramus undulatoplicatus*. Further discussion on macrofossil criteria were reported by W.J. Kennedy (1995).

Published calcareous nannofossil events do not precisely define the Coniacian-Santonian boundary [CSB], which Sissingh (1977) placed in CC14 (above the first occurrence (F.O.) of *Micula staurophora* (Gardet) Stradner). For example, the FO of *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen is unreliable (Wagreich, 1992), and recent studies (e.g., at Ten Mile Creek; Burnett, written comm.) show, however, that this event [the CSB] actually lies above the F.O. of *Reinhardtites anthophorus* (i.e. in CC15 of Sissingh, 1977). Nannofossil events which approximate the boundary are (from stratigraphically old to young): F.O. of *Lithrastrinus grillii* Stradner, last occurrence (L.O.) of *Quadrum gartneri* Prins & Perch-Nielsen, L.O. of *Flabellites oblongus* (Bukry) Crux (all below the boundary) and the L.O. of *Lithrastrinus septenarius* Forchheimer above the boundary. All these events fall within CC15. Other nannofossil events, such as the L.O. of *Eprolithus floralis* (Stradner) Stover, and F.O. of *Micula concava* (Stradner) Verbeek occur later or earlier than the entries of *Texanites* and *Platyceramus undulatoplicatus*. Nevertheless, Flores et al. (1987) commented that *Micula concava* and *Lithrastrinus grillii* are present in greater abundances in the Santonian than in the Coniacian, and this may serve as a general guide, although nannofossil abundance is related to ecological and taphonomical factors which are generally not cosmopolitan in their extent.

First occurrences of the planktonic foraminifera *Sigalia deflaensis* (Sigal) and *Sigalia carpatica* Salaj have been used as markers of the latest Coniacian and the Coniacian-Santonian Boundary (Salaj, 1975; Sigal, 1977, respectively). Also, the first occurrence of *Dicarinella asymetrica* (Sigal), belonging to the *Dicarinella concavata* group, dates the early Santonian, since it post-dated the lower *Texanites* and *Platyceramus undulatoplicatus*. Successive occurrences of *Sigalia deflaensis, Sigalia carpatica and Dicarinella asymetrica* are very promising for correlation with macrofaunal ranges, and a definition of the Coniacian-Santonian Boundary.

Boundary criteria proposed at Copenhagen, and other ones mentioned in the Working Group reports, were discussed at Brussels during the 2nd Symposium in 1995.

1.1. Criteria proposed for the Coniacian-Santonian boundary (Lamolda and Hancock, 1996)

1) F.O. of *Texanites* (*Texanites*)
2) F.O. of *Sigalia carpatica*
3) F.O. of *Dicarinella asymetrica*
4) F.O. of *Platyceramus siccensis*
5) F.O. of *Platyceramus undulatoplicatus*
6) F.O. of *Sphenoceramus pachti*

No nannofossil event was considered suitable for the Coniacian-Santonian boundary

1.2. Selected marker for the Coniacian-Santonian boundary

Primary marker: The lowest occurrence of *Platyceramus undulatoplicatus* (Roemer). It is an easily recognisable and widespread taxon. It is known from N. America, Europe, Africa, Madagascar, and Central Asia.

This proposal was supported by a majority at Brussels. (Yes=23; No=1; Abstentions=2)

Postal votes: 20 votes (out of 39 WG members) were returned (Yes= 17; No= 1; Abstentions=2).

Secondary marker: The FO of *Sigalia carpatica*. This planktonic foraminiferan is widespread in the Mediterranean Region of the Tethys. It is associated with

Inoceramus siccensis and *Texanites* in Tunisia. In north Spain (Navarra) it is very close to the lowest occurrence of *Platyceramus undulatoplicatus*.

This secondary marker has been supported by a postal ballot (Yes=10; No=3; Abstentions=7).

Some voting members emphasized the usefulness of other planktonic foraminiferan (D. Herm) and the convenience of benthic forms as secondary markers in the Boreal Realm (L. Kopaevich).

1.3. Rejected

Texanites (*Texanites*). Its first occurrence is below the lowest *Platyceramus undulatoplicatus*. It has been cited in assemblage with inoceramids normally regarded as Coniacian.

Dicarinella asymetrica. Its first appearance is above the lowest *Sigalia carpatica*, and therefore is not suitable to characterize the Coniacian-Santonian boundary. It is restricted to basinal facies.

Platyceramus siccensis. Only known from N. Africa, although it may be correlated with other areas through the lowest *S. carpatica*.

Sphenoceramus pachti. It is a boreal species, rare at middle latitudes and unknown in palaeotropics (Tethys).

1.4. Boundary Stratotype Section

At that time we could not make a formal proposal, because we needed to know and integrate the biostratigraphy better.

We selected three candidates:

1) Olazagutia Quarry (Navarra, Spain). Prof. Lamolda would collate data and report to the Chairman.

2) Seaford Head (Sussex, England). Dr. Mortimore and Mr. Wood would collate data and report to the Chairman.

3) Ten Mile Creek (Dallas, Texas). Prof. Kauffman and Dr. Gale would collate data and report to the Chairman.

This proposal was approved UNANIMOUSLY. (Yes=34; No=0; Abstentions=0)

The postal ballot also supported this porposal (Yes=18, No=1, Abstentions=1).

Dr. J. Salaj sent a new proposal for the C/S boundary stratotype in the El Kef Area, in Tunisia, whose fossil content is cited above elsewhere. Ch. Colom sent a proposal for this boundary stratotype in the Boreal Province; several sections are located at the Smoky River, Bad Heart River and Tipper's Coulee, all of them in west-central Alberta (Canada), having a very rich fossil content. Also, Dr. L. Kopaevich has proposed a section at Emdy-Kurgan, Eastern Boreal Europe, which is being studied by Naidin, Kopaevich and Gale.

2. The workshop at Bilbao, September 2002

Seven year after the Brussels meeting, the Santonian Working Group (SWG) met at Bilbao and visited both Olazagutia and Villamartin localities. Below are reproduced some excepts of the report produced by late Dr. Annie V. Dhondt, vice-chairperson of the ISCS (the full report was circulated to SWG members, and is available at the website: http://www.ugr.es/~mlamolda/swg/report.html)

> *"On Saturday, September 14, we travelled to Olazagutia. In the Cementos Portland quarry (Cantera de Margas) at Olazagutia (Navarra) two sides of the quarry were studied by the group, but more time was spent on the east side. M. Lamolda, J. Gallemi, G. Lopez, R. Martinez, J.M. Pons and C.R.C. Paul explained the results of their work on the quarry below and above the level of the Coniacian/Santonian boundary. Among the macrofossils found while our group was studying the eastern side mainly echinoids and magnificent inoceramids should be mentioned. The condition of the outcrop was not ideal but the indications of the excursion leaders were thorough and the various levels were clearly marked."*
>
> *"On Monday, September 16 we had scientific sessions: Jake Hancock gave an introductory lecture on "Some Coniacian-Santonian boundary sections in the USA" explaining amongst other things why the Texan locality Ten Mile Creek near Dallas mentioned in Brussels (1995) as a possible candidate for the Coniacian-Santonian boundary is not completely satisfactory."*
>
> *"The last item on the scientific agenda concerned the suitability of Olazagutia as a possible boundary stratotype. Long discussions stressing positive and negative aspects of the quarry followed."*
>
> *"On the negative side the discussion mainly stressed the fact that the Olazagutia section is situated in a working quarry and that the ammonite fauna is poor. The first aspect means that its accessibility in the present circumstances is not fully guaranteed. The lack of ammonites means that the correlation on macrofossils towards other regions can best be based on inoceramids and echinoids."*
>
> *"On the positive side it was mentioned several times that the micropalaeontological data on the section are well studied including nannofossils, foraminifers (both planktonic and benthic), and that stable isotope data exist. Also*

the inoceramid Cladoceramus undulatoplicatus occurs fairly commonly thus making it possibly to locate the Coniacian/ Santonian boundary fairly precisely."
"It was proposed by several participants that other sections should be designated – or in case this is not possible according to the ICS rules to add a "para boundary stratotype" f.i. at Villamartin. The alternative sections studied in the same area were shown to be either not better because situated in sediments with poor microfauna or to be less studied."
"It was finally agreed upon by the participants to the meeting that the Olazagutia section could be chosen among the three possible candidates for the Coniacian-Santonian boundary stratotype designated in Brussels (1995)."
"For the immediate future our Spanish colleagues agreed to prepare a very detailed description of the eastern side of the Olazagutia quarry as it is today and to publish this, possibly in Cretaceous Research. This description can also be used for submission first to the members of the WG and then to the voting members of the Cretaceous Subcommission, even if for this report to the Subcommission and to the ICS some aspects must be added (such as the comparison to other similar sections)."
"It was stressed and agreed upon that beyond the agreement with the present quarry owners a complete protection of the geological site should be obtained if possible by the authorities of the region (Navarra). According to the Spanish participants, laws existing in Spain make this possible."

2.1. Post-workshop

On September 21, 2002, Jake Hancock wrote a letter to Marcos Lamolda in which he gave his support to the Olazagutia section, remarking that it would be a permanent and accessible site for researchers. Other members of the SWG mailed to this Chairman their support for the Olazagutia section as the best GSSP for the base of the Santonian.

M. Lamolda subsequently contacted the Geological Survey of Spain (Instituto Geológico y Minero de España), the Navarran Regional Government and the owner of the Cantera de Margas, asking them to prepare an agreement that would enable preservation of the section on the eastern side of the quarry and allow access to it for research purposes. Eventually, all parties agreed to support both preservation and accessibility. The Director of the Olazagutia factory, Portland Valderrivas, sent a letter to this Chairman with the formal agreement of the quarry owner, on March 26th, 2007 (a copy was sent to Prof. Isabella Premoli-Silva, Chairperson of the ISCS)

The Olazagutia section was mentioned in the ICS annual report for 2002: "*Santonian: The Olazagutia section near Bilbao (Spain) is the leading candidate for the GSSP section*", as well as in the Minutes of the 51st Executive Committee Meeting of the IUGS, 2003.

2.2. Results and comment on the Coniacian-Santonian transition

Results on the three candidates have been published in a special issue of Cretaceous Research "*Stratigraphy of the Coniacian–Santonian transition*", vol. 28 no. 1 (most of contributions had been completed in their final version in 2003), and a recent one is on line since late June in Acta Geological Polonica (see References for all of them).

The locality of Seaford Head, southern England, is no longer a candidate GSSP for the base of the Santonian. In fact, Hampton et al. (2007, p. 47) wrote:

> *"The Seaford Head sea-cliff section is being proposed herein as providing international reference sections in chalk facies for the basal boundaries of the Santonian and Campanian stages; these sections are not to be regarded as candidate GSSPs (Global Basal Boundary Stratotype sections and Points) for the two stages concerned."*

therefore, two candidates remain: Olazagutia (northern Spain) and Ten Mile Creek (Texas, USA).

2.2.1. The opinions of Howe et al. (2007)

These authors present a study on the three candidates (Olazagutia, Seaford Head and Ten Mile Creek), by means of both foraminifers and nannoplankton, with a comparison between them. Both the Olazagutia and Ten Mile Creek sections Hill be discussed here.

Sections studied in both localities are only a part of the whole section, 8.65 m thick in Ten Mile Creek (TMC), and 14 m in Olazagutia. In both cases, the FO of *P. undulatoplicatus* is located more or less in the middle of each section studied. As a complement to the Santonian part, they have studied three partial sections in Arbor Park, around 34.5 km north-norhwestwards TMC, which add about 9 m more above the top of the TMC section. They identified two uncorformities in Arbor Park, at around 11.5 and 12.5 m height in the composite section (Howe et al., fig. 12).

Howe *et al.* suggested that the primary biomarker for this boundary, the FO of the inoceramid bivalve, *Platyceramus undulatoplicatus*, occurred later at Olazagutia, Spain than at Ten Mile Creek, Texas based on other nannofossil and foraminiferal evidence. If one accepts that the micro- and nanno-fossil bioevents are reliable time planes, then the bivalve bioevent is diachronous. However, if one accepts that the bivalve bioevent is a good time plane, the micro- and nanno-fossil events are diachronous. This is a common problem in biostratigraphy, and to decide between alternatives, it is necessary to use an independent and accurate reference system, such as chemostratigraphy, carbon stable isotopes in this case (Paul and Lamolda, 2008). Howe et al.'s proposal is wrong as demonstrated below (see "Comparison between Olazagutia and Ten Mile Creek sections).

Howe et al., p.79, argued for palaeoecological control on the FO of *P. undulatoplicatus* at Olazagutia:

> *"The middle Olazagutia biofacies probably marks the culmination of an increase in productivity first indicated by the upsection increase in benthic foraminiferal abundance noted in the lower part of the section."*
> *"A stratigraphic concern raised by this biofacies analysis is the implication that the first occurrence of inoceramids in the Olazagutia section is palaeoenvironmentally controlled. If so, the first appearance in this section of* Cladoceramus undulatoplicatus*, the recommended boundary datum for the Coniacian/Santonian boundary, is unlikely to represent the evolutionary appearance of the species."*

but the same argument may be used on TMC, too (Howe et al., p. 86):

> *"Up-section from this interval, the Ten Mile Creek foraminifera exhibit a pattern of increasing relative abundance of* Whiteinella *among planktonic species and of* Planulina *in the benthic assemblage. Initially, in the +3.79 to +4.95 m part of the section that straddles the Coniacian/Santonian boundary, diversity of both assemblages rises. This probably reflects an increase in productivity and organic flux to the benthos as indicated by the lowest occurrence of benthic species known as eutrophic opportunists, including* Neobulimina irregularis *and* Planulina texana*, plus increased abundance of the previously rare* Nonionella austinana *and* Planulina austinana*."*
> *"It may be not be coincidental that the lowest occurrence of* Cladoceramus undulatoplicatu*s is accompanied by microfossil evidence of increased oceanic productivity in such widely separated locales as the Olazagutia and Ten Mile Creek sections. If such admittedly limited evidence is indicative of a global increase in oceanic productivity at this time, one response could have been the evolution of the first very large, "platter-like" inoceramid bivalves. Such a change could have been initiated by a climatic cooling that would have increased oceanic circulation and turnover rates."*

In fact, it is well known that a turn-over of planktonic and benthic foraminifers occurs across the Coniacian-Santonian transition, together with other fossil groups. It is a general characteristic, not exclusive to Olazagutia. Therefore their proposal that this weakens the case for one candidate section, but not the other is inconsistent.

2.2.2. Comments on the Ten Mile Creek section (Gale et al., 2007)

These authors proposed the section of Ten Mile Creek, near the WalMart store, Dallas, Texas, 23 m thick, which crops out in both sides and the floor of the river. The

FO of *P. undulatoplicatus* is located at 18.4 m, within an interval between 11 and 21 m, which "*comprise poorly defined beds of marl and marly limestone, containing oyster and inoceramid bivalves at some levels"* (p. 120). "*.. and the section can be easily worked when the water level is low*" (p. 118).

To complete the WalMart (WM) section, the authors proposed the Nazarene section, about 4 km northwestwards of WM, which is thrusted. After Gale et al. (p. 116): "*The section comprises cutting in the sides and floor of Ten Mile Creek…Access to the lower section is only possible when the water level is low, and requires some shallow wading."* The thrust subdivides the section into Nazarene 1, dated late Coniacian, and Nazarene 2 which comprises the Coniacian-Santonian transition and the lowermost Santonian. An additional section was studied in Arbor Park, 34.5 km north-northeastwards of the WM section, dated early Santonian. It is not clear how many subsections are used to draw the Arbor Park section, but at least four are shown in their figure 5.

There are some differences between Gale et al. (2007) and Howe et al. (2007), in both the Ten Mile Creek and Arbor Park sections. In the former the thickness of exposures studied is quite different, although Gale et al. do not comment on it. The Arbor Park section is so different in both works that a correlation is not reliable, e.g., channels in the lower part after Gale et al. (pp. 115, 120), and two uncorformities in the middle part after Howe et al. (p. 89, fig. 12). Furthermore, the Arbor Park section after Gale et al. has no correlatable levels with the WM section, whereas Howe et al. proposed a continuity between the two localities.

2.2.2.1. Macrofauna (inoceramid information was extracted from Walaszczyk, in Gale et al. 2007)

The inoceramids from the WalMart section provide a representative record for the southern Euramerican biogeographical region (after terminology used by Kauffman, 1973), characterized by a *Magadiceramus*-dominated Upper Coniacian and a *Platyceramus*-rich Lower Santonian. Although the change to the *Platyceramus* fauna is quite rapid, the inoceramid succession appears to be complete. Most of the material from the WalMart section comes from four fossiliferous horizons (levels around 11 m, 17 m, 18.4-18.5 m and 22 m). Further details on inoceramid fauna are discussed in the subchapter 3.1., see below.

No other macrofauna is relevant to characterise the CSB, including ammonites. *Texanites* (*Texanites*) *gallicus* is the only widespread species, but it has a long stratigraphic range (from early late Coniacian to the middle part of the Santonian), see also the subchapter 3.2., below.

2.2.2.2. Planktonic Foraminifers (extracted from Petrizzo, in Gale et al. 2007)

In general, planktonic foraminifera are poorly to moderately preserved. In the large-sized fraction, marginotruncanids dominate the assemblages. The double-keeled globotruncanids are absent except for rare representatives of *Globotruncana arca* that occur in the upper part of the WalMart section, above the FO of the inoceramid *P. undulatoplicatus. Archaeoglobigerina* dominates the assemblages throughout the section accompanied by other globigeriniforms such as *Costellagerina* spp., which increase in number of specimens at the top of the section. *Dicarinella concavata* is present from the base of the studied stratigraphic interval. *Dicarinella asymetrica* has been found at the 6.1 m level in the Nazarene 1 section, and the species is consistently present from the 8 m level upwards.

The small-sized fraction is dominated by simple heterohelicids (*Heterohelix globulosa* and *H. reussi*) and *Laeviheterohelix. Pseudotextularia nuttalli* and *Pseudoguembelina costellifera* are consistently present. Complex heterohelicids (e.g. *Sigalia*) are totally absent and only rare representatives of *Ventilabrella austinana* occur in the upper part of the composite section above the FO of *Cl. undulatoplicatus*.

Based on the planktonic foraminiferal assemblages the stratigraphic interval from the first occurrence of *D. asymetrica* at the 6.1 m level in the Nazarene 1 section to the top of the composite section studied is assigned to the *Dicarinella asymetrica* Zone. Because of the absence of the *Sigalia* group, this interval cannot be further subdivided using the first appearance of *Sigalia carpathica*, a datum proposed as a secondary marker for the Coniacian/Santonian boundary during the Second International Symposium on Cretaceous Stage Boundaries (Lamolda & Hancock, 1996).
Further details on planktonic foraminifers are discussed in subchapter 3.3.1., see below.

2.2.2.3. Nannofossils (extracted from Lees, in Gale et al. 2007, p. 139; text-fig.4)

Calcareous nannofossils are a moderately abundant component of the overall sediment. Application of the biozonation was not straightforward in these sections, particularly in the middle part, the WalMart outcrop that includes the candidate GSSP. A number of LOs, one of them a biostratigraphical marker-event used in the UC biozonation, here lie above the levels indicated by Burnett (1998), in a different stratigraphical order. There is no clear indication from the data that these nannofossils are reworked, although they are rare and spasmodic in their stratigraphical distributions. Local palaeobiogeographical influences cannot be ruled out.

The oldest sample examined comes from the 0.4 m level in the Nazarene 1 section and lies within UC10, based on the presence of the marker *Micula staurophora* (= *M. decussata* of some authors), together with *Lucianorhabdus arcuatus* and *Rhagodiscus achlyostaurion*, the respective FO and LO of which Burnett (1998) showed to lie within this biozone. The next sample above this, from the 3.3 m level, contains rare *Lithastrinus grillii*, the marker for UC11a. The marker for UC11c, *Lucianorhabdus cayeuxii*, lies above this, at the 11.0 m level in the WalMart outcrop. This biozone is somewhat confirmed by the FOs of some taxa that Burnett (1998) indicated to lie within this zone, including *Micula concava* (at 18.35 m), *Amphizygus minimus* (at 21.2 m) and *Microrhabdulus undosus* (at 11.5 m).

At 23.0 m, at the top of the WalMart outcrop, *Lithastrinus septenarius* (= *L. moratus* of some authors) is still present, but is then absent from the lowest sample in the Nazarene 2 section (10.6 m). Thus, the base of UC12 lies at 10.6 m in Nazarene 2.

The FO of the boundary marker, the inoceramid *Platyceramus undulatoplicatus*, lies in the WalMart outcrop at the 18.4 m level, that is, within UC11c. This is consistent with the placement of the Coniacian/Santonian in this biozone by Burnett (1998). Consequently, the order of utilisable nannofossil occurrences around the boundary appears to be, with the most reliable emboldened (from youngest to oldest): **LO *L. septenarius* (base UC12),** FO *A. minimus* (within UC11c), FO *Cl. undulatoplicatus* (inoceramid; boundary marker), FO *M. concava* (within UC11c), **FO *L. cayeuxii* (base UC11c),** FO *L. grillii* (base UC11a), LO *R. achlyostaurion* (within UC10), FO *L. arcuatus* (within UC10), FO *M. staurophora* (base UC10).

Further details on nannofossils are discussed in the subchapter 3.5., see below.

2.2.2.4. Carbon Stable Isotopes (extracted from Gale, in Gale et al. 2007)

A positive excursion in $\delta^{13}C$ found between the 3 and 6 m level in the Nazarene 1 section represents the Kingsdown Event of Jarvis et *al*. (2006). Above this level, $\delta^{13}C$ values follow a declining trend through to the top of the WalMart section. This declining curve includes a number of short positive and negative excursions of less than 0.5 ppt $\delta^{13}C$. These are correlated with the K1, K2, Michel Dean and Bedwell Events in the southern England. The FO of *Platyceramus undulatoplicatus* thus falls 3.5 m below the correlative of the Michel Dean Event in southern England, and coincides with a minor negative event. The higher *P. undulatoplicatus* concentration identified in the Nazarene 2 and Arbor Park sections coincides with a minor positive $\delta^{13}C$ excursion that corresponds to the Bedwell Event in southern England (Jarvis et *al.* 2006), where it is also associated with a second, higher concentration of *P. undulatoplicatus*.

The identity and correlation of individual events can be confirmed using high-resolution inoceramid stratigraphy. A combination of carbon isotope stratigraphy and biostratigraphy enables transatlantic correlations in Coniacian and Santonian chalks at a resolution of one to several metres. This demonstrates that in both areas the first occurrence of *P. undulatoplicatus*, the boundary marker for the base of the Santonian Stage, corresponds to the minor negative excursion between the K2 and Mitchel Dean Events of Jarvis et *al.* (2006) and their Texan correlative.

Further details on carbon stable isotopes are discussed in the subchapter 3.6., see below.

2.2.3. <u>The "Cantera de Margas" (Olazagutia) section, selected candidate for the basal Santonian GSSP by the Santonian Working Group (ISCS) in November 2007.</u>
(content has been mainly extracted from: Lamolda and Paul, 2007; Melinte and Lamolda, 2002; Peryt and Lamolda, 2007)

The Olazagutia section is located in the Basque-Cantabrian Region (BCR) of northern Spain, to the west of the Pyrenees. During the Late Cretaceous the area around Olazagutia was a distal part of the Navarro-Cantabrian Platform, except in the Maastrichtian when it was a proximal ramp with shallow-water facies. The platform is subdivided by both longitudinal (NW-SE) and transverse (NE-SW) faults. In spite of local and/or temporary fluctuations, the platform remained typically an outer shelf environment where deposits are mainly fine pelitic sediments (Amiot et al., 1983; Wiedmann et al., 1983; Gallemi et al., 2007a).

In the area studied both Coniacian and Santonian stages consist of intercalated marls and marly limestones. The thickness of Coniacian strata is estimated to be 400-600 m (Ramírez del Pozo, 1971; Zander, 1988). Kannenberg (1985) estimated the thickness of the Santonian strata in the "Cantera de Margas" at Olazagutia to be about 230 m.

The section is located in a working quarry to the south of Olazagutia, Navarra, Spain (Fig. 1). Its geographical location is 42º 52.019'N, 2º 11.760'W; Lambert Coordinates 919, 722, 1:25000 topographic sheet no. 113-4 Olazagutia.

Further details on the general stratigraphy around Olazagutia are given by Küchler (2002). A general overview of Upper Cretaceous sequence stratigraphy of the BCR is given by Gräfe and Wiedmann (1998), who defined the boundary between cycles UC11 and UC12 above, but close to, the Coniacian/Santonian boundary.

2.2.3.1. Lithostratigraphy

The section on the disused eastern side of the Cantera de Margas quarry exposes ca. 160 m of marls and marly limestones and extends from the middle Coniacian to the Middle Santonian. The lower, more marly part is referred to the La Barranca Member of the Zadorra Formation; the higher part to the Olazagutia Formation (Fig. 2), as defined by Amiot (1982). A part of the section has been studied in more detail, on a ramp into the middle level of the quarry, and belongs to the lower part of the Olazagutia Formation (Figs. 3, 4). Thin (10-20 cm) limestone beds occur from ca. 20 m below to 10 m above the Coniacian/Santonian boundary (as defined by the first appearance of *P. undulatoplicatus*), which occurs at ca. 95 m above the base of the section. Higher up, more uniform and thicker-bedded limestones occur. Marcasite nodules, often rusty-weathered, occur from ca. 7-14 m above the boundary. There are also very weak suggestions of at least five larger scale cycles ca. 10 m thick, each starting with rather thicker limestone beds in the boundary interval that we studied. The base of the lowest cycle lies in the covered interval below our section and has been used to define the boundary between the Zadorra and Olazagutia formations (Amiot, 1982).

Macrofossils are sufficiently common in parts of the section to contribute to the lithological characteristics of the beds. They are rare at the base of the section, but echinoids and inoceramid bivalves occur sporadically in the first 75 m or so. Echinoids are particularly abundant in the 12 m below, and are fairly common up to at least 20 m above, the boundary. Inoceramids, especially *P. undulatoplicatus*, appear abundantly at the boundary (Fig. 5). *Platyceramus undulatoplicatus* is very common in the first 2 m, is then sporadic for nearly 10 m, with its higher occurrence about 12 m above the boundary. Almost certainly, lowermost and uppermost levels correspond to events 1 and 2 of the Kent coast in England (Jenkyns et al., 1994). Sponges (sometimes iron-rich and rusty-weathered) occur both sporadically and in distinct sponge-rich beds from 2.5 m below to 15 m above the boundary.

2.2.3.2. Biostratigraphy

Inoceramids, planktonic foraminifera and calcareous nannofossils can be used to define biostratigraphic zones across the boundary (Fig. 3), but at Olazagutia ammonites first appear well above the boundary (Lamolda, 2002).

