The Santonian – Campanian boundary in Navarra and Alava, northern Spain. A multistratigraphic approach

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Abstract: Three Santonian – Campanian boundary sections (San Roman E, Olazagutia, Sarasate I) were investigated in northern Spain (Alava and Navarra provinces). In the absence of the crinoid *Marsupites testudinarius*, which is the proposed boundary marker, secondary markers such as ammonites, echinoids, calcareous nannoplankton and planktic foraminifera, and the correlation of sections have been used to identify the boundary interval and to establish a multistratigraphic zonation. The following succession of marker events has been recognized in the Late Santonian: the FO of *Calculites obscurus*, defining the base of nannofossil standard zone CC17, the FO of curved *Lucianorhabdus cayeuxii*, defining the base of nannofossil subzone CC17b, the FO of the planktic foraminifer *Globotruncanita elevata*, a local ammonite mass occurrence of *Jouaniceras hispanicum*, and the LO of the planktic foraminifer *Dicarinella asymetrica*. The base of the Campanian boundary is indicated by the FO and a following mass occurrence of the irregular echinoid *Offaster pomeli*, followed by the FO of the ammonite *Scaphites hippocrepis* III, and the FO of the calcareous nannofossil marker *Broinsonia parca para*, defining the base of nannofossil zone CC18.

Keywords: Santonian-Campanian Boundary, Ammonites, Calcareous Nannoplankton, Foraminifera, Biostratigraphy, Navarra, Alava, Northern Spain

1. INTRODUCTION AND GEOLOGICAL SETTING

Three northern Spanish sections in the Alava and Navarra provinces were investigated in detail for their fossil content. Bed-by-bed collecting gave an integrated biostratigraphy around the Santonian-Campanian boundary in terms of macro-, micro- and nannofossils as well as an event stratigraphy. In the absence of the proposed marker event for the base of the Campanian, the last occurrence (LO) of the crinoid *Marsupites testudinarius*, we evaluated the stratigraphic relationships between some of the proposed secondary markers (HANCOCK & GALE, 1996) for the base of the Campanian, namely the FO of the ammonite *Scaphites hippocrepis* DEKAY and the echinoid *Offaster pomeli* MUNIER CHAMAS, the FO of the planktic foraminifer *Globotruncanita elevata* (BROTZEN), the LO of the *Dicarinella concavata/asymetrica* group and the FO of the nannofossil *Broinsonia parca parca*.

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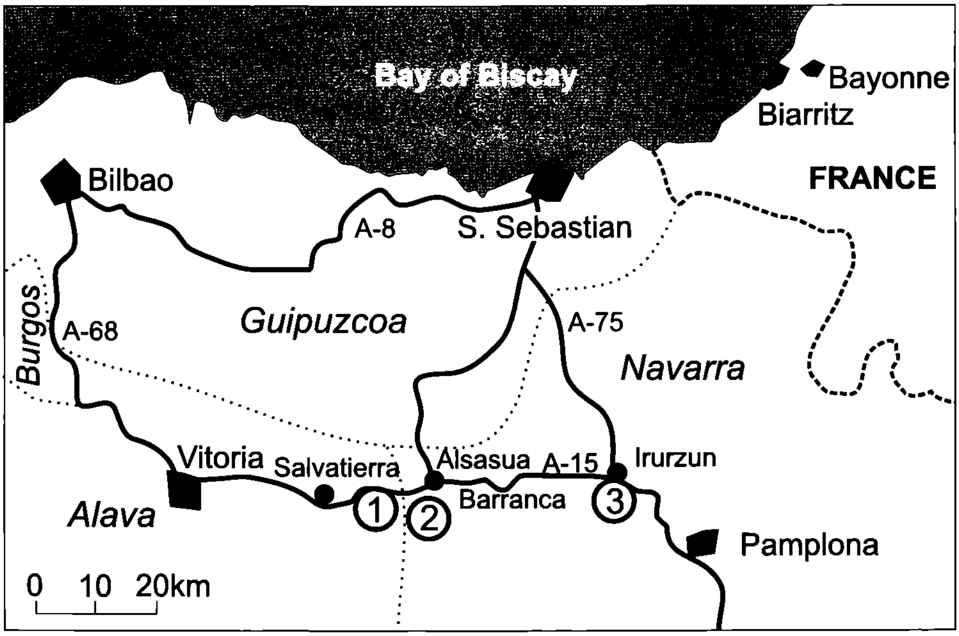


Fig. 1: Location map of the investigated sections in Alava and Navarra, along highway A-15, northern Spain. 1 San Roman E (de San Millan) section; 2 Olazagutia Quarry, 3 Sarasate Ia section.

During the Late Cretaceous, the three sections presented were situated in an outer-shelf area of the Cretaceous Iberian continent, an ESE – WNW trending zone of intra-shelf basins (Navarro-Cantabrian basins sensu Küchler, 1998) with different sedimentary facies and subsidence histories as a result of block-tilting within a strike-slip- and/or oblique-slip fault system (Wiedmann et al., 1983; Engeser et al., 1984). The zone of intra-shelf basins stretched from western Navarra, through the province of Alava, to the northern part of the province of Burgos. Two sections, Olazagutia and Sarasate I, are situated in the most north-easterly located unit called the Barranca (Fig. 1). Shelf to deeper basin paleo-water depths have been reconstructed for these basins by Gräfe (1994). From the late Cenomanian to the later early Campanian, the Barranca exhibited a complex depositional pattern, largely controlled by tilted block geometries.

2. SANTONIAN-CAMPANIAN BOUNDARY CRITERIA AND ZONAL SUBDIVISIONS

2.1. Macrofossils

At the stage boundary conference in Brussels 1995, the LO of the crinoid *Marsupites testudinarius* (Schlotheim) was proposed as the primary marker for the base of the Campanian (Hancock & Gale, 1996). Secondary marker events around this boundary, such as the FO of the ammonite *Placenticeras bidorsatum* (Roemer), the FO of the nannofossil *Broinsonia parca parca* or the LO of the planktic foraminifera *Dicarinella asymetrica*, were suggested.

