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Upper Cretaceous of the Barranca (Navarra, northern Spain); integrated litho-, bio- and event stratigraphy. Part I: Cenomanian through Santonian

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ABSTRACT:

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Fossiliferous Upper Cenomanian to Lower Maastrichtian strata in Navarra, northern Spain, particularly in the eastern Barranca, were investigated in terms of lithostratigraphy, macrofossil biostratigraphy and event stratigraphy. Extensive bed-by bed-collections of ammonites, inoceramids, and echinoids allow the establishment of combined standard zonal schemes of inter-regional significance. Data on geochronological boundaries, macrofossil distribution, the succession of events and the inter-relations between bioevents, eustato-events and tectonic movements in northern Spain are presented.
The Upper Cenomanian – Turonian successions of the Barranca sections (Arardi, Izurdiaga, Satrustegui) and of the Estella area (Ganuza, Ollogoyen), differ considerably in both lithofacies and thickness and, periodically, in faunal composition, as a result of their palaeogeographical positions within an stable outer shelf and an unstable mid-shelf, respectively. The Ganuza/Ollogoyen standard section is revised. In the context of the established event stratigraphical scheme, discrepancies in previously applied ammonite zonation are pointed out and discussed in terms of their regional relevance. The expanded and relatively complete Turonian of the Estella area is subdivided into an unnamed interval devoid of ammonites (Upper Cenomanian *Metoicoceras geslinianum* Zone to the mid-Lower Turonian), six ammonite zones and an inoceramid/ammonite assemblage zone. The upper Lower Turonian *Kamerunoceras ganuzai/Mammites nodosoides* Zone is succeeded by the Middle Turonian zones of *K. turoniense*, *Romaniceras kallesi*, *R. ornatissimum* and *R. deverianum*; and the Upper Turonian *Subprionocyclus neptuni* and *Cremnoceramus waltersdorfensis/ Prionocyclus germari* zones. The Lower Turonian zonal scheme given by WIEDMANN (1979a) for the Estella area is shown to be impracticable, and neither Lower Turonian *Choffaticeras quaasi* Zone *sensu* SANTAMARIA (1992) nor a *Watinoceras coloradoense* Zone *sensu* LAMOLDA & *al.* (1989) can be recognized. On the other hand, the refined French Middle Turonian ammonite zonation of AMÉDRO & *al.* (1982) is readily applicable, while the application of a *Collignoniceras woollgari* Zone is hardly possible. The base of the Middle Turonian has been placed at the FAD of *K. turoniense*, at a level stratigraphically lower (upper Lower Turonian) than the one recently accepted. *C. woollgari* is rare and appears no lower than the *ornatissimum* Zone. The base of the Upper Turonian is placed at the FAD of *Subprionocyclus neptuni*. *Romaniceras deverianum* appears considerably lower than the former, but has

its main occurrence in the *neptuni* Zone, ranging up to overlap with *Prionocyclus germari*. The Barranca succession is condensed and includes hiati from the Upper Cenomanian *Neocardioceras juddii* Zone to the upper *ganuzai/ nodosoides* Zone; between the Middle Turonian *kallesi* and *ornatissimum* zones; and in the lower Upper Turonian *neptuni* Zone. Twelve bio-events that are significant for regional and inter-regional correlations are differentiated and dated: the *Mytiloides kossmati*, *ganuzai*, *reveliereanus*, *turoniense/hercynicus*, *kallesi/ornatissimum*, *Scaphites geinitzii*, *Subprionocyclus* I, *Micraster* ex gr. *normanniae-cortestudinarium*, *Subprionocyclus* II events. Most of these events are time-equivalents of events already recognised by ERNST & *al.* (1983) in Germany. The biostratigraphic framework permits a dating and correlation of the major tectono-sedimentary and eustato-events, namely the Cenomanian-Turonian Boundary Event (CTBE), the Middle Turonian Event (MTE) and the Lower Upper Turonian Event (LUTE).

The calcareous Coniacian – Santonian succession of the eastern Barranca (Izurdiaga, Ecay and Zuazu sections), is divided into Lower Izurdiaga, Zuazu and Upper Izurdiaga formations, and into numerous component members. The succession is rich in echinoids, and is biostratigraphically important because of the cooccurrence of inoceramids and ammonites. The Coniacian ammonite assemblages show affinities to those of the French type region and to the largely endemic ones of the Spanish standard sections in Burgos. The data obtained permit a confident correlation of the biostratigraphic frameworks of these two areas for the first time. In contrast to the widespread basal Coniacian hiatus, the Barranca succession at this level is locally relatively complete. The lower Coniacian *Cremnoceramus rotundatus*, *Forresteria petrocoriensis* and *Peroniceras subtricarinatum* zones, the Middle Coniacian *Gauthiericeras margae* Zone and the lower Upper Coniacian *Protexanites bourgeoisi* Zone are recognized. In marginal sections, the *bourgeoisi* Zone is followed by an hiatus which comprises the late Upper Coniacian *Magadiceramus subquadratus* and the Lower Santonian *Cladoceramus undulatoplicatus* inoceramid zones recognized in the continuous section of the western Barranca. By means of ammonites, the Santonian at Olazagutia is divided into an unnamed interval devoid of ammonites; the middle Coniacian *Texanites quinquenodosus* and the Upper Santonian *Jouaniceras hispanicum/Scalarites cingulatum* Zone. This scheme has affinities with the zonation applied by KENNEDY & *al.* (1995) in the Corbières, France. In addition to a sequence of regionally important events and marker-beds, some events, namely the *Didymotis* II, *Micraster* ex gr. *cortestudinarium* and *Cladoceramus undulatoplicatus* events, are of inter-basinal importance.

Contents

Dedicated to my whife M. Repáraz-Berastegui

Introduction

During the Late Cretaceous, the territory of northern Spain was situated palaeobiogeographically between the northern Boreal and the Tethyan Mediterranean provinces. It was a region of periodical faunal overlap and exchange of varying intensity (*compare* WIEDMANN 1962, 1979b; WIEDMANN & KAUFFMAN 1978). This is why the Cretaceous successions of northern Spain are particularly suitable for the study of the European standard stratigraphical divisions. Northern Spain was already mentioned by WIEDMANN as one of the key areas for the understanding of the mid-Cretaceous. In contrast to other areas in Europe, the upper Upper Cretaceous sections of northern Spain are characterized by relatively thick and complete successions, which, at the same time, contain biostratigraphically important groups such as ammonites, inoceramids and echinoids. This makes northern Spain particularly attractive for a biostratigraphical investigation of the Campanian stage, since the classic areas, in SW France (northern Aquitaine) and in northern Germany (Westphalia) are characterized by predominantly very shallow-marine, abruptly changing facies and, today, by an absence of available sections, giving very limited opportunities to study the continuous zonal succession. This is also the case in the Campanian succession of the Vistula section, Central Poland, where a refined ammonite zonation was established by BŁASZKIEWICZ (1980). Most of the localities mentioned by him have disappeared and there is therefore little opportunity to undertake new studies of this succession.

The main objective of this paper is to establish a detailed chronostratigraphical zonation of the Upper Cretaceous of the Navarra area, northern Spain. The existence of a fossiliferous Upper Cretaceous succession in the main part of the Barranca, and the lack of stratigraphical investigation in that area, were the main reasons for undertaking multistratigraphical, *i.e* litho-, bio-, and event stratigraphical studies. The Barranca succession allows the establishment of a practical, ammonite and/or inoceramid standard zonal scheme of inter- regional significance.

Supplementary comparative studies were undertaken in the Estella area, in the Ganuza and Ollogoyen standard sections for the Turonian of northern Spain; and in eastern Navarra in the area of the Oroz-Betelu Massif. In contrast to the Barranca, the Oroz-Betelu Massif sections are better exposed and provide more continuous successions of the topmost Campanian and the Campanian/Maastrichtian boundary interval.

The aim of the event stratigraphical studies was to recognize the succession of events in northern Spain and to test the methodology, developed originally by ERNST & *al.* (1983) in northern Germany. Also of importance was investigation of the correlation potential of particular events between the Barranca and central Europe. The paper provides data on geochronological boundaries, fossil distribution and eustato- and tectoevents in northern Spain. The interrelationships between bio-, eustato- and tectoevents were also investigated.

The second part of this paper (the Campanian – Maastrichtian of the Barranca), inlcuding also summary chapters for the whole paper, appear in part 3 of *Acta Geologica Polonica* for 1998.

Geographical and tectonic setting

The studies were concentrated on Upper Cretaceous occurrences west and east of the town of Irurzun, in the eastern Barranca (Text-fig. 1). The Barranca, known as La Barranca or, in Basque, Sakana, is a geographical unit comprising a narrow, E – W orientated valley along the Burunda-Araquil river, in the western part of the Province of Navarra. To the north, the Barranca valley is bordered by the Lower Cretaceous deposits of the Sierra de Aralar. Its southern border is formed by the Tertiary high plateaus of Sierra Andia and Sierra Satrustegui in the east, and Sierra de Urbasa in the west (*see* Text-fig. 1). The Barranca valley begins near the town of Irurzun and stretches for some 34 km to the west, as far as Olazagutia, where it passes into the Vitoria plain (Text-fig. 1).

Within the Barranca, in addition to 2000 m of Albian clays, predominantly marine, Upper Cretaceous sediments crop out, structurally forming a large synclinorium. In the northern part of the eastern Barranca the E-W Aralar Fault separates the synclinorium from the Aralar anticline, which is formed of Aptian – Albian reef limestones with a core of Triassic and Jurassic limestones and dolomites. Parallel to the Aralar Fault, in the south, runs the Satrustegui Fault, which separates parts of the Upper Cretaceous Synclinorium from the synclinorium of the Tertiary high plateau, the core of which is composed of Eocene limestones. In structural terms, the Barranca can be interpreted as a graben (RAMIREZ 1987).

In the eastern Barranca, the Upper Cretaceous is tightly folded, with mostly WNW-ESE trending (Pyrenean direction) and south-vergent synclines and anticlines which generally plunge to the ESE at low angles. Numerous E-W trending faults divide the fold structures into separate blocks. The margins of the synclinorium are marked by zones of faulting and overthrusting, and the synclinorium is additionally traversed by N – S faults.

The core area of the eastern Barranca was affected by the Estella-Dax Diapir Zone (*sensu* LOTZE 1955), a SW-NE trending lineament with, in close proximity to the studied area, the associated diapirs of Anoz, Ollo and Echalecu. According to KIND (1967) the diapirs of Anoz and Ollo, situated today *ca*. 1.5 to 2.5 km south of the study area, comprised a single structure with a common chimney. The uplift of this "double diapir", which first reached the surface during the Late Cretaceous and entered the diapir stage in the Eocene, decisively influenced the sedimentary development in the vicinity of Irurzun during the latest Santonian and Early Campanian (*see* RADIG 1973, and later in this paper).