Inoceramids

Inoceramids occur discontinuously, although they are abundant in the upper half of the section. The first examples of *Magadiceramus* occur at 64.6 m, ca. 11 m below the base of our studied section, and indicate the presence of the *M. subquadratus* Zone of late Coniacian age. *Platyceramus undulatoplicatus* first appears at 94.4 m and defines both the base of the eponymous zone and the Santonian Stage (Fig. 3). It occurs through a total range of 11.5 m. Both, its FO and LO are reliable bioevents (see subchapter 3.6.). *Platyceramus cycloides* subspp. and *Cordiceramus* spp. are commonly recorded in the lower part of the Santonian.

Details of macrofossils recorded at Olazagutia are given in Figure 6 and Table 1 (after Gallemí et al., 2007a).

Planktonic foraminifera

The main planktonic taxa belong to keeled, trochospiral species of genera such as *Contusotruncana*, *Dicarinella, Globotruncana* and *Marginotruncana*. The most abundant components are biconvex species of *Marginotruncana*. Planktonic foraminiferal assemblages found in the samples studied enable recognition of biozonations based on globotruncanids and heterohelicids (Fig. 7). *Dicarinella asymetrica* (Sigal) occurs throughout the section studied (Lamolda et al., 2007), which thereby belongs entirely to the *Dicarinella asymetrica* Zone. Heterohelicid species are also useful for biozonation. The first occurrence of *Sigalia carpatica* Salaj and Samuel is located ca. 7 m below the first occurrence of *Platyceramus undulatoplicatus*, and is used to characterize the lower boundary of the eponymous biozone, according to Nederbragt's (1990) biozonation. The underlying sediments belong to the *Pseudotextularia nuttalli* Zone.

More details on planktonic foraminifers are given in Lamolda et al. (2007), and below subchapter 3.3.1.

Nannofossils

Melinte and Lamolda (2002) studied nannofloral assemblages, which belong to nannofossil zones CC15-CC16 of Sissingh (1977), and calcareous nannofossil zones UC10-UC12 of Burnett (1998), respectively (Fig. 8). A succession of bioevents characterizes the Coniacian/Santonian boundary interval in the section studied (Fig. 3). Of special note is the local first occurrence of *Lucianorhabdus inflatus* Perch-Nielsen and Feinberg, which is very close to the base of the Santonian (1.75 m below), as in the Romanian Carpathians (Melinte and Lamolda, 2007). Other nannofossil events observed in the succession at Olazagutia are high abundances of *Lucianorhabdus* spp. and *Micula concava* (Stradner) Verbeek in the Coniacian/Santonian boundary interval, followed by the increasing abundance of *Calculites* within the lowermost Santonian (Melinte and Lamolda, 2002). Further comments are given in subchapter 3.5.

Stable Isotopes

Carbon isotope values across the Coniacian/Santonian boundary only vary by a maximum of 0.37 ‰ (Fig. 9). There is no major excursion, such as occurs across the Cenomanian/ Turonian boundary. Nevertheless, they do show a gradual and continuous decline through the sampled interval from a maximum of +3.05‰ (sample 2) to +2.68‰ (sample 45), with some fluctuations (Fig. 9). In particular, there is a relatively large drop from 2.98 to 2.71‰ over four samples just below the first appearance of *P. undulatoplicatus*. Above this level values increase again to 2.91‰ over the next four samples.

Results from Olazagutia are compared with the carbon isotope curve of Jenkyns et al. (1994) for east Kent (Figs. 9), since the first and last occurrences of *P. undulatoplicatus* are recorded in both sections. We used the total ranges of *P. undulatoplicatus* to estimate relative sedimentation rates at both localities and adjusted the scales of the sections accordingly to produce our correlation (Figs. 9). Both carbon isotope curves lack major excursions, but do show similar features. In both, carbon isotope values decline across the Coniacian/ Santonian boundary, with one or two brief reversals. In particular, three minima (the late Coniacian, at the boundary, and in the early Santonian) can be recognized in both curves.

Using the total thickness of the Coniacian and Santonian in east Kent (Jenkyns et al., 1994, fig 13), the Harland et al. (1989) timescale and our best correlation (Figs. 9), we estimate that the mean sampling interval at Olazagutia was approximately 22,000 years. Within the limits of our sampling, $\delta^{13}C$ curves and the total range of *P. undulatoplicatus* give equally accurate correlations. This, in turn, confirms that the first occurrence of *P. undulatoplicatus* is a very good primary marker for the Coniacian/Santonian boundary, at least in Western Europe.

Further comments are given below in an overview of carbon stable isotopes (subchapter 3.6.).

Palaeobiogeography

Palaeogeographic reconstructions of the region around the CSB provide a 30º N palaeolatitude for northern Spain (around 42º N at present). This part of the northern Tethys had direct communications with the North Atlantic to the west, and the London-Paris basin to the north. It was a part of the palaeotropics but with influences of the northern temperate regions.

Most of the nannofossils occurring around the Coniacian/Santonian boundary interval herein are cosmopolitan taxa, although a small number of them are more related to low-latitudes than to the high latitudes. A significant component of the nannofloras from Olazagutia section is *Watznaueria barnesae*, the most abundant Cretaceous cosmopolitan nannofossil. Concerning this taxon, Thierstein (1981) indicated that it showed a latitudinal distribution pattern: it is more common at low latitudes, becoming decreasingly common towards higher latitudes, although it is still an important component of high-latitude nannofloral assemblages. The presence of the nannofossils *Lithastrinus grillii* and *Lithastrinus septenarius*, both identified in the Olazagutia section, indicates, according to Varol (1992), warm to temperate waters of low-mid latitudes. Another important component of the assemblages identified in the studied section is the genus *Nannoconus*, which reached, at certain levels, >15% of the nannofloral assemblage. It is noteworthy that the Upper Cretaceous nannoconids are also believed to be indicative of low-middle latitudes, rather than high ones.

In contrast*, Kamptnerius magnificus* and *Gartnerago segmentatum,* nannofossils recorded infrequently and discontinuously in our samples, and mainly restricted in Olazagutia to the Lowermost Santonian, are usually common to abundant at high latitudes (Thierstein, 1976,). Svabenicka (1995) cited *K. magnificus* as a cold-water species, too. It is present in the Tethyan Realm, but infrequently, often related to cold-water incursions into lower latitudes (e.g. in the Romanian Carpathians, where a similar distribution pattern has been recorded also for *Reinhardtites anthophorus* - Melinte, 1999). The $\delta^{18}O$ curve shows higher values in the lowermost Santonian at Olazagutia, overlying a decreasing value trend in the uppermost Coniacian and CSB, which is consistent with occurrences of the cited species from temperate regions, mainly in the same levels. This could reflect global climatic changes or a more local effect involving the balance between Tethyan and Atlantic water source (Lamolda and Paul, 2007).

Also noteworthy is the high abundance of holococcoliths in the section studied. These taxa are believed to be more abundant in nearshore and epicontinental areas, than in open oceans (Thierstein, 1976; Perch-Nielsen, 1985). This observation is consistent with the palaeogeographical setting of the Olazagutia section, situated in the Navarro-Cantabrian Platform, with sediments deposited on a rapidly sinking shelf.

Planktonic foraminifer assemblages are typical of the Tethyan Realm, mostly of globotruncanids s.l., whereas globigeriniforms (e.g., *Archaeoglobigerina*) are usually minor components. The genus *Sigalia* occurs, especially *S. carpatica*, which characterises the palaeotropics between the Atlantic and Iraq. Interestingly, the occurrence of benthic foraminifers, mainly *Neoflabellina* and *Stensioeina*, allows a correlation with the temperate northern region, especially in the CSB interval.

The inoceramid fauna belongs to the southern Euroamerican Province (following Kauffman, 1973). In fact, the upper part of the Coniacian in northern Spain, including southern central Pyrenees, is characterised by a *Magadiceramus* spp. fauna, and the lowermost Santonian by *P. undulatoplicatus*. No sphenoceramids are known in the region.

In summary, most of the fauna and calcareous nannofossils are cosmopolitan or with a wide palaeogeographic distribution in low and middle latitudes. It is noteworthy that some planktonic foraminifers (e.g., *Globotruncana*, *Costellagerina*), and benthic foraminifers (e.g., *Neoflabellina*, *Stensioeina*) enable correlation with northern temperate and austral regions.

2.2.4. The Villamartín section (mainly extracted from Gallemí et al., 2007b)

This section was visited and discussed during the Santonian Working Group meeting, at Bilbao September 2002, noting its rich macrofauna in the middle and late Coniacian, in comparison to the Olazagutia section. Because of this characteristic, the Villamartín section is a suitable complementary locality to the palaeogeographically close succession at Olazagutia, as its CSB is well defined by inoceramids and ammonites, too.

The Villamartín section is located on the northern slope of the El Paño Range, Burgos province, northern Spain. Palaeogeographically the area is situated in the outermost and/or distal part of the North Castilian Platform, which directly communicated with the eastern domains of the Navarro-Cantabrian Basin, where the proposed C/S boundary stratotype section of Olazagutia is located (Fig 10).

The Coniacian-Santonian interval is represented by outer platform sediments with diverse, well-preserved macrofossils, and in the Villamartín section the record of ammonites is particularly good. Lithostratigraphy, biostratigraphy, sequence stratigraphy and regional synthesis of the Upper Cretaceous of the North Castilian Platform and its relationship with the Navarro-Cantabrian Basin are provided by, among others, Floquet et al. (1982), Floquet (1991), Gräfe (1994) and Martínez et al. (1996).

The Villamartín section was described in detail by López (1992) and Santamaría (1992). It crops out along a gully running down the steep slope of the El Paño Range and has been measured and appropriately identified with metallic labels. Wiedmann (in

Lamolda et al., 1981) figured another section nearby, measured on the slope of the Peñola Range, closer to Villamartín.

The part of the section studied in detail comprises both the marls with a few intercalated marly limestones of the Nidáguila Formation and the alternation of marly limestones and limestones of the lower part of the Nocedo de Burgos Formation, at the foot and slope of the El Paño Range. The CSB is situated around the middle of the slope, just 3.9 m above the contact between the two formations. The section is rich in macrofossils (ammonites, inoceramids and echinoids, as well as bivalves and brachiopods), occurring mainly in the marls and marly limestones of both formations, but becoming scarce in the limestones of the Nocedo de Burgos Formation, in the upper part of the slope (Fig.11, Table 2). Most beds studied in the section are well exposed and can be easily followed westwards along the foot and slope of the El Paño Range.

The following points are stressed. The occurrence of the inoceramid bivalve *Platyceramus undulatoplicatus* encompasses only 1.9 m of the section. Although this is a short record when compared with that in Olazagutia (11.5 m) and other deeper areas of the Basque-Cantabrian Region, it is to be expected in the North Castilian Platform and near the Navarro-Cantabrian Basin. Above the *P. undulatoplicatus* Zone, inoceramids are rare and only *P. cycloides* has been recorded at 66.1 m above the C/S boundary. Below, inoceramids are abundant, particularly in the lower part of the section where the base of the *Magadiceramus subquadratus* Zone is marked by the FO of its index species at 95.6 m below the C/S boundary, one of the thickest sections through the *M subquadratus* Zone, and the middle Coniacian *Platyceramus mantelli mantelli* is recorded at 113.3 m below this boundary. The record of ammonites is fairly good and regular through the section. Five successive ammonites zones are recognised: *Gauthiericeras margae*, *Prionocycloceras iberiense*, *Protexanites bourgeoisi*, *Hemitissotia* spp. and *Placenticeras polyopsis* zones, defined respectively by the FO of the nominate species. *Gauthiericeras margae* and *Placenticeras polyopsis* zones are standard ammonite zones, and the *Hemitissotia* spp. Zone corresponds to the upper part of the standard *Paratexanites serratomarginatus* Zone. The boundary between the *P. polyopsis* and *Hemitissotia* spp. zones lies within the *Platyceramus undulatoplicatus* Zone, and the C/S boundary is in the uppermost part of the *Hemitissotia* spp. Zone. The FO of *Texanites*, *T. hispanicus*, is recorded in the lowermost part of the *Hemitissotia* spp. Zone, 59.1 m below the C/S boundary and 1.7 m below the LO of *Protexanites bourgeoisi*.

In the Villamartín section, both its thick *M. subquadratus* Zone, and the close FOs of the ammonite *P. polyopsis* and the inoceramid *Platyceramus undulatoplicatus*, are noteworthy, and show the significance of the FO of the ammonite *P. polyopsis* as a proxy for the CSB, in absence of the primary marker.

3. An overwiew of main fossil groups and events

3.1 Inoceramids

The first occurrence of *Platyceramus undulatoplicatus* (Roemer) was proposed by the Santonian Working Group of the ISCS as the primary marker for the base of the Santonian (Lamolda and Hancock, 1996). This species, clearly distinguishable by its strongly divergent ribs, dominating over the concentric ornament, has been assigned to either *Platyceramus* Seitz or *Cladoceramus* Seitz, depending on the different interpretations of inoceramid experts (Harries et al., 1996, Gallemí et al., 2007a). This species is widely distributed in N America, the Caribbean, Europe, to Central Asia (Turkmenistan), and in the E African Province.

The CSB is still unresolved in the Pacific Realm (Japan and Sakhalin). No record of *Platyceramus undulatoplicatus* (Roemer) is known as recently reported by Yazykova (2004) and Toshimitsu et al. (2007), nor *P. cycloides* (Jagt-Yazykova, written com. 2008). Nevertheless, inoceramid species showing very well developed divergent ribs also occur in the Pacific Realm but they are related to *Platyceramus japonicus* (Nagao and Matsumoto), which first occurs at the base of the Campanian in Japan (Toshimitsu et al., 2007), and in the upper part of the Santonian in Sakhalin (Yazykova, 2004). The lowest occurrence of the species *Inoceramus amakusensis* (Nagao and Matsumoto), an apparently endemic platyceramid, defines the base of the *Inoceramus amakusensis* Zone, and is the usual marker of the CSB. Below the boundary in Japan, the upper part of the Coniacian is characterised by the occurrence of *Inoceramus uwajimensis* Yehara and *I. mihoensis* Matsumoto (Toshimitsu et al., 2007).

The WalMart section, Ten Mile Creek, in the Western Interior (Texas, USA), contains a continuous inoceramid record just across the CSB (Gale et al., 2007), although a part of the material comes from four fossiliferous horizons. Late Coniacian inoceramids are mainly restricted to *Magadiceramus* species that are recorded over 17 m, ranging up to 0.4 m below the entry of *Platyceramus undulatoplicatus*. The main Coniacian species are: *Magadiceramus crenelatus* (Seitz), *M. complicatus* (Heine), *M. subquadratus* (Schlüter), and *M.* cf. *crenistriatus* (Heinz). Some platyceramid species that might belong to the *mantelli* group are also recorded (Gale et al., 2007). The entry of *Platyceramus undulatoplicatus* occurs at the 18.4 m level, and is quite common in the overlying metre of the section. It becomes less common in the higher parts of the WalMart succession. There is a second abundance peak in the Bruceville Member in other sections: between 12.5 and 14 m in the Nazarene 2 section, and between 4.6 and 8 m in the Arbor Park section (Gale et al., 2007). The lowest *Cordiceramus* is located at 18.4 m in the WalMart section. They are juvenile specimens of *C. arnoldi* (Seitz), and co—occur with *P. undulatoplicatus*. *Cordiceramus* cf. *cordiformis* (Sowerby) and other cordiceramids dominate the highest assemblage, from 3.6 m above the CSB. The FO of the Santonian species *Platyceramus cycloides* was located in the same level.

Coniacian and Santonian inoceramids are well known in northern German and Polish sections, where some zones have been defined, and where almost all species recognised in northern Spain occur, as well as many other species and subspecies. Coniacian *Cremnoceramus* and *Inoceramus* species are better represented, and genus *Volviceramus* is quite common, whereas it is not present in northern Spain. *Platyceramus undulatoplicatus* is not very common or rare; by contrast sphenoceramids of the *cardissoides-pachti* group are abundant (Tröger, 1989; Remin, 2004). The FO of these species defines the base of the "*Cardissoides* Zone" of Seitz (1965), which is equivalent to Zone 25 of Tröger (1989). Nevertheless, these sphenoceramids are reputed to make their first appearance slightly below the first occurrence of *P. undulatoplicatus* (Seitz, 1965).

Coniacian and Santonian sections in northern Africa are well known, but *Platyceramus undulatoplicatus* is unrecorded, only one inoceramid fragment with divergent ribs was collected in Algeria by Prof. Busnardo years ago. Dhondt (in Robaszynski et al., 2000) cited the record of *Platyceramus cycloides ahsenensis* (Seitz) and *P. cycloides* cf. *vanuxemiformis* (Nagao and Matsumoto) at level 151.5 m, at Kalaat Senan section, co-occurring with *Cordiceramus* aff. *platycephalus* (Sornay) and

Texanites (*Texanites*), an ecoevent which is taken in the literature of the region as a proxy for the CSB. Below this level there is a record of *Platyceramus* sp. aff. *mantelli* (Barrois). Big platyceramids related to *P. cycloides* and to *Platyceramus siccensis* (Pervinquière) are abundant close to the boundary, but a revision of *P. siccensis* as well as its biostratigraphic relationship with *P. undulatoplicatus* and texanitids are required.

Some platyceramids with divergent ribs are also present in the East African Province, in KwaZulu-Natal, South Africa (Kennedy et al., 2008) and Madgascar (Sornay 1969). Nevertheless, South African distributions of *Platyceramus* cf. *japonicus* Nagao and Matsumoto, *P. mammillatus* Sornay, *P. hokkaidoensis* Noda and their associated ammonite faunas suggest a middle or even late Santonian age. New data are required to support Kennedy's et al. (2008) recent suggestion that the first occurrence of these species might be related to the first occurrence of *P. undulatoplicatus* in the Euramerican region. In fact, neither uppermost Coniacian nor lowermost Santonian are recorded in KwaZulu (Kennedy et al., 2008).

In the Olazagutia section scattered occurrences of inoceramids are recorded Gallemí et al. (2007a). They are abundant in the upper half but very poorly represented below the CSB. Inoceramid records in the lowermost levels are restricted to a few poorly preserved specimens of *Cremnoceramus deformis* (Meek), *C. crassus* (Petrascheck) and *Cremnoceramus* sp. belonging to the *Cremnoceramus deformis* Zone. The overlying succession has not yielded any inoceramids until the FO of *Magadiceramus subquadratus subquadratus* (Schlüter), at the 64.60-m level. Nevertheless, its eponymous zone is characterised by a few incomplete and poorly preserved specimens of *M. subquadratus subquadratus*. The next record is the FO of *Platyceramus undulatoplicatus* at the level of 94.4 m, its LO is recorded at 11.5 m higher. Around 54 m above the CSB, several inoceramid taxa of the *Cordiceramus cordiinitialis* Zone (middle part of the Santonian), have been identified, mostly collected ex situ. Specimens of *Cordiceramus bueltenensis* subsp. indet., *Selenoceramus gladbeckensis* (Seitz), *Cordiceramus cordiinitialis riedeli* (Seitz) and *C. koeplitzi* (Seitz) have been identified. The subspecies *Platyceramus cycloides cycloides* (Wegner) has the longest stratigraphic range in the quarry; it has been recorded from 4.7 m above the CSB up to highest levels in the section studied, around 60 m above the CSB. It is especially abundant in the *Cordiceramus cordiinitialis* Zone, with specimens reaching heights of up to 2 m and more. The subspecies *Platyceramus cycloides vanuxemiformis* (Nagao and Matsumoto) is very common in the upper part of the section.

There are other well-known sections showing the CSB in northern Spain, such as the Villamartín section, where the inoceramid fauna is not continuously present (Gallemí et al., 2007b). Inoceramids are abundant in the lower part, early Late Coniacian age. In the middle part, an 80-m-thick interval contains no inoceramid records below the first occurrence of *Platyceramus undulatoplicatus*. The species *Platyceramus mantelli mantelli* (Barrois) is the oldest inoceramid recognised in the section, located in the middle part of the Coniacian, around 112 m below the CSB. A record of the species *Inoceramus stantoni* Sokolow occurs around 6 m above *P. mantelli mantelli*, in this middle part of the Coniacian, too. Walaszczyk and Cobban (2002) noted that *I. stantoni* and *Platyceramus platinus* (Logan) are both commonly mentioned as examples of "American" species and represent well-known species groups, although classified with different names in Europe. The first occurrence of *Magadiceramus* species, namely *Magadiceramus subquadratus* subsp. inc. and *M. villamartinensis* (López), characterises the base of the *Magadiceramus subquadratus* Zone, at 95.6 m below the CSB. This zone, widely recognised in N Spain corresponds to the Upper Coniacian and is equivalent to zones 23 and 24 of Tröger (1989). The FO of *Platyceramus undulatoplicatus* is recorded at the 144.1 m level in the section studied, and defines the base of its epponymous zone. Its record at Villamartín is restricted to two levels separated by 2 m of sediment, only. Generally, the specimens of *P. undulatoplicatus* are fragmented, neither large nor abundant, and are found orientated parallel in the sediment. They display an almost monotypic distribution, and are bioclast-supported, showing a stacking fabric in section (López and Soler, 1999). The occurrence of inoceramids above the highest record of *Platyceramus undulatoplicatus* is very sparse and limited to a few specimens of *P. cycloides*.

Coniacian to Santonian sections are also present in other northern Spain localities, especially in the Losa Valley and in the northern Burgos province (López, 1994; Martínez et al., 1996), where the following zones were recognized: *Platyceramus mantelli* Zone is middle Coniacian in age, and equivalent to Zone 22 of Tröger (1989). *Magadiceramus subquadratus* Zone is late Coniacian in age; it is recognised by FO of *M. subquadratus subquadratus* (Schlüter) and *M. villamartinensis* (López).

Platyceramus undulatoplicatus Zone is recognised by FO of the eponymous species, which is well distributed in northern Spain basin and platform facies. In the uppermost part of this zone also occur other inoceramid species with divergent ribs as *P. cycloides wegneri* Böhm or *Cordiceramus cordiinitialis ickemensis Seitz.* The *Cordiceramus cordiformis* Zone is recognised in northern Spain by the FO of *Cordiceramus cordiformis* subsp. inc. and *C.* cf. *haenleini* Müller; this zone is equivalent to zones 27 and 28 of Tröger (1989).

Complete Coniacian to Santonian sections are recognised in the Riu de Carreu Valley, in the South central Pyrenees (Spain). Sections range from carbonate platform to upper slope facies and are rich in inoceramids, ammonites and echinoids, allowing distinction of a complete biostratigraphic framework (Gallemí et al., 2004). The middle Coniacian *Platyceramus mantelli* Zone is recognised by FO of *P. mantelli mantelli* (Barrois). This subspecies and *P. mantelli undatus* (Seitz) are the most common platyceramid species that co-occur with *Inoceramus percostatus* Müller and *I. dolosoensis* McLearn. The upper Coniacian *Magadiceramus subquadratus* Zone is recognised by FO occurrences of *Magadiceramus* species, especially *M. subquadratus subquadratus* (Schlüter) and *M. obesus* (Seitz). The lowermost Santonian *Platyceramus undulatoplicatus* Zone usually consists of a single continuous bed through the valley. The *Cordiceramus cordiformis* Zone, lower and middle parts of the Santonian, is recognised by FO of *C. cordiformis boehmi* (Seitz) and *Platyceramus cycloides cycloides* (Wegner); both species *P.* cf. *romboides* (Seitz) and *P. confertim-annulatus* (Seitz) co-occur, too.

Summary

The geographic distribution of inoceramid species relevant for the CSB highlights a bioprovinciality in their assemblages. The primary marker *Platyceramus undulatoplicatus* has a wide geographic distribution, but it is not known in the Boreal Realm, in the Pacific Realm, nor in N Africa. The FOs of the species *Platyceramus cycloides* and subspecies, seem a good proxy for the CSB, in absence of *P. undulatoplicatus*. They occur in N Africa, where they used to be the marker for the local CSB. They co-occur with *P. undulatoplicatus* in Ten Mile Creek, N. Spain (see above references), N Germany (López et al., 1992), and Austria (Tröger and Summesberger, 1994). The LO of *Magadiceramus* spp. is not a good proxy for the CSB, as it has been recorded well below the FO of *P. undulatoplicatus*. The FO of *Cordiceramus cordiformis*, in the lower part of the Santonian, could help recognise the CSB, as it co-occurs with *P. undulatoplicatus* in northern Spain and Ten Mile Creek. It is also known in the lower part of the Santonian from Germany. In the Boreal Realm, the FO of *Volviceramus cardissoides-pachti* group seems to be a good proxy for the CSB.

3.2. Ammonites

After the Brussels meeting, Lamolda and Hancock (1996) summarised the ammonite situation about the Coniacian/Santonian boundary (CSB). The subgenus *Texanites* (*Texanites*), which was identified by Birkelund et al. (1984) as a good marker of the CSB, was considered as not adequate to characterise the boundary as its known stratigraphic range spans from well below the FO of *Platyceramus undulatoplicatus* to the middle part of the Santonian. In addition most of its species have a regional geographical distribution, except *Texanites* (*T.*) *gallicus* which is found on several continents.

In the Pacific Realm, Japan and Sakhalin, no record of *Platyceramus undulatoplicatus* is known in spite recent researches (Yazykova and Zonova, 2002; Yazykova, 2004; Toshimitsu et al., 2007), apart of some isolated finds of *Inoceramus* sp. aff. *undulatoplicatus* from the upper part of the Santonian in Sakhalin (Zonova et al., 1993). Usually, the lowest occurrence of the species *Texanites quinquenodosus* is a marker for the Coniacian/Santonian boundary in Japan, correlated to the base of *Inoceramus amakusensis* Zone (Toshimitsu et al., 2007), which characterised the cited boundary in Japan. Below these markers, both *Magadiceramus* cf. *subquadratus* and *Paratexanites orientalis* are found (Noda, 1994; Toshimitsu et al., 2007). In northern areas from the Russian Far East, Koriakia and Chukotka, the genus *Texanites* is not present. The FOs of *Texanites* (*Plesiotexanites*) *kawasakii* and *Inoceramus amakusensis* are the two best criteria for the base of the Santonian in Sakhalin (Yazykova 1996, 2002; Yazykova & Zonova, 2002), despite the fact that both are endemic. However, lending support to this interpretation is the co-occurrence of these taxa with the cosmopolitan ammonites *Desmophyllites diphylloides* and *Phyllopachyceras* *forbesianum*. Nevertheless, *Plesiotexanites kawasakii* has a youngest record in Japan, occurring in the upper part of the Santonian.

In the Western Interior, ammonites show different assemblages. In Montana and Alberta endemic assemblages with scaphitids, e.g., *Clioscaphites saxitonianus* are associated with *P. undulatoplicatus*, characterising the CSB. In contrast, *C. saxitonianus* occurs in the upper part of the *Scaphites depressus* Zone, a few metres above the FO of *P. undulatoplicatus* in the Pueblo section, Colorado (Walaszczyk and Cobban, 2007). In Montana, in the upper part of the Coniacian *Scaphites depressus* co-occurs with *Protexanites bourgeoisi*, a cosmopolitan species from the upper part of the Coniacian (Cobban et al., 2005).