Up to now, neither *Marsupites testudinarius* nor *Placenticeras bidorsatum* have been reported from Spain (KÜCHLER, 2000b; WAGREICH et al., 1998). However, a detailed ammonite zonation for the Santonian – lower Campanian is possible in northern Spain. WIEDMANN (in GISCHLER et al., 1994) proposed a three-fold division of the Santonian by means of *Texanites* species, including a late Santonian *Texanites presoutoni* Zone. KÜCHLER (1998, and this volume) quoted three ammonite zones in the Santonian of Navarra. The *Texanites quinquenodosus* Zone represents the middle Santonian and lower-most late Santonian, and the *Jouaniceras hispanicum/Scalarites cingulatum* Zone the uppermost late Santonian. This zonation, showing close affinities to the ammonite zonation of the French Corbières sensu KENNEDY et al. (1995), is used herein. In the investigated Olazagutia and San Roman E. sections, the base of the Late Santonian is provisionally defined at the FO of the inoceramid *Cordiceramus muelleri* (PETRASCHECK) (see discussion in KÜCHLER, 1998).

For the present paper, we used the macrofossil zonation of KÜCHLER & KUTZ (1989) and KÜCHLER (2000b) for the lower Campanian. This consists of a combination of ammonite partial range and assemblage zones, local echinoid partial range, peak, and echinoid/ammonite assemblage zones. The oldest Campanian strata belong to the *Scaphites hippocrepis* III Partial Range Zone. In addition to early forms of *S. hippocrepis* III, this zone contains an irregular echinoid fauna that enables direct correlation with north-western German and southern English sections, indicating equivalence with the middle lower Campanian upper *Offaster pilula* or basal *Galeola senonensis* Zones of those areas (KÜCHLER, 2000b).

2.2. Planktic Foraminifera

According to GALE et al. (1995), the Santonian-Campanian boundary is situated within the *elevata-asymetrica* Concurrent Range Zone, a rather short time interval characterized by the presence of both *Globotruncanita elevata* (BROTZEN) and *Dicarinella asymetrica*. Several authors placed the lower boundary of the Campanian at the first appearance datum of *G. elevata* (WAGREICH, 1988) but others at the extinction level of *D. asymetrica* or the *D. asymetrica-concavata* group (e.g. CARON, 1985).

The foraminiferal zonations for the investigated area have already been reviewed by WOLZ & ZANDER (1987) using the terminology and zonation of ROBASZYNSKI et al. (1984; see also GRÄFE, 1994). Their results have been used here for correlation to planktic foraminifera zones.

2.3. Calcareous Nannofossils

The subdivision at the Santonian-Campanian boundary interval based on calcareous nannoplankton uses the standard zonations introduced by SISSINGH (1977), PERCH-NIELSEN (1985) and BURNETT (1998). In the late Santonian/early Campanian interval, PERCH-NIELSEN (1985) recognized the standard zones CC16, characterized by the FO of *Lucianorhabdus cayeuxii* DEFLANDRE, CC17, characterized by the FO ("first regular occurrence" of SISSINGH, 1977) of *Calculites obscurus* (DEFLANDRE), and CC18, characterized by the FO of *Broin-*

sonia parca parca (STRADNER). Most nannofossil workers have placed the base of the Campanian within CC17 or at the base of CC18 (e.g. PERCH-NIELSEN, 1985; WAGREICH, 1992; CUNHA et al., 1997).

However, the definition of *B. parca parca* probably differs from author to author, as a morphological lineage from *Broinsonia parca expansa* to *B. parca parca* and *B. parca constricta* is present in the Santonian to basal Campanian, characterized by a decrease in size of the central-plate area (e.g., CRUX, 1982). WAGREICH (1988, 1992) recognized the FO of curved *Lucianorhabdus cayeuxii* in Tethyan sections within CC17, near the Santonian – Campanian boundary, and thus divided this zone into two subzones, CC17a and CC17b. *Calculites obscurus* can be divided into two morphologically slightly different morphotypes, *Calculites* cf. *obscurus* (not all sutures at 45° to main axes of ellipse) and *C. obscurus* sensu stricto. According to the newer global standard zonation for the Upper Cretaceous (BURNETT, 1998) the following Santonian to basal Campanian zones can be distinguished: zone UC12, base defined by the LO of *Lithastrinus septenarius* (middle to Late Santonian), UC13, base defined by the FO of *Arkhangelskiella cymbiformis* VEKSHINA, and UC14a, base defined by the FO of *Broinsonia parca parca*. According to BURNETT (1998), the Santonian – Campanian boundary is situated within the uppermost part of UC 12, just below the FO of *Arkhangelskiella cymbiformis*.

3. SECTIONS IN NORTHERN SPAIN

3.1. San Roman E [de San Millan] (upper Santonian – lower Campanian)

The San Roman E section (Fig. 1, 2) consists of outcrops along an erosional gully ca. 560 m SE of the village San Roman [de San Millan], E of Salvatierra, Alava, at 680 to 700 m altitude (WOLZ, 1985). The base of the measured section, ca. 39 m in thickness, comprises a 0.1–0.2 m thick bed made up of a triplet of glauconitic calciturbidites intercalated within a succession of dark grey marls. The marls above the calciturbidites contain intercalations of 0.1 to 0.3 m thick marly limestones.

3.1.1. Macrofauna

The macrofauna consists of ammonites, inoceramids and echinoids; the inoceramids are rare and poorly preserved. According to WOLZ (1985, pl. 9, figs 1–2), *Cordiceramus muelleri* is present about 13 m below the level of glauconitic calciturbidites. It occurs sporadically up-section up to bed 98 (Fig. 2). The inoceramids from immediately above bed 92 and from bed 94g (*hispanicum* Event) are *Cordiceramus muelleri recklingensis* STEIZ according to SEELING (pers. comm. 2002). The first *Cataceramus balticus* appears in bed 94g (not shown in Fig. 2). WOLZ (1985) also quoted single finds of *Platyceramus* sp. and *Platyceramus cycloides* in bed 94i. The ammonite fauna is dominated by *Jouaniceras hispanicum* WIEDMANN in the lower 17.5 m of the section. *J. hispanicum* has an abundance maximum (*hispanicum* Event) between level 14.5 and 17.5 m (Fig. 2). *Baculites* sp. occurs sporadically in the same interval. The irregular echinoid fauna found, especially *Micraster*, need a taxonomic revision and therefore their ranges are not plotted in Fig. 3. However, the *Micraster* fauna is typical for the upper Santonian part in all the studied sections. The *Echinocorys* found is referred to as *Echinocorys scutata cincta* BRYDONE.