Palaeogeographical situation

During the Late Cretaceous, the Barranca formed an independent tectonic-sedimentary and faunistic unit of the northern outer shelf region of the Iberian microcontinent, known variously as the Navarro-Cantabrian Region (CIRY 1940), Navarro-Cantabrian Basin (FEUILLÉE 1967) or "plateform distale" (AMIOT & *al*. 1983, FLOQUET 1983). The outer shelf area represented an ESE – WNW zone comprising several intra-shelf basins with different sedimentary facies and subsidence histories related to tilted block tectonics (*see* Text-fig. 2) within a strike-slip- and/or oblique-slip-fault system (WIEDMANN & *al*. 1983, ENGESER 1985, ENGESER & *al*. 1984). This zone stretched from western Navarra, through the province of Alava, to the northern part of the province of Burgos. Fault-zones, interpreted as the Bilbao transcurrent and Losa transcurrent faults (Text-fig. 2), separate the unit of intra-shelf basins from the deep marine basins to the north and the proximal shelf of the "plateform nordcastillane" (*sensu* ALONSO & FLOQUET 1982, AMIOT & *al*. 1982) to the south. Within the zone of the Navarro-Cantabrian basins, the Barranca represented the most northeasterly located unit. It is limited by the SW-NE trending lineament, known variously as the Estella-Dax Diapir Zone (*sensu* LOTZE 1955), Estella Fault (*sensu* SCHWENTKE 1990) or part of the Basco-Landaise Transversals (*sensu* SCHOEFFLER 1982) (*see* Text-fig. 2). This lineament separates the Barranca from the higher lying region of the

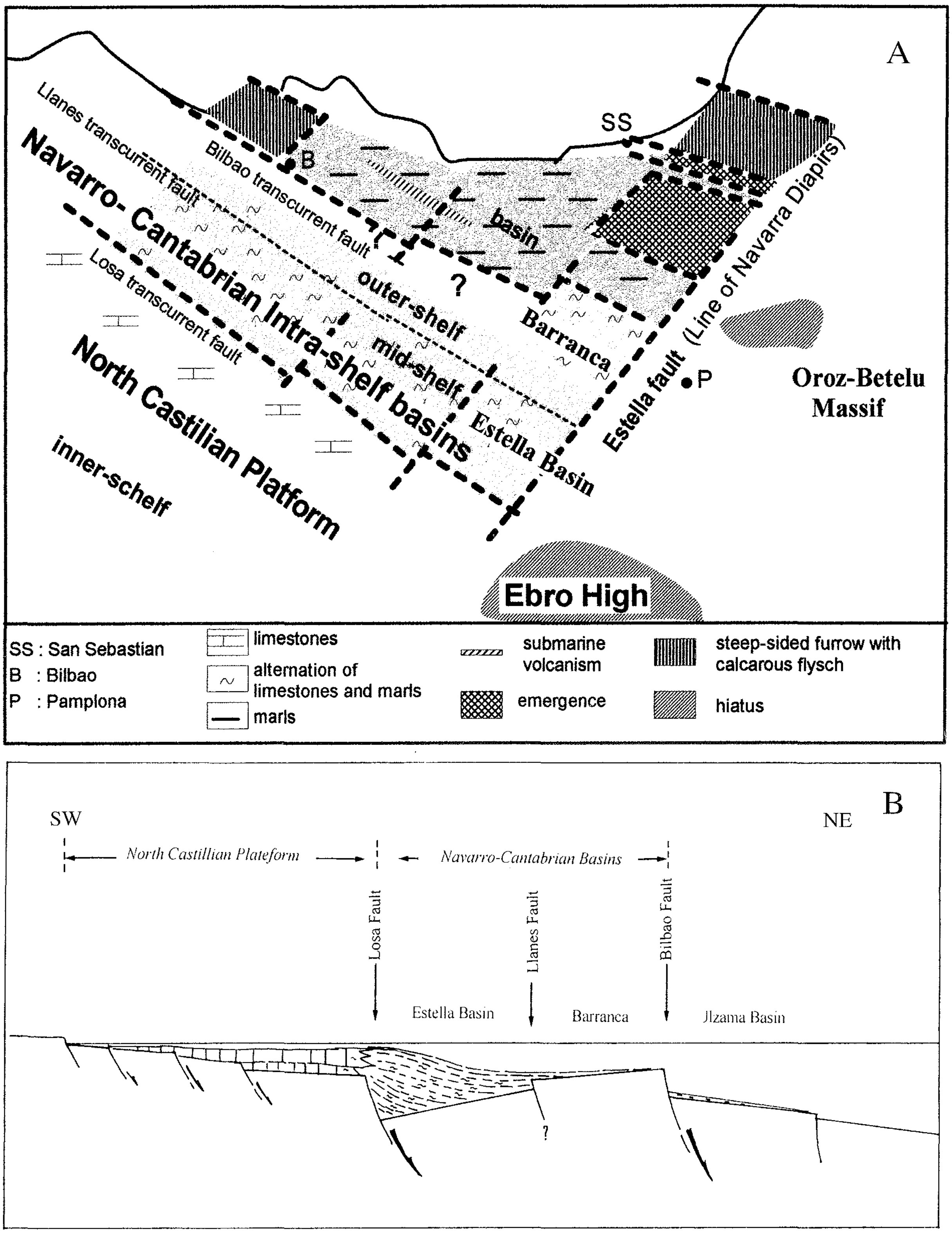


Fig. 2. A – Palaeogeographical position of the Barranca within the zone of Navarro-Cantabrian intra-shelf basins during the Turonian (*modified after* ALONSO & FLOQUET 1982 and AMIOT & *al.* 1982);
B – Structural-facies cross section through Navarro-Cantabrian intra-shelf basins during the Turonian

so-called Pamplona Basin. Based on thickness differences between it and the Estella Basin in the south, and the adjoining deep-marine Biscaya (or Ulzama) Basin to the north, the Barranca is interpreted as a zone of tectonic uplift (Text-fig. 2B). In the Estella area, the Upper Cretaceous succession (the Upper Campanian is usually lacking) is approximately 1500 to 2500 m thick (*compare* WIEDMANN & *al.* 1983, SCHWENTKE & WIEDMANN 1985), while in the Biscaya (or Ulzama Basins) it reaches 3000 to 3500 m (*compare* EWERT 1964, VÖLTZ 1964, WIEDMANN 1979a, SCHWENTKE 1990). Within the Barranca, the thickness of the Cenomanian through Maastrichtian succession is estimated at *ca.* 800 to 1050 m in the eastern part (DEGENHARDT 1983, KÜCHLER 1983), and a maximum 1350 m in the west (KANNENBERG 1985, ZANDER 1988).

WIEDMANN (*see* LAMOLDA & *al.* 1981, SCHWENTKE & WIEDMANN 1985) called the Barranca the Barranca Horst, and ENGESER (1985) regarded it as the submerged part of the Aizgorri-Basement-High.

It can be generally demonstrated that the Barranca depth developed westwards, while at the same time, from the Late Cenomanian to the late Early Campanian, exhibiting a mosaic, largely controlled by tilted block tectonics, of internal swells and sub-basins that are clearly documented by strong facies differentiation, thickness variations and hiati of varying duration from east to west. Consequently, the Barranca can be subdivided into a West, Middle and East Barranca (*see* FEUILLÉE 1967).

Previous research

In spite of a large number of stratigraphically important publications in the last 35 years on the Upper Cretaceous of northern Spain, only a few of them were devoted to the Barranca region. Among them the microbiostratigraphical and microfacies studies on the Cenomanian and the entire Upper Cretaceous, mainly of the western Barranca, of FEUILLÉE (1966, 1967) and RAMIREZ DEL POZO (1971), respectively, are of great importance. Preliminary data on the stratigraphy and sedimentology of the Olazagutia Quarry were presented by RADIG (1973), LAMOLDA & *al.* (1981) and GRÄFE (1994). Some data on isolated, mainly unhorizoned ammonite finds from the Barranca, as well as a faunal list for Olazagutia, were included in papers by WIEDMANN (1962, 1965, 1979a, b) on the stratigraphy and palaeontology of northern Spain in general. With inoceramids the case is similar (WIEDMANN & KAUFFMAN 1978; LOPEZ 1990, 1996). The Campanian echinoids of the Barranca were first studied by RADIG (1973), who investigated their vertical and geographical distribution and provided useful sections. His sections served as a basis for the present study, and for the establishment of an integrated ammonite-echinoid biozonation for the eastern part of the Barranca and for the Urdiroz/Imiscoz area (*see* KÜCHLER & KUTZ 1989). Detailed stratigraphical studies and mapping in the context of Diploma projects of the Free University, Berlin, were carried out by KÜHN (1982), DEGENHARDT (1983) and KÜCHLER (1983), describing the eastern part of the Barranca, and by ZANDER (1988) and KANNENBERG (1985) for the western part. The eastern part of the Barranca was also treated by COSULLUELA SOLANILLA (1986). Details of the biostratigraphy of the Turonian/Coniacian boundary and of the Lower Coniacian from the environs of Irurzun, including detailed sections with ammonite and inoceramid distribution, were provided by KÜCHLER & ERNST (1989). LOPEZ & *al.* (1992) presented the first list of Upper Campanian inoceramids from the eastern Barranca within the biostratigraphical framework of KÜCHLER & KUTZ (1989) based on ammonites and echinoids.

Cenomanian – Turonian

SELECTED SECTIONS OF THE EASTERN BARRANCA

The lithological character and faunal composition of the Cenomanian – Turonian succession of the eastern Barranca discussed in this paper are based on the Arardi, Izurdiaga and Satrustegui sections, including 6 outcrops over a distance not exceeding 7 km (*see* Text-fig. 1). Only the first two sections are stratigraphically relatively complete: uniquely for the Barranca a macrofossil-rich succession with ammonites, inoceramids and irregular echinoids that extends from the Cenomanian to the basal Coniacian. The sections more to the west, including those of Satrustegui, partly because of faulting are more or less discontinuous, and partly due to the existence of stratigraphical hiati. In general they represent condensed successions of the outer shelf with predominantly fine-grained carbonate sedimentation, whereby the Turonian of the eastern Barranca reaches a maximum thickness of 56 m, compared to the 220 m of the Estella area. The Arardi and Izurdiaga sections were situated close to a local swell area, detected in the Middle Turonian by turbiditic ("calcisphere" packstones and echinoderm debris packstones) sequences within the background pelagic sedimentation ("calcisphere"-foraminiferal wackestones). In the Late Turonian the sedimentary basin became shallower, shifting its position from deeper to shallower subtidal towards the high or swell region. The shallow subtidal is indicated by shallow marine hardgrounds (echinoderm debris wacke/packstones) of *neptuni* Zone age and terrigenously influenced, silty and strongly glauconitic carbonates in the Turonian/Coniacian boundary interval. The Satrustegui section was located in the transitional area to the basinal facies, while clearly basinal conditions are documented by the sections of the western Barranca in the area between Iturmendi and Alsasua (*see* ZANDER 1988).