The Ten Mile Creek composite section has yielded several ammonite species from the upper part of the Coniacian and the lower part of the Santonian. The three recorded specimens of *Texanites* (*Texanites*) *gallicus* encompass the CSB, marked by the FO of *P. undulatoplicatus*. The lowest specimen is 2.5 m below the boundary, the highest one was found at 3.6 m above it, in the WalMart section. The FO of *Menabites* (*Australiella*) *austinensis* is close and above the LO of *T*. (*T*.) *gallicus*. The species *Texanites* (*Texanites*) *vanhoepeni* has two occurrences, its LO is located 16.8 m below the CSB, and its FO is associated with *Protexanites* (*Protexanites*) *planatus*, in the Nazarene I section, around 20.2 m below the CSB. Only the species *T*. (*T*.) *gallicus* is known from a wide geographical area, northern Spain, southern France, Austria, Hokkaido (Japan), Madagascar and Zululand. Usually, it has been considered an early Santonian species, but in Ten Mile Creek, as in northern Spain (Lamolda and Hancock, 1996), and in the S. Pyrenees, it is found below the CSB (Gallemí et al., 2004). The species *T*. (*T*.) *vanhoepeni* is known from South Africa as well. The other two species, *Menabites* (*A*.) *austinensis* and *Protexanites* (*P*.) *planatus* are endemic to North America.

In Germany (Münster Basin) Kaplan and Kennedy (2000) noted the endemic character of most ammonites from the upper Coniacian and lower Santonian, therefore correlation is difficult even to adjacent basins. *Platyceramus undulatoplicatus* is present in some sections in that basin. *Texanites* (*Texanites*) spp. are abundant in addition to *Texanites pseudotexanus* and a single specimen of *Texanites gallicus*, from the upper part of the Coniacian, *Texanites pseudotexanus* Zone, which is correlated with the *Sphenoceramus pachti* inoceramid Zone. The FOs of *Kitchnites emscheris* and *Baculites* *incurvatus* characterise the base of the *Kitchnites emscheris* Zone, which may be correlated with the *Platyceramus undulatoplicatus* Zone. Thus, the ammonite species *K. emscheris* would be a good proxy for the base of the Santonian in the Münster Basin.

In the area of Kalaat Senan the Coniacian-Santonian transition shows a record of the subgenus *Texanites* (*Texanites*) from 39.5 m below to 17.5 m above the FO of *P. cycloides* (Robaszynski et al., 2000). This FO of *P. cyloides* is coincident with the FOs of the genera *Eulophoceras* and *Pseudoschloenbachia* (including *P. insconstans*). Such a rich level was typified as an ecoevent by Robaszynski et al. (2000), and a good proxy for the CSB, in the absence of *P. undulatoplicatus*. In fact, current records of both genera *Eulophoceras* and *Pseudoschloenbachia* are known from several European countries only in the Santonian. Nevertheless, the LO of *Paratexanites serratomarginatus*, index species of its eponymous zone, from the upper part of the Coniacian, occurs at 55.5 m below the FO of *P. cycloides*.

In northern Spain several localities are known where the CSB is well located. In the Barranca, where the Olazatutia section is located, Küchler (1998, 2000) cited some of them. In the cantera de Eguibil (GSSP candidate) ammonites are very rare and patchy so no biozonation is possible. Gallemí et al. (2007a) cited a *Damesites* sp. with affinities to *D. sugata* recorded at level 128 m, about 33.6 m above the FO of *P. undulatoplicatus*. A specimen of *Pseudoschloenbachia* sp. at 44.8 m above the CSB, and the species *Placenticeras polyopsis* at 61.6 m above the CSB, have been found. Both *Damesites* and *Pseudoschloenbachia* are known from the upper Coniacian to the lower Santonian, whereas *P. polyopsis* is known from lower Santonian (Gallemí et al., 2007a). Other sections near Olazagutia, in the Barranca area, are richest in ammonite species for the middle and upper parts of the Coniacian and the middle and upper parts of the Santonian, but with a noteworthy poor record around the CSB. As in the Olazagutia section, this precludes any biozonation based on ammonites for the uppermost Coniacian and lowermost Santonian (Küchler, 1998). In adition, in these sections a hiatus embraces the lower Santonian, whereby even *P. undulatoplicatus* is not preserved (Küchler, 1998).

The Villamartín section, in the North Castillian platform (Burgos province), shows the CSB marked by the FO of *P. undulatoplicatus*, which occurs at level 144.1 m, together a good ammonite succession (Gallemí et al., 2007b). This section was considered as a complement to that of Olazagutia (Dhondt et al. 2007). Both ammonites and inoceramids are abundant across the CSB, allowing distinction of the following zones (from oldest to youngest): the *Protexanites bourgeoisi-Hemitissotia* spp.-*Placenticeras polyopsis* zones, the latter lying in the lower part of the Santonian (Martínez *et al*. 1996, Gallemí *et al*. 2007b). *Protexanites burgeoisi* and *Protexanites* sp. occur between 73.5 m and 57.5 m below the CSB. Several species of the genus *Hemitissotia*, *H. turzoi*, *H. dullai*, and *H. lenticeratiformis* occur between 65.5 m below to 1 m above the CSB. The species *Texanites hispanicus* and other *Texanites* spp. are recorded between 59.1 m below and 67.4 m above the CSB. The species *P. polyopsis* has its FO at 1.1 m above the CSB, which should be a good proxy for the CSB (Dhondt et al., 2007).

In other sections east of Villamartín, texanitids and other ammonites occur commonly. Species of *Texanites* (*Texanites*) occur well below the CSB, e.g., *Texanites* (*T.*) *gallicus* around 46 m below, in the Oteo section. The subgenus *Texanites* (*Texanites*) is recorded through a relevant stratigraphic range, from the lower upper part of the Coniancian, in an equivalent level to the lowest occurrence of *Magadiceramus* spp., up to the middle part of the Santonian. Based on this succession, Martinez et al. (1996) proposed from oldest to youngest, the *Protexanites burgeoisi*, *Hemitissotia* spp., and *P. polyopsis* zones. The first two occur in the upper part of the Coniacian, and the latter in the lower part of the Santonian. Both *Eulophoceras* and *Pseudoschloenbachia* occur well below the FO of *P. undulatoplicatus*, therefore their interest as markers of the lowermost Santonian is only valid in some localities, e.g., in Tunisia, as was cited by Robaszynski et al. (2000).

In the south-central Pyrenees, Riu de Carreu Valley (Lleida province, Spain), the FO of *P. undulatoplicatus* is well documented and traced along 15 km of continuous outcrop belonging to the transition between a carbonate platform and an upper slope. In this area there is an ammonite fauna from the middle part of the Coniacian to the lower part of the Santonian (Gallemí et al., 2004), with *Texanites* (*T.*) *hispanicus*, *T.* (*T.*) *gallicus, Novakites carezi*, *Parapuzosia daubreei*, *Pseudoschloenbachia inconstans, Protexanites bourgeoisi*, and *Damesites sugata*, sometimes associated with *Magadiceramus subquadratus*, and always below the FO of *P. undulatoplicatus*. Early Santonian ammonites are not so frequent, and are represented by *Texanites* gr.

americanus/*rarecostatus*, and *P. inconstans*. The succession of biozones of *Peroniceras tridorsatum-Gauthiericeras margae-Protexanites bourgeoisi-Hemitissotia turzoi* was reported by Gallemí et al. (2004).

Summary

Most ammonite species occurring across the Coniacian-Santonian transition are not cosmopolitan. Nevertheless, they allow a biozonation through the middle part of the Coniacian to the middle part of the Santonian. The LO of the late Coniacian species *Protexanites bourgeoisi*, which has a wide geographical distribution, is not a proxy for the CSB as its known records lie well below the FO of *P. undulatoplicatus*. Several species of *Hemitissotia* have their LOs close and above the FO of *P. undulatoplicatus* in nothern Spain, and they could thus be a proxy for the CSB, but of local interest only. The FO of *Kitchnites emscheris* may be a good proxy for the CSB, but exclusively in the Münster basin (Germany). The FO of *Placenticeras polyopsis* in the lowermost Santonian was regarded by Dhondt et al. (2007) as a good proxy for the CSB, but it needs to be checked in other sections to ascertain whether or not it is a reliable marker.

3.3. Planktonic Foraminifers

This group shows different assemblages controlled by biogeography. In general, low and middle latitudes have good occurrences of planktonic foraminifers, whereas in the Temperate Realm benthic foraminiferal assemblages characterize the Coniacian-Santonian boundary.

"*In the Mediterranean area of the Tethys, the succession of species* Sigalia deflaensis *(Sigal),* Sigalia carpatica *Salaj and* Dicarinella asymetrica *(Sigal) characterize the Coniacian-Santonian transition.* Sigalia deflaensis *has a widespread occurrence in the Tethyan Realm (see Master, 1977), but* S. carpatica *is not so common and, like* D. asymetrica*, was also rare in shallow water facies. Nevertheless, as the lower occurrence of* S. carpatica *is associated with* C. undulatoplicatus *and* Texanites *(*Texanites*) spp. in N. Spain (Lamolda and Martínez, 1987; Martínez et al., 1996), or with* Platyceramus siccensis *in N. Africa (Salaj, 1980), it is a good regional index (Sigal, 1977; Robaszynski and Caron, 1995) which should be checked throughout the*

Tethyan Realm, where both Sigalia deflaensis *and* D. asymetrica *are associated with inoceramids and texanitids. Both species* S. deflaensis *(*=Sigalia carpatica*; Wagreich, written comm.) and* D. asymetrica*, with* Dicarinella concavata *(Brotzen), were cited by Wagreich (1992) in Austria, as markers of the Coniacian-Santonian Boundary. Especially, in the Bad Ischl-Nussensee section successive occurrences of* S. deflaensis*,* D. asymetrica *and* Sigalia decoratissima *(de Klasz) are similar to Tunisian localities.*"

This was the situation as known in 1995 (Lamolda and Hancock) and accepted in 2002, during the Santonian Working Group Workshop (Lamolda, 2002).

3.3.1. Up-to-date overview of main taxa

Dicarinella asymetrica (Sigal)

The FO of this species was cited commonly as an early Santonian event. Nevertheless in Romania it is found in the middle part of the Coniacian, associated with a fauna located in the lower part of the *Peroniceras tridorsatum* Zone and/or *Inoceramus mantelli* Assemblage Zone (Ion and Szasz, 1994). Interestingly, this is confirmed by the isotopic correlation between England and Italy after Jarvis et al. (2006, p. 595): "*..the isotopic correlation (Figs. 13, 14) place the base of the* D. asymetrica *Zone at the summit of the Middle Coniacian rather than at the base of the Santonian*".

In the Shakh-Bogota section, Mangishlak Peninsula (Kopaevich et al., 2007), the FO of *D. asymetrica* is just above the FO of *P. undulatoplicatus*, although records are sporadic. In central Tunisia (Kalaat Senan) the FO of *D. asymetrica* is located in the upper part of the Coniacian, overlying the FO of the genus *Texanites*, but below *Platyceramus cycloides* (Robaszynski et al., 2000). A similar result has been reported by El Amri and Zaghbib-Turki (2005), in the same region of Tunisia, near El Kef and Ellés.

In the Southern Ocean (Exmouth Plateau, NW Australia) the FO of *D. asymetrica* occurs close but overlying the FO of *Heterohelix papula* (Belford) which could be a proxy for the Coniacian/Santonian boundary (Petrizzo, 2000).

In Ten Mile Creek sections (Texas, USA), the FO of *D. asymetrica* is found below the FO of *P. undulatoplicatus*, and well below the local FO of *Texanites* (*Texanites*) *gallicus*, and even below the local FO of *Protexanites* (*Protexanites*) *planatus* and

Texanites (*T.*) *vanhoepeni* (after Gale et al., 2007), thereby it is an early late Coniacian event, probably. In contrast to the Southern Ocean, the FO of *H. papula* is younger than the FO of *D. asymetrica*, and well below the FO of *P. undulatoplicatus*.

In the Olazatutia section, the species *D. asymetrica* occurs through the studied section, from at least 19 m below the FO of *P. undulatoplicatus* (Lamolda et al., 2007) confirming previous results in the Losa Valley (westwards of Olazagutia) (Lamolda and Martínez, 1987). Abundance of *D. asymetrica* is quite different in the upper part of the Coniacian and lowermost Santonian where it is rare and there are transitional specimens between *D. concavata* and *D. asymetrica*, whereas in the rest of the Santonian it is common and as abundant as *D. concavata*. This could explain, in part, the usual reference of the FO of *D. asymetrica* to the lower part of the Santonian.

Sigalia carpatica Salaj and Samuel

Sigal (1977) showed the validity of the FO of *S. carpatica* as a marker for the Coniacian/Santonian boundary in the Mediterranean Region. This was confirmed by Salaj (1980) who found *S. carpatica* associated with *Platyceramus siccensis* (=*P. cycloides*) and texanitids in Tunisia.

In northern Spain, *S. carpatica* has been cited associated with the FO of *Texanites* (*Texanites*) in the Losa Valley (Lamolda and Martínez, 1987), or with the FO of *Platyceramus undulatoplicatus* in Olazagutia (Lamolda, 1995). Consequently, the species *S. carpatica* was selected as a secondary marker of the Coniacian/Santonian boundary (Lamolda and Hancock, 1996).

Although *S. carpatica* is better known from the Mediterranean Region, from Spain to Iraq, at both northern and southern margins of the Tethys, it is also known from the Atlantic Ocean. In fact, Nederbragt (1991) cited *S. carpatica* in DSDP Site 95 (Gulf of Mexico) associated with *Sigalia deflaensis* in the lower part of the *D. asymetrica* Zone, and in DSDP Site 356 (São Paulo Plateau, SW Atlantic) in the top of *Dicarinella concavata* Zone, which agrees with data from northern Spain (Losa Valley) cited above.

According to Lamolda et al. (2007), the FO of *S. carpatica* is located 7 m below the FO of *P. undulatoplicatus* at Olazagutia. Both in the uppermost Coniacian and in the lowermost Santonian *S. carpatica* is very rare, and it becomes a rare but persistent taxon close to the first common occurrence of *D. asymetrica*, but overlying it. *S. carpatica* keeps a persistent rare occurrence through the section studied at Olazagutia, more than 25 m above the FO of *P. undulatoplicatus*. This is similar and close to where *D. asymetrica* also increases in abundance, hence explaining the records of their first occurrences in lower Santonian strata in the literature.

S. carpatica has a wide palaeogeographical occurrence, along a belt between palaeolatitudes 30º N and 30º S, from the SW Atlantic Ocean and the Gulf of Mexico to Iraq. Both its FO and its first "common" occurrence are good proxies for the Coniacian/Santonian boundary. Thereby, the proximity of its FO to the Coniacian/Santonian boundary, as well as its wide palaeogeographical distribution confirm its validity as a secondary marker for the Coniacian/Santonian boundary, as was approved during the Brussels meeting (Lamolda and Hancock, 1996).

Costellagerina pilula (Belford)

C. pilula has been reported from Santonian strata from both the Tethyan and Austral provinces (Belford, 1960; Robaszynski et al., 1984). More recently it has been found in the Exmouth Plateau, lower part of the *D. asymetrica* Zone (Petrizzo, 2000) and the Kerguelen Plateau, early Santonian and close to the FO of *Heterohelix papula* (Petrizzo, 2001). In central Tunisia (El Kef and Ellès) *C. pilula* has been found in the lower part of the Santonian (El Amri and Zaghbib-Turki, 2005).

In Ten Mile Creek (WalMart section) the FO of *C. pilula* is in the lower part of *D. asymetrica* Zone, around 13 m below the FO of *P. undulatoplicatus* (Gale et al., 2007).

The FO of *C. pilula* lies near the *Pseudotextularia nuttalli*/*Sigalia carpatica* zonal boundary, and 4.5 m below the FO of *P. undulatoplicatus*, in the Olazagutia section (Lamolda et al., 2007).

Globotruncana linneiana (d'Orbigny)

G. linneiana is a widely distributed species, having been recorded from the upper part of the Coniacian through the Maastrichtian in tropical and temperate regions of both hemispheres. The first occurrence of typical ''pill-box-like'' morphotypes of this species is noteworthy. In the Olazagutia section this is close to the first record of *P. undulatoplicatus* (Lamolda et al., 2007). This bioevent may be used as a very practical proxy for the Coniacian/Santonian boundary. In fact, ''pill-box-like'' morphotypes of *G.*

linneiana had already been used as an index marker for the Santonian *G. linneiana* Interval Zone by Hart et al. (1989) and Walaszczyk and Peryt (1998) in United Kingdom and Poland, respectively. In both areas the lower boundary of the zone was defined by the FO of ‘‘pill-box-like’’ morphotypes. In the Carpathian domain, Romania, across a lower Santonian succession the following bioevents are recorded: FO of *Lucianorhabdus cayeuxii* (morphotype B, after Wagreich, 1992), FO of *Globotruncana bulloides*, and FO of *G. linneiana* “pill-box-like” morphotypes (after Ion et al., 1997, fig. 7). Its correlation with Olazagutia suggests that the FO of *G. linneiana* could be a proxy for the CSB in the Carpathian area. Olferiev et al. (2007, pl. VII, figs. 9–12) have illustrated several specimens of *Marginotruncana lapparenti* which are similar to *G. linneiana* “pill-box-like” morphotypes, from the Vishnevoe Section, Saratov area, Russian Platform, associated to *G. bulloides*, *Heterohelix globulosa*, *Whiteinella bornholmensis*, and an assemblage of benthic foraminifers whose stratigraphic location at Shakh-Bogota section is just above the FO of *P. undulatoplicatus*.

3.3.2. Summary

The species *Sigalia carpatica*, the secondary marker of the CSB (Lamolda and Hancock, 1996), is a relatively widespread taxon in the palaeotropics from the Atlantic Ocean to Iraq. Both its FO and consistent occurrence lie near the CSB, below and above respectively.

The FO of pill-box-like morphotypes of *Globruntanca linneiana* is close to the CSB in Europe, either in typicial Tethyan or in temperate northern localities. It is a proxy of the CSB to be checked in other regions where neither *P. undulatoplicatus* nor *S. carpatica* are found.

Relative common abundance of *D. asymetrica*, similar to that of *D. concavata*, is known from lowermost Santonian strata in many localities. Thus,it is an additional proxy of the CSB in the palaeotropics, except in shallow facies.

3.4. Benthic foraminifers

At Brussel meeting it was stated (Lamolda and Hancock, 1996):

> *“The species* Stensioeina polonica *Witwicka used to be a good marker of the Coniacian-Santonian boundary in the North Temperate Region, from England to*

East Europe. In S.E. England Stensioeina polonica *occurs with lower* C, undulatoplicatus*, which marks a significant macrofaunal and microfaunal turnover (Wood, written comm.). In Eastern Boreal Europe the F.O. of* Stensioeina exsculpta exsculpta *(Reuss) is a very convenient marker for the Coniacian-Santonian boundary (Kopaevich, written comm.). Other benthic species, such as* Neoflabellina gibbera *(Wedekind), occur in N. Africa and Western Carpathia, and its stratigraphical range is similar to* Sigalia carpatica *(Salaj, 1980). Furthermore, this author correlated the* Sigalia carpatica *Zone from W. Carpathia with the lower part of the* Anomalina *(*Anomalina*)* infrasantonica *Zone (Vasilenko, 1961), allowing a correlation of Western Tethys with its Eastern European areas."*

The lower part of the Santonian is characterized by a high diversity of benthic foraminifers, and near the CSB a turnover is recorded. The genera *Stensioeina* and *Neoflabellina* are particularly significant in the stratigraphy of the Coniacian-Santonian transition. The following data confirm and complete preliminary results given by Lamolda and Hancock (1996).

In the Seaford Head section, S. England (Hampton et al., 2007), the FO of the subspecies *Stensioeina granulata polonica* Witwicka is located 7 m below the FO of *Platyceramus undulatoplicatus*, but it is found consistently 1 m below the CSB and above this level. The LO of the Coniacian subspecies *Stensioeina granulata granulata* (Olbertz) occurs in the uppermost 1 m of the Coniacian, together with the FO of *Cibicides beaumontianus* (d'Orbigny). Howe et al. (2007) have cited other bioevents near the CSB, e.g., the FO of *Gavelinella erikdalensis* around 6 m below the CSB, and the FOs of *Stensioeina granulata incondita* 2 m below the CSB, and *Reussella szajnochae praecursor* 1 m above the CSB.

In S England an interesting bioevent is the last occurrence of *Gavelinella arnagerensis* Solakius, which is located around 1 m above the LO of *P. undulatoplicatus*, and 2 m below the LO of *Lithastrinus septenarius* Forchheimmer (Hampton et al., 2007).

In the Mangishlak Peninsula and in the Russian Platform, Saratov area, benthic foraminifer assemblages allow characterization of the CSB. A first event includes the FOs of *Stensioeina exsculpta exsculpta*, *Cibicidoides erikdalensis* (=*Gavelinella erikdalensis*), and *Neoflabellina suturalis suturalis*, all of them in upper Coniacian beds (Kopaevich et al., 2007). The FO of *Neoflabellina gibbera* is just below the FO of *P. undulatoplicatus* at Shakh-Bogota section, Mangishlak. Eventually, the FOs of

Stensioeina incondida and *Neoflabellina santonica* occur, as well as an increase in the abundance *of N. gibbera, N. suturalis suturalis* and *C. erikdalensis*.

In the Olazagutia section emphasis has been put on *Neoflabellina* spp. (Peryt and Lamolda, 2007). *Neoflabellina suturalis* and *N. praerugosa* are recorded from the upper Coniacian through the section studied. The FO of *N. gibbera* is located about 1.8 m below the FO of *P. undulatoplicatus*, and is followed by the FO of *Neoflabellina praecursor* 1.7 m above the CSB. Howe et al. (2007, fig. 6 V,W,X) figured a specimen of *Stensioeina exsculpta* sampled at 3.5 m below the CSB, but no additional data are given. Nevertheless, the occurrence of *S. exsculpta* in that level at Olazagutia is consistent with its known lower stratigraphic range elsewhere.

Summary

The uppermost Coniacian is characterized by the LO of *Stensioeina granulata*, and the FOs of *S. granulata polonica*, *S. exsculpta exsculpta*, *S. granulata incondita*, *G. erickdalensis*, and *Neoflabellina gibbera*. In the lowermost Santonian, the species *S. granulata incondita*, *G. erickdalensis*, and *N. gibbera* increase their abundances, and the FOs of *Neoflabellina praecursor* and *N. santonica* are recorded. All cited species, except the two latter, have a wide geographical distribution, especially in the transitional region between the Tethys and the Boreal Realm. *Neoflabellina* spp. are known from North America (Texas, USA), Russian Platform, Western Carpathia, Germany, northern Spain and Tunisia, thereby they are potentially a good index for the CSB in different paleogeographical areas.

3.5. Calcareous Nannoplankton

Several calcareous nannoplankton biozonations were published in the last few decades for the Upper Cretaceous (including the Coniacian/Santonian boundary interval). One of the first attempts was published by Manivit (1971), who studied the historical stratotype of the Santonian (Saintes, W France), and assigned to this stage one calcareous nannofossil zone, characterized by the first occurrence (FO) of *Kamptnerius magnificus* and *Broinsonia parca parca*. Later, the FO of *Kamptnerius magnificus* was recorded from the Turonian, whereas the FO *Broinsonia parca parca* is now placed within the Early Campanian (Perch-Nielsen, 1985; Wagreich, 1992; Burnett, 1998).

The historical stratotype of the Santonian (Saintes and adjacent areas) and comparative Tethyan sections (*i.e*., Tunisia) were investigated by Sissingh (1977), who placed the Coniacian/Santonian boundary within Zone CC14, above the FO of *Micula decussata* (=*M. staurophora*), and below the FO of *Reinhardtites anthophorus.* The nannofossil *Reinhardtites anthophorus* is thought to have evolved from *R. scutula* (Bergen, 1994) in the Upper Turonian. The gradual transition, and the presence of rare specimens of *R. anthophorus* in the Upper Turonian, makes the use of this event unsuitable for the Lower Santonian interval (Burnett, 1996; Howe et al., 2007). Perch-Nielsen (1985), who revised Sissingh's Cretaceous Zonation (1977, 1978), indicated that the FO of *R. anthophorus* (the base of the CC15 Biozone of Sissingh, 1977) almost coincides with the FOs of *Lithastrinus grillii* and *Micula concava*, all of them being Lower Santonian events. Therefore, she considered that the Coniacian/Santonian boundary falls within the CC14 *Micula decussata* Biozone of Sissingh (1977). Burnett (1996) recalibrated the calcareous nannofossil zones of Sissingh (1977) and considered that the Coniacian/Santonian boundary falls within zone CC15.

Burnett (1998) produced a new Upper Cretaceous calcareous nannofossil zonation. Based on the correlation of nannofossils with macrofaunas of the Coniacian/Santonian boundary interval (*Micraster coranguinum* echinoid Zone in sections in southern England, and the *Platyceramus* (=*Cladoceramus*) *undulatoplicatus* inoceramid Zone of the Lägerdorf Quarry - Schönfeld et al., 1996), she found that the boundary between the two above-mentioned stages falls within nannofossil zone UC 11, which extends from the first occurrence (FO) of *Lithastrinus grillii* to the last occurrence (LO) of *Lithastrinus septenarius* (=*L. moratus* of some authors). She identified the CSB (Coniacian/Santonian Boundary) within her UC11c Subzone, approximately coincident with the FO of *Amphizygus minimus,* and just above the FO of *Micula concava.*

In the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 1995) it was emphasized that there were no published nannofossil events that approximated the recommended inoceramid CSB event, that is the FO of the inoceramid *Platyceramus undulatoplicatus* (Lamolda and Hancock, 1996). The subsequent study of calcareous nannofossils in the three selected candidates of the Global Boundary Stratotype Section and Point for the base of the Santonian Stage (*i.e*., Olazagutia – N Spain, Ten Mile Creek, Dallas County - N Texas, and Seaford Head, S England), indicated that the CSB falls (according to Lamolda et al., 1999; Melinte and Lamolda, 2002; Gale et al., 2007, and Howe et al., 2007) within the CC16 Calcareous Nannofossil Zone of Sissingh (1977), and in the UC11c Subzone of Burnett (1998), being placed between the FO of *Lucianorhabdus cayeuxii* and the LO of *Lithastrinus septenarius*. The later event marks the base of the UC12 Calcareous Nannofossil Zone of Burnett (1988).

The calcareous nannofossil investigation of the Seaford Head, S England (Howe et al., 2007) led to the identification of the Subzone UC11c of Burnett (1998) across the CSB, between the FO of *Lucianorhabdus cayeuxii* and the LO of *Lithastrinus moratus* (= *L. septenarius*). In the Upper Coniacian, the successive FOs of *Amphizygus brooksii nanus, Micula cubiformis,* and *Lithastrinus grillii* were recorded (Howe et al., 2007). *Eprolithus floralis* was not found by the above-mentioned authors in the studied sequence at Seaford Head. Hampton et al. (2007) recorded the FO of *Amphizygus minimus* above the CSB, coincident with the FO of *Prediscosphaera grandis*, placed lower by Burnett (1998) at the same level with the FO of *M. concava*, which was not reported in the Seaford Head section (Hampton et al*.,* 2007; Howe et *al.,* 2007).