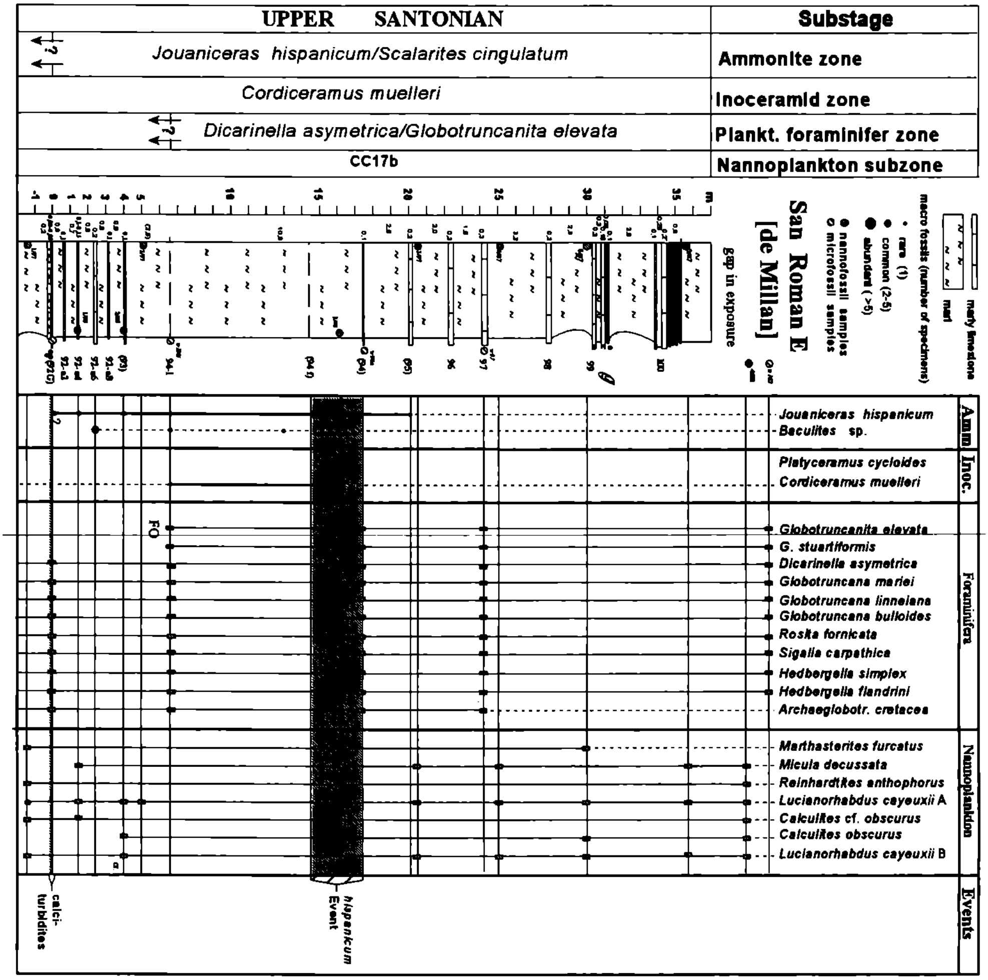


Fig. 2: Upper Santonian San Roman E section; foraminifer data according to Wolz (1985) and Zander & Wolz (1987).

3.1.2. *Microfauna and Nannofossils*

The FO of the foraminifer *Globotruncanita elevata* is recorded in bed 94-i together with *G. stuartiformis*, which indicates the beginning of the concurrent range zone of *G. elevata* and *D. asymetrica* at this level (Wolz, 1985; Wolz & Zander, 1987). The following part of the investigated section lies in the *asymetrica-elevata* Zone, including *Sigalia carpathica*.

Nannofossil standard zone CC17, subzone CC17b, is indicated by the presence of *Calculites obscurus* and curved *Lucianorhabdus cayeuxii* throughout the investigated section, which generally point to a late Santonian to early Campanian age (WAGREICH, 1992). According to BURNETT's (1998) zonation, zone UC 12 can be recognized, indicated by the presence of *Calculites obscurus* and the absence of *A. cymbiformis*. Secondary markers present include *Reinhardtites anthophorus*, *Lucianorhabdus cayeuxii*, *Micula decussata* and very rare *Marthasterites furcatus*.

3.2. Olazagutia (Santonian-Campanian boundary interval)

The Olazagutia Quarry, ranging from the upper Coniacian into the middle lower Campanian is located at the northern edge of the Urbasa, south of Olazagutia and Alsasua (Fig. 1). The quarry has been selected as one of the possible stratotypes for the definition of the Coniacian-Santonian boundary (LAMOLDA & HANCOCK, 1996; GALLEMI et al., 1997, 2000; LAMOLDA et al., 1999; MELINTE & LAMOLDA, this volume). A preliminary macrozonation for the whole section, mainly based on data from KANNENBERG (1985) is given by KÜCHLER (1998, and this volume). This work concentrates on the upper Santonian to lower Campanian part of the section (Fig. 3), using the lithological log of KANNENBERG (1985).

KANNENBERG (1985) measured a thickness of about 326 m for the entire succession, using an interval of glauconitic calciturbidites (bed 167) as the reference zero-level for his section (Fig. 3). This prominent horizon is found in the uppermost part of the section on the western side of the quarry. From level -80 m upwards, an alternation of marls, calcareous marls and prominent marly limestones is developed. KÜCHLER (1998) tentatively correlated the limestone-marl alternation with the Olazagutia Formation of AMIOT (1982), although the original definition of this formation given by AMIOT (1982) is very imprecise and its thickness is limited to 30 m by definition. The formation in the sense used here has at least a thickness of about 100 m according to KANNENBERG (1985).