Arardi Section (Upper Cenomanian to Upper Turonian)

The Arardi section (Text-fig. 3) is situated *ca.* 3 km SE of Irurzun, south of the motorway A-15 at the Arardi Mount. It is represented by a natural outcrop (Topographical map Gulina, sheet 115-9, 1:10 000; R=597.450, H=750.400), in parallel to a brook running about N-S east of the Arardi Mount. The figured succession (albeit largely overgrown) is about 50 m thick and comprises the interval from the *Metoicoceras geslinianum* Zone of the Upper Cenomanian up to the *Subprionocyclus neptuni* Zone of the Upper Turonian.

Lithostratigraphy

The Turonian succession of the Arardi section can be divided into seven informal lithological units, briefly characterized below (in ascending order).

Unit A: Ca. 12 m thick unit, overlying Upper Cenomanian limestones, of thin-bedded calcareous marls (~ 78% $CaCO_3$), with thin (0.1-0.3 m) limestone intercalations passing gradually upwards into marls of the overlying Unit B1.

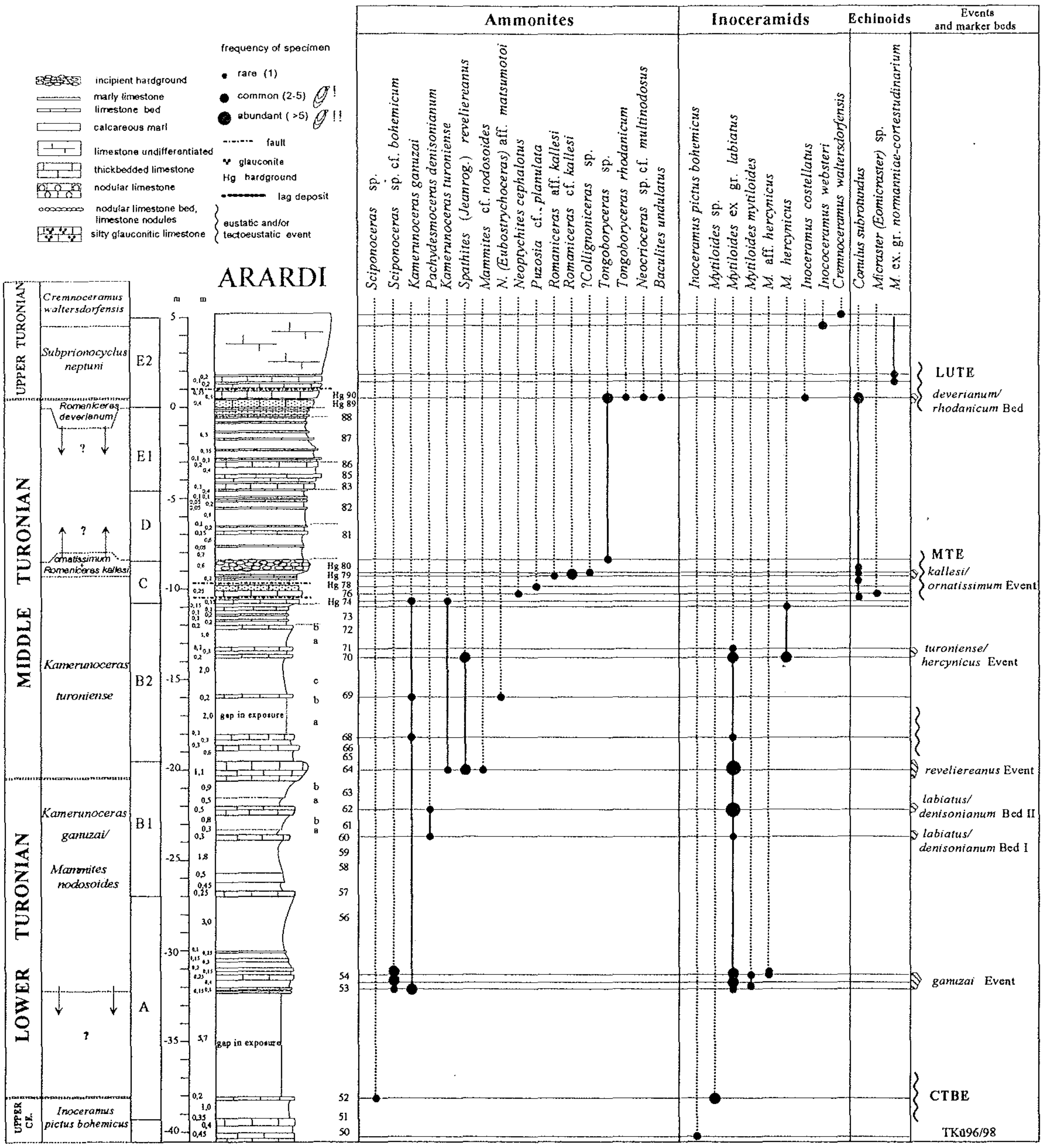
Unit B1: It is represented by a *ca.* 8 m thick unit of alternating calcareous marls, hard calcareous marl horizons and thin-bedded limestones. The limestone beds increase upwards in thickness from 0.3 m at the bottom to about 1.1 m at the top (thickening upward sequence). The whole unit is characterized by thin horizons with inoceramids at the base of and within the limestone beds.

Unit B2: It ranges from the *revelliereanus* Event up to the hardground Ar-74, and represents an 8 to 9 m thick succession again composed of an alternation of initially metre thick calcareous marls (decreasing in thickness upwards) and thin-bedded (0.1-0.2 m) limestones.

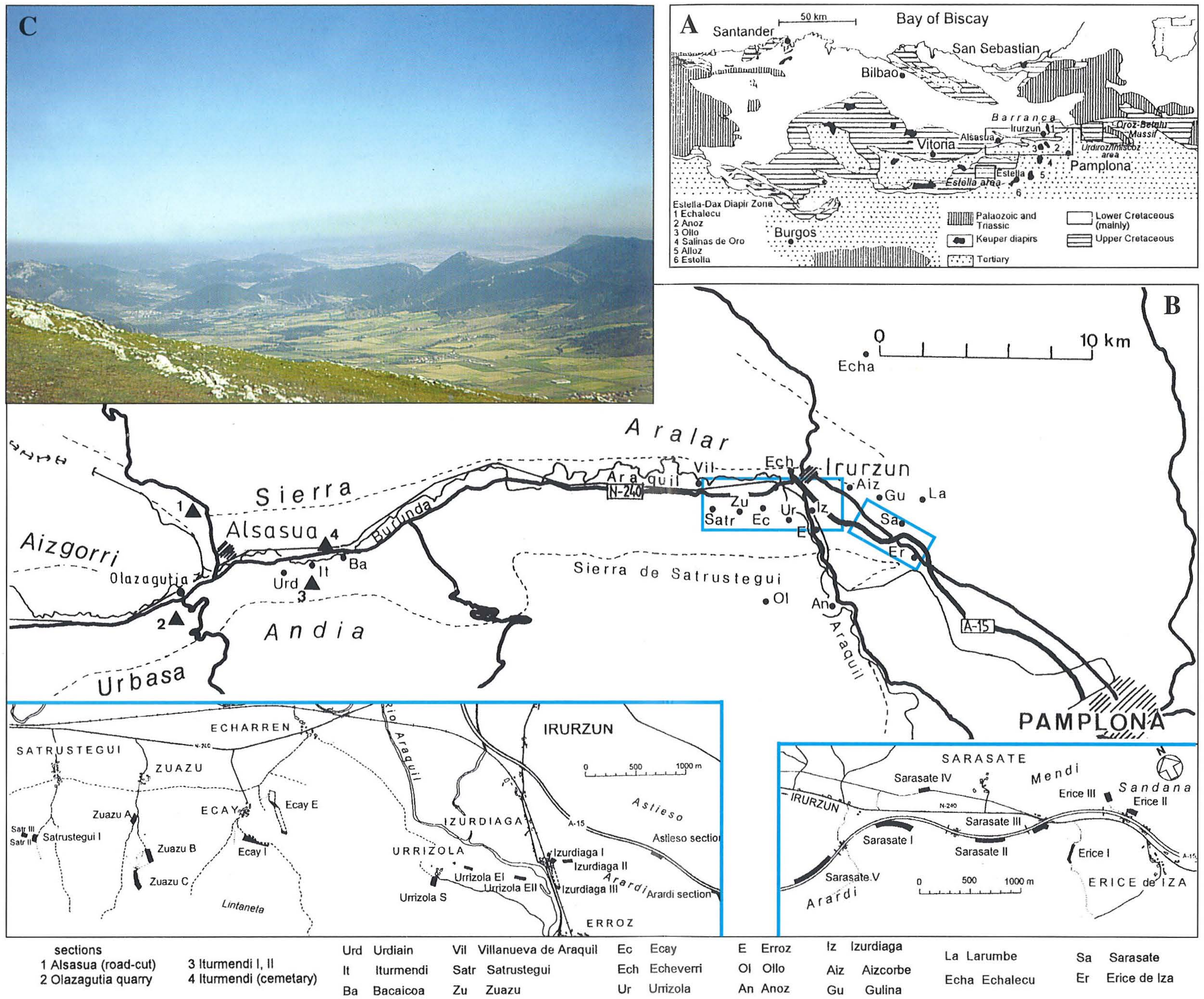
Unit C: At the Arardi it is a *ca.* 2 to 2.4 m thick (tectonically reduced) succession of alternating, nodular, 0.15 to 0.3 m thick limestones and 0.15 m thick marls. The unit is characterized by four hardground horizons (*Thalassinoides* hardgrounds) and two (between beds Hg-74 and Hg-78a), 0.2 to 0.3 m thick calcarenitic beds. The three lower hardgrounds are penetrated by large-sized *Thalassinoides* burrow systems with glauconite coatings. Between the hardgrounds and the overlying marls there is an erosional contact. The burrows are infilled with calcarenitic marls (packstones with echinoid debris) and intraclasts of the hardground. Intraclasts, partly bored, and with a glauconitic skin, also occur within the marls above the hardgrounds Hg-74 and Hg-78a. The hardground suite is capped by a 0.6 m thick nodular limestone bed (Ar-80) penetrated by *Thalassinoides* burrows, representing a "composite hardground" in the classification of KENNEDY & GARRISON (1975).

Unit D: A limy marlstone unit with single 0.1 to 0.2 m thick limestone intercalations. Compared to the Izurdiaga section, the unit is tectonically reduced to about 4 m.