In the Vishnevoe section, Russian Platform, the proposed nannofossil biozonation does not match the chronostratigraphy characterized by other fossil groups (inoceramids and foraminifers). Nevertheless, in the "cardissoides marl" an increase of *Micula concava* is found (Olferiev et al., 2007, fig. 12). This increase could be correlated with similar increases across the CSB found in both N Spain and S Romania (Melinte and Lamolda, 2007), which is consistent with an early Santonian age for the "cardissoides marl" (see above general comments on inoceramids and foraminifers, subchapters 3.1 and 3.3.1., respectively).

Based on the calcareous nannofossil events observed in Ten Mile Creek, and their correlation with other sections, Lees (in Gale et al., 2007) proposed the following best succession of nannofossil events across the Coniacian-Santonian boundary interval (from oldest to youngest), with most reliable emboldened: FO *M. staurophora* (base UC10), FO *L. arcuatus* (within UC10), LO *R. achlyostaurion* (within UC10), FO *L. grillii* (base UC11a), **FO *L. cayeuxii* (base UC11c), FO *Cl. undulatoplicatus* (inoceramid; boundary marker) within UC11c, LO *L. septenarius* (base UC12)**.

Additionally, Gale et al. (2007) recorded some other nannofossil events, for example the LO of *Quadrum gartneri*, which marks the base of the UC11b Subzone of Burnett (1998), followed by the LO of *Marthasterites furcatus* just below the FO of *P. undulatoplicatus*, and by the LO of *Flabellites oblongus* above the CSB. The authors did not exclude the possibility that these taxa are reworked, or they may have an extended distribution as in European sections. Gale et al. (2007) identified the nannofossil *Eprolithus floralis* in a sample located above the CSB.

Howe et al. (2007), who investigated the calcareous nannoplankton from the Ten Mile Creek and Arbor Park composite section (Dallas County - N Texas), reported a sequence of nannofossil events similar to that found by them in the Olazagutia and Seaford Head sections, with the FO of *Lucianorhabdus cayeuxii* at the base of the section, and the LO of *Lithastrinus moratus* (= *L. septenarius*) at the top of the section, correlating it with Subzone UC11c of Burnett (1998). These authors also identified the FOs of *Amphizygus brooksii nanus, Micula cubiformis,* and *Lithastrinus grillii* in the Upper Coniacian. The FO of *Amphizygus minimus* was observed by Howe et al (2007) below the CSB, whereas Gale et al (2007) identified this event above the boundary. Taking into account these data, Gale et al (2007) noted that the use of *Amphizygus minimus* as a marker in Ten Mile Creek is severely undermined by its scarce presence and sporadic distribution. Howe et al. (2007) noted also that *Eprolithus floralis*, a species with the LO placed in the Upper Coniacian, does not occur in the section.

In the Olazagutia section, across the Coniacian/Santonian boundary, the following calcareous nannofossil events (youngest at the top) were observed (Lamolda et al., 1999; Melinte and Lamolda, 2002; Melinte and Lamolda, 2007):

LO *Lithastrinus septenarius* (base UC12), at 18 m above the CSB.

FO *Platyceramus undulatoplicatus*, marker of the CSB

Common *Micula concava*, within the CSB transition.

FO *Lucianorhabdus inflatus* (within UC11c), at 1.8 m below the CSB.

FO (local) *Calculites obscurus*, at 7 m below the CSB.

FO *Lucianorhabdus cayeuxii* (base UC11c), at 12.5 m below the CSB.

FO *Lithastrinus grillii* (base UC11a), at 16.5 m below the CSB.

The CSB falls within the CC16 Biozone of Sissingh (1977) and in the UC11c Subzone of Burnett (1998). The UC11b Subzone of Burnett (1998), marked by the last occurrence (LO) of *Quadrum gartneri*, could not be detected in the Olazagutia section, as *Q. gartneri* occurs up to the top of the section (including within the UC12 Zone of Burnett). The FO of *Calculites obscurus* at Olazagutia has a similar location to that at the Ten Mile Creek section (Gale et al., 2007), and at Rasnov, S Romania (Melinte and Lamolda, 2007). These local FOs could be correlated to the "consistent occurrence" of *C. obscurus* above the FO of *Lucianorhabdus cayeuxii* in N Europe cited by Butnett (1998, fig. 6.4), and in the Lotrului section, S Romania (Melinte and Lamolda, 2007).

Additional nannofloral events recognized by Melinte and Lamolda (2002) in the Olazagutia section are the significant increased abundance of holococcoliths (genera *Lucianorhabdus* and *Calculites*), followed by the increased abundance of *Micula concava*, within the CSB interval. A similar increase in abundance of *M. concava* was observed in other sections of northern Spain (western Alava Province – Gorostidi et al., 1990), southern Romania (Melinte and Lamolda, 2007), and Russian Platform (Olferiev et al., 2007). The increased abundance of the holococcoliths (*Lucianorhabdus* and *Calculites*) was also observed in other European Tethyan sections (*i.e.*, Gosau Group of Austria – Wagreich, 2002; Romanian Carpathians – Melinte and Lamolda, 2007), which have a continous record across the CSB interval. In both Olazagutia and southern Romania the FO of *Lucianorhabdus inflatus* is associated with the increase of holococcoliths.

Howe et al. (2007) identified in Olazagutia, besides the FO of *Lithastrinus grillii*, followed by the FO of *Lucianorhabdus cayeuxii*, several other nannofossil lowest occurrences in the upper part of the Coniacian, including *Amphizygus brooksii nanus* and *Micula cubiformis*, whereas *Amphizygus minimus* ranges throughout the section.

In conclusion, nannofossil workers agree that the CSB is placed between the FO of *Lucianorhabdus cayeuxii* and the LO of *Lithastrinus septenarius*, within the CC16 Zone of Sissingh (1977), and in the UC11c Subzone of Burnett (1998). Above the FO of *L. cayeuxii* a consistent occurrence of *Calculites obscurus* is recorded, which in other localities is recorded as its local FO. Another nannofossil event identified in northern Spain, Austria and southern Romania, that could be further checked for its reliability in other sections, is an increase of holococcoliths sometimes associated to the FO of *Lucianorhabdus inflatus*, above the FO of *Lucianorhabdus cayeuxii* and below the CSB.

In addition, a reliable event could be a higher abundance of *Micula concava*, which occurs across the CSB.

3.6. Carbon Stable Isotopes

Carbon stable isotope curves have been published for the two candidate sections for the Coniacian-Santonian boundary GSSP (Gale et al. 2007; Lamolda and Paul 2007). In addition, Jarvis et al. (2006) have published several carbon isotope curves covering the same interval for sections in southern England in which they name a series of carbon isotope events. Jarvis et al.'s isotope events are always local maxima, (that is peaks) in the carbon isotope curve, but the intervening minima (troughs) may also be used in correlation. The correlation of the isotope events in England is further supported by very detailed bio- and lithostratigraphy. Jarvis et al. (2006) list 45 bioevents between the base of the Cenomanian and the top of the Campanian as well as showing over 30 lithological marker horizons used for detailed correlation. These sections in southern England provide an international standard for carbon isotope correlation of the Cenomanian through the Campanian.

Gale et al. (2007) were able to suggest where some of the isotope events recognized by Jarvis et al. (2006) occurred in the sections at Ten Mile Creek and Arbor Park, Texas, and to relate these to other bioevents in the Ten Mile Creek candidate section. Unfortunately, due to the delay in the publication of the papers presented at the Bilbao meeting on the Coniacian-Santonian boundary (Lamolda, 2002) the information in Jarvis et al. (2006) was not available at the time of submission of the final version of Lamolda & Paul (2007). Thus the latter authors referred to an earlier publication of Jenkyns et al. (1994) to suggest correlations between carbon isotope events at Olazagutia with those in southern England and Italy. Here it is possible to present suggested correlations of the carbon isotope events recognized by Jarvis et al. (2006) in southern England with those at both Olazagutia and Ten Mile Creek (Fig. 12).

At Ten Mile Creek, Gale et al. (2007) published a composite carbon isotope curve from the Ten Mile Creek (candidate GSSP) and Arbor Park sections, which extended from just over 30 m below to just over 10 m above the first occurrence (FO) of *Platyceramus undulatoplicatus*, the primary biomarker for the base of the Santonian stage. The interval included all the events recognized by Jarvis et al. (2006) from the minimum below the Kingsdown Event (late Coniacian) to the minimum above the Bedwell Event (early Santonian) (Fig. 12). At Olazagutia Lamolda and Paul (2007) presented a carbon isotope curve from approximately 18 m below to 20 m above the FO of *Platyceramus undulatoplicatus*. This curve extends from the Kingsdown Event to the minimum above the Bedwell Event or possibly Jarvis et al.'s event L1 (Fig. 12). The FO of *Platyceramus undulatoplicatus* may be used to correlate all these sections (FO in Fig. 12). The second level with abundant *Platyceramus undulatoplicatus* occurs at the base of the Bedwell Event. Graphic correlation of peaks and troughs in the isotope curves between pairs of sections shows that both these bioevents are of essentially the same age in all sections (Figs. 13, 14, 15) and are thus reliable for international correlation. Other bioevents vary in age, sometimes significantly, between sections (see below the subchapter 4.10., Fig. 15).

4. Comparison between Cantera de Margas (Olazagutia) and Ten Mile Creek

Ten Mile Creek (TMC-CS) is a composite section. The Ten Mile Creek s.s. (TMC) (Howe et al., 2007) is a part of the WalMart section (WM) (Gale et al., 2007).

4.1. Outcrop nature and characteristics

TMC-CS: River sides and floor. Thickness given by Howe et al. and Gale et al. are quite different, especially below the FO of *Platyceramus undulatoplicatus*. It is a composite section, from 4 to 6 partial sections are necessary to have a complete idea of the scenario. The distance between the two groups of partial sections (Ten Mile Creek and Arbor Park) is 34.5 km (Howe et al.).

Thickness

WM: The WalMart section extends through about 23.5 m, but only about 5 m above the FO of *P. undulatoplicatus*. To investigate the full details of the Coniacian-Santonian boundary requires the use of a composite section (see above subchapter 2.2.2., and Gale et al., 2007 for full details).

Olazagutia: A continuous section of approximately 320 m from the middle part of the Coniacian to beyond the Santonian/Campanian boundary. On the disused east side of the quarry at present a track obscures a short section the top of which is about 19 m below the FO of *P. undulatoplicatus*. On the west side the section is continuous, but currently less accessible since it is in the working part of the quarry.

Thickness

The candidate GSSP section extends through about 160 m from the middle part of the Coniacian to the middle part of the Santonian. A more detailed study has been made in a 46 m thick section from 19 m below to 27 m above the FO of *P. undulatoplicatus* (Figs. 3, 4).

4.2. Structural complication

TMC-CS: a fault in one of the partial sections (Nazarene).

Olazagutia: no complication.

4.3. Characteristics of sedimentation: continuity and cyclicity

TMC-CS

Correlation of partial sections above the TMC and WM, given by Howe et al., and Gale et al., respectively, is not reliable. There are several channels in the lower part (Gale et al., pp. 115, 120), and two possible unconformities in the middle part (Howe et al., p. 89, fig. 12). In fact, the latter authors (p. 91) pointed out: "*study of the Arbor Park section of Dallas County, Texas defines a major unconformity that occurs stratigraphically just above the Ten Mile Creek section. This unconformity denotes the absence of at least the lower Santonian as currently defined by microfossils (Hardenbol et al., 1998), a time partially equivalent to the "boundary" interval in the Olazagutia section.*"

This section shows a lithologic alternation, which suggests a Milankovitch cyclicity, and is amenable to cyclostratigraphic correlation (Gale et al.).

Olazagutia

No evidence of discontinuities in sedimentation. Howe et al. have suggested that the FO of *P. undulatoplicatus* is younger at Olazagutia than at TMC based on biostratigraphical criteria, e.g., the LO of *Whiteinella paradubia* at TMC 2 m below the FO of *P. undulatoplicatus*, but this species occurs at Olazagutia well above the FO of *P.*

undulatoplicatus (sample 98-13, ~10.20 m above the FO of *P. undulatoplicatus*), and *Whiteinella* spp. occur throughout the section studied. Therefore the LO of *W. paradubia* is not a good index for the upper part of the Coniacian. Howe et al.'s argument that the occurrence of *Dicarinella asymetrica* below the FO of *P. undulatoplicatus* at Olazagutia implies an early Santonian age for that event is not justified, as *D. asymetrica* occurs throughout the Olazagutia studied section, and is known even in the middle part of the Coniacian in Romania (Ion and Szasz, 1994). Therefore their inferred truncation of the lower part of the stratigraphical range of *P. undulatoplicatus* at Olazagutia is rejected. (Further discussion in subchapter 4.9., see below).

There are very weak suggestions of at least five large scale cycles ca. 10 m thick, each starting with rather thicker limestone beds in boundary interval studied in more detail (Lamolda and Paul, 2007).

4.4. Thickness of Platyceramus undulatoplicatus *Zone*

TMC-CS: around 14.5 m, but requires correlation with other local sections to establish the thickness.

Olazagutia: around 11.5 m (not ca. 2 m, as Howe et al., noted). Through the first 2 m, the primary marker is very common. In total, 19 stratigraphic occurrences have been found by Gallemí et al. (Table 1).

4.5. Paleoenvironment (mainly extracted from Howe et al., 2007)

TMC-CS: middle to outer shelf (Paul Sikora, pers. comm. on August 7, 2007).

In Coniacian strata planktonic foraminiferal assemblages are similar to those noted at higher latitude, deep-sea localities, indicating colder surface-water temperature than those from Olazagutia. Benthic foraminiferal assemblages consist of typical mesotrophic taxa from a middle-outer shelf. Up-section, across the CSB foraminiferal diversity increases and eutrophic, opportunistic taxa occur, e.g., globigeriniforms are strongly dominant among the planktonic foraminifers, which could be related to an outflow of colder water from the Western Interior Seaway. The upper parts of the Ten Mile Creek and the Arbor Park sections show frequent and abrupt changes in the assemblage composition between mesotrophic and eutrophic environments, which started at the Coniacian-Santonian transition, and are accompanied by the lowest *Platyceramus undulatoplicatus* and other occurrences of large inoceramids.

Olazagutia: open outer shelf to upper bathyal.

Planktonic foraminiferal relative abundance is almost the same, throughout the section, except in lower Santonian strata, where they decrease equaling the relative abundance of benthic foraminifers (Lamolda et al., 1999). The lower part of the section is characterised by high abundance of planktonic foraminifers and low diversity and abundance of benthic foraminifers. This probably represents an oligotrophic environment. Across the CSB there is an increase of benthic foraminifers, up to 50% in lower Santonian strata, and higher diversity in planktonic foraminifers, which would indicate a mesotrophic environment. This environmental change across the CSB and lower Santonian is contemporaneous with northern temperate influences as was noted above in Ten Mile Creek. Up-section foraminiferal assemblages increase their planktonic component up to 80% (Lamolda et al., 1999).

Howe et al. argued for palaeoecological control on the FO of *P. undulatoplicatus* at Olazagutia, but the same argument may be used at TMC, too. Therefore, their proposal is inconsistent (see above the subchapter 2.2.1.). Furthermore, high-precision correlation using carbon stable isotopes indicates the FO of *P. undulatoplicatus* is the same age at all localities.

4.6. Fossils

4.6.1. Main markers

TMC-CS: The primary marker *P. undulatoplicatus* is recorded. The secondary marker *Sigalia carpatica* is not found.

Olazagutia: Both the primary and secondary markers are recorded. A consistent occurrence of *S. carpatica* is recorded in the lowermost Santonian strata, and up-section.

4.6.2. Other potential markers

TMC-CS

Inoceramids such as *Platyceramus cycloides* and *Cordiceramus* spp. co-occur with *P.*

undulatoplicatus.

The planktonic foraminifer *G. linneiana*, whose pill-box-like morphotypes are relevant for the CSB, has not been found (in addition to the lack of *S. carpatica*).

Olazagutia

The inoceramid *P. cycloides* co-occurs with *P. undulatoplicatus*. *Cordiceramus* spp. are recorded well above the range of *P. undulatoplicatus*, but they co-occur in other localities in northern Spain.

In addition to *S. carpatica*, other significant planktonic foraminiferal bioevents occur close to the CSB: the FO of pill-box-like morphotypes of *G. linneiana*, and an increase of *D. asymetrica*, equaling the abundance of *D. concavata*. Both these latter species, occur in the lowermost Santonian.

An increase of holococcoliths and *Micula concava* close to and/or across the CSB appears to be of significance in Europe.

4.6.3. <u>Diversity and abundance</u>

TMC-CS

High diversity. Main stratigraphic groups occur, except relevant benthic foraminiferal taxa, and some key planktonic foraminifers.

Macrofauna: inoceramids and ammonites are well represented, especially in the lower Santonian strata from several localities studied.

Foraminifers are abundant, but benthic foraminifers decrease in the upper part of the composite section. Nannofossils are abundant and with a moderate preservation in most samples.

Olazagutia

High diversity. Main stratigraphic groups occur.

Macrofauna: inoceramids are abundant in the Santonian strata, but rare in the Coniacian. Ammonites are rare in the section, although they are well represented in many other localities in northern Spain.

Foraminifers are abundant, and dominated by planktonic species, except in the lowermost Santonian where planktonic and benthic foraminifer are equally frequent. Nannofossils are abundant with a moderate preservation in most samples. Around the CSB some taxa (holococcoliths and *Micula concava*) are more common than in the rest of the section.

4.7. Biogeography

TMC-CS.

Temperate–boreal, somewhat restricted (southern border of the Western Interior Seaway).

Nannofossil assemblages have both warm water species, such as *Nannoconus* spp., and cold water species, such as *Gartnerago obliquum* and *Kamptnerius magnificus*, which suggests that the area underwent temperate influences from the Western Interior Seaway, as well as warm water influences from southern areas.

The main components in planktonic foraminiferal assemblages are *Marginotruncana* spp. and *Archaeoglobigerina* spp. in Coniacian strata, whereas close to the CSB and up-section assemblages are dominated by globigeriniforms. This is consistent with the temperate influences indicated by the nannofossils and with somewhat restricted marine facies. The almost complete absence of double-keeled globotruncanids, as well as *Sigalia* spp. is consistent with such a scenario.

Inoceramid assemblages are typical from the southern Euroamerican province, which agrees with both nannofossil and planktonic foraminiferal biogeographic analyses.

Ammonites are mainly endemic, except the cosmopolitan, long-ranging *Texanites* (*Texanites*) *gallicus*.

Olazagutia.

Subtropical with temperate influence.

Belonging to the southern Euroamerican province like Ten Mile Creek, by its inoceramid assemblages, it presents typical subtropical (Tethyan) assemblages, of both planktonic foraminifers and nannofossils. There is a weak temperate influence shown by the rare occurrence of some cold-water nannofossils and benthic foraminifers.

Ammonite assemblages in the region are mixed, some are endemic, whereas others such as *Protexanites burgeoisi*, *Paratexanites serratomarginatus*, and *Placenticeras polyopsis*, are known from a wide region in the western Tethys. Furthermore, the latter two taxa are the nominative species of their eponymous biozones of the standard Mediterranean ammonite biozonation.

4.8. Geochronometry

TMC-CS: No study has been made, although a clay bed lying well below the FO of *P. undulatoplicatus* was reported to be bentonitic.

Olazagutia: No study has been made.

4.9. Stable isotope studies

TMC-CS: available (Gale et al., 2007)

Olazagutia: available (Lamolda and Paul, 2007)

Graphic correlation of stable isotope curves is used to assess how closely the primary boundary marker (*P. undulatoplicatus*) lies to the line of correlation (Figs. 13, 14, 15), because the stable isotope data provide a much higher precision timescale than biostratigraphic data do.

Figure 15 is a cross plot with δ ^{13}C values from TMC composite and Olazagutia sections (Gale et al., 2007, and Lamolda and Paul, 2007, respectively). Correlation is excellent, r^2= 0.950, and the FO of *P. undulatoplicatus* is close to the line of correlation, but below it. This suggests the bioevent occurs earlier in the Olazagutia section than it does in the TMC composite section, which is counter to the assertion of Howe et al. about the truncation of the stratigraphical range of *P. undulatoplicatus* at Olazagutia. The LO of *P. undulatoplicatus* is a reliable event, too, as it is close to the line of correlation.

In Figures 13 and 14, Olazagutia section is correlated with Culver Cliff and Dover sections, respectively (data for Dover and Culver Cliff after Jarvis et al., 2006). Both the FO and the LO of *P. undulatoplicatus* lie very close to the correlation line, confirming the excellence of these bioevents for correlation between different biogeographic provinces. Furthermore, the FO of *P. undulatoplicatus* occurs at Olazagutia earlier than in both the Culver Cliff and Dover sections.Therefore the FO of the primary marker for the CSB at Olazagutia is the earliest occurrence in any of the sections discussed.

4.10. Bioevents

To check the accuracy of bioevents at both TMC-CS and Olazagutia sections, a cross plot with data on bioevent location has been drawn (Fig. 15). As can be seen, most bioevents do not plot close to the line of correlation.

4.10.1. Inoceramids

In both WM and Olazagutia sections the FO of *P. undulatoplicatus* lies between carbon isotope events K2 and Michel Dean. In particular, the bioevent is accompanied by a minimum just below the Michel Dean event. This bioevent is accurate.

The location of the FO of *P. undulatoplicatus* within biozones is not as appropriate, since the likely error of the bioevent is much smaller than those of any of the biozones involved.

* The FO of *Platyceramus cycloides*.

It is detected at both WM and Olazagutia sections and is potentially an accurate bioevent.

* The FO of *Magadiceramus subquadratus*

This species is known at Olazagutia from a single level and so is very poorly constrained. The level may well correlate better with the FO of *Magadiceramus subquadratus* at WM section. Furthermore, this event at Olazagutia is earlier than at WalMart section (Fig. 15), even if the FO of *Magadiceramus* spp. were considered. Thereby, the WalMart section has a partial representation of the *M. subquadratus* stratigraphic range from Olazagutia.

* The LO of *Magadiceramus* found at WM is not reliable at Olazagutia and northern Spain localities, and is inferred at Seaford Head (Hampton et al.).

Not a good bioevent.

4.10.2. Nannofossils

The FO of *Lithastrinus grillii* is recorded at both WM and Olazagutia sections and is potentially a reasonably accurate bioevent, but not stratigraphically close to the primary marker (see Melinte and Lamolda, 2002, for Olazagutia data).

The FOs of *Calculites obscurus*, *Lucianorhabdus cayeuxi*, and LO of *Lithatrinus septenarius* (=*L. moratus*) are recorded at both WM and Olazagutia sections but are inaccurate compared with the stable isotope best-fit line.

4.10.3. Planktonic foraminifers

The FO of *Costellagerina* is recorded at both WM and Olazagutia sections and potentially a reasonably accurate bioevent, but not stratigraphically close to the primary marker.

The LO of *Whiteinella*. This cannot be accurately located at Olazagutia as the genus ranges throughout the section studied. A very inaccurate bioevent. Best ignored.

The FO of *Heterohelix papula*. This cannot be detected at either Olazagutia or Seaford Head. Its FO is not yet well established (Petrizzo, in Gale et al. 2007).

4.10.4. Ammonites

The FO and LO of *Texanites gallicus*.

These cannot be detected at Olazagutia or Seaford Head and are poorly constrained in the WalMart section. The 50 % confidence interval on FO or LO is 2.5 m compared with a total range of 6 m. Furthermore, the FO of *T. gallicus* is known from the early late Coniacian, e.g., at the Oteo section, northern Spain (see subchapter 3.2.), and therefore too early to be useful for the CS boundary. It implies that the local FO at WM section is not the earliest known occurrence of *T. gallicus*. Thereby, the WM section has a partial representation of the actual *T. gallicus* stratigraphic range (see other comments in Lamolda and Hancock, 1996, where *Texanites* was rejected).

4.10.5. Summary

Gale et al. proposed at TMC-CS 9 bioevents, in addition to the FO of *P. undulatoplicatus* and the Michel Dean isotope event. Of these, 3 cannot be detected at Olazagutia or Seaford Head. Of the remaining 6, 5 are inaccurate compared to the stable isotope best-fit line or not close to the primary marker. Thus only 1 additional bioevent is reasonable accurate: the FO of *Platyceramus cycloides*, and so could be used to strengthen the case for either Ten Mile Creek or Olazagutia.

4.11. Access

TMC-CS

> "*there will be a need to clarify ownership of the section, guarantee access rights, and preserve the section for future reference*." (Gale et al., p. 155).

Access has to be clarified for the several outcrops, especially on Ten Mile Creek where the critical interval lay (this was one of the concerns of J. Hancock, see above).

Exposures in the lower and middle parts (including WM section) are easily accessible during the dry season, only.

Ownership of the Nazarene and WalMart sections, on Ten Mile Creek, is not clear. Is it private property or does it belong to the state? Not all rivers have an open access in the USA, as adjoining landowners may have riparian rights.

Olazagutia

Owner of the quarry has agreed to allow access for research (letter on April 26th, 2007). The agreement letter was produced after a meeting between the quarry owners, the Navarran Regional Government, and the Instituto Geológico y Minero de España (IGME; Spanish Geological Survey).

4.12. Preservation of site

TMC-CS

> "*there will be a need to clarify ownership of the section, guarantee access rights, and preserve the section for future reference*." (Gale et al., 2007, p. 155).

Status uncertain. However, WalMart section alone is probably insufficient since it extends only a few metres into the Santonian. Other sections need to be preserved as well to ensure future international correlation.

WalMart and other sections in Dallas County, Texas, are in a growing urban area (another concern of J. Hancock). It could make both access and preservation difficult if new buildings were constructed.

Even if Ten Mile Creek were under the state control, thus providing open access now, will it continue? The USA has a long history of canalizing, etc., rivers in the name of flood control. Does state control make that procedure easier, or more difficult?

Olazagutia

Owner of the quarry has agreed to preserve the non-active eastern border of the quarry where the section studied is located (letter on April 26th, 2007. A copy of this letter was sent by M. Lamolda to the Chairperson of the ISCS, Prof. Isabella Premoli-Silva).

The section would be improved enlarging its present exposure, with an additional cut in the middle part of the present section at the critical interval (detailed section studied by Lamolda and Paul, and others).

4.13. Conclusions

The stable isotope curves are the most accurate means of correlation at present, especially between the expanded sections at Ten Mile Creek and Olazagutia (which have the thickest successions). All isotope points can be correlated, they plot close to a straight line, and the precision of correlation is much greater than with bioevents. Interestingly, the FO of *P. undulatoplicatus* plots about 1 m lower at Olazagutia than at Ten Mile Creek, which is close to the + or – 1 m precision imposed by isotope sampling intervals. This correlation does not support Howe et al.'s conclusion that the FO of *P. undulatoplicatus* is higher at Olazagutia because the section is incomplete. The conclusion was based on other biostratigraphic criteria, which are likely to be as inaccurate as the majority of bioevents we can compare with the isotope correlation (Fig. 15).