3.2.1. Macrofauna

The macrofauna comprises rare ammonites, common inoceramids, and abundant echinoids. The base of the late Santonian was provisionally taken at the FAD of the inoceramid *Cordiceramus muelleri*, albeit the position of this datum has not yet been precisely determined (KÜCHLER, 1998). The species first appears between 47 m and 41 m below the calciturbidite interval. In terms of inoceramid stratigraphy, two third of the figured part of the section belongs to the *Cordiceramus muelleri* Zone (sensu KÜCHLER, 1998). The lowest finds of *Scalarites cingulatum* (Schlüter) and *J. hispanicum* WIEDMANN derive approximately from bed 138–139 (-14 m level). Two specimens were found *in situ* in bed 167. Above this horizon, in bed 169, *Sc. cingulatum* appears to be the dominant species. Additionally, *Glyptoxoceras* sp. 1, smooth baculitids and *Gaudryceras mite* VON HAUER occur in bed 169. Further specimens of *J. hispanicum* and a single find of *Boehmoceras krekeleri* (WEGNER) come from bed 188, somewhat higher in the succession. KANNENBERG (1985) identified two abundance maxima of the echinoid genus *Micraster* around bed 150 and within bed 166; the *Micraster* type from bed 150 was referred to as *Micraster* sp. aff. *antiquus* by WOLZ & ZANDER (1987).

26 m above the calciturbidite interval, a Campanian age is indicated by the echinoid fauna. The assemblage is similar to that in the lower Campanian *Menabites* spp./ *Sc. hippocrepis* III Zone of the Sarasate area (KÜCHLER, 2000b).

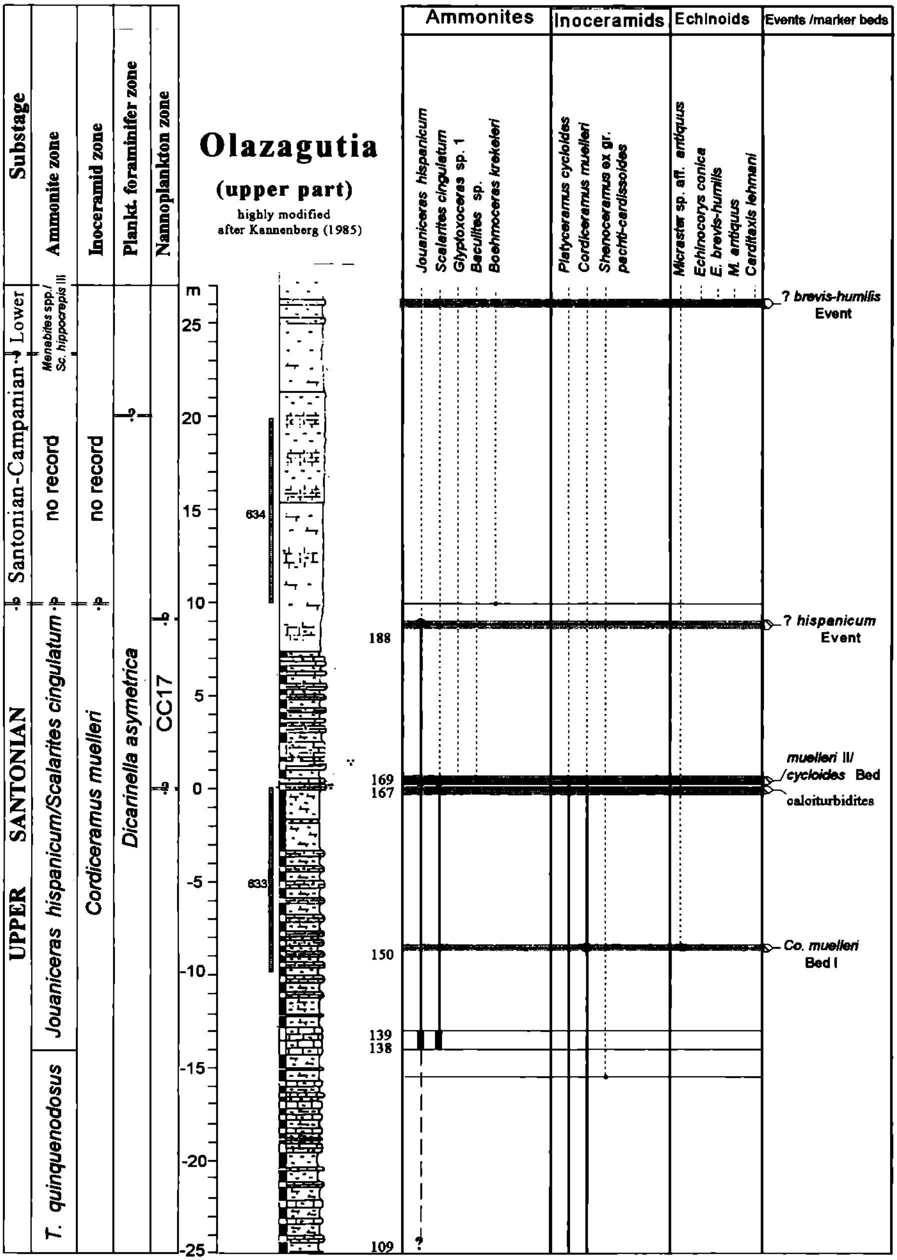


Fig. 3: Upper Santonian to lower Campanian part of the Olazagutia Quarry ("Cantera de Margas"); macrofossil distribution (ammonites, echinoids and inoceramids); lithologic column (highly simplified) and m-scale after Kannenberg (1985); macrofossil data mainly based on the investigation of Kannenberg (1985) and macrofossil collections of G. Ernst (Berlin); stratigraphic subdivision according to Küchler (1998).

3.2.2. *Microfauna and Nannofossils*

Nannofossil assemblages sampled from ammonite specimens of the section are rather poor and display moderate to bad preservation. Therefore, some of the marker species are missing and an exact zonation cannot be given for this section. However, nannofossil zone CC17 could be recognized due to the presence of *Calculites obscurus* (UC12 of Burnett, 1998). Subzones CC17a and CC17b could not be distinguished, probably due to the bad preservation.

In terms of foraminifera, the investigated section still falls into the *D. asymetrica* Zone, although Gräfe (1994, text-fig. 8 and pers. com. 2001) found in his samples 633 (ca. –10 to 0 m level, comp. Fig. 3) and 634 (10 to 20 m level) species such as *Globotruncana mariei* and *Globotruncana stuartiformis* which are common in the Campanian *elevata-asymetrica* and *elevata* Zones. He pointed out that the top of the quarry in 1991 was near the boundary of the *asymetrica* and *elevata* zones.