Unit E1 (4.6 m): A 1.4 m thick succession of alternating 0.3 to 0.4 m thick limestones and calcareous marls occurs at the bottom of this unit. The higher part of the unit comprises a much more closely spaced alternation of decimetric calcareous marls and 0.05 – 0.1 m, nodular, finely arenitic limestones or nodular limestones (glauconitic echinoid debris-packstones). The unit represents reworked sediments redeposited into the area of deeper subtidal. The allochtonous material comes from a nearby swell area with echinoid facies. The unit terminates in a planar hardground (Ar-89) with a well developed *Thalassinoides* burrow system.



Upper Cenomanian through Turonian succession of the Arardi section; integrated litho-, bio- and event stratigraphy, and local ranges of stratigraphically important macrofossil groups



Geological sketch-map of northern Spain with location of the Barranca and other reference areas mentioned in the text (1A), and the geographical location of the investigated sections in the western and eastern Barranca (1B); 1C. General view of the eastern Barranca (Sakana) and the eastern part of Sierra de Satrustegui, as viewed from WNW; Upper Cretaceous exposures are located mostly at the northern slope of Sierra de Satrustegui and in the east, at the slopes of the Arardi and Astieso mounts near Irurzun.

Unit E2: In the Arardi section the 5 m thick unit starts with two horizons of reworking: the Arardi Conglomerate and an intraclast horizon. Above this, there is a marked lithofacial and microfacial change to the so-called Lower Izurdiaga Limestones. The Arardi Conglomerate is composed of a layer of flat centimetre to decimetre limestone pebbles with phosphatic and glauconitic coatings. The nodules are bored all around and are partly encrusted by oyster-like bivalves and serpulids. The overlying, intraclast horizon, *ca.* 0.2 m thick, is characterized by irregularly shaped, in part fist-sized matrix-supported intraclasts, phosphatized steinkerns of ammonite as well as corroded echinoid tests. This horizon is followed by nodular, 0.2 to 0.3 m thick on average, silty and glauconitic limestones and marls (echinoid debris packstones). The unit is marked by the first appearance of *Micraster* ex gr. *normanniae – cortestudinarium*.

Integrated bio- and event stratigraphy

Six ammonite zones can be distinguished within the Turonian of the studied section (*see* Text-fig. 3). The inoceramid associations occurring within the Lower to middle Middle Turonian are attributed to the corresponding ammonite zones but an inoceramid-based zonation was not established here. By contrast, ammonites are rare in the topmost Turonian of the Barranca, so that only on the basis of a similarly sparse inoceramid fauna can this part of the succession be assigned to the *Cremnoceramus waltersdorfensis* Zone.

Conforming to the regional situation, the Cenomanian/Turonian boundary interval, the Middle Turonian (between the *Romaniceras kallesi* Zone and *Romaniceras ornatissimum* Zone), as well as the lowermost Upper Turonian (*Subprionocyclus neptuni* Zone) of the Arardi section are characterized by stratigraphical gaps.

Lower Turonian: In the Arardi section, the lower boundary of the Turonian is located at horizon Ar-52, the level of the first occurrence of poorly preserved inoceramids transitional between *Inoceramus pictus* and *Mytiloides mytiloides* that belong to the Cenomanian – Turonian transition (TRÖGER, *pers. comm.*). The Turonian age of this horizon is also indicated by a planktonic foraminiferal fauna comprising *Praeglobotruncana* and double-keeled forms of the genus *Marginotruncana* (NEUWEILER, *pers. comm.*). Unequivocal upper Lower Turonian *Mammites nodosoides* Zone or *ganuzai/nodosoides* Zone is first documented by an ammonite and inoceramid fauna occurring 5.7 m higher, following an unexposed interval. *Kamerunoceras ganuzai* (WIEDMANN) (Pl. 5, Figs 9-10), characteristic of the zone in northern Spain, appears together with *Sciponoceras* cf. *bohemicum* FRITSCH (Pl. 5, Figs 5-6) in a *ca.* 0.3 m double limestone (bed Ar-53), in the so-called *ganuzai* Event. *Mytiloides* ex gr. *labiatus* (VON SCHLOTHEIM) and *Mytiloides mytiloides* (MANTELL) are also associated with this form. The succeeding 0.6 m thick interval contains several horizons with *Sciponoceras* and *Mytiloides*. The *Mytiloides* assemblage comprises *Mytiloides labiatus*, *M.* aff. *duplicostatus* (ANDERSON), *M.* aff. *mytiloides*, and *M.* aff. *hercynicus* (PETRASCHECK). The assemblage exhibits a high species diversity, as well as containing morphotypes with great morphological variability, both features that are typical of upper Lower Turonian *Mytiloides* assemblage elsewhere (SEIBERTZ, *pers. comm.*). *M.* aff. *hercynicus* is abundant within the assemblage. It was interpreted by SEIBERTZ as a *hercynicus* form with *labiatus* characters, but was referred by J.C. WOOD (*pers. comm.*) to *Mytiloides hercynicus* sensu SORNAY.

The topmost Lower Turonian of the Arardi section is marked by an upper *Mytiloides* acme-zone, 3.5-4.0 m thick. It is characterized by several horizons with mainly late forms of *Mytiloides labiatus*, associated in beds Ar-60 and Ar-62 with *Pachydesmoceras denisonianum* (STOLICZKA) (Pl. 6, Fig. 1). This acme-zone in the Barranca extends up into the *Kamerunoceras turoniense* Zone (lower Middle Turonian of this paper).

Middle Turonian: The lower boundary of the Middle Turonian, following the traditional definition in France, and also for practical reasons, is placed here at the FAD of the ammonite species *Kamerunoceras turoniense* (D'ORBIGNY). This is contrary to the proposal of the 2nd International Symposium on Cretaceous Stage Boundaries in Brussels, Brussels 95 (BENGTSON 1996), which placed this boundary at the FAD of *Collignoniceras woollgari* (MANTELL). The latter species does not, however, occur in off-shore areas. The level adopted here is stratigraphically lower than the one accepted in NW Europe.

In Arardi section the lower boundary of the Middle Turonian lies in bed Ar-64 (Text-fig. 3).

It is characterized by the co-occurrence, in approximately equal numbers, of *Mytiloides labiatus* and *M.* m.f. *labiatus/hercynicus*, as well as subordinate *M.* m.f. *labiatus/subhercynicus*. According to SEIBERTZ (*pers. comm.*) the *hercynicus*-like forms occurring here do not represent true *hercynicus* forms but morphotypes that have been ecologically controlled. This level, referred to here as the *Spathites reveliereanus* Event, coincides with the level of first appearance of the ammonite species *Kamerunoceras turoniense* (Pl. 6, Fig. 2), a form used in France as the guide form for the base of the Middle Turonian (*turoniense* Zone). The dominating *S. reveliereanus* (COURTILLER) (Pl. 6, Fig. 6) is locally accompanied by *Mammites* cf. *nodosoides* (SCHLÜTER) (Pl. 6, Fig. 5). Single horizons within the *turoniense* Zone yield *Kamerunoceras ganuzai* (Pl. 6, Fig. 3) co-occurring with *Mytiloides labiatus* and *Nostoceras* (*Eubostrychoceras*) aff. *matsumotoi* COBBAN. Single *Mytiloides labiatus* and *Mytiloides hercynicus*, occurring within beds Ar-70 to Ar-71 indicate the *turoniense/hercynicus* Event. In contrast to the Izurdiaga section, the event here yields an impoverished ammonite fauna, represented only by juveniles of *S. reveliereanus*. The top of the *turoniense* Zone lies in the lower part of the Arardi Hardground suite (Unit C). The fossil association occurring here is composed of *Kamerunoceras ganuzai*, *K. turoniense*, *Neoptychites cephalotus* (COURTILLER), *Puzosia* cf. *planulata* (BAYLE) and *Conulus subrotundus* (MANTELL).

The succeeding, *kallesi* Zone is recognized by the finds of *Romaniceras* aff. *kallesi* ZAZVORKA (Pl. 8, Fig. 2) and *R.* cf. *kallesi*. The zone is restricted to a 0.2 m limestone bed (hardground 78a) and a thin (0.05 m) marly bed. Both, the eroded hardground and the intraclasts within the marl, as well as the occurrence of *Romaniceras ornatissimum* (STOLICZKA) at this level in the Izurdiaga section (in the Arardi section this form was not found), indicate strong condensation and/or extensive reworking of the *kallesi* Zone (MTE – Middle Turonian Event). As in the case of the *kallesi* Zone, the *ornatissimum* Zone is also strongly condensed; it lies here within the composite hardground Ar-80 (*see* Text-fig. 3).

Directly above enters *Tongoboryceras* sp. which, in the Barranca, generally represents a characteristic element of the succeeding, *deverianum* Zone. This genus, accompanied by *Romaniceras deverianum* (D'ORBIGNY), occurs primarily in the upper part of the *deverianum* Zone. Due to rarity of the index taxon, the lower boundary of the zone in the Arardi section cannot be precisely placed. In contrast, its upper boundary with the *neptuni* Zone is well marked by two superimposed horizons of reworking, yielding both Middle as well as Late Turonian ammonites. These include mainly juvenile *Tongoboryceras* sp. and *Tongoboryceras rhodanicum* (ROMAN & MAZERAN).

Upper Turonian: The base of the Upper Turonian is defined by the FAD of *Inoceramus costellatus* WOODS. The ammonite marker of this boundary, *Subprionocyclus neptuni* (GEINITZ), is absent in the off-shore areas of the Barranca.

The *neptuni* Zone is indicated here by single finds of the ammonite species *Neocrioceras* (*Schlueterella*) cf. *multinodosum* (SCHLÜTER) and *Baculites undulatus* D'ORBIGNY (Pl. 8, Fig 5), as well as *I. costellatus*. *Micraster* ex gr. *normanniae – cortestudinarium* appears 0.7 m above the Arardi Conglomerate.

The *Cremnoceramus waltersdorfensis* Zone is characterized by extremely rare and poorly preserved inoceramids, represented by *C. waltersdorfensis* (ANDERT) and *Inoceramus websteri* sensu WOODS, about 3.8-4.5 m above the reworking horizon.