Ten Mile Creek (Wall Mart) only extends about 5 m above the boundary. This is really not enough to encompass the changes that occur in the early Santonian. To make full sense of the Dallas sections requires at least the three used in the Gale et al. paper. Quite apart from the security of conservation of the proposed GSSP, other sites would need to be conserved to make the most of the section.

Both in structural complication and continuity of sedimentation the TMC-CS has problems.

The biogeographical location of Olazagutia section gives a better representation of middle and low paleolatitude fossil assemblages, than the temperate-boreal and somewhat restricted TMC-CS.

Main merits of TMC-CS rely to a great extend of macrofossil data (late Coniacian age), but it has been above demonstrated that really accurate correlation has to be based on isotope data. Thus although there are potentially more macrofossil events at the Texan composite section, many cannot be correlated with other sections (e.g., ammonites) or can be shown not to be good time planes, as the primary biomarker is. In fact, *Texanites* was rejected during the Brussels meeting, as its first occurrence is well below the FO of *Platyceramus undulatoplicatus*. Even, such a difference is compensated when upper Coniacian macrofossils at Villamartín and other sections in northern Spain are considered as complementary to the macrofauna at Olazagutia.

Foraminifers and nannofossils should not be neglected. Many bioevents based on these fossils are useful at low and middle (palaeo)latitudes. In contrast, macrofauna, e.g., *P. undulatoplicatus*, has not been found at low latitudes, in N Africa, or in the Pacific Realm. The advantage of foraminifers and nannofossils is overwhelming in deep sea and other research. Potential application of both to characterise the CSB, as they do at Olazagutia, covers several times as much of the Earth's surface compared to known macrofauna occurrences. It may be said that either or both foraminifers and nannofossils, supported by stable isotopes and/or cyclostratigraphy, will allow us to correlate the Coniacian/Santonian boundary accurately in those areas where *P. undulatoplicatus* has not been found. Furthermore, Olazagutia allows correlation with temperate-boreal regions by means of some benthic foraminifers, e.g., neoflabellinids (Lamolda and Hancock, 1996, Kopaevich et al., 2007, and Peryt and Lamolda, 2007).

Access and preservation of Olazagutia section is confirmed formally, whereas TMC-CS has uncertainties either in access or preservation.

5. The sequence of events across the Coniacian-Santonian transition in Olazagutia, with complementary data from the Villamartín section.

According to results discussed above, the sequence of events across the Coniacian-Santonian transition in the eastern border of the "Cantera de Margas" (Olazagutia) section (Fig. 16), complemented with results from the Villamartín section, in stratigraphic order from youngest to oldest (reliable events emboldened, relevant events underlined), is as follows:

1 – The LO of *Lithastrinus septenarius* at the 112.4 m level.

2 - The Bedwell δ ^{13}C stable carbon isotope event at the 106.75 m level.

3 - The LO of *Platyceramus undulatoplicatus* at the 105.9 m level.

4 – The FO of *Platyceramus cycloides* at the 99.1 m level.

5 – The Michael Dean δ ^{13}C stable carbon isotope event and <u>consistent occurrence of *Sigalia carpatica* at the 98.6 m level.</u>

<u>6 – The FO of *Neoflabellina praecursor* and the first common occurrence of *Dicarinella asymetrica* at the 95.8 m level.</u>

7 – The FO of *Placenticeras polyopsis* at the 145.2 m level (in the Villamartín section: 1.1 m above the FO of *Platyceramus undulatoplicatus*).

8 – The FO of the pill-box-like morphotypes of *Globotruncana linneiana* at the 94.5 m level.

9 – The FO of *Platyceramus undulatoplicatus* at the 94.4 m level.

10 – The FO of abundant *Micula concava* at the 93.8 m level.

11 – The FOs of *Neoflabellina gibbera* and *Lucianorhabdus inflatus*, and the FO of abundant holococcoliths at the 92.6 m level.

12 – The Peak 3 $\delta^{13}C$ stable carbon isotope event at the 90.85 m level.

13 – The FO of *Costellagerina pilula* at the 90.4 m level.

14 – The Peak K2 upper $\delta^{13}C$ stable carbon isotope event at the 89.45 m level.

15 – The Peak K2 lower $\delta^{13}C$ stable carbon isotope event at the 87.45 m level.

16 – The FOs of *Sigalia carpatica* and *Calculites obscurus* at the 87.4 m level.

17 – The FO of *Lucianorhabdus cayeuxii* at the 81.9 m level.

18 – The Peak K1 $\delta^{13}C$ stable carbon isotope event at the 81.6 m level.

19 – The FO of *Lithastrinus grillii* at the 79.9 m level.

20 – The Kingsdown $\delta^{13}C$ stable carbon isotope event at the 77.2 m level.

21 – The FO of *Magadiceramus subquadratus* at 64.6 m level.

22 – The FO of *Texanites hispanicus* at 85 m level (in the Villamartín section: 59.1 m below the FO of *P. undulatoplicatus*).

23 – The FO of *Protexanites bourgeoisi* at 70.65 m level (in the Villamartín section: 73.45 m below the FO of *P. undulatoplicatus*).

24 – The FO of *Gauthiericeras margae* at 52.35 m level (in the Villamartín section: 91.75 m below the FO of *P. undulatoplicatus*).

6. Conclusions

- The “Cantera de Margas” section has a continuous exposure, in its eastern border, through about 160 m thick, from the middle part of the Coniacian to the middle part of the Santonian.

- The GSSP candidate for the base of the Santonian Stage lies at 94.4 m level, marked by the first occurrence of the inoceramid *Platyceramus undulatoplicatus*. It occurs through 11.5 m, and is very common in the first 2 m.

- The CSB is bracketed by the Michael Dean and the Peak 3 $\delta^{13}C$ stable carbon isotope events, 4.4 m above and 3.55 m below the CSB, respectively. It lies immediately above the $\delta^{13}C$ minimum between these two peaks.

- The graphic correlation, cross plot, of stable carbon isotope events is one of the most accurate tools for internacional correlation. It allows calibration of bioevents, plus distinction of which are good time planes and which are not. It should be a standard procedure to calibrate GSSPs.

- Only 4 bioevents are reliable as time planes: both the FO and LO of *P. undulatoplicatus*, the FO of the nannofossil *Lithastrinus grillii*, and the FO of the inoceramid *Platyceramus cycloides*. The latter is also a good proxy for the CSB.

- In the critical interval, e.g., between the FO of the planktonic foraminifer *Sigalia carpatica*, 7 m below the CSB and the FO of *P. cycloides*, 4.7 m above the CSB, there are 10 additional noteworthy bioevents to characterise the CSB interval. These allow correlation of Olazagutia with northern and southern temperate provinces, in addition to Tethyan localities.

The proposed GSSP fulfils most of the requirements pointed out by Remane et al. (1996):

- Exposure extends from the middle part of the Coniacian to the middle part of the Santonian.
- There is no evidence of discontinuities nor condensation near the boundary.
- There is a sufficient rate of sedimentation, which allows good separation between ancillary biomarkers and carbon stable isotope events. Large scale cycles are weakly suggested, starting with thicker limestone beds, near the boundary.
- Neither synsedimentary nor tectonic disturbances are evident near the boundary.
- Absense of both metamorphism and strong diagenetic alteration.
- Common main fossil groups, inoceramids, foraminifers and nannofossils, are recorded through the section, except inoceramids which are rare in the Coniacian strata. Ammonites are very rare in the section.

- No facies change across or near the boundary is shown. In addition to the primary marker, the secondary marker – the planktonic foraminifer *Sigalia carpatica*, is recorded.
- The Olazagutia section was a part of an outer platform-upper slope in the northern Tethys, directly connected with the Atlantic Ocean and the northern temperate province.
- Sequence stratigraphy is established. The CSB lies close to, but below, the sequence boundary UC11/UC12.
- The carbon and oxygen stable isotope record is well preserved.
- The owners of the "Cantera de Margas" have agreed to allow access for research.
- The section is permanent since the owner of the quarry has agreed to preserve the disused eastern border. Both, access and preservation, are supported by a governmental agreement.
- Lithology is favorable to Strontium stable isotopes and palaeomagnetic analyses.

Acknowledgements

This proposal of the "Cantera de Margas" as a candidate GSSP for the base of the Santonian Stage is the result of the collaboration of many members of the Santonian Working Group. The collaboration of C. R. C. Paul has been especially useful. We thank Cementos Portland, owner of the Cantera de Margas, for their facilities to this working group and their agreement to allow access and permanent preservation of the section. Both, the Instituto Geológico y Minero de España (Spanish Geological Survey) and the Navarran Regional Government are thanked for their support to this candidate section. This has been a long task since the '90, and with a priority after the Brussels meeting, not always without difficulties, which produced delays from time to time.

References

Amiot, M., 1982. El Cretácico Superior de la Región Navarro-Cántabra. In: García, A. (Coord.), El Cretácico de España. Universidad Complutense, Madrid, pp. 88–111.

Amiot M., Floquet, M., Mathey, B., 1983. Relations entre les trois domaines de sédimentation. In: Vue sur le Crétacé basco-cantabrique et nord-ibérique. Mémoires Géologiques Université Dijon 9, 169–175.

Belford, D. J., 1960. Upper Cretaceous foraminifera from the Toolonga Calcilutite and Gingin Chalk, Western Australia. Bureau of Mineral Resources, Geology and Geophysics, Bulletin 57, 1–198.

Bergen, J.A., 1994. Berriasian to Early Aptian calcareous nannofossils from the Vocontian Trough (SE France) and Deep Sea Drilling Site 534: new nannofossil taxa and a summary of low-latitude biostratigraphic events. Journal of Nannoplankton Research 16, 59-69.

Birkelund, T., Hancock, J.M., Hart, M.B., Rowson, P.F., Remane, J., Robaszynski, F., Schmid, F. & Surlyk, F., 1984. Cretaceous stage boundaries-Proposals. Bulletin geological Society of Denmark, 33: 3-20.

Burnett, J.A., 1996. Nannofossil and Upper Cretaceous (sub-) stage boundaries – State of the art. Journal of Nannoplankton Research 16, 23-32.

Burnett, J.A., 1998. Upper Cretaceous. In: Calcareous Nannofossil Biostratigraphy (ed. P.R. Bown). British Micropaleontological Society Publications Series (Chapman & Hall Ltd/ Kluwer Academic Press), 132-199.

Cobban, W.A.; Dyman, T.S.; Porter, K.W. 2005. Paleontology and stratigraphy of upper Coniacian-middle Santonia ammonite zones and application to erosion surfaces and marine transgressive strata in Montana and Alberta. *Cretaceous Research*: **26**, 429-449.

Coquand, H., 1857. Position des Ostrea columba et biauriculata dans le groupe de la craie inférieure. Bulletin Societé géologique de France, 2(4): 745-766.

Dhondt, A.V.; Lamolda, M.A.; Pons, J.M. 2007. Stratigraphy of the Coniacian-Santonian transition. *Cretaceous Research*: **28**, 1-4.

El Amri, Z.; Zaghbib-Turki, D. 2005. Caractérisation biostratigraphique du passage Coniacien/ Santonien dans les régions d'Ellès et El Kef (Tunisie septentrionale). *Journal of Iberian Geology*: **31(1)**, 99-111.

Floquet, M., 1991. La plate-forme Nord-Castillane au Crétacé supérieur (Espagne). Mémoires géologiques de l'Université de Dijon 14, 925 pp.

Floquet, M., Alonso, A., Meléndez, A., 1982. El Cretácico superior. Cameros-Castilla. In: García, A. (Coord.). El Cretácico de España. Universidad Complutense, Madrid, pp. 387–456.

Flores, J.A., Gorostidi, A., Lamolda, M.A., 1987. Nanoflora y bioestratigrafía del paso Coniaciense-Santoniense en Alava noroccidental. Paleontologia i Evolució, 20(1986), 151-163.

Gale, A.S., Kennedy, J.W., Lees, J.A., Petrizzo, M.R., Walaszczyk, I., 2007. An integrated study (inoceramid bivalves, ammonites, calcareous nannofossils, planktonic foraminifera, stable carbon isotopes) of the Ten Mile Creek section, Lancaster, Dallas County, north Texas, a candidate Global boundary Stratotype Section and Point for the base of theSantonian Stage. Acta Geologica Polonica, 57, 113-160.

Gallemí, J., López, G., Martínez, R., Pons, J.M., 2004. El límite Coniaciense/Santoniense en el valle del Riu de Carreu y en Prats de Carreu, Pirineos centro-meridionales. Geotemas, 6(2), 55-58.

Gallemí, J., López, G., Martínez, R. and Pons, J.M., 2007a. Macrofauna of the Cantera de Margas Section, Olazagutia (Coniacian/Santonian boundary, Navarro Cantabrian Basin, N Spain). Cretaceous Research, 28, 5-17.

Gallemí, J., López, G., Martínez, R. and Pons, J.M., 2007b. Macrofauna of the Villamartin Section (Coniacian-Santonian boundary, North-Castilian Platform, Burgos, Spain). Cretaceous Research, 28, 93-107.

Gorostidi, A., Flores, J.A., Lamolda, M.A., 1990. Aspectos tafonómicos y paleoecológicos de la nannoflora calcárea del Cretácico superior de Álava Occidental. In Civis, J., Flores, J.A. (Eds.), Actas de Paleontología 68, 159-171.

Gräfe, K.-U., 1994. Sequence stratigraphy in the Cretaceous and Paleogene (Aptian to Eocene) of the Basco-Cantabrian Basin (N Spain). Tübinger geowissenschaftliche Arbeiten A 18, 1–148.

Gräfe, K.U., Wiedmann, J., 1998. Sequence stratigraphy on a carbonate ramp: the late Cretaceous Basco-Cantabrian Basin (northern Spain). In: Graciansky, P. C. de, Hardenbol, J., Jacquin, T., Vail, P.R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. SEPM Special Publication 60, 333–341.

Hampton, M.J., Bailey, H.W., Gallagher, L.T., Mortimore, R.N., Wood, C.J. 2007. The biostratigraphy of Seaford Head, Sussex, southern England; an international reference section for the basal boundaries for the Santonian and Campanian Stages in chalk facies. Cretaceous Research, 28, 46-60.

Hancock, J.M., 1991. Ammonite scales for the Cretaceous System. Cretaceous Research, 12, 259-291.

Harland, W. B., Armstrong, R. L., Cox, A. V., Craig, L. E., Smith, A. G., Smith, D. G., 1989. A geologic Time Scale 1989. The British Petroleum Company plc, London.

Harries, P.J., Kauffman, E.G., Crampton, J.S. (redactors), Bengtson, P. et al. (10 other authors), 1996. Lower Turonian Euramerican Inoceramidae: a morphologic, taxonomic, and biostratigraphic overview. Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg 77 [Jost Wiedmann Memorial Volume], 641–671.

Hart, M. B., Bailey, H. W., Crittenden, S., Fletcher, B. N., Swiecicki, A., 1989. Cretaceous. In: Jenkins, D. G., Murray, J. W. (Eds.), Stratigraphical Atlas of Fossil Foraminifera, second edition. British Micropalaeontological Society Series. Ellis Horwood Limited, Chichester, pp. 273–371.

Howe, R.W., Sikora, P.J., Gale, A.S., Bergern, J.A. 2007. Calcareous nannofossil and planktonic foraminiferal biostratigraphy of proposed stratotypes for the Coniacian/Santonian boundary: Olazagutía, northern Spain; Seaford Head, southern England, and Ten Mile Creek, Texas, USA. Cretaceous Research, 28, 61-92.

Ion, J., Antonescu, E., Melinte, M. C., Szasz, L. 1997. Upper Cretaceous integrated biostratigraphy of Romania. Acta Palaeontologica Romaniae, I, 241-253.

Ion, J., Szasz, L., 1994. Biostratigraphy of the Upper Cretaceous of Romania. Cretaceous Research 15, 59–87.

Jarvis, I., Gale, A.S., Jenkyns, H.C., Pearce, A., 2006. Secular variation in Late Cretaceous carbon isotopes: a new δ13C carbonate reference curve for the Cenomanian-Campanian (99.6-70.6 Ma). Geological Magazine, 143, 561-608.

Jenkyns, H. C., Gale, A. S., Corfield, R. M., 1994. Carbon- and Oxygen-isotope stratigraphy of the English Chalk and Italian Scaglia and its palaeoclimatic significance. Geological Magazine 131, 1–34.

Kannenberg, M., 1985. Stratigraphische Arbeiten in der Kreide der westlichen Barranca in Navarra, Nordspanien und statistische Untersuchungen der Echiniden-Gattung *Micraster* im Steinbruch Olazagutia (Coniac-Campan). Diplom Thesis, Freie Universität Berlin, 100 pp.

Kaplan, U., Kennedy, W.J., 2000. Santonian ammonite stratigraphy of the Münster Basin, NW Germany. Acta Geologica Polonica, 50, 99-117.

Kauffman, E.G., 1973. The Upper Cretaceous Inoceramus of Puerto Rico. Transactions of the Fourth Caribbean Geological Conference, Trinidad 1965, 203-218.

Kennedy, W.J., 1995. Defining the base of the Santonian and its substages using macrofossils. Report to the Santonian Working Group.

Kennedy, W.J., Walaszczyk, I., Klinger, H.C., 2008. Associations of *Cladoceramus* (Bivalvia, Inoceramidae) and ammonites from the Santonian of KwaZulu, South Africa. Cretaceous Research, 29, 267-293.

Kopaevich, L.F., Beniamovski, V.N., Sadekov, A.Yu., 2007. Middle Coniacian to Santonian foraminiferal bioevents around the Mangyshlak Peninsula and the Russian Platform. Cretaceous Research, 28, 108-118.

Küchler, T., 1998. Upper Cretaceous of the Barranca (Navarra, northern Spain); integrated litho, bio- and event stratigraphy. Part I: Cenomanian through Santonian. Acta Geologica Polonica 48, 157–236.

Küchler, T., 2000. Upper Cretaceous of the Barranca (Navarra, northern Spain); integrated litho, bio- and event stratigraphy. Part II: Campanian and Maastrichtian. Acta Geologica Polonica 50, 441–449.

Küchler, T., 2002. Additional macrofossil biostratigraphic data on the Upper Coniacian and Santonian of the Olazagutia, Iturmendi and Zuazu sections in the Barranca (Navarra), northern Spain.). In: Wagreich, M. (Ed.), Aspects of Cretaceous Stratigraphy and Palaeobiogeography. Österreichische. Akademie der Wissenschaften,, Schriftenreihe der Erdwissenschaftlichen Kommissionen 15, 315–331.

Lamolda, M.A. (compiler), 1995. The Santonian Working Group. In: Dhondt, A. V. (Ed.), Second International Symposium on Cretaceous Stage Boundaries, Subcommision on Cretaceous Stratigraphy. Brussels, 16-18 September, 1995. Abstracts pp. 156–158.

Lamolda, M.A., 2002. (Compiler), Meeting on the Coniacian-Santonian Boundary. Abstracts. Santonian Working Group, Subcommission on Cretaceous Stratigraphy. International Commission on Stratigraphy and Instituto Geológico y Minero de España, Bilbao, September 14-16, 2002.

Lamolda, M.A. (compiler), 2002. An overview of the Upper Cretaceous of the Basque-Cantabrian region. In: Lamolda, M.A. (Compiler), Meeting on the Coniacian-Santonian Boundary, Bilbao, September 14-16, 2002. Field guide, pp. 35-54.

Lamolda, M. A., Hancock, J.M., 1996. The Santonian Stage and substages. In: Proceedings "Second International Symposium on Cretaceous Stage Boundaries" Brussels 8-16 September, 1995 (Eds. P.F. Rawson, A.V. Dhondt, J.M. Hancock and W.J. Kennedy). Bulletin de l'Institut Royal des Sciences Naturelles de Belgique. Sciences de la Terre, 66-suppl., 95-102.

Lamolda, M.A., Martínez, R., 1987. Bioestratigrafía del Coniaciense y Santoniense en el Norte de Burgos-Oeste de Alava. Paleontologia i Evolució 20 (1986), 225–234.

Lamolda, M.A, Melinte, M.C., Peryt, D. 1999. Datos micropaleontológicos preliminares sobre el límite Coniaciense-Santoniense en Olazagutia (Navarra, España). Revista Española de Micropaleontología, 31, 337-345.

Lamolda, M.A., Paul, C.R.C., 2007. Carbon and Oxygen Stable Isotopes across the Coniacian-Santonian boundary at Olazagutia, N. Spain. Cretaceous Research, 28, 37-45.

Lamolda, M.A., Peryt, D., Ion, J., 2007. Planktonic foraminiferal bio-events in the Coniacian/Santonian boundary interval at Olazagutia (Navarra province), Spain. Cretaceous Research, 28, 18-29.

Lamolda, M.A., Rodríguez-Lázaro, J., Wiedmann, J., 1981. Field guide: excursions to Coniacian-Maastrichtian of Basque-Cantabric Basin. Publicaciones de Geología. Universidad Autónoma de Barcelona 14, 1–53.

López, G. 1992. Paleontología y Bioestratigrafía de los inocerámidos (Bivalvia) del Cretácico superior de la Cuenca Navarro-Cántabra y de la Plataforma Norcastellana. Parte IV: Estudio sistemático del subgénero *Cordiceramus* Seitz y bioestratigrafía. Boletín Geológico y Minero, 103 (5), 837-892.

López, G. 1994. Bioestratigrafía de los inocerámidos (Bivalvia) de la Cuenca Navarro-Cántabra y de la Plataforma Norcastellana. Comparación con zonaciones de otras áreas de Europa. *Cuadernos de Geología Ibérica*, 18: 309-336.

López, G., Lamolda, M.A. and Martínez, R. (1992). Biogeographic aspects of the Coniacian and Santonian inoceramids (Bivalvia) in northern Spain: Their tethyan affinities. *Palaeogeography,Palaeoclimatology,Palaeoecology*, 92: 249-261

López, G., Soler, 1999. La zona de *Platyceramus undulatoplicatus* en el Santoniense (Cretácico superior) del norte de España. In: Rábano, I. (Ed.). Actas XV Jornadas de Paleontología. Temas Geológico-Mineros 26, 253–257.

Manivit, H., 1971. Nannofossiles calcaires du Cretacé français. (Aptien-Maastrichtian). Essai de Biozonation appuyée sur les stratotypes. Thèse de Doctorat, Université de Paris, 387 pp.

Martínez, R., Lamolda, M.A., Gorostidi, A., López, G. and Santamaría, R. (1996). Bioestratigrafía integrada del Cretácico superior de la región Vascocantábrica. *Revista Española de Paleontología, (Núm. ext.)*: 160-171.

Master, 1977 Mesozoic planktonic foraminifera, a world-wide review and analysis. *In*: Ramsay, A.T.S. (*Ed*.), Oceanic Micropaleontology, vol.1, 301-731. Academic Press, London.

Melinte M.C., Lamolda M.A., 2002. Calcareous nannofossils around the Coniacian/Santonian boundary in the Olazagutía section (N. Spain). In: Wagreich, M. (Ed.), Aspects of Cretaceous stratigraphy and palaeobiogeography. Österreich. Akad. Wissensch., 15, 351-364.

Melinte M.C., Lamolda M.A., 2007. Calcareous nannofossil biostratigraphy of the Coniacian/ Santonian boundary interval in Romania and comparison with other European regions. Cretaceous Research, 28, 119-127.

Nederbragt, A.J., 1990. Biostratigraphy and paleoceanographic potential of the Cretaceous planktic foraminifera Heterohehicidae. Ph.D. thesis. Centrale Huisdrukkerij Vrije Universiteit, Amsterdam.

Nederbragt, A.J., 1991, Late Cretaceous biostratigraphy and development of Heterohelicidae (planktic foraminifera). Micropaleontology 37, 329–372.

Noda, M., 1994. Cretaceous inoceramids from the Tano and Onogawa Groups in Kyushu. Special Issue of the Geological Society of Oita 1, 1–49 (in Japanese).

Olferiev, A.G., Beniamovski, V.N., Vishnevskaya, V.S., Ivanov, A.V., Kopaevich, L.F., Pervushov, E.M., Selitser, V.B., Tesakova, E.M., Kharitonov, V.M., Shcherbinina, E.A., 2007. Upper Cretaceous deposits in the Northwest of Saratov Oblast, Part 1: Litho- and Biostratigraphy Analysis of the Vishnevoe Section. Stratigraphy and Geological Correlation, 15, 610-655.

Paul, C.R.C., Lamolda, M.A., 2008. Accuracy and completeness in the stratigraphic record: stable isotopes and bioevents. 5ª Reunión sobre Tafonomía y Fosilización/3rd International Meeting on Taphonomy and Fossilization. Granada, 11-14 de junio, 2008.

Perch-Nielsen, K, 1985. Mesozoic calcareous nannofossils. In: Bolli, H.M., Saunders, J.B., Perch-Nielsen, K. (Eds.), Plankton Stratigraphy. Cambridge University Press, Cambridge, pp. 329-426.

Petrizzo, M.R., 2000. Upper Turonian-lower Campanian planktonic foraminifera from southern mid-high latitudes (Exmouth Plateau, NW Australia): biostratigraphy and taxonomic notes. Cretaceous Research*,* 21, 479-505.

Petrizzo, M.R., 2001. Late Cretaceous planktonic foraminifera from Kerguelen Plateau (ODP Leg 183): new data to improve the Southern Ocean Biozonation. Cretaceous Research 22, 829–855.

Peryt, D., Lamolda, M.A., 2007. Neoflabellinids (benthic foraminifers) from the Upper Coniacian and Lower Santonian at Olazagutia, Navarra province, Spain; taxonomy and correlation potential. Cretaceous Research 28, 30-36.

Rámirez del Pozo, J. 1971. Bioestratigrafía y microfacies del Jurásico y Cretácico del Norte de España (Región Cantábrica). Memorias del Instituto Geológico y Minero de España 78, 1–357.

Remane, J., Bassett, M.G., Cowie, J.W., Gohrbandt, K.H., Lane, H.R., Michelsen, O., Naiwen, W., 1996. Revised guidelines for the estalishement of global chronostratigraphic standards by the International Commission on Stratigraphy (ICS). Episodes 19, 77-81.

Remin, Z. 2004. Biostratigraphy of the Santonian in the SW margin of the Holy Cross Mountains near Lipnik, a potential reference section for extra-Carpathian Poland. *Acta Geologica Polonica,* Vol. 54 (2004), No. 4, pp. 587-596.

Robaszynski, F., Caron, M., 1995. Foraminiferès planctoniques du Crétacé: commentaire de la zonation Europe-Méditerrannée. Bulletin de la Société Géologique de France 166, 681–692.

Robaszynski, F., Caron, M., González Donoso, J.M., Wonder, A.A.H., 1984. Atlas of Late Cretaceous Globotruncanids. Revue de Micropaléontologie 26, 145–305.

Robaszynski, F., Gonzalez Donoso, J.M., Linares, D., Amedro, F., Caron, M., Dupuis, C., Dhondt, A.V., Gartner, S., 2000. Le Crétacé supérieur de la région de Kalaat Senan, Tunisie centrale. Litho-Biostratigraphie intégrée: zones d'ammonites, de Foraminifères planctoniques et de Nannofossiles du Turonien supérieur au Maastrichtien. Bulletin du Centre de Recherches Elf Exploration Production, 22, 359-490.