3.3. Sarasate Ia (upper Santonian – lower Campanian)

The Sarasate I section is a motorway cutting along the A-15 (Autopista de Navarra), about 1.5 km west of the village of Sarasate, south of Irurzun, Navarra (Figs. 1, 4). During the late Santonian the Sarasate area was a continuously shallowing region, demonstrated by the shallow subtidal and intertidal carbonate sedimentation. The section is marked by an unconformity within the Santonian-Campanian boundary interval, between the upper Izurdiaga Formation and the Sarasate Formation (Küchler & Kutz, 1989, Küchler, 1998). Thick-bedded, pale grey subtidal to intertidal limestones characterize the Upper Izurdiaga Formation (Küchler, 1998), of which the upper 5 to 6 m consist of a silty calcarenite with erosional pockets and broken cavities, terminating in a mineralized hardground (HgSal) with a wavy glauconitized and phosphatized upper surface. The hardground is unconformably overlain by alternations of silty, glauconitic marls/clay rich marls and thin-bedded (0.1–0.2 m) marlstones or nodular marlstone of which the lowest ca. 13–14 m are highly glauconitic.

The section has been measured and described in detail by Küchler (1983, 2000b). Küchler & Kutz (1989) and Küchler (2000b) gave the first stratigraphic interpretations of the section, using macrofossils, echinoids and ammonites.

3.3.1. *Macrofauna*

The first *Offaster pomeli* appears immediately above the unconformity (level zero) and the first *Scaphites hippocrepis* III (early form) as an indicator for an early Campanian age at the 2.0 m level. An acme-occurrence of *Offaster pomeli* was found at level 13.5 m within the *Scaphites hippocrepis* III Partial Range Zone. The following ammonite zone can be ascribed to the *Menabites* spp./*Sc. hippocrepis* III Zone.

3.3.2. *Microfauna and Nannofossils*

Nannofossil samples from the Sarasate I section yielded a moderately preserved assemblage indicative of nannofossil standard zone CC 17 (UC12 of Burnett, 1998), Subzone CC17b. Marker species include *Calculites obscurus* and curved *Lucianorhabdus cayeux-*

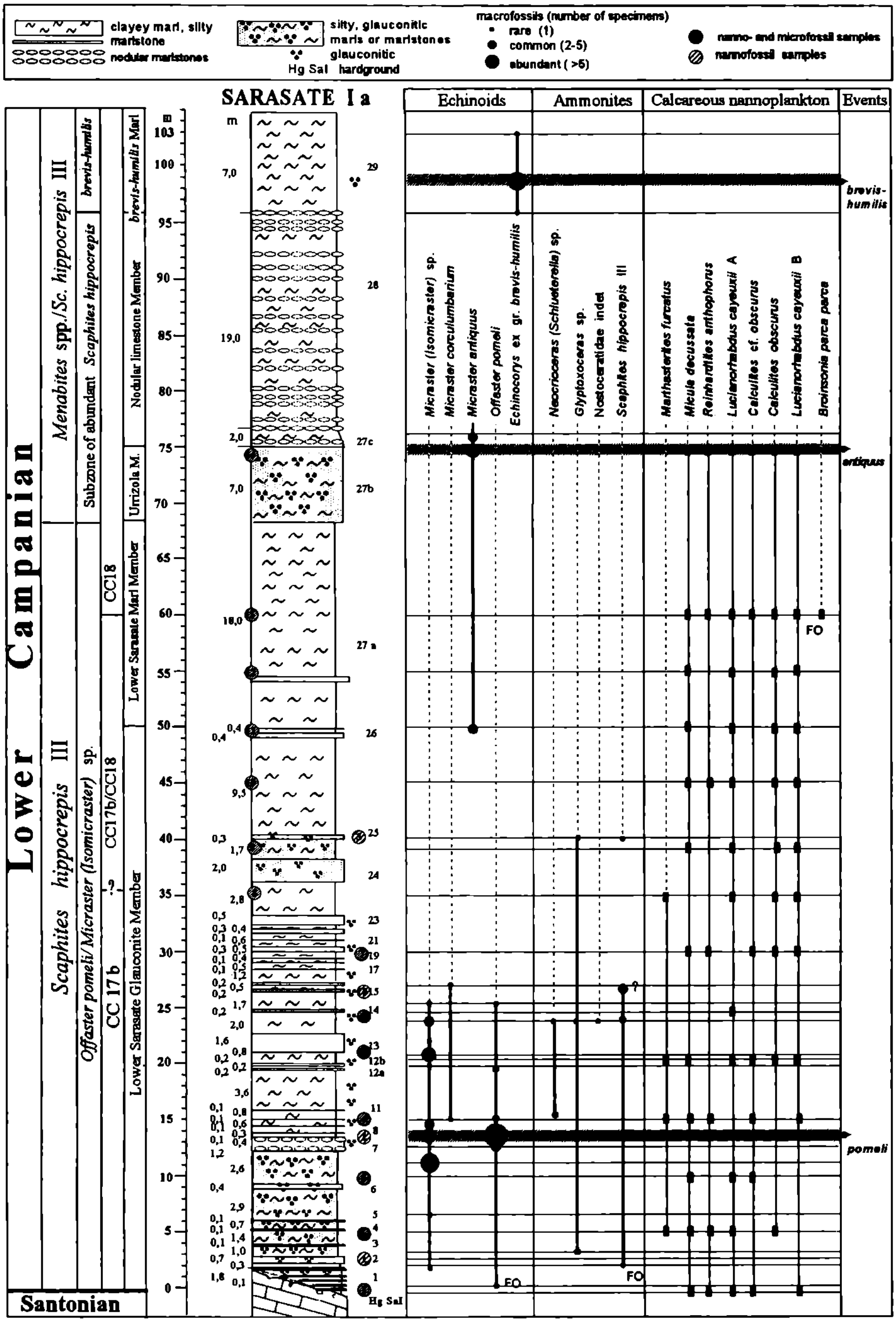


Fig. 4: Santonian-Campanian boundary interval at the Sarasate Ia motorway section. Note unconformity at the base of the Campanian.

ii. *Marthasterites furcatus*, which should be still present in CC17 and CC18, is very rare. In the higher part of the section, rare transitional *Broinsonia* species of the *B. expansa – parca* lineage occur and the first appearance of *B. parca parca* [as defined by an a:b ratio (CRUX, 1982) below 1.3] is approximately at the 60 m level, in the uppermost part of the *Scaphites hippocrepis* III Zone.