Izurdiaga Section (uppermost Lower Turonian to lowermost Coniacian)

South of Irurzun, between the villages of Izurdiaga and Erroz, the Rio Araquil cuts through the Upper Cretaceous succession (*see* Text-fig. 1). This transverse section, situated east of the railway, and some other nearby sections served CABAYO & *al.* (1978) for a rough description of the Upper Albian through Maastrichtian succession in the area, in the context of the geological mapping of the Gulina sheet. The biostratigraphy was based on the microfauna. The locality Izurdiaga is known also from the palaeontological studies of WIEDMANN (1962), as well as from the stratigraphical studies of FEUILLÉE (1967), RADIG (1973) and KÜCHLER & ERNST (1989). The lithological characteristics of the section were described by DEGENHARDT (1983) in his Diplom Thesis. Unfortunately, he referred the Turonian strata to the Coniacian. His section at the northern boundary of the village is referred to here as

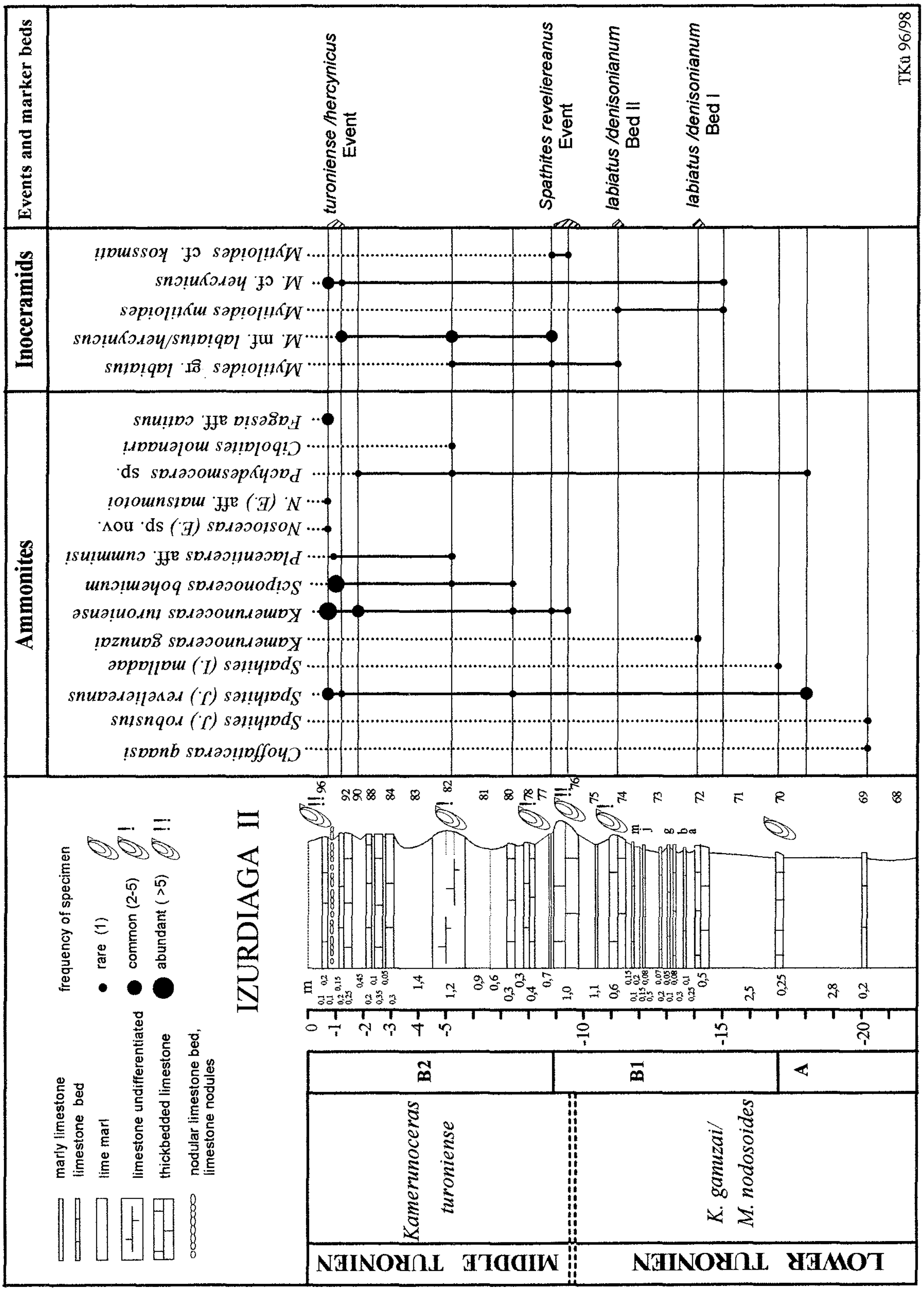


Fig. 4. Lower to Middle Turonian succession of the Izurdiaga II section; integrated litho-, bio- and event stratigraphy; and local ranges of ammonites and inoceramids

the Izurdiaga I section. The succession exposed in the Izurdiaga I section can be continued downwards in a section exposed later in a forest track, somewhat further west of and above the village, referred to here as the Izurdiaga II section.

The sections situated 2 km south of Irurzun (Text-fig. 1 and Pl. 1, Fig. 2) begin above a fault zone with the beds of the *Kamerunoceras ganuzai/Mammites nodosoides* Zone of the upper Lower Turonian and extend up into the Coniacian, with a largely undisturbed Turonian/Coniacian boundary transition (*see* KÜCHLER & ERNST 1989). The Turonian in the Izurdiaga composite section reaches 52 m in thickness (Text-figs 4-5).

Izurdiaga I

The section (Topographical map Gulina, sheet 115-9, 1:10 000; R=595.800, H=4.750.800) is located at the eastern boundary of the village of Izurdiaga (Text-fig. 1 and Pl. 1). The exposed succession starts within the *Kamerunoceras turoniense* Zone (several metres below the *turoniense/hercynicus* Event) of the Middle Turonian and extends up into the Lower Coniacian (Text-fig. 5).

Izurdiaga II

The section (Topographical map Gulina, sheet 115-9, 1:10 000; R=595.900, H=4.750.880) is situated on the northern side of Arardi, above the village of Izurdiaga, along a forest track, which runs more or less parallel to the strike of the Turonian beds. Strongly weathered Turonian strata are exposed for a distance of *ca.* 30 m, ranging from the *ganuzai/nodosoides* Zone of the upper Lower Turonian to the upper part of the *turoniense* Zone of the Middle Turonian. In comparison with the Arardi section, the lower part of the *ganuzai/nodosoides* Zone, including the *ganuzai* Event, is either not exposed, or large parts of the succession have been displaced downwards, most probably at an E-W trending fault. The section ends above the *turoniense/hercynicus* Event (*see* Text-fig. 4).

Lithostratigraphy

The succession of the Izurdiaga sections is lithologically and microfacially very similar to that of the Arardi section, situated 1 km away. Nine informal lithological units are distinguished here (*see* Text-figs 4-5) and characterized in ascending order.

Unit A: This unit comprising calcareous marls, *ca.* 5 m thick, represents an equivalent of Unit A in the Arardi section. Only the upper part of this unit, above the *ganuzai* Event, is exposed here.

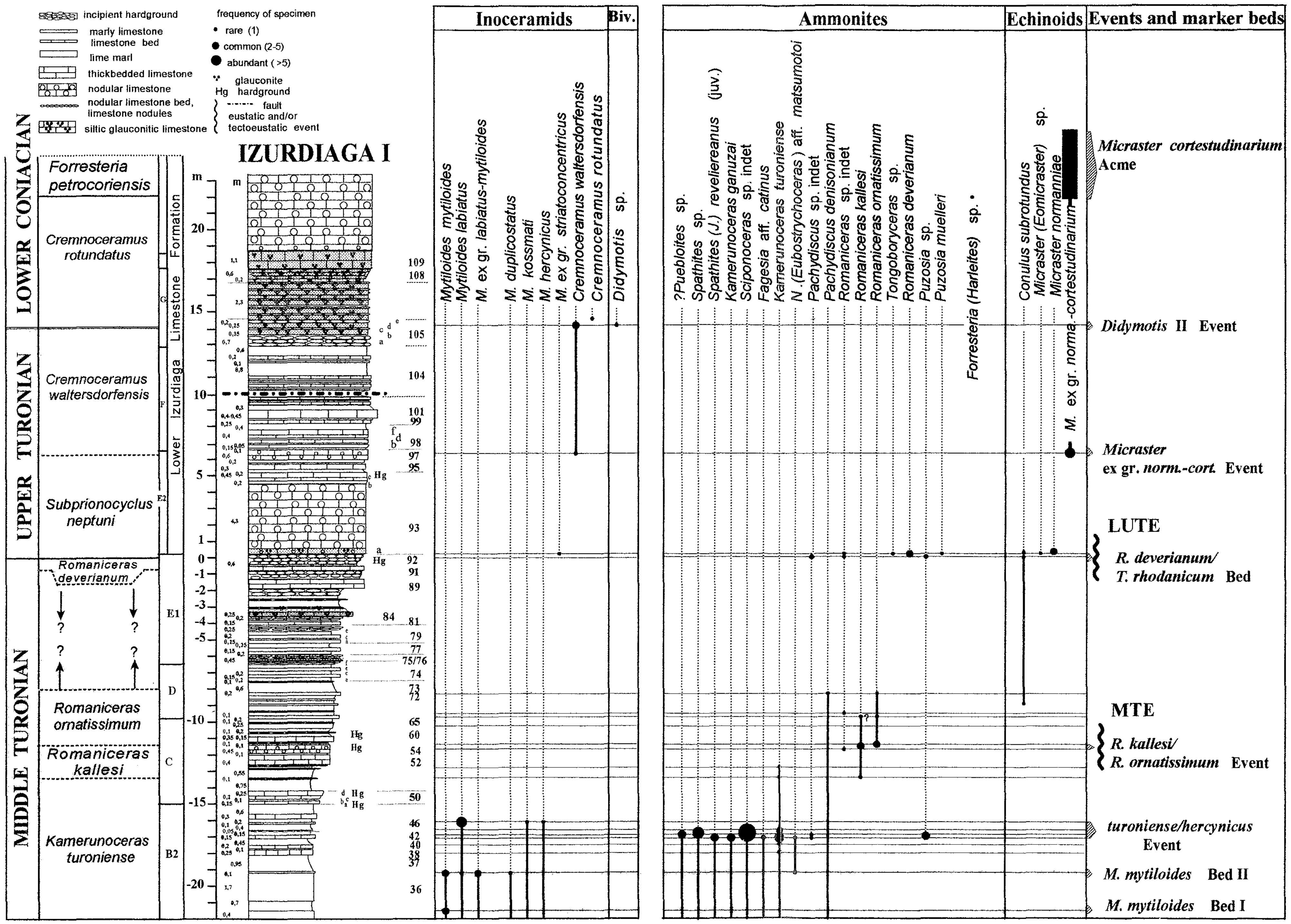
Unit B1: It is represented by *ca.* 8 m thick alternating limestones and calcareous marls, with the thickness of the limestone beds increasing upwards. The three conspicuous beds in the corresponding unit of the Arardi section (beds Ar-60, Ar-62 and Ar-64) are also distinguishable here. Five dm-thick limestone or nodular limestone beds occur between beds IzII-72 and IzII-74. The topmost bed, IzII-76, reaches *ca.* 0.9-1.0 m in thickness.

Unit B2: As in the Arardi section this 9 m thick unit is characterized by two, up to 0.4 m thick limestone beds (IzII-78 and IzII-90) in a 2 m interval above the *reveliereanus* Event. They are characterized by thin layers of inoceramids or of inoceramid debris. They are overlain by 4 m thick marls including a 1.2 m thick calcareous marl bed, containing an ammonite/inoceramid layer. Toward the top, the unit passes into a closely spaced alternation of limestones and marls with 0.1 to 0.2 m thick limestone beds.