Salaj, J., 1975. Contribution à la microbiostratigraphie du Mésozoïque et du Tertiaire de la Tunisie septentrionale. Ve Colloque Afriquain Micropaléontologie, Addis Ababba. Revista española de Micropaleontología. Monografías: 703-783.

Salaj, J., 1980. Microbiostratigraphie du Crétacé et du Paléogène de la Tunisie septentrionale et orientale (Hypostratotypes tunisiens). Institut Géologique de Dionýz Štúr, Bratislava, 238 pp.

Santamaría Zabala, R., 1992. Los Ammonoideos del Cenomaniense superior al Santoniense de la plataforma nord-castellana y la cuenca navarro-cántabra. Parte I. Bioestratigrafía y sistemática: Phylloceratina, Ammonitina (Desmocerataeae y Hoplitacea) y Ancyloceratina. Treballs del Museu de Geologia de Barcelona 2, 171–268.

Schönfeld, J., Schulz, M-G. (coordinators), McArthur, J.M., Burnett, J., Gale, A., Hambach, U., Hansen, H.J., Kennedy, W.J., Rasmussen, K.L., Thirlwall, M.F., Wray, D., 1996. New results on biostratigraphy, palaeomagnetism, geochemistry and correlation from the standard section for the Upper Cretaceous white chalk of northern Germany (Lägerdorf-Kronsmoor-Henmmoor). Proceedings of the 4th International Cretaceous Symposium, Hamburg, 1992.

Mitteilungen des Geologisch-Paläontologischen Instituts der Universität Hamburg 77, pp. 545-575.

Seitz, O. 1965. Die Inocerumen des Sarton und Unler-Campan von Nordwestdeulschland II. Teil (Biometie, Dimorphismus und Stratigraphie des Untergattung Sphenoceramus J. Böhm). Beihefte zum Geologischen Jarhhuch, Heft 69, 194 p.

Sigal, J., 1977. Essai de zonation du Crétacé méditerranéen à l'aide des foraminifères planctoniques. Géologie Méditerranéenne, 4: 99-108.

Sissingh, W. 1977. Biostratigraphy of Cretaceous calcareous nannoplankton. Geologie en Mijnbouw, 56, 37-65.

Sissingh, W., 1978. Microfossil biostratigraphy and stage-stratotypes of the Cretaceous. Geologie en Mijnbouw, 57, 433-440.

Sornay, J. 1969. Espèces et sous-espèces senoniennes nouvelles de la faune d'Inocérames de Madagascar. Annales de Paléontologie (Invertebres), 5, 195-222.

Svábenická 1995 Common occurrences of the ecologically restricted nannofossils in the Campanian sediments of the Ždánice Unit and Waschberg Zone, West Carpathians. – Proceedings XVth Congress Carpatho-Balkan. Geological Association, Geological Society of Greece Spec. Publ., 4, 282-287.

Thierstein, H.R. 1976. Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. – Mar. Micropaleontology, 1, 325-362.

Thierstein, H.R. 1981. Late Cretaceous nannoplankton and the change at the Cretaceous/ Tertiary boundary. – SEPM Spec. Publ., 32, 355-394.

Toshimitsu, S., Hasegawa T. and Tsuchiya, K. 2007 Coniacian–Santonian stratigraphy in Japan: a review. *Cretaceous Research*, 28: 128-131

Tröger, K.-A., 1989. Problems of Upper Cretaceous inoceramid biostratigraphy and palaeogeography in Europe and western Asia. En: *Cretaceous of the Western Tethis*, *Proceedings of the 3rd International Cretaceous Symposium, Tübingen 1987* (J. Wiedmann, Ed.). E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart. 911-930.

Tröger, K.-A., Summesberger, H., 1994. Coniacian and Santonian inoceramid bivalves from the Gosau-Group (Cretaceous, Austria) and their biostratigraphic and palaeobiogeographic significance. Annals Naturhistorische Museum Wien, 96A, 161-197.

Varol, O., 1992. Taxonomic revision of the Polycyclolithaceae and its contribution to Cretaceous biostratigraphy. – Newsletters on Stratigraphy, 27/3, 93-127.

Vasilenko, V.P., 1961. Upper Cretaceous Foraminifera from the Mangyshlak peninsula. Trudy VNIGRI 171.

Wagreich, M., 1992. Correlation of Late Cretaceous calcareous nannofossil zones with ammonite zones and planktonic Foraminirera: the Austrian Gosau sections. Cretaceous Research, 13: 505-516.

Wagreich, M., 2002. Nannoplankton and foraminifera in Coniacian-Santonian boundary sections in Austria. In: Lamolda, M.A. (Ed.), Meeting on the Coniacian/Santonian Boundary, Bilbao 2002. Abstract Volume, p. 27.

Walaszczyk, I., Cobban, W.A. 2007. Inoceramid fauna and biostratigraphy of the upper Middle Coniacian-lower Middle Santonian of the Pueblo Section (SE Colorado, US Western Interior). *Cretaceous Research*: **28**, 132-142.

Walaszczyk, I., Peryt, D., 1998. Inoceramid-foraminiferal biostratigraphy of the Turonian through Santonian deposits of the Middle Vistula Section, Central Poland. Zentralblatt für Geologie und Paläontologie I, 11/12, 1501–1513.

Wiedmann, J., Reitner, J., Engeser, T., Schwenkte, W., 1983. Platten-tektonik, Fazies und Subsidenzgeschichte des basko-kantabrischen Kontinentalrandes während Kreide und Alttertiär. Zitteliana 10, 207–244.

Yazykova, E.A. 2002. Ammonite and inoceramid radiations after the Santonian-Campanian bioevent in Sakhalin, Far East Russia. *Lethaia,* 35, 51-60.

Yazykova, E. 2004. Ammonite biozonation and litho-/chronostratigraphy of the Cretaceous in Sakhalin and adjacent territories of Far East Russia. *Acta Geologica Polonica*, 54 (2), 273–312.

Yazykova, E., Zonova, T.D., 2002. The problem of the Coniacian-Santonian boundary in far eastern regions of Russia. Meeting on the Coniacian-Santonian Boundary. Abstracts. Santonian Working Group, Subcommission on Cretaceous Stratigraphy. International Commission on Stratigraphy and Instituto Geológico y Minero de España, 30-31.

Zander, J., 1988. Die Ober-Kreide der Barranca im Raum Alsasua (Provinz Navarra, Nordspanien), aus mikropaläontologischer Sicht. Unpublished Diploma Thesis, FU Berlin, 127 pp.

Zonova, T.D., Kasintsova, L.I. & Yazykova, E.A. 1993. Atlas of the main groups of Cretaceous fauna from Sakhalin, pp.1-327, Nedra, Sankt-Petersburg [in Russian].

Figure captions

Fig. 1. Location of the Olazagutia section in northern Spain. CM=Cantera de Margas (after Lamolda and Paul, 2007, fig. 1).

Fig. 2. The Cantera de Margas section, with indication of the FO and LO of *Platyceramus undulatoplicatus*, and the location of metal labels (modified from Gallemí et al., 2007a, fig. 5).

Fig. 3. Stratigraphic column of the Olazagutia section with lithostratigraphy, biostratigraphy and main bioevents across the Coniacian–Santonian boundary. Columns for zones as follows. A=inoceramid zones, B=globotruncanid zones, C =heterohelicid zones, D and E=calcareous nannofossil schemes of Sissingh (1977) and Burnett (1998), respectively (after Lamolda and Paul, 2007, fig. 2)

Fig. 4. A general view of the Cantera de Margas section. The aproximate location of the Coniancian-Santonian boundary is shown by the white line.

Fig. 5, The Coniacian-Santonian transition at the Cantera de Margas section. The level of the FO of *P. undulatoplicatus* is marked by the white line.

Fig. 6. The Cantera de Margas section, with indication of main first and last occurrences (FO and LO) in inoceramid, echinoid and ammonite taxa (after Gallemí et al., 2007a, fig. 5).

Fig. 7. Stratigraphical distribution of planktonic foraminifers and planktonic foraminiferal zonation of the Upper Coniacian and Lower Santonian in the Olazagutia section (small squares indicate occurrences of pill-box-like morphotypes of *Globotruncana linneiana* (after Lamolda et al., 2007, fig. 2).

Fig. 8. Range-chart of nannofossil species in the Olazagutia section. Abundances were recorded as follow: A=abundant, >1 specimen/field of view (FOV); C=common, 1 spec imen/2-10 FOV; F=few, 1 specimen/11-20 FOV; R=rare, 1 specimen/>20 FOV.

Fig. 9. Carbon isotope curve for the Olazagutia section and suggested correlation with East Kent (data from Jenkyns et al.,1994). Horizontal lines indicate positions of the first (FO) and last (LO) occurrences of *Platyceramus undulatoplicatus* (Roemer), which have been used to calibrate relative sedimentation rates at the two sections (after Lamolda and Paul, 2007, fig. 3).

Fig. 10. Upper Cretaceous outcrops in the Basque-Cantabrian Region. Aproximate boundary between relevant palaeogeographic units, during Late Coniacian and Early Santonian times, are outlined by dotted lines. Location of Olazagutia, the proposed Coniacian/Santonian boundary stratotype section, is also indicated (after Gallemí et al., 2007b, fig. 2)

Fig. 11. The Villamartín section, with indications of the main first and last occurrences (FO and LO) in inoceramid, echinoid and ammonite taxa (after Gallemí et al., 2007b, fig. 3).

Fig. 12. Suggested carbon isotope correlation between three sections in southern England (Dover, Culver Cliff, and the Trunch Borehole), and the two candidate GSSP sections (Ten Mile Creek, Texas and Olazagutia, Spain). FO, first occurrence of *Platyceramus undulatoplicatus*, the primary biomarker for the base of the Santonian stage. Vertical line against the Ten Mile Creek – Arbor Park isotope curve indicates the extent of the candidate GSSP section. Note that the vertical scale for the Trunch borehole is in metres below surface.

Fig. 13. Graphic correlation of peaks and troughs in the carbon stable isotope curves across the Coniacian-Santonian boundary between Olazagutia, Spain and Culver Cliff, England, together with the position of the first occurrence (FO) of *Platyceramus undulatoplicatus*. P2 base of the upper level of *P. undulatoplicatus* (after Paul and Lamolda, submitted, fig. 3).

Fig. 14. Graphic correlation of peaks and troughs in the carbon stable isotope curves across the Coniacian-Santonian boundary between Olazagutia, Spain and Dover, England, together with the positions of the first occurrence (FO) of *Platyceramus undulatoplicatus*. P2 base of the upper level of *P. undulatoplicatus* (after Paul and Lamolda, submitted, fig. 4).

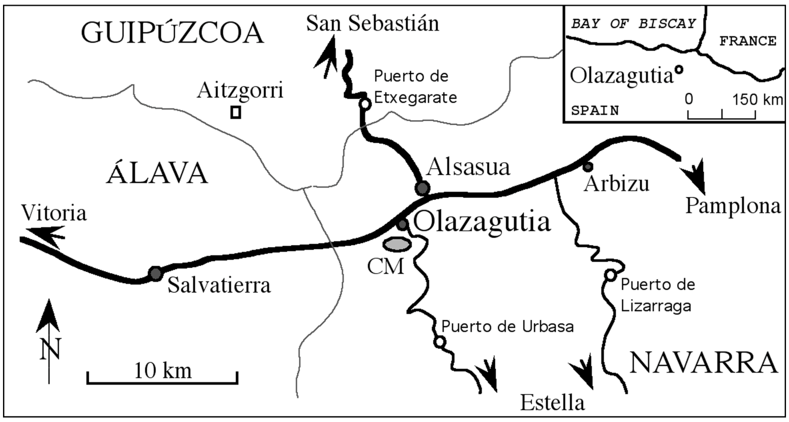
Fig. 15. A Carbon stable isotope curve for Olazagutia, Spain, showing the peaks and minima (M1-M7) used in the graphic correlation with Ten Mile Creek. Named peaks follow Jarvis *et al.* (2006), whereas the four peaks between the Kingsdown and Michel Dean events are labelled as in Gale *et al.* (2007) except that 'peak 3' is a new term. B, Graphic correlation of peaks and troughs in the carbon stable isotope curves across the Coniacian-Santonian boundary between Olazagutia, Spain and Ten Mile Creek, USA, together with the positions of ten bioevents common to both sections. Bioevents are: 1, the first occurrence (FO) of *Magadiceramus subquadratus*, 2, FO of *Lithastrinus grillii*, 3, FO of *Lucianorhabdus cayeuxi*, 4, FO of *Calculites obscurus*, 5, FO of *Costellagerina*, 6, FO of *Platyceramus undulatoplicatus*. 7, FO of *Platyceramus cycloides*, 8, last occurrence (LO) of *Platyceramus undulatoplicatus*, 9, LO of *Lithastrinus septenarius*, 10, FO of *Cordiceramus* (after Paul and Lamolda, submitted, fig. 6).

Fig. 16. The sequence of events across the Coniacian-Santonian transition in the Cantera de Margas, eastern border section, Olazagutia, northern Spain (modified after Lamolda and Paul, 2007, fig. 2). (See Appendix 1, which reproduces the fig. 25 of Gale et al., 2007, for a comparisson between WalMart and Olazagutia).

Table captions

Table 1. Distribution of macrofauna samples in the Cantera de Margas section. Cells in black indicate *in situ* occurrences, half-tone indicates *ex situ* occurrences. Some comprehensive samples are indicated with their interval span. OL-(number) refers to location of micropalaeontological samples described by Lamolda et al. (1999) (after Gallemí et al., 2007a, tab. 1).

Table 2. Distribution of the macrofauna samples in the Villamartín section. Cells in black indicate *in situ* occurrences, half-tone indicates *ex situ* occurrences. Some comprehensive samples are indicated with their interval span. 1=*Platyceramus undulatoplicatus*, 2=*Placenticeras polyopsis*, 3=Prionocycloceras iberiense, 4=*Protexanites bourgeoisi*, 5=*Gauthiericeras margae* (after Gallemí et al., 2007b, tab. 1).


GUIPÚZCOA
San Sebastián
Puerto de
Etxegarate
Aitzgorri
ÁLAVA
Alsasua
Arbizu
Pamplona
Vitoria
Olazagutia
CM
Salvatierra
Puerto de
Lizarraga
Puerto de Urbasa
N
10 km
NAVARRA
Estella
BAY OF BISCAY
FRANCE
Olazagutia
0
150 km
SPAIN
Fig 1.

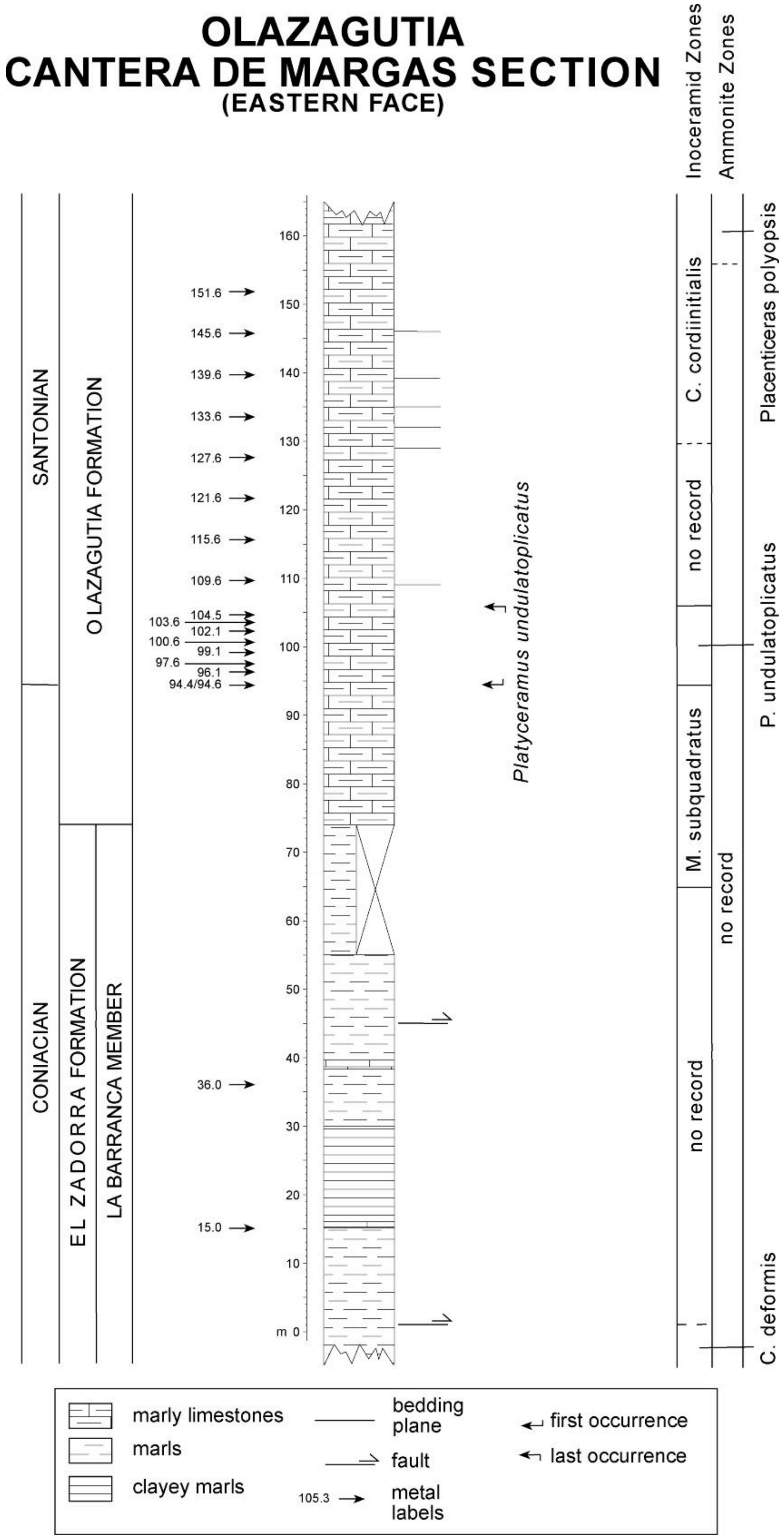

OLAZAGUTIA
CANTERA DE MARGAS SECTION
(EASTERN FACE)
Inoceramid Zones
Ammonite Zones
SANTONIAN
CONIACIAN
OLAZAGUTIA FORMATION
EL ZADORRA FORMATION
LA BARRANCA MEMBER
151.6
145.6
139.6
133.6
127.6
121.6
115.6
109.6
104.5
103.6
102.1
100.6
99.1
97.6
96.1
94.4/94.6
36.0
15.0
m 0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Platyceramus undulatoplicatus
C. cordiinitialis
no record
M. subquadratus
no record
no record
Placenticeras polyopsis
P. undulatoplicatus
C. deformis
marly limestones
marls
clayey marls
bedding plane
fault
105.3
metal labels
first occurrence
last occurrence

Fig.2

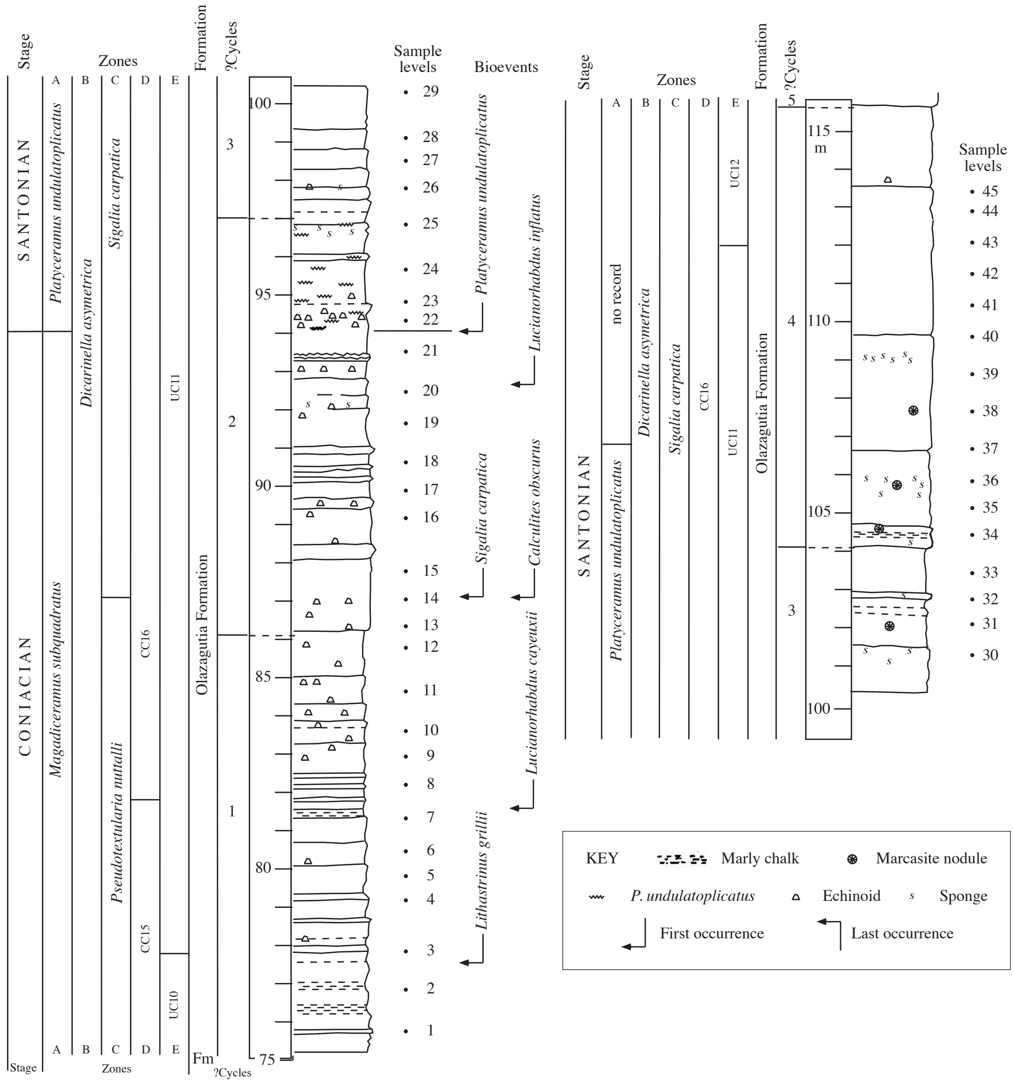

Stage
Zones
Formation
?Cycles
Sample levels
Bioevents
SANTONIAN
CONIACIAN
Platyceramus undulatoplicatus
Magadiceramus subquadratus
Dicarinella asymetrica
Sigalia carpatica
Pseudotextularia nuttalli
CC15
CC16
UC10
UC11
UC12
Olazagutia Formation
Fm
no record
Lucianorhabdus inflatus
Calculites obscurus
Lucianorhabdus cayeuxii
Lithastrinus grillii
Lithastrinus septenarius
115 m
KEY
Marly chalk
Marcasite nodule
P. undulatoplicatus
Echinoid
Sponge
First occurrence
Last occurrence