According to COSULLUELA SOLANILLA (1986), who investigated the foraminifera in this section, referred to as "Corte de la autopista", the first *Globotruncanita elevata* was found within the limestones about 12.5 m below the formation boundary (hardground HgSal in Fig. 4), which is the boundary between the Upper Izurdiaga and Sarasate formations as used herein (see discussion in KÜCHLER, 2000b). The last *Dicarinella asymetrica* was found in sample 12, at the top of the Upper Izurdiaga Formation, immediately below the unconformity (COSULLUELA SOLANILLA, 1986). Thus, approximately the upper 12,5 m of the Upper Izurdiaga Formation below the hardground belongs to the *asymetrica/elevata* concurrent range Zone and the overlying Sarasate Formation is tentatively ascribed to the *elevata* Zone. However, due to the shallow water glauconitic facies of the lower part of the Sarasate Formation, planktic foraminifera are extremely rare and the top of the *asymetrica/elevata* Zone is rather questionable.

4. DISCUSSION

The investigated sections are partly incomplete due to gaps in exposure or hiati in the Santonian-Campanian boundary interval. However, based on lithological and marker fossil correlations of the three sections, a fairly good stratigraphic succession of the marker events can be achieved. The San Roman E section covers the uppermost upper Santonian part and probably also the lowermost Campanian (Fig. 5). In the Olazagutia section, the transition interval may be complete but was not sampled bed-by-bed in the highest parts of the quarry because of dangerously steep exposure. The Sarasate I section covers the Santonian – Campanian boundary interval and exposes a relatively complete stratigraphical record of lower Campanian strata, together with the common occurrence of biostratigraphically significant faunas. Sedimentological and biostratigraphical data indicate a hiatus that at this locality comprises probably the uppermost Santonian and basal Campanian.

Olazagutia and San Roman E were correlated by a horizon of calciturbidites together with a mass occurrence of inoceramids and a mass occurrence of heteromorph ammonites, the *hispanicum* Event, somewhat younger in age (compare Figs. 2, 3, 5). A late Santonian age in these two sections is indicated by the macrofossil assemblage of *Scalarites cingulatum, Jouaniceras hispanicum, Boehmoceras krekeleri, Cordiceramus muelleri, Platyceramus cycloides,* and *Spenoceramus* sp. In northern Europe (Lower Saxony and Westphalia, Germany), *Scalarites cingulatum* is known from the upper Santonian *Boehmoceras arculus* ammonite Zone or *Sphenoceramus pinniformis* inoceramid Zone (KAPLAN & KENNEDY, 2000) and also from the lowermost Campanian *Gonioteuthis granulataquadrata* to *Inoceramus lingua/Gonioteuthis quadrata* Zones (see SCHLÜTER, 1871–1876; MÜLLER & WOLLEMANN, 1906; KENNEDY & KAPLAN, 1995; KAPLAN & KENNEDY, 2000). *Jouaniceras hispanicum* in northern Spain already occurs in the middle Santonian *Texanites hourqi* Zone sensu WIEDMANN in GISCHLER et al. (1994), together with

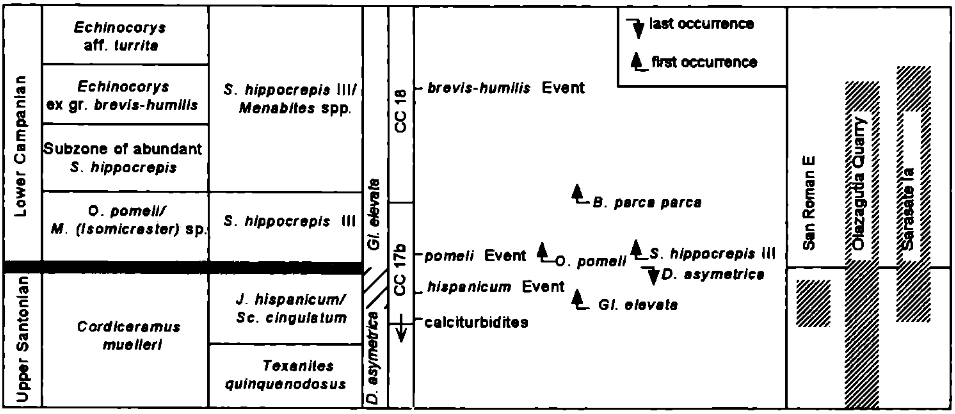


Fig. 5: Integrated biostratigraphy and marker beds around the Santonian-Campanian boundary in Navarra and Alava, northern Spain.

Cordiceramus bueltenensis (Seitz) but ranges also up into the lowermost Campanian (Küchler, in prep.). The FO of the inoceramid *Cordiceramus muelleri* (Petrascheck) is considered as a reasonable boundary marker for the base of the upper Santonian in northern Spain (Küchler, 1998). *Cordiceramus muelleri* is common both in Cantabria (Oppermann, 1996) and in Navarra at Olazagutia (Kannenberg, 1985; Küchler, 1998). In north-west Europe, its first occurrence falls into the *Sphenoceramus pinniformis* Zone according to Seitz (1961) or in the inoceramid Assemblage Zone 28 and Zone 29 *sensu* Tröger (1989). Tröger (1989) suggests that this corresponds to the *Uintacrinus* [*socialis*] Zone or *Gonioteuthis westfalica-granulata* to *G. granulata* Zone, respectively. *Boehmoceras krekeleri* indicates late Santonian in terms of ammonite biostratigraphy. This species occurs in the *Marsupites/granulata* Zone of Westphalia (see Schönfeld, 1985; Kennedy & Christensen, 1993) or *Boehmoceras arculus* Zone (Kaplan & Kennedy, 2000).

The Spanish late Santonian *cingulatum/hispanicum* ammonite fauna shows affinities with the French *Placenticeras paraplanum* Zone fauna of the Corbières (compare Kennedy et al., 1995) which yields, beside the characteristic *Placenticeras paraplanum* Wiedmann and *Pl. maherndli* Summesberger, similar faunal elements, e.g. *Jouaniceras sicardi* (de Grossouvre) and *Boehmoceras krekeleri*. The Olazagutia fauna also correlates to the latest Santonian Gosau IV fauna of Austria (Summesberger, 1985; Tröger & Summesberger, 1994) with abundant *Placenticeras polyopsis*, *P. paraplanum*, *Boehmoceras arculus* (Morton), *B. krekeleri*, *Cordiceramus muelleri muelleri* (Petrascheck), *Cordiceramus muelleri germanicus* (Heinz) and *Platyceramus cycloides ahsenensis* (Seitz). This fauna was placed into the inoceramid assemblagezone 29 of Tröger (1989) and was correlated to nannozone CC17b by Wagreich (1992).