Unit C: It comprises a 5 m thick hardground series, ranging stratigraphically from the upper *turoniense* Zone to the *ornatissimum* Zone (*see* Pl. 1, Fig. 2). Lithologically it is composed of alternating bioturbated calcareous marls and 0.1 to 0.2 (max. 0.45) m thick nodular limestones.

The 0.7 m thick basal part of the unit is composed of two distinctly bedded, grey limestones (beds IzI-50), penetrated by *Thalassinoides* burrow systems. The burrows are coated with glauconite. The top of the basal bed (50 a) is developed as a hardground horizon with glauconite concentrations and intraclasts in the burrow infillings. Below the discontinuity surface the bed passes into a nodular horizon. Above lies a bioturbated calcarenitic marl (0.1 m) containing isolated matrix-supported, glauconitized intraclasts. The *Thalassinoides* bed 50d has a green, convolute upper surface with loose, horizontal *Thalassinoides* burrows. Immediately above the top of the bed there is a layer of irregularly rounded and slightly green coloured pebbles (0.05-0.07 m long, 0.04-0.05 m wide, and 0.02-0.03 m high).

Unit D: A series of dark grey, weakly bioturbated 0.15 to 0.2 (max. 0.6) m thick marls, harder marl horizons



Middle Turonian to Lower Coniacian succession of the Izurdiaga I section; integrated litho-, bio- and event stratigraphy, and local ranges of stratigraphically important macrofossil groups

Izurdiaga I section

1 – General view of the Middle Turonian to Lower Coniacian strata of the section exposed at the eastern boundary of the village of Izurdiaga

2 – Middle Turonian (top of the *turoniense* to *ornatissimum* Zone) hardground succession; beds position in the succession – *see* Text-fig. 5

and thin-bedded (0.1 to 0.2 m) marlstones, reaching a total thickness of 3.4 m, starts with bed IzI-65. Between IzI-65 and Iz-67, in the *Romaniceras ornatissimum* Zone, there is a discordant contact, as in the Arardi section. In the later section the discordance is associated with a non-sequence.

Unit E1: This 5.5 m thick unit is composed of well-bedded, bioturbated limestones, in the lower part alternating with marls (0.1-0.25 m). Toward the top it passes gradually into nodular limestones and calcareous marls with *Thalassinoides* burrows. Many of the limestone beds pass into nodular horizons delimited by seams of marls. There are several intercalations of 0.2 to 0.6 m thick well-bedded, glauconitic limestones. The unit terminates in a 0.6 m thick, nodular calcareous marl horizon (bed IzI-92) with a conspicuous *Thalassinoides* hardground at its top.

Unit E2: The unit, 5 m thick, comprises a series of glauconitic, fine-grained arenitic limestones and calcareous marls ("calcisphere"/echinoid packstones) with the bedding obliterated by deeply penetrating *Thalassinoides* burrows and diagenetic processes. The beds coalesce to form m-thick horizons of nodular appearance. The basal 2 m of the succession is composed of incipient hardgrounds. As in the case of the underlying unit, the unit terminates in a hardground.

Unit F: This 7 m thick unit is composed of very thin-bedded calcareous marls, 0.25 to 0.4 m thick, and partly well-bedded, partly nodular limestones of varying thickness.

Unit G: The base of this unit marks an important lithological and microfacies change within the Turonian – Lower Coniacian succession, slightly below the Turonian/Coniacian boundary. The marls, calcareous marls and nodular limestones (with bed thickness from *ca.* 0.1 to 0.2 m) contain a marked amount of angular silt-sized quartz and glauconite.

Integrated bio- and event stratigraphy

Lower Turonian: In this section, the presence of the Lower Turonian is testified by single finds of *Spathites* (*Jeanrogericeras*) *robustus* (WIEDMANN) (Pl. 5, Fig. 7) and *Choffaticeras quaasi* PERON (Pl. 9, Fig. 8) in the basal part and of *S.* (*J.*) *reveliereanus* (COURTILLER) from bed IzII-69 of the Izurdiaga II section. The occurrence of *Spathites* (*Ingridella*) *malladae* (FALLOT) (Pl. 5, Fig. 8) and *Kamerunoceras ganuzai* (WIEDMANN), about 3 and 6 m, respectively above the appearance of *S. robustus* unequivocally proves the *ganuzai*/*nodosoides* Zone. The inoceramid fauna comprises *Mytiloides mytiloides*, *M.* cf. *hercynicus* and *M.* ex gr. *labiatus*.

Middle Turonian: Only rare inoceramids, *M.* cf. *kossmati*, are known from the level of the *reveliereanus* Event (bed IzII-76). The first Middle Turonian ammonites appear immediately above the *reveliereanus* Event. They include *Kamerunoceras turoniense* (D'ORBIGNY), and *S. reveliereanus* (COURTILLER), as well as *Sciponoceras bohemicum* (FRITSCH), a particularly typical element in the Izurdiaga and Satrustegui sections. The associated inoceramids are represented mainly by late forms of *M. labiatus* and *M.* m.f. *labiatus*/*hercynicus*. The ammonite species *Collignoniceras woollgari* was not found. In general, collignoniceratids are rare in the Barranca. The first record of *Cibolaites molenaari* COBBAN & HOOK (Pl. 6, Fig. 7), which co-occurs with *Placenticeras* aff. *cumminsi* CRAGIN, in bed IzII-82 is therefore particularly noteworthy in a northern Spanish context. In comparison to the Arardi section, bed IzII-82 lies about 4 m above the appearance level of *K. turoniense*.

Two *Mytiloides* levels, characterized by representatives of the *mytiloides* – *labiatus* group (according to SEIBERTZ, *pers. comm.*, the *mytiloides* characters predominate) occur in the Izurdiaga I section about 3.6 and 1.5 m below the *turoniense*/*hercynicus* Event. The higher *Mytiloides* horizon contains *M. labiatus*, *M.* ex gr. *labiatus* and *M. kossmati*, according to TRÖGER's determinations. *Nostoceras* (*Eubostrychoceras*) aff. *matsumotoi* COBBAN was also found in this horizon.

The topmost, 1.5 m, part of the succession in the Izurdiaga II section is characterized by several, fossiliferous horizons (*turoniense*/*hercynicus* Event), yielding a diverse ammonite fauna. Completely preserved steinkerns, mainly of *K. turoniense* occur parallel to the bedding in the lowest 0.8 m. *S.* cf. *bohemicum* (FRITSCH) tends to occur in concentrations on the upper surfaces of the limestone beds or within the overlying marl, where it is accompanied by *M. hercynicus* (PETRASCHECK).

The upper part of this fossil rich interval contains an association typical of the *turoniense*/*hercynicus* Event at Izurdiaga, comprising

K. turoniense (Pl. 7, Figs. 2-5), *S. bohemicum*, juvenile *S. reveliereanus*, as well as rare *N.* (*Eubostrychoceras*) sp., *Placenticeras* aff. *cumminsi* (Pl. 7, Fig. 1) and *Fagesia* aff. *catinus* (MANTELL). The Izurdiaga II section is characterized by a local enrichment of large-sized *K. turoniense* and associated large gastropods (*Pleurotomaria*) within a pebble horizon (bed IzII-94). The *turoniense/hercynicus* Event in the Izurdiaga I section is characterized by a mass-occurrence of *Sciponoceras* sp. and *M. labiatus* within the marly horizons. Less frequent are *M. hercynicus* and M. *duplicostatus* (ANDERSON). In contrast, the limestone intercalations contain predominant *K. turoniense*, *K. ganuzai*, *S.* (*J.*) *reveliereanus*, and *Spathites* (*J.*) sp., as well as *N.* (*Eubostrychoceras*) sp., *Fagesia* aff. *catinus*, and *Pachydesmoceras* sp. *K. turoniense* ranges up into the hardground series, the highest occurence being just below the limestone bed IzI-52.

The *Romaniceras kallesi* and *R. ornatissimum* zones are significantly reduced in thickness, reaching a combined thickness of *ca.* 3 m, extending from the upper part of the hardground succession to about 1.8 m above the hardground. The *kallesi* Zone is possibly only 0.45 m thick and is limited to a condensed or erosively reduced hardground horizon, which yielded a few poorly preserved specimens of *Romaniceras* sp. The overlying marl (bed IzI-55) already contains *R. ornatissimum*. The boundary of the zone falls into an hiatus and lies within the marl (*kallesi/ornatissimum* Event). In the Izurdiaga section *R. ornatissimum* (Pl. 8, Figs 1, 3) is locally common in the 1.8 m thick interval above the hardground series, particularly in the marl below bed IzI-65. Equivalent strata are apparently missing in the Arardi section.

In the overlying *Romaniceras deverianum* Zone, the index taxon (Pl. 8, Fig. 4) occurs more commonly only in the upper part of the zone, where it is associated with *Tongoboryceras* sp. and *Puzosia* sp., in the interval of, and particulary above, the *Thalassinoides* hardground IzI-92. The latter horizon is here referred to as the *deverianum/rhodanicum* Bed and seems to correspond to the level of reworked Middle and Upper Turonian ammonites and inoceramids occurring above the Arardi conglomerate in the Arardi section. This level indicates an hiatus between the *deverianum* and *neptuni* zones, caused by the LUTE (Lower Upper Turonian Event).

Upper Turonian: The *neptuni* Zone is *ca.* 4.5 m thick in the Barranca. The boundary of the zone is taken at bed IzI-92. The genus *Micraster* first appears at the base of bed IzI-93. Besides *Micraster* (*Eomicraster*) sp. advanced forms of *Micraster normanniae* BUCAILLE also occur. The appearance of the latter species characterizes the upper part of the *neptuni* Zone (FOURAY 1981) in France. In Germany, early representatives of the *bucailli* group, regarded by KÜCHLER & ERNST (1989) as geographical variants of the *precursor-normanniae* group, occur in the boundary interval between the *neptuni* and *normalis* zones of KAPLAN (1987), *i.e.* in the so-called *Micraster* Event. The presence of the Spanish *Cremnoceramus waltersdorfensis* Zone or its time--equivalent, the *Cremnoceramus waltersdorfensis/Prionocyclus germari* Zone which replaces the *Subprionocyclus normalis* Zone of KÜCHLER & ERNST (1989), is indicated by the record of *C. waltersdorfensis* as well as by the first mass-occurrence of *Micraster* ex gr. *normanniae-cortestudinarium* in bed IzI-97. This mass-occurrence of *Micraster* ex gr. *normanniae-cortestudinarium* is interpreted as corresponding to the German *Micraster* Event of ERNST & *al.* (1983) at the base of the *Mytiloides scupini* Zone.