Fig.3

Fig.4

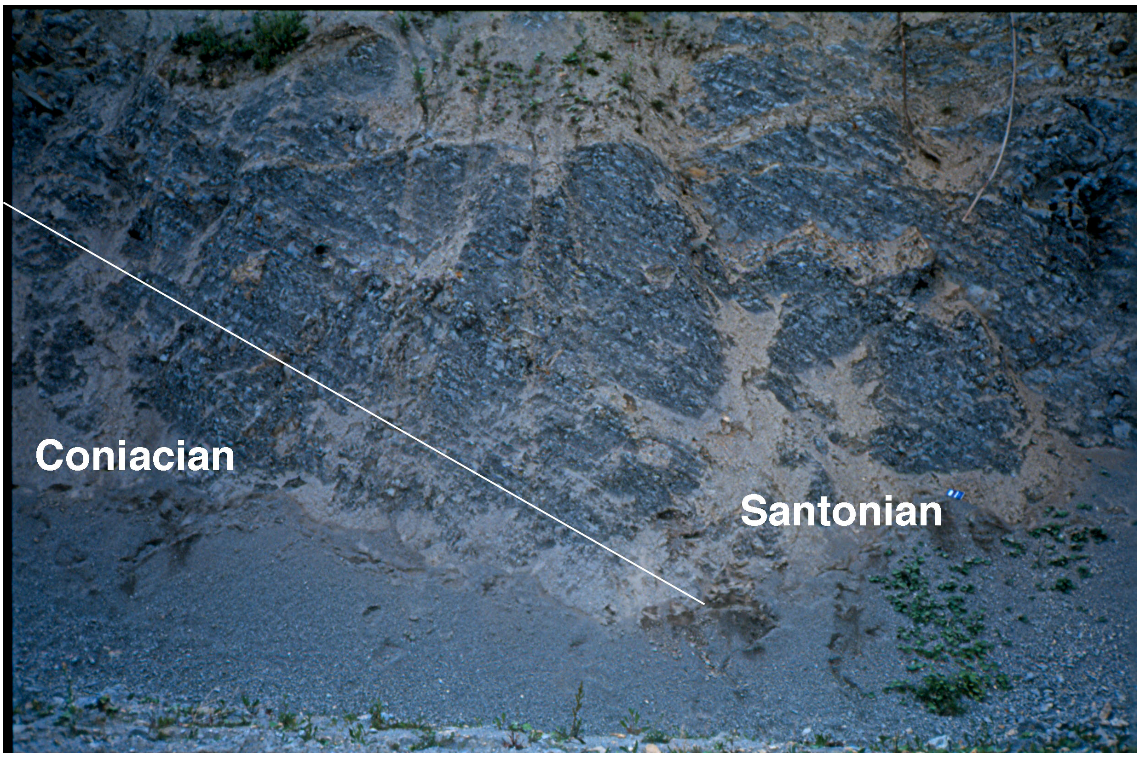


Fig.5

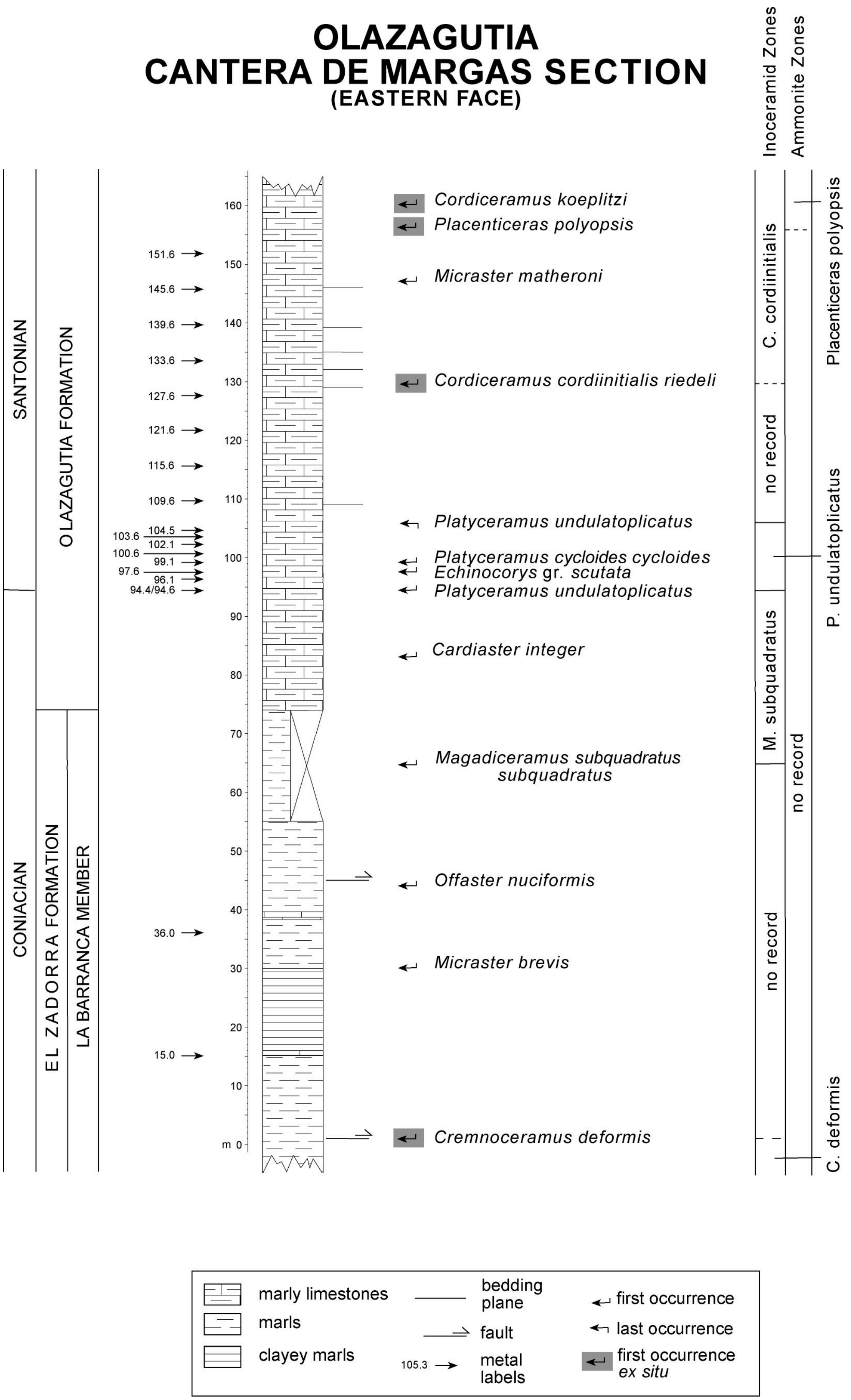
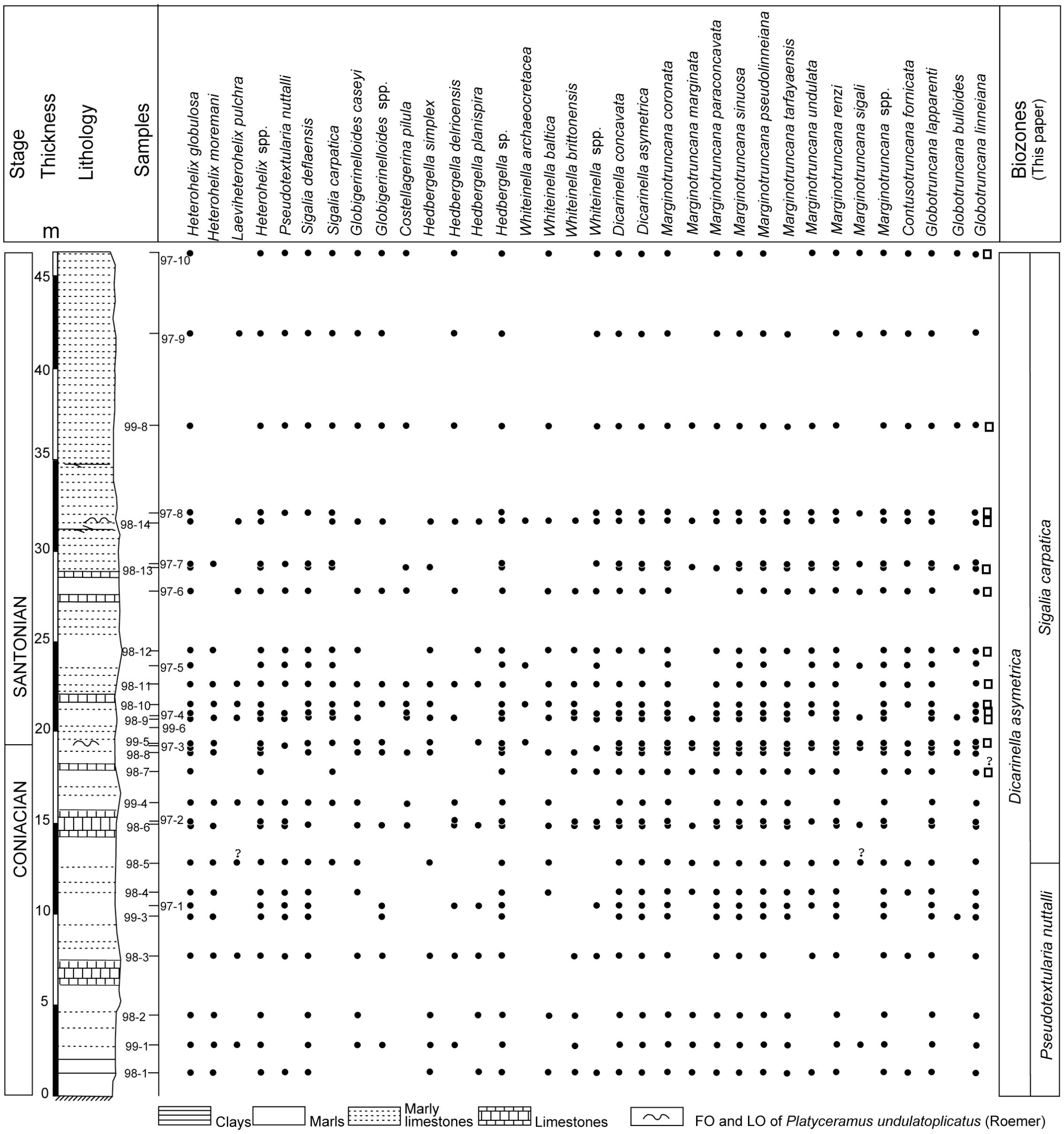

OLAZAGUTIA
CANTERA DE MARGAS SECTION
(EASTERN FACE)
Inoceramid Zones
Ammonite Zones
SANTONIAN
CONIACIAN
OLAZAGUTIA FORMATION
EL ZADORRA FORMATION
LA BARRANCA MEMBER
151.6
145.6
139.6
133.6
127.6
121.6
115.6
109.6
104.5
103.6
102.1
100.6
99.1
97.6
96.1
94.4/94.6
36.0
15.0
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
m 0
Cordiceramus koeplitzi
Placenticeras polyopsis
Micraster matheroni
Cordiceramus cordiinitialis riedeli
Platyceramus undulatoplicatus
Platyceramus cycloides cycloides
Echinocorys gr. scutata
Platyceramus undulatoplicatus
Cardiaster integer
Magadiceramus subquadratus subquadratus
Offaster nuciformis
Micraster brevis
Cremnoceramus deformis
C. cordiinitialis
no record
M. subquadratus
no record
no record
Placenticeras polyopsis
P. undulatoplicatus
C. deformis
marly limestones
marls
clayey marls
bedding plane
fault
105.3
metal labels
first occurrence
last occurrence
first occurrence ex situ

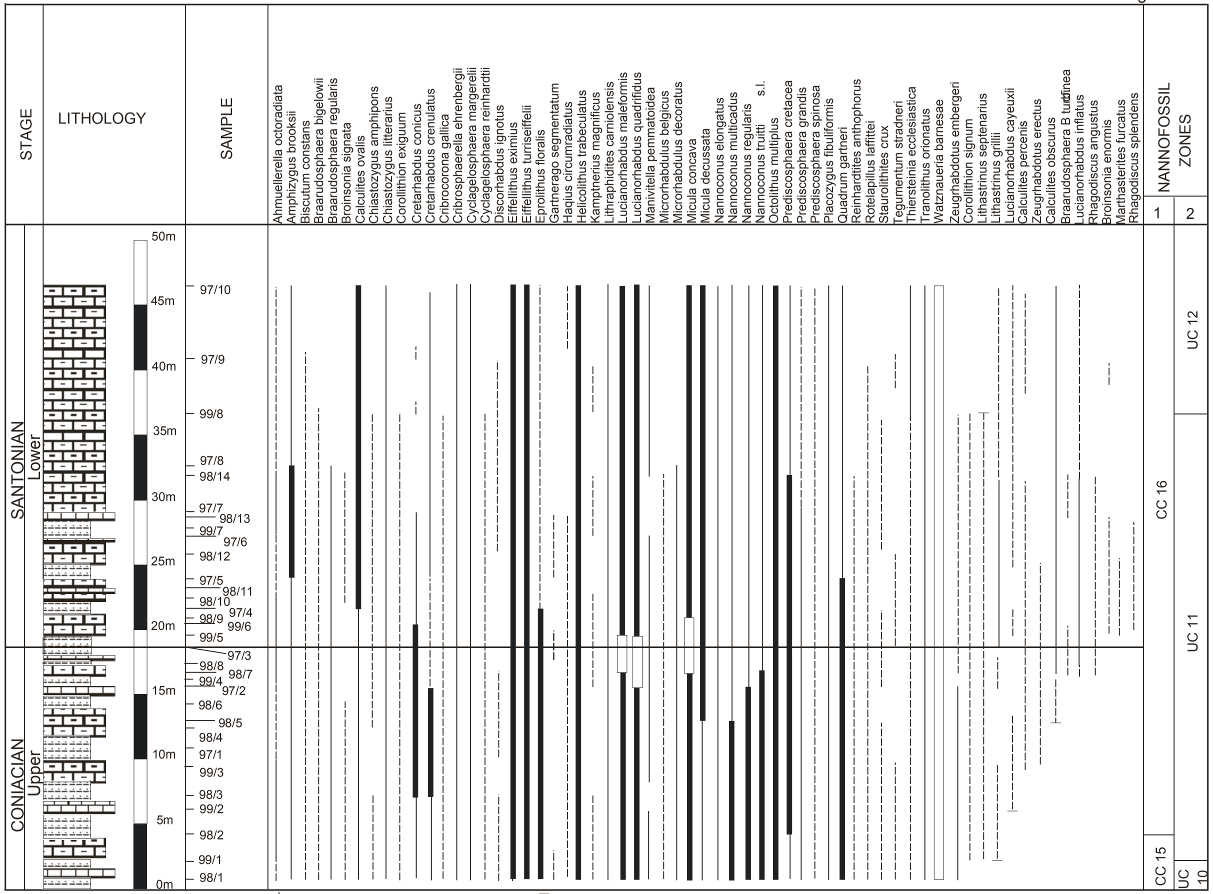
Fig.6



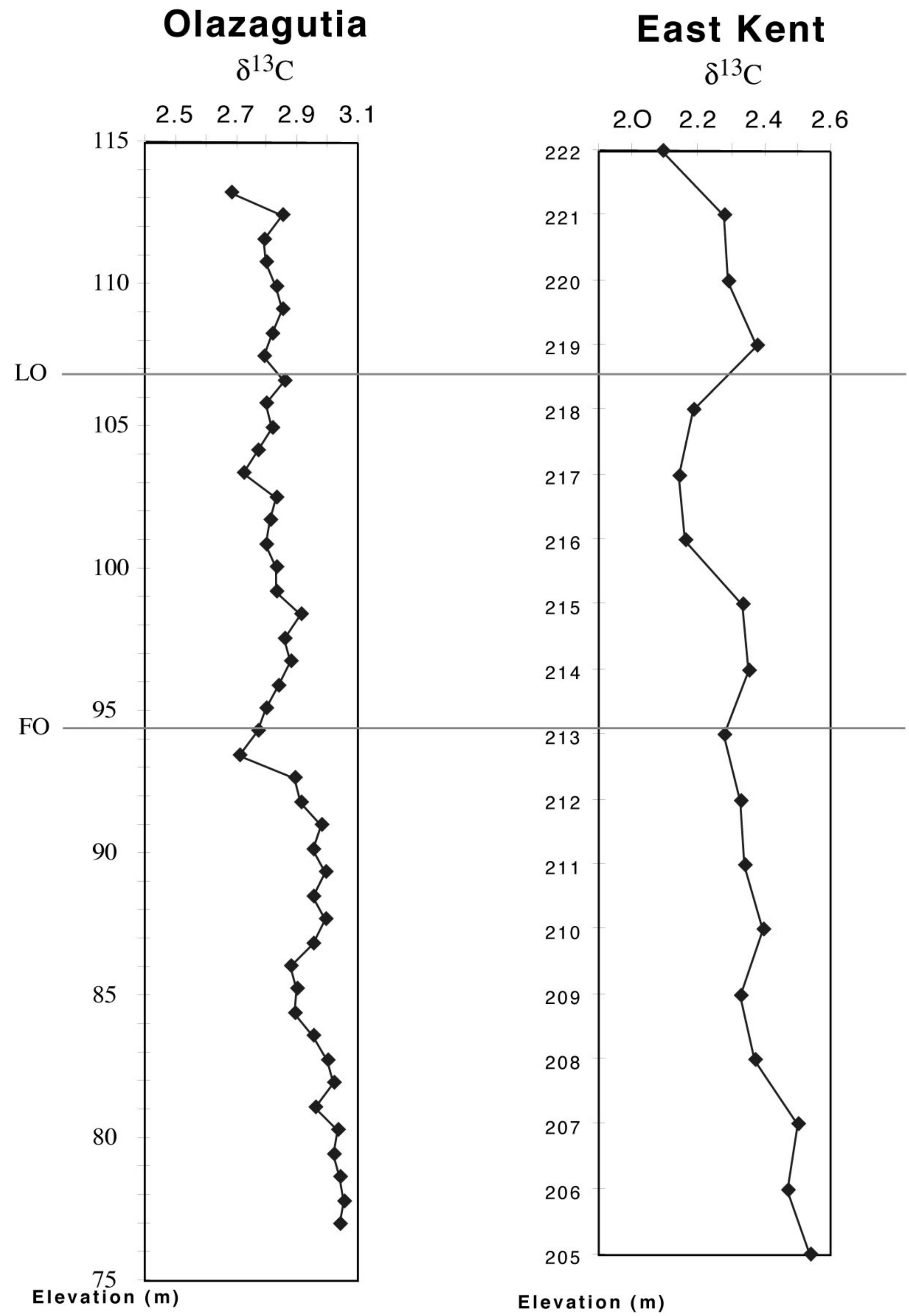
Stage
Thickness
m
Lithology
Samples
Heterohelix globulosa
Heterohelix moremani
Laeviheterohelix pulchra
Heterohelix spp.
Pseudotextularia nuttalli
Sigalia deflaensis
Sigalia carpatica
Globigerinelloides caseyi
Globigerinelloides spp.
Costellagerina pilula
Hedbergella simplex
Hedbergella delrioensis
Hedbergella planispira
Hedbergella sp.
Whiteinella archaeocretacea
Whiteinella baltica
Whiteinella brittonensis
Whiteinella spp.
Dicarinella concavata
Dicarinella asymetrica
Marginotruncana coronata
Marginotruncana marginata
Marginotruncana paraconcavata
Marginotruncana sinuosa
Marginotruncana pseudolinneiana
Marginotruncana tarfayaensis
Marginotruncana undulata
Marginotruncana renzi
Marginotruncana sigali
Marginotruncana spp.
Contusotruncana fornicata
Globotruncana lapparenti
Globotruncana bulloides
Globotruncana linneiana
Biozones
(This paper)
SANTONIAN
CONIACIAN
Dicarinella asymetrica
Sigalia carpatica
Pseudotextularia nuttalli
Clays
Marls
Marly limestones
Limestones
FO and LO of Platyceramus undulatoplicatus (Roemer)

Fig.7

Figure 2



Nannofossil distribution: rare few common abundant Nannofossil zones: 1-after Sissingh (1977); 2 - after Burnett (1998)



Olazagutia
δ13C
2.5 2.7 2.9 3.1
115
110
105
100
95
90
85
80
75
LO
FO
Elevation (m)
East Kent
δ13C
2.O 2.2 2.4 2.6
222
221
220
219
218
217
216
215
214
213
212
211
210
209
208
207
206
205
Elevation (m)

Fig.9

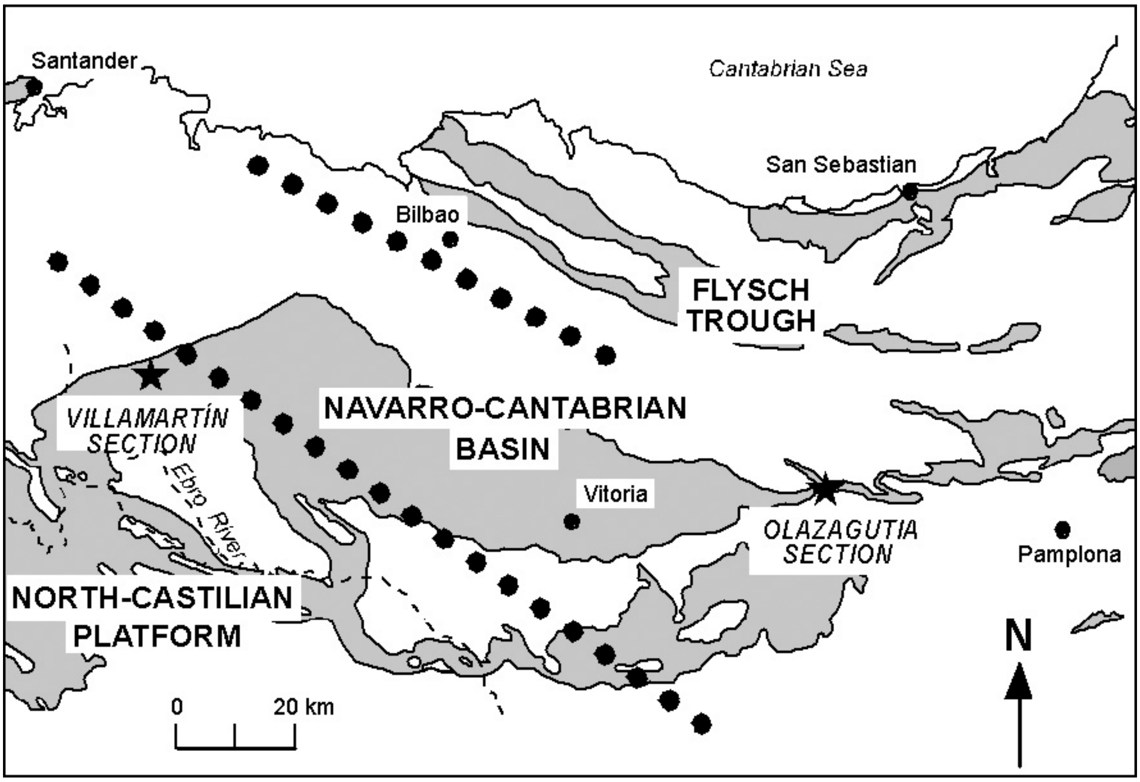

Santander
Cantabrian Sea
San Sebastian
Bilbao
FLYSCH
TROUGH
NAVARRO-CANTABRIAN
BASIN
VILLAMARTÍN
SECTION
Ebro River
Vitoria
OLAZAGUTIA
SECTION
Pamplona
NORTH-CASTILIAN
PLATFORM
0
20 km
N

Fig. 10

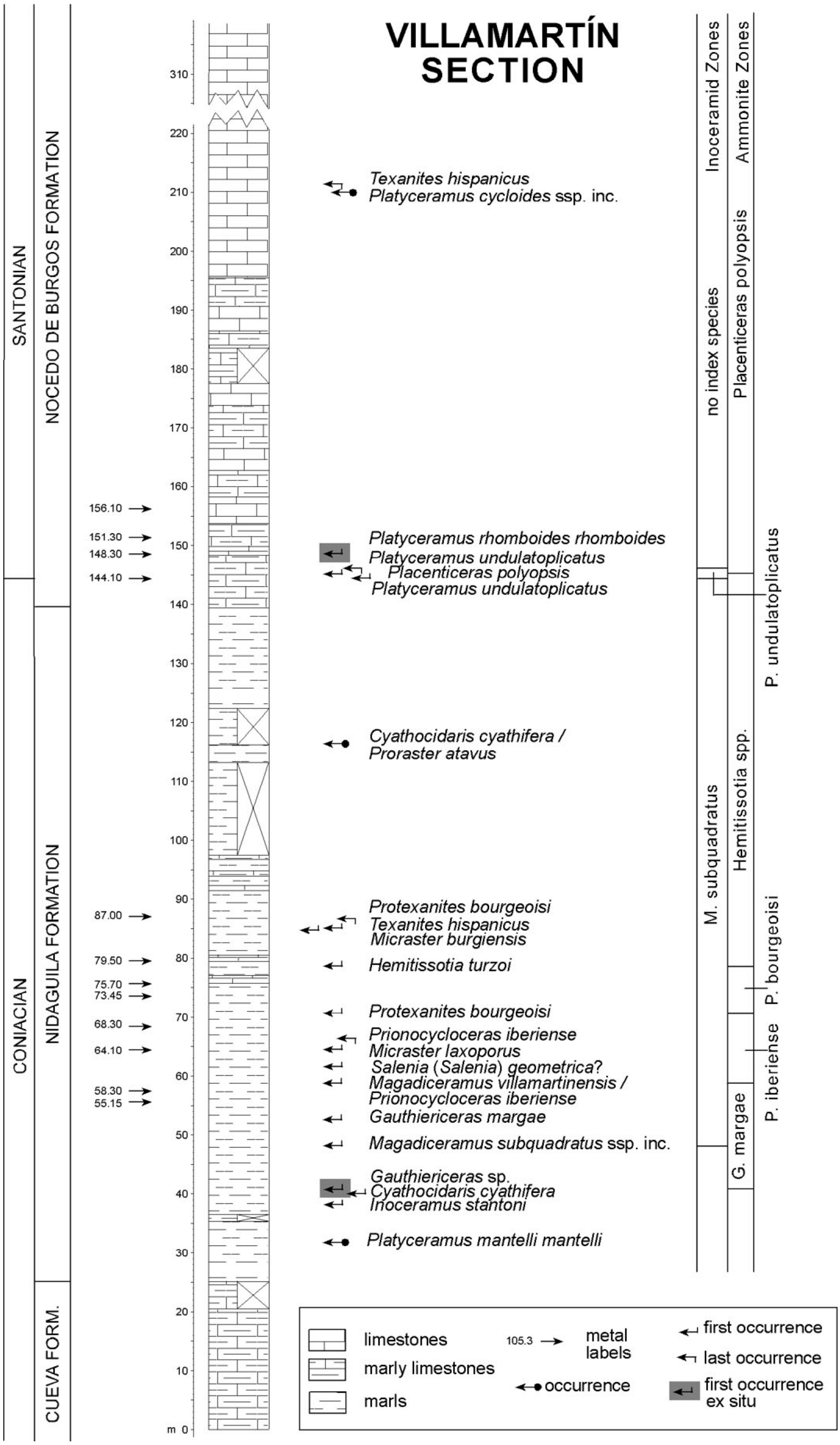

VILLAMARTÍN SECTION
SANTONIAN
CONIACIAN
NOCEDO DE BURGOS FORMATION
NIDAGUILA FORMATION
CUEVA FORM.
156.10
151.30
148.30
144.10
87.00
79.50
75.70
73.45
68.30
64.10
58.30
55.15
Texanites hispanicus
Platyceramus cycloides ssp. inc.
Platyceramus rhomboides rhomboides
Platyceramus undulatoplicatus
Placenticeras polyopsis
Platyceramus undulatoplicatus
Cyathocidaris cyathifera /
Proraster atavus
Protexanites bourgeoisi
Texanites hispanicus
Micraster burgiensis
Hemitissotia turzoi
Protexanites bourgeoisi
Prionocycloceras iberiense
Micraster laxoporus
Salenia (Salenia) geometrica?
Magadiceramus villamartinensis /
Prionocycloceras iberiense
Gauthiericeras margae
Magadiceramus subquadratus ssp. inc.
Gauthiericeras sp.
Cyathocidaris cyathifera
Inoceramus stantoni
Platyceramus mantelli mantelli
Inoceramid Zones
Ammonite Zones
no index species
Placenticeras polyopsis
M. subquadratus
Hemitissotia spp.
G. margae
P. undulatoplicatus
P. bourgeoisi
P. iberiense
limestones
marly limestones
marls
105.3 metal labels
occurrence
first occurrence
last occurrence
first occurrence ex situ

Fig. 11

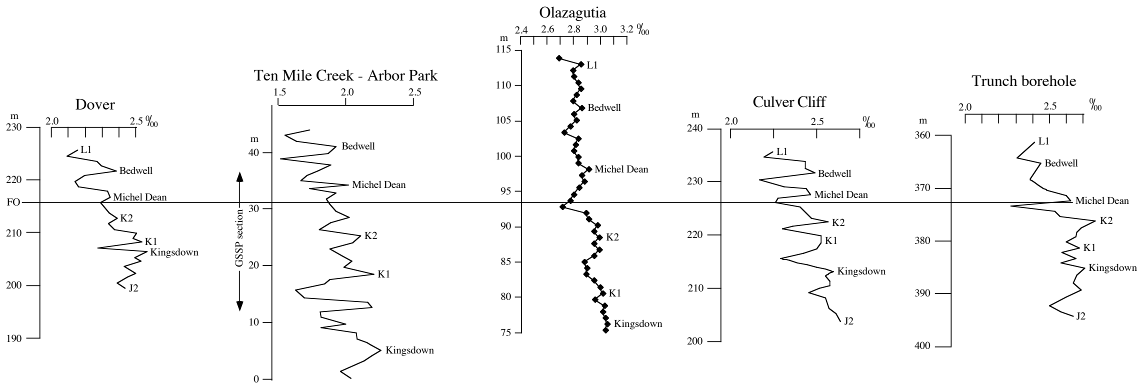

Dover
Ten Mile Creek - Arbor Park
Olazagutia
Culver Cliff
Trunch borehole
L1
Bedwell
Michel Dean
K2
K1
Kingsdown
J2
FO
GSSP section