Assuming a synchronous deposition of the calciturbidite layers at Olazagutia and San Roman E, then there is a slight discrepancy between the inferred stratigraphic positions of the macrofaunas around that level. The Olazagutia ammonite/inoceramid assemblage seems to be stratigraphically lower than the San Roman fauna in respect to the micro- and nannofossil zonation. At Olazagutia, the calciturbidites occur within zone CC17 and

Plate 1

All figures are of natural size.
Ammonites are housed in the private collections of Th. Küchler (Berlin).

Figs. 1, 4: *Scalarites cingulatum* (Schlüter, 1872)

Fig. 1: (Olaz-K167; Olaz-D/1). Olazagutia, upper Santonian *Jouaniceras hispanicum/ Scalarites cingulatum* Zone. Leg. P. Wolz.

Fig. 4: (Olaz-RW 198). Olazagutia, upper Santonian *hispanicum/ cingulatum* Zone, within the track from the second to the third floor of the quarry sensu Kannenberg (1985). Coll. Küchler.

Figs. 2, 3: *Jouaniceras hispanicum* Wiedmann, 1994

Fig. 2: (Olaz-Ju/1a). Olazagutia, upper Santonian *hispanicum/ cingulatum* Zone, point 221–222 sensu Radig (1973) [= ?K167 of Kannenberg, 1985)]. Coll. Judenhagen.

Fig. 3: (SRE 94e/1); San Roman E, Alava; upper Santonion, *hispanicum/ cingulatum* Zone. Leg. P.Wolz.

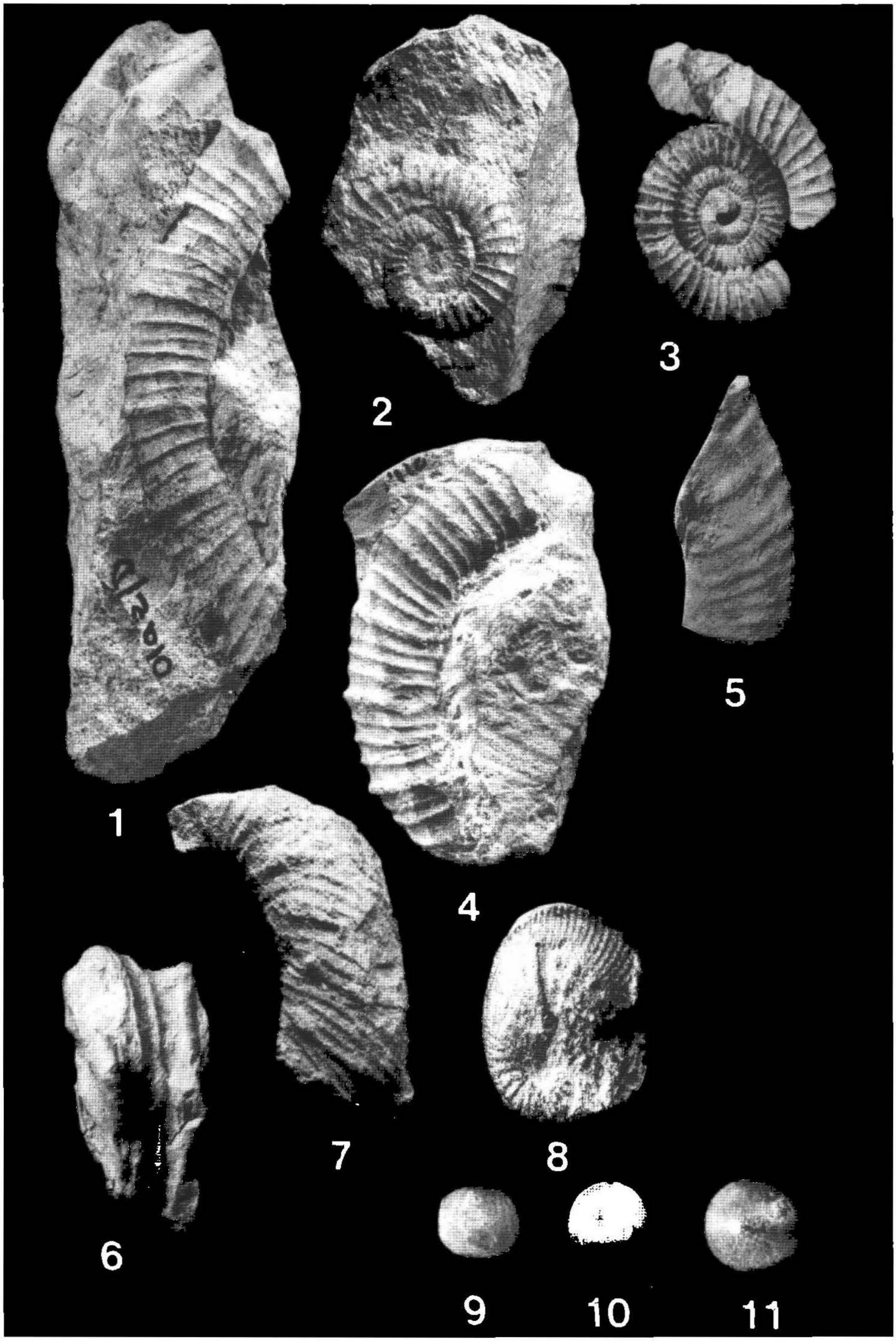
Fig. 5: *Boehmoceras krekeleri* (Wegner, 1905)

(RW 188); Olazagutia; upper Santonian *hispanicum/ cingulatum* Zone, within the track from the second to the third floor of the quarry (Kannenberg, 1985). Coll. Küchler.

Figs. 6, 7: *Neocrioceras* (*Schlueterella*) sp. [Sal (13/14)-1, Sal (13/14)-2]. Sarasate la, Navarra; lower Campanian, *Offaster pomeli/ Micraster* (*Isomicraster*) sp. Zone. Coll. Küchler.