Coniacian: At Izurdiaga, the base of the Coniacian is documented by a single find of the index species for the base of the Lower Coniacian, *Cremnoceramus rotundatus* (TRÖGER *non* FIEGE). It was found some cm above a level with poorly preserved *C. waltersdorfensis* (ANDERT). Of great importance is the additional record of *Didymotis* sp., since the co-occurrence of these three taxa can be used to recognize the Turonian – Coniacian boundary in inter-regional correlation (WOOD & *al.* 1984, CECH 1989, KÜCHLER & ERNST 1989, WIESE 1997). About 8 m above the first appearance of *C. rotundatus*, a single specimen of *Forresteria* (*Harleites*) sp. (*see* Pl. 12, Fig. 1) was found, indicating the Lower Coniacian in ammonite terms. This horizon coincides with the first acme of *Micraster cortestudinarium* (GOLDFUSS).

Satrustegui I Section (Upper Cenomanian to Middle Turonian)

The section (Topographical map Ecay, sheet 114-12, 1: 10 000, R=590.770, H=475.030) is

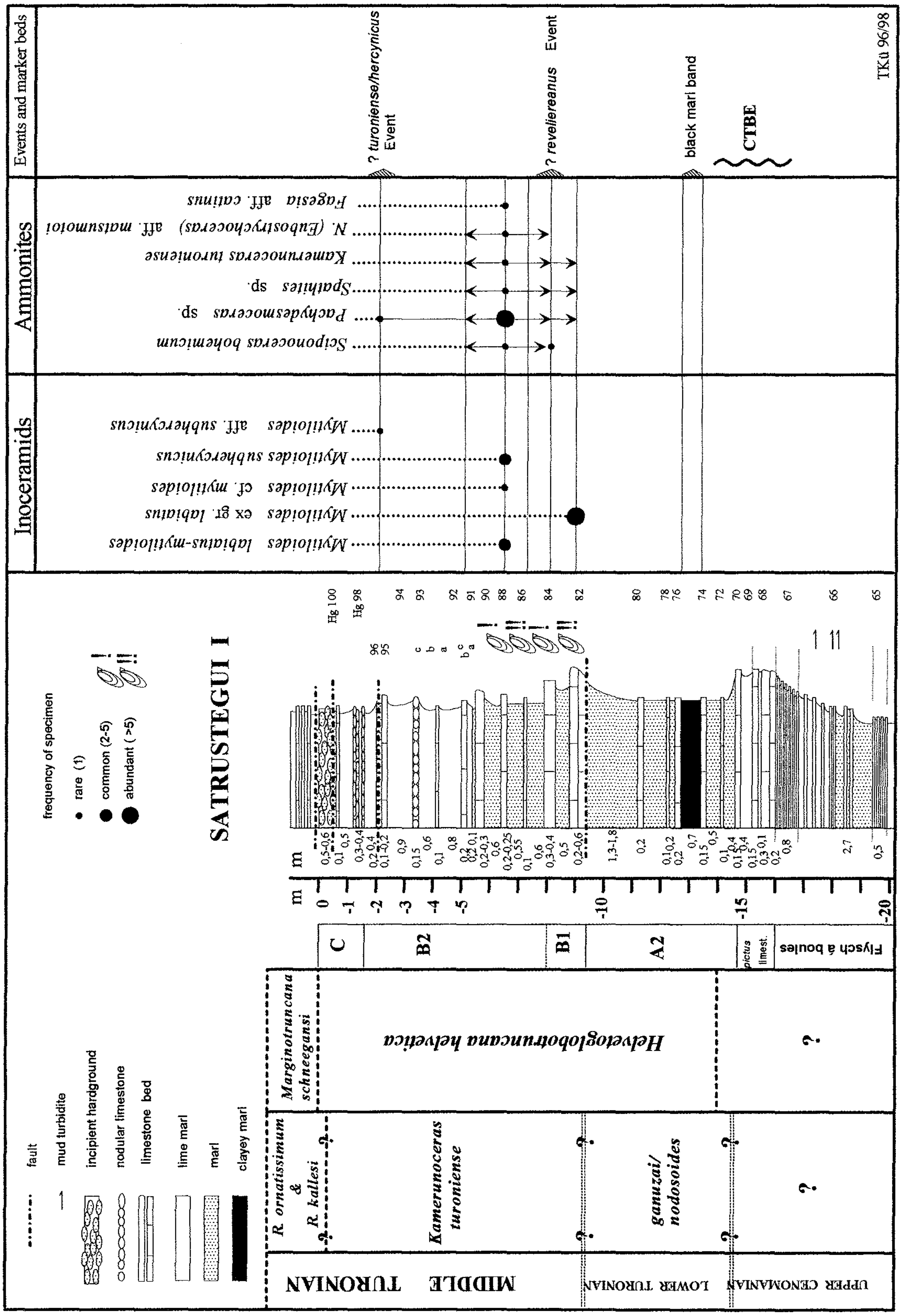


Fig. 6. Satrustegui I section; Upper Cenomanian to Middle Turonian succession; integrated litho-, bio- and event stratigraphy and vertical distribution of inoceramids and ammonites

represented by an outcrop along a track (*see* Text-fig. 6), about 550 m SSW of the village of Satrustegui (*see* Pl. 2).

The Upper Cenomanian to Coniacian succession south of Satrustegui was first described by KÜHN (1982). Only the lower part of his section, which was referred by him to the Turonian, was re-investigated here, and supplemented with two small outcrops, situated about 100 m apart. The Upper Cenomanian is developed as a *ca.* 18 m thick calciturbiditic series ("flysch à boules" *sensu* CIRY & MENDIZABAL 1949) in the Satrustegui I section. The Turonian is reduced in thickness to about 15 m (*see* Text-fig. 6) due mostly to E-W faults. A stratigraphically and tectonically reduced Lower Turonian succession is exposed in the Satrustegui I section. In contrast to the sections located in the eastern part of the Barranca (Arardi, Izurdiaga), it is more argillaceous, and resembles the characteristics of the "flysch à boules", with black shale-like intercalations. Based on foraminifera, it is dated as late Early Turonian, *Helvetoglobotruncana helvetica* Zone.

Above a major fault-zone Middle Turonian strata are exposed in all three of the Satrustegui sections, ranging stratigraphically from the *Kamerunoceras turoniense* Zone into the *Romaniceras ornatissimum* Zone (*see* Text-figs 6, 9). These beds are characterized by limestone and calcareous marl alternations with *Mytiloides* layers in the lower and nodular hardgrounds in the upper part of the succession. Lower Coniacian (*Peroniceras subtricarinatum* Zone) marls follow discordantly above the hardground series. The hiatus at this discordance comprises the Upper Turonian and the lower Lower Coniacian. This hiatus, recorded also in the vicinity of Alsasua about 24 km to the W, reflects the Intra-Lower Coniacian Event (ILCE).

Lithostratigraphy

In the Satrustegui I section five lithological units may be distinguished (*see* Text-fig. 6), described in ascending order below.

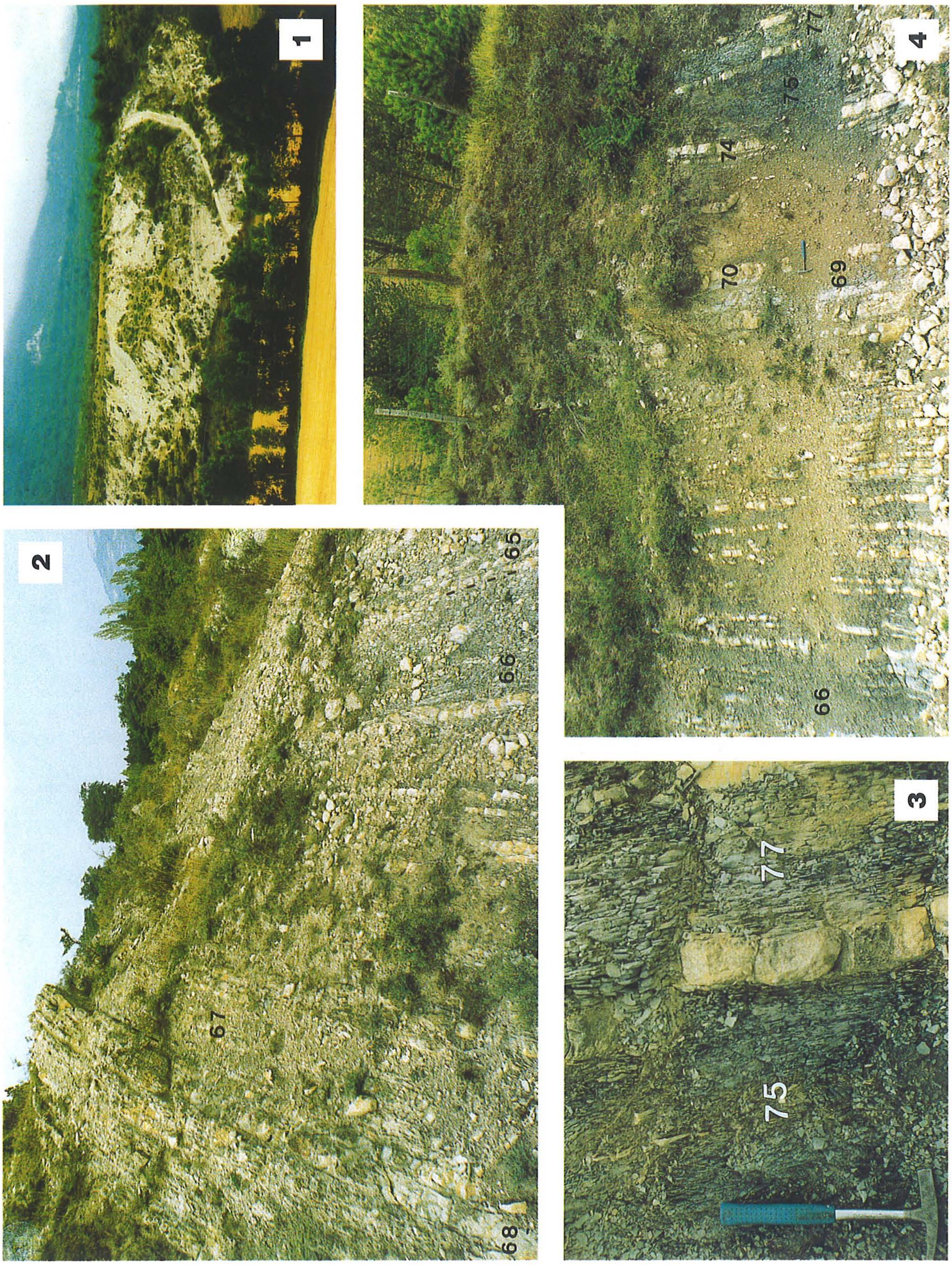
Flysch à boules Formation: The Flysch à boules Formation (=Ciordia Formation of AMIOT 1982) represents the basal part of the Satrustegui I section, and is here about 18 m thick. E-W running faults cause a repetition of the succession. Only its topmost 5 m thick part, represented by a closely spaced alternation of light grey, in part strongly bioturbated, calcareous marls and fine-grained calciturbidites, is studied here in detail.

The section starts with a conspicuous 0.7 m thick horizon of dark grey calcareous marls. In the overlying 2.0 m thick interval, the marls are represented by 0.2 m thick beds. The intercalated limestones, 0.05 to 0.1 m thick, are characterised by wavy bottoms and sharp, locally planar, upper boundaries. A few of the beds display a strongly expressed fine lamination and characters indicative of distal calciturbidites. The number of turbiditic events increases markedly in the topmost 1.2 m thick part of the formation; here the turbidites are 0.05 m thick, on average. Bed complex 67 and 68 form the first pronounced positive topographic feature (Text-fig. 6 and Pl. 2, Fig. 2).

pictus Limestones: The Flysch à boules Formation is overlain by a 1.4 m thick limestone unit, starting with an 0.9 m interval composed of 0.15-0.3 m thick limestones. The following 0.4 m thick, fine-bedded horizon of calcareous marls, topped by the 0.2 m thick top limestone, is very characteristic. There is no direct biostratigraphical dating of the unit. Based on lithostratigraphic simulations, however, it is inferred to represent a distal equivalent of the limestones containing *Inoceramus pictus bohemicus* at Arardi. It also appears to equate with the Iturmendi section of ZANDER (1988).

Unit A2 (Black Marls): At Satrustegui, as well as near Iturmendi in the western Barranca (*see* ZANDER 1988), the Cenomanian/Turonian boundary is marked by a lithological change. In the Iturmendi section the *pictus* Limestones of the *cushmani* Zone are overlain by light to dark grey, thin-bedded calcareous marls, characterised by slightly increased C_{org} content. Compared with the Arardi section, the A2 unit in the studied section is more clayey, and is distinctly reduced in thickness in the upper part by a fault zone, reaching 4.7 m. According to ammonite data, the middle Lower Turonian in particular, *i.e.* the lower part of the *ganuzai*/*nodosoides* Zone, is lacking in the section.

The 0.1 to 0.2 m thick limestone beds alternate with the dm- to m-thick calcareous marls, the thickness of which generally increases upwards. KÜHN (1982) already mentioned black shale-like horizons at this locality. A 0.7 m thick horizon of dark grey marl ($CaCo_3$ content 43%) enriched in C_{org} (0.91%) and black when wet, is particularly striking in this part of the section. This horizon (bed SatrI-75) displays the following characteristics: The base is composed of a 0.03 m thick



Satrustegui I section

1 – General view of the exposure; **2** – Upper Cenomanian calciturbiditic succession ("flysch à boules" Formation) in the west of the section overlain by the *pictus*-Limestones (bed complex 67 and 68); **3** – The Cenomanian – Turonian boundary interval exposed in the track at the east side; the boundary is placed above bed 70; beds position – *see* Text-fig. 6; **4** – Close-up view of the Lower Turonian black marl band (bed 75)

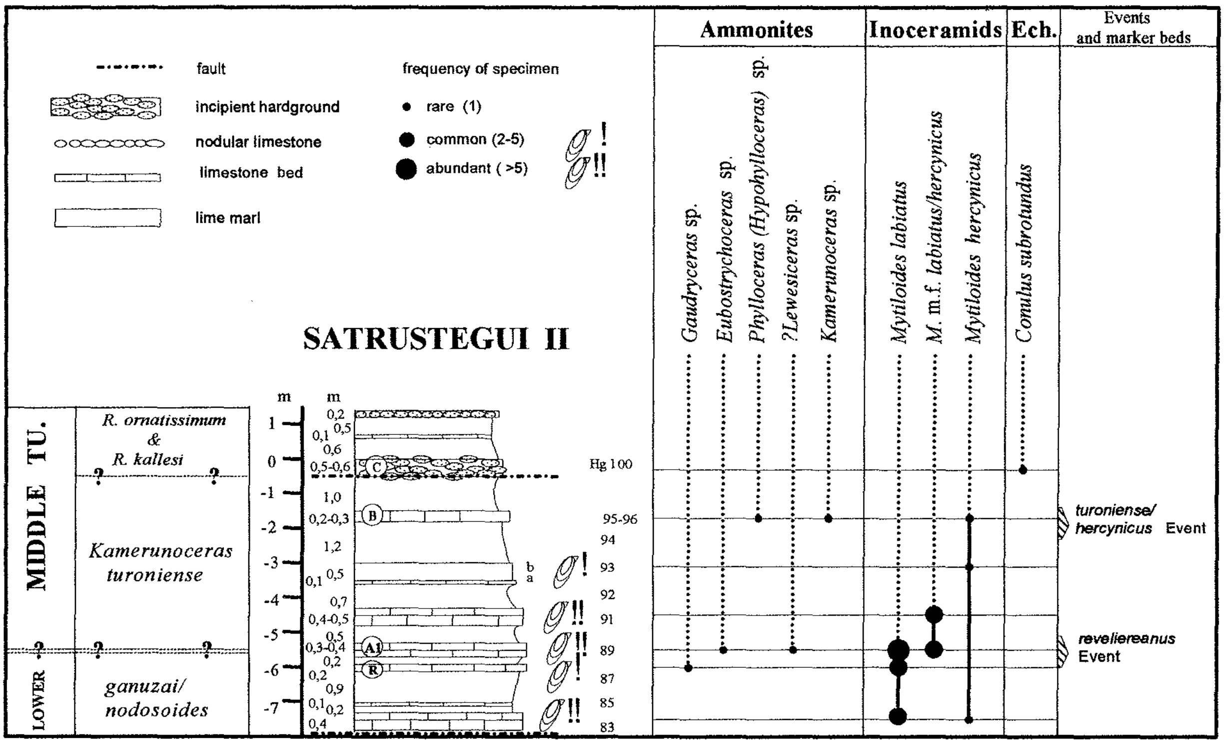


Fig. 7. Lithologic-stratigraphical succession of the Satrustegui II section; events and local ranges of ammonites and inoceramids

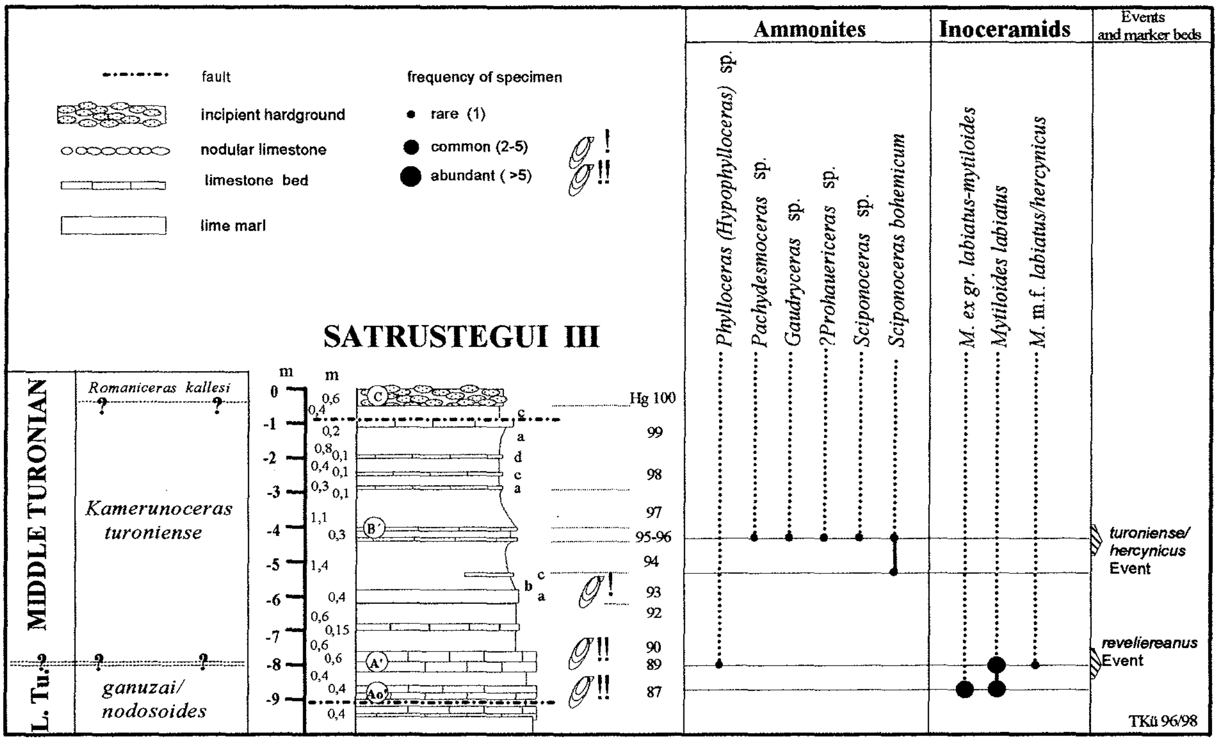


Fig. 8. Lithologic-stratigraphical succession of the Satrustegui III section; events and local ranges of ammonites and inoceramids

marl bed, followed by a 0.07 m thick, light grey to white bed of calcareous marl with crumbly texture. The true, 0.6 m thick, black marl, non-bioturbated, fissile and with pale -coloured mica on bed surfaces, displays mm-thick lamination emphasised by layers rich in ferric sulphides. Cm-size pyrite concretions within a 0.5 m thick interval occur. SatrI-75 is delimited upwards by massive, strongly bioturbated marly limestones.

Unit B1 – B2: The black marls are succeeded by an alternation of inoceramid-rich, in parts strongly bioturbated, limestones and dark grey to blue grey marls as well as thin-bedded calcareous marls. The lower 2 m of the succession are particularly characterized by the occurrence of *Mytiloides*.

Unit C: The upper part of the section is represented by intercalations of strongly bioturbated, yellowish to reddish when weathered, nodular marly limestones and beds of nodular limestones. These beds show the characteristics of the onset of hardground development, and can be assigned according to the KENNEDY & GARRISON (1975) classification to the nodular chalk and incipient hardground stage.

Satrustegui II and III sections

They comprise two small outcrops in two upstanding topographic ribs about 100 m SW of the Satrustegui I section. The exposed 9 to 10 m thick succession spans the uppermost Lower and the Middle Turonian (*see* Text-figs 7-8). The Middle Turonian, as throughout the Barranca, is characterized by stratigraphical condensation and the Satrustegui sections are, moreover, tectonically reduced. Parts of the Lower Turonian and the whole Upper Turonian are lacking. Some metres above the incipient hardgrounds marls of the Coniacian already occur. In the Satrustegui III section an horizon about 24 m above the incipient hardgrounds contains middle Lower Coniacian strata with a *Peroniceras – Scaphites* fauna.

Lithology and fauna

The succession of these sections corresponds to the succession of the Satrustegui I section as seen above the major fault.

Unit B: The unit is represented by an alternation