Fig. 12

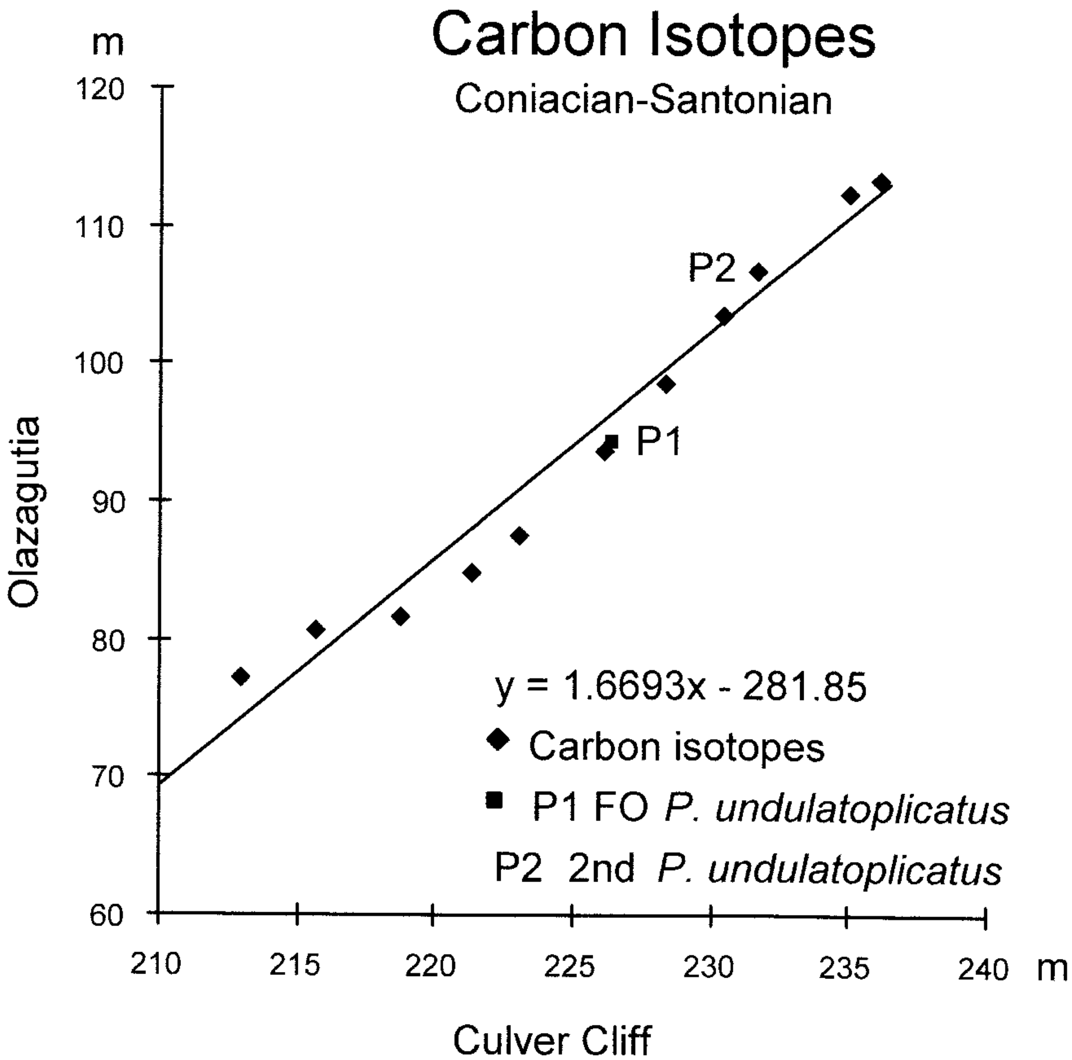

Carbon Isotopes
Coniacian-Santonian
m
Olazagutia
Culver Cliff
P1
P2
y = 1.6693x - 281.85
Carbon isotopes
P1 FO *P. undulatoplicatus*
P2 2nd *P. undulatoplicatus*

Fig. 13

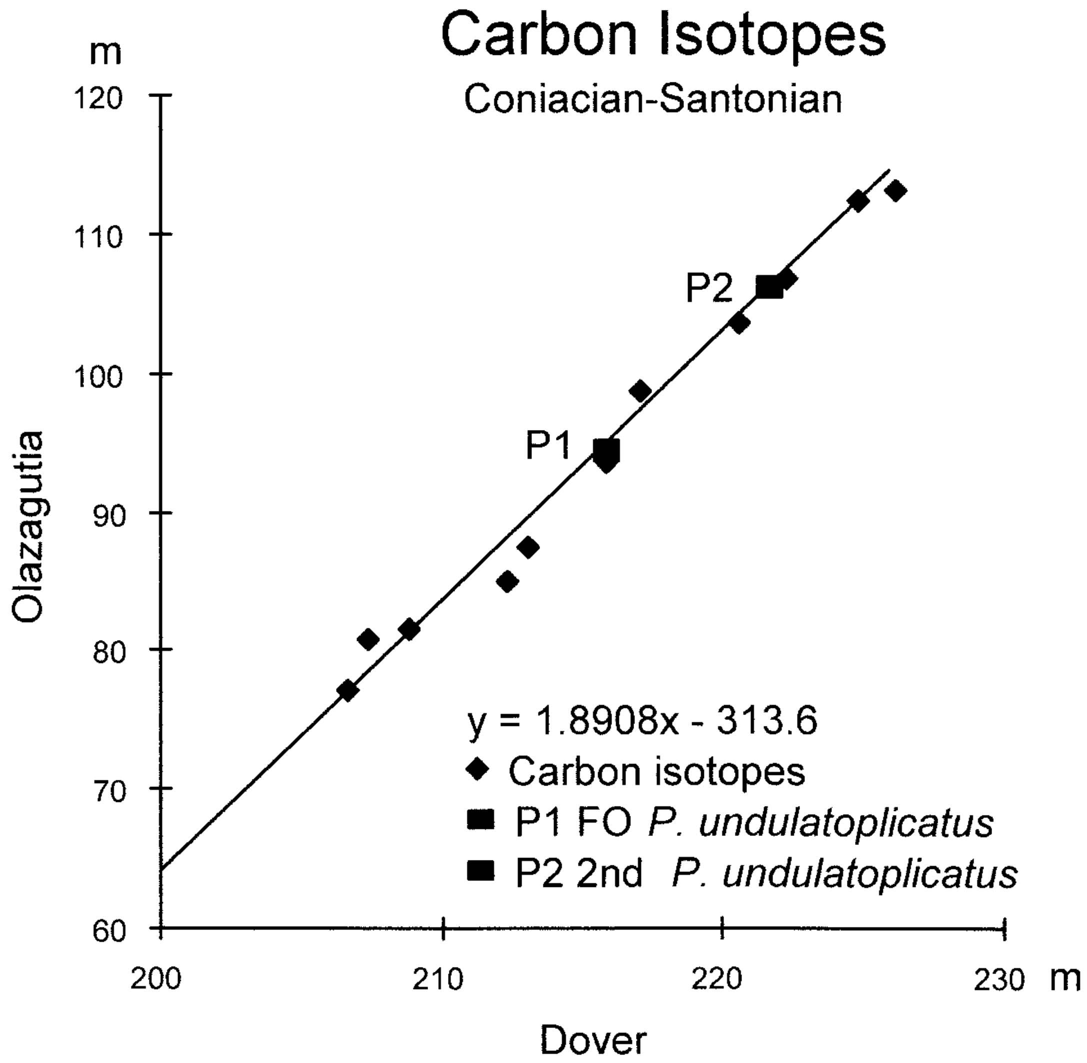

Carbon Isotopes
Coniacian-Santonian
m
120
110
100
90
80
70
60
Olazagutia
P1
P2
y = 1.8908x - 313.6
Carbon isotopes
P1 FO *P. undulatoplicatus*
P2 2nd *P. undulatoplicatus*
200
210
220
230
m
Dover

Fig. 14

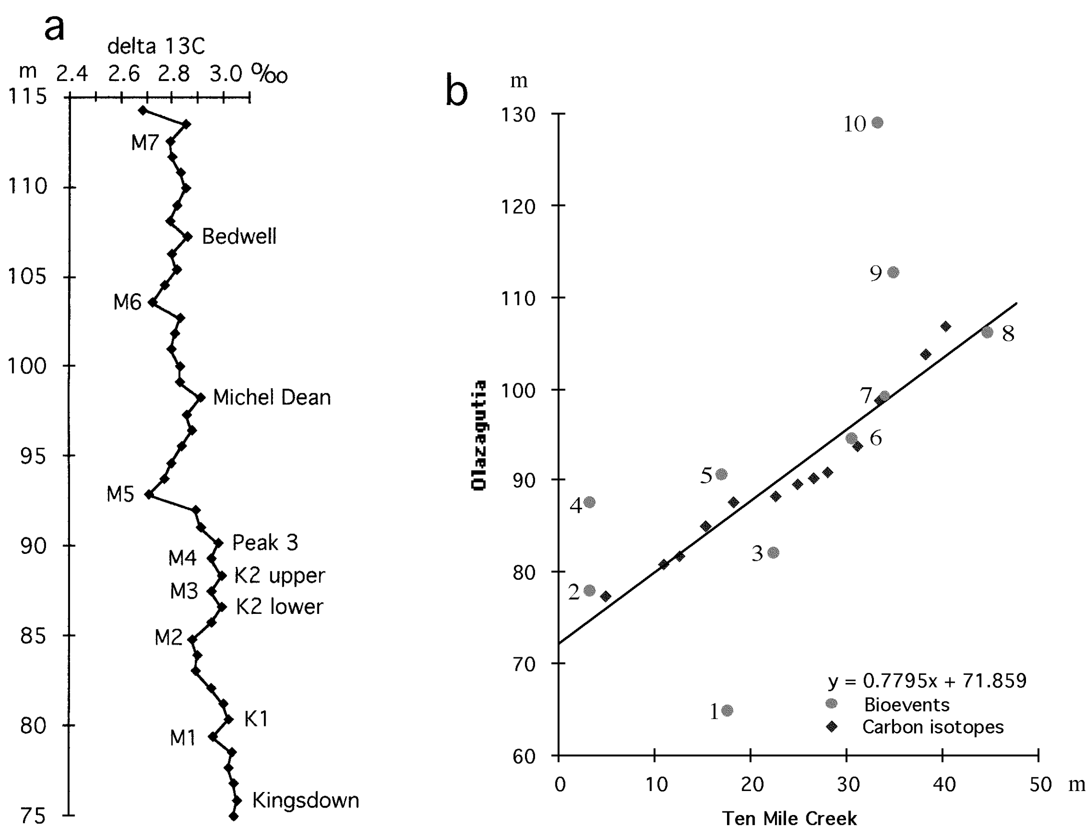

a
delta 13C
m 2.4 2.6 2.8 3.0 ‰
115
110
105
100
95
90
85
80
75
M7
Bedwell
M6
Michel Dean
M5
Peak 3
M4
K2 upper
M3
K2 lower
M2
K1
M1
Kingsdown
b
m
130
120
110
100
90
80
70
60
Olazagutia
10
9
8
7
6
5
4
3
2
1
y = 0.7795x + 71.859
Bioevents
Carbon isotopes
0 10 20 30 40 50 m
Ten Mile Creek

Fig. 15

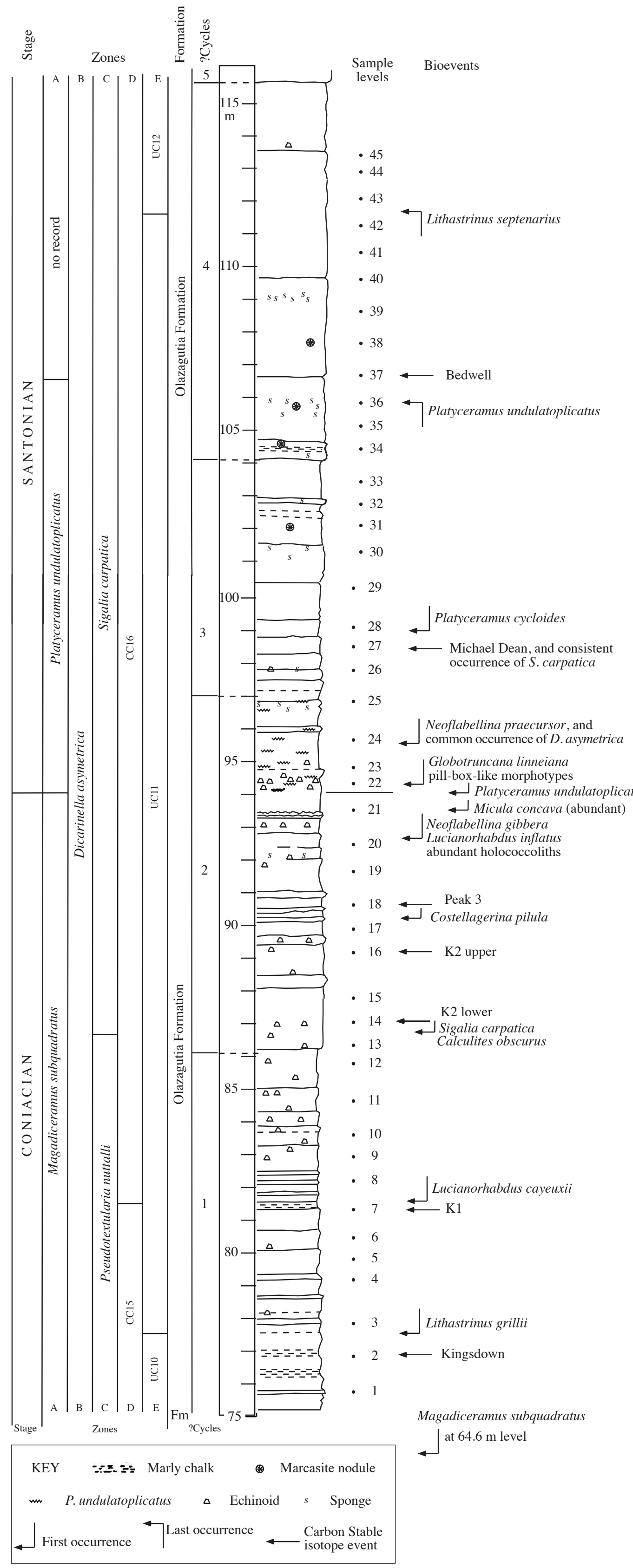

Stage
Zones
Formation
?Cycles
Sample levels
Bioevents
SANTONIAN
CONIACIAN
no record
Platyceramus undulatoplicatus
Magadiceramus subquadratus
Dicarinella asymetrica
Sigalia carpatica
Pseudotextularia nuttalli
CC16
CC15
UC12
UC11
UC10
Olazagutia Formation
Lithastrinus septenarius
Bedwell
Platyceramus undulatoplicatus
Platyceramus cycloides
Michael Dean, and consistent occurrence of S. carpatica
Neoflabellina praecursor, and common occurrence of D. asymetrica
Globotruncana linneiana pill-box-like morphotypes
Platyceramus undulatoplicatus
Micula concava (abundant)
Neoflabellina gibbera
Lucianorhabdus inflatus
abundant holococcoliths
Peak 3
Costellagerina pilula
K2 upper
K2 lower
Sigalia carpatica
Calculites obscurus
Lucianorhabdus cayeuxii
K1
Lithastrinus grillii
Kingsdown
Magadiceramus subquadratus at 64.6 m level
KEY
Marly chalk
Marcasite nodule
P. undulatoplicatus
Echinoid
Sponge
First occurrence
Last occurrence
Carbon Stable isotope event

Fig. 16

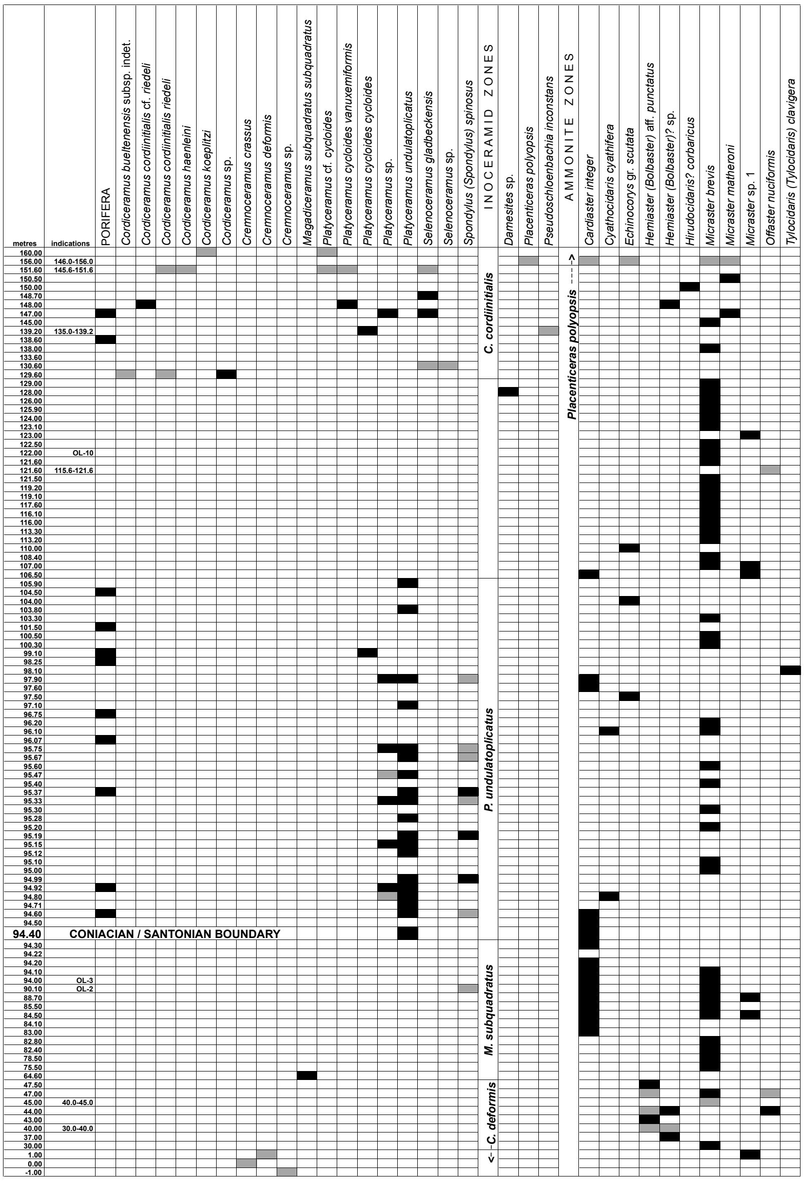

metres
indications
PORIFERA
Cordiceramus bueltenensis subsp. indet.
Cordiceramus cordinitialis cf. riedeli
Cordiceramus cordinitialis riedeli
Cordiceramus haenleini
Cordiceramus koeplitzi
Cordiceramus sp.
Cremnoceramus crassus
Cremnoceramus deformis
Cremnoceramus sp.
Magadiceramus subquadratus subquadratus
Platyceramus cf. cycloides
Platyceramus cycloides vanuxemiformis
Platyceramus cycloides cycloides
Platyceramus sp.
Platyceramus undulatoplicatus
Selenoceramus gladbeckensis
Selenoceramus sp.
Spondylus (Spondylus) spinosus
I N O C E R A M I D Z O N E S
Damesites sp.
Placenticeras polyopsis
Pseudoschloenbachia inconstans
A M M O N I T E Z O N E S
Cardiaster integer
Cyathocidaris cyathifera
Echinocorys gr. scutata
Hemiaster (Bolbaster) aff. punctatus
Hemiaster (Bolbaster)? sp.
Hirudocidaris? corbaricus
Micraster brevis
Micraster matheroni
Micraster sp. 1
Offaster nuciformis
Tylocidaris (Tylocidaris) clavigera
146.0-156.0
145.6-151.6
135.0-139.2
OL-10
115.6-121.6
94.40 CONIACIAN / SANTONIAN BOUNDARY
OL-3
OL-2
40.0-45.0
30.0-40.0
C. cordinitialis
P. undulatoplicatus
M. subquadratus
<-- C. deformis
Placenticeras polyopsis --->
160.00
156.00
151.60
150.50
150.00
148.70
148.00
147.00
145.00
139.20
138.60
138.00
133.60
130.60
129.60
129.00
128.00
126.00
125.90
124.00
123.10
123.00
122.50
122.00
121.60
121.60
121.50
119.20
119.10
117.60
116.10
116.00
113.30
113.20
110.00
108.40
107.00
106.50
105.90
104.50
104.00
103.80
103.30
101.50
100.50
100.30
99.10
98.25
98.10
97.90
97.60
97.50
97.10
96.75
96.20
96.10
96.07
95.75
95.67
95.60
95.47
95.40
95.37
95.33
95.30
95.28
95.20
95.19
95.15
95.12
95.10
95.00
94.99
94.92
94.80
94.71
94.60
94.50
94.30
94.22
94.20
94.10
94.00
90.10
88.70
85.50
84.50
84.10
83.00
82.80
82.40
78.50
75.50
64.60
47.50
47.00
45.00
44.00
43.00
40.00
37.00
30.00
1.00
0.00
-1.00

Table 1

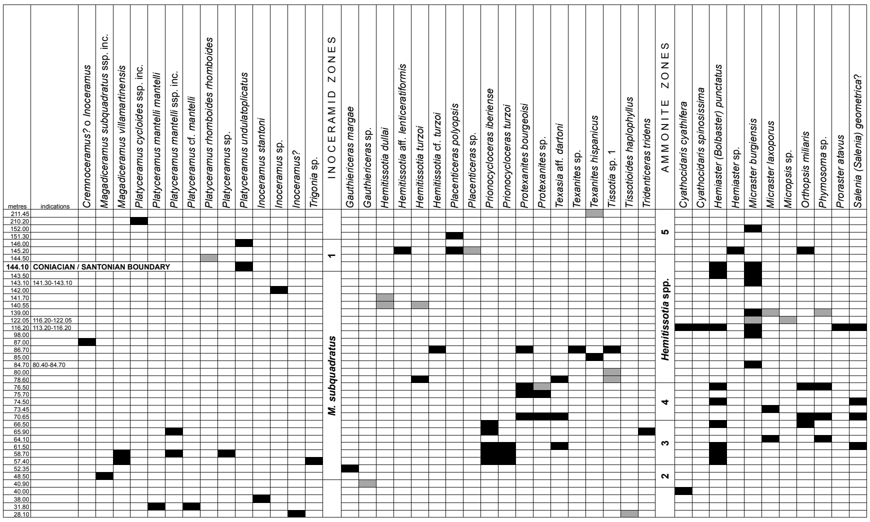


Table 2

APPENDIX 2

It containts comment on the 'report', and additional information of the Santonian Working Group Chairman.

<u>Comments on the "*Report on the candidates of the base of the Santonian Stage GSSP*"</u>

Dr. <u>Haidon Bailey's</u> comment:
"It is obvious from the data available for both sections under discussion that neither is ideal as the GSSP for the base of the Santonian.
My vote for Ten Mile Creek is purely based on the fact that this section appears to be the better of the two.
My personal preferences would be:
i) delay the vote until additional work on Ten Mile Creek is done or
ii) find an alternative site altogether.
Sorry to be so negative, but I don't see the necesity to be forced into a vote at this stage."

Dr. <u>Matthew Hampton's</u> comments:
"My preference would be to postpone the vote on the candidates for the Santonian GSSP. There are still issues outstanding regarding the suitability of both sections as a GSSP which need resolving before a decision can take place."

Dr. Jana Ion's comment:
"In Romania, in the Carpathian domain (with the continuous succession from Coniacian to Santonian) no macrofanua has been known for to mark the Coniacian-Santonian boundary. But across the successions from Coniacian to Santonian have been identified the following successive bioevents (Ion, Antonescu, Melinte, Szasz, 1997, 1998, 1999): FO of *Lucianorhabdus cayeuxii* – FO of *Globotruncana bulloides* – FO of *Calculites obscurus* and FO of the "pill-box-like" morphotype of *Globotruncana linneiana*.
According to the Olazagutia section/data, in Romania the Coniacian-Santonian boundary: - in planktonic foraminifera terms (Ion) is located by the FO of the "pill-box-like" morphotype of *G. linneiana*, as proxy marker; - in calcareous nannofossil term (Melinte) it falls into the *L. cayeuxii* Zone (CC 16).
It is to note that in Romania:

- the FO of *Dicarinella asymetrica* (In Carpathians and North Dobrogea) is associate with the first levels with the fauna belonging to the *Peroniceras tridorsatum* Zone and / or the *Inoceramus mantelli* Ass. Zone (Szasz & Ion 1998; Ion & Szasz 1994; Ion et al. 1997, 1998, 1999), Middle Coniacian.
- - *Sigalia carpatica* is very rarely, practically it not exist for a biostratigraphy.
- The Coniacian-Santonian boundary falls into the *D. asymetrica* Zone and into the *G. bulloides* SZ respectively (Ion in op. cited)"
-

Dr. Jackie Lees' comments:
"Although this (Ten Mile Creek) would be a useful 2° reference section.
But note that the nannos *C. obscurus* and *L. cayeuxii* are not reliable markers in relation to this boundary and should not be advertised as such."

Dr. Mihaela C. Melinte's comment:
"I consider that the proposed section of Olazagutia (N Spain) contains all the important biostratigraphic markers recommended by the Santonian Working Group, for pointing out the Santonian GSSP. It is also a continuous section, not disturb tectonically point of view. It is accessible and could be well preserved.
By contrast, the Ten Mile Creek section is a composite section, made by 4 to 6 partial sections. I think to select a composite section for a GSSP is not suitable for any stratigraphic point of view. Aditionally, structural complication are present in some of the partial sections of the Ten Mile Creek. Only one of the primary markers proposed by the GSSP was recognized in the Ten Mile Creek.
Taking in account these facts, I agree that the Olazagutia section could be selected as a Santonian GSSP."

Dr. Seiichi Toshimitsu's comments:
"I think the Olazaguita section is a good one for a candidate of the GSSP section of the Santonian, but I want to abstain from the vote at this time. The reason is that the primary marker (*Inoceramus undulatoplicatus*) and the secondary marker (*Sigalia carpatica*) do not occur from Japan and adjacent areas (NW Pacific realm), and so I cannot exactly commentate this problem now. So, if the formal GSSP section of the Santonian recommended by the Santonian Working Group will be adopted, we will be able to refer this section to our Japanese sections by means of not only fossil markers but also other tools

for example isotope stratigraphy, in future research. I think, however, that we need a reference section in the northern Pacific realm for a short while, as we do not have firm markers above-mentioned and recommended by the Subcommision on Cretaceous Stratigraphy in the Japanese and Russian Far East sections, under the existing circumstances."

<u>Comment and additional information of M. Lamolda, Chairman of the Santonian Working Group, ISCS</u>:

I have no special answers to this correspondence, reproduced above.

There had other three letter/messages in respect to the 'report on the candidates', all of them sent (posted and e-mailed) after the dead-line for voting.

Nevertheless, there had one produced following inappropriate procedures (and other one as a consequence).
This was a sad circumstance which was communicated to the International Commission on Stratigraphy and the IUGS on December 18th, 2007, as the tasks of both the Santonian Working Group and its chairman were being undermined. In fact, instead of presenting their objections or comments to me, and consequently to the Santonian Working Group, before and during the time of voting on candidate sections, they tried to annul the whole process.
The whole affair is known by the Santonian Working Group members, too.

This Chairman is open to give additional information if necessary.

Granada, July 11st, 2008.

Marcos A. Lamolda
Chairman, Santonian Working Group
ISCS, ICS, IUGS