Fig. 8: *Scaphites hippocrepis* (DeKay, 1828) III Cobban, 1969. (Sal -Ju), macroconch; Sarasate la, Navarra; from bed Sal-1 of the basal *pomeli/ M. (Isomicraster)* sp. Zone, lower Campanian. Coll. Judenhagen.

Figs. 8–11: *Offaster pomeli* Munier Chalmas, 1884. (Sal-(7–8)/22580-2). Sarasate la, lower Campanian, *pomeli/M.* (*Isomicraster*) sp. AZ, *pomeli* Event. Coll. Küchler.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far below the base of the *asymetrica/elevata* concurrent range Zone (fide GRÄFE, 1994), whereas at San Roman E these calciturbidite occur within zone CC17b. However, low abundances and poor preservation of planktic foraminifera and nannofossils in the Olazagutia section result in a poor stratigraphic resolution and questionable zonal boundaries. Therefore, correlations of the Olazagutia section to the other sections strongly relies on macrofossils and lithologies.

An early Campanian age for the macrofossil fauna of Sarasate I section is indicated by *Scaphites hippocrepis* DEKAY III COBBAN together with *Offaster pomeli* MUNIER CHALMAS. *Scaphites hippocrepis* III occurs in the early Campanian *Galeola senonensis* Zone in Westphalia/ Germany, or possibly even lower, in the *Offaster pilula* Zone (WIPPICH 1994, 1995) which two zones equate according to KÜCHLER (2000a, b) to the *Scaphites hippocrepis* III or *Offaster pomeli/ M. (Isomicraster)* sp. Zone of the investigated section. *Offaster pomeli* is assumed to represent the ancestor of *Offaster pilula* (LAMARK). The FO of *Offaster pomeli* may be already of late Santonian age (ERNST 1971, MOSKVINA et al. 1959). However, the species is typical but rare in the lower Campanian of Germany, where its first occurrence is below the *pilula* Zone. In the Sarasate I section, a peak occurrence of *Offaster pomeli* (= *pomeli* Event) is located within an acme-zone of *Micraster (Isomicraster)* sp. The *Offaster* Event and the associated echinoid assemblage correlates with the higher part of the *Offaster pilula* Zone recognized in southern England and the top of the *pilula* to *pilula/senonensis* Zone of northern Germany (see discussion in KÜCHLER & KUTZ, 1989; KÜCHLER, 2000b).

Considering planktic foraminifera and calcareous nannoplankton, our study largely confirms the succession of events previously defined around the Santonian-Campanian boundary (e.g. WAGREICH, 1992; CUNHA et al., 1997): The FO of *Globotruncanita elevata* and/or *Globotruncanita stuartiformis* is followed by the LO of the *Dicarinella asymetrica-concavata* group, and the FO of *Broinsonia parca parca*. Correlations with the LO of the pelagic crinoid genera *Uintacrinus* and *Marsupites* indicate that the base of the Campanian defined by the LO of *Marsupites* is significantly below the FO of *Broinsonia parca parca* (BAILEY et al. 1984; GALE et al., 1995). The LO of *Marsupites* was found in NE England (BURNETT & WHITHHAM, 1999) within UC12 below the FO of *Biscutum magnum* and *Orastrum campanensis* – both events can only be recognised in high latitudes and both species have not been recorded in the Spanish sections, whereas the FO *Broinsonia parca parca* (= base of UC14 of Burnett, 1998) correlates with the Campanian basal *Offaster pilula* MFZ in NE England and a horizon below the M1 marl in the Lägerdorf section (SCHÖNFELD et al., 1996). GALE et al. (1995) noted that the LO of *Dicarinella asymetrica* lies just above the LO of *Marsupites*, which is in agreement with our definition of the lower boundary of the Campanian by secondary markers.

5. CONCLUSIONS

Based on the three northern Spanish sections, a detailed integrated biostratigraphy around the Santonian-Campanian boundary has been given, despite the fact that the sections comprise different lithofacies and the boundary intervals are partly incomplete due to gaps in exposure or hiati. In the absence of *Marsupites testudinarius*, the proposed primary marker for the base of the Campanian, our zonation relies on a succession of ammonite zones and faunas and the correlation of lithoevents, i.e. calciturbidite beds.

Secondary markers such as ammonites and echinoids, as well as section correlation have been used successfully to approximate the lower boundary of the Campanian. In the upper Santonian San Roman E section, Alava, the nannofossil standard zone CC17, subzone CC17b is indicated by the presence of *Calculites obscurus* and curved *Lucianorhabdus cayeuxii* in the *Jouaniceras hispanicum/ Scalarites cingulatum* ammonite Zone and the *Cordiceramus muelleri* inoceramid Zone. The *G. elevata/ D. asymetrica* concurrent range Zone starts some meters above a calciturbidite triplet. The ammonite *J. hispanicum* has an abundance maximum in the lower part of the *asymetrica-elevata* Zone. These events can be correlated to the Olazagutia section, where also nannofossil standard zone CC17 has been recognized and a complete Santonian-Campanian boundary section seems to be present. In the Sarasate I section, Navarra, the last *D. asymetrica* was found immediately below an unconformity, the first *Offaster pomeli* immediately above and the first *Scaphites hippocrepis* III 2.0 m above that level. *O. pomeli* has its acme-occurrence at level 13.5 m within the *hippocrepis* III Partial Range Zone. The nannofossil assemblages indicate also nannofossil standard zone CC 17b (UC12), overlain by zone CC18.

The succession of events recognized in the northern Spanish sections thus include: The FO of *Calculites obscurus* (base of CC17a); the FO of curved *Lucianorhabdus cayeuxii* (base of CC17b), the FO of the foraminifer *Globotruncanita elevata,* a local *Jouaniceras hispanicum* ammonite Event, the LO of the foraminifer *Dicarinella asymetrica,* the FO of the echinoid *Offaster pomeli* followed by an *Offaster pomeli* Event, the FO of the ammonite *Scaphites hippocrepis* III, and the FO of the calcareous nannoplankton species *Broinsonia parca parca.* The Santonian-Campanian boundary most probably lies between the local *Jouaniceras hispanicum* ammonite Event and the FO of the echinoid *Offaster pomeli* followed by the FO of the ammonite *Scaphites hippocrepis* III.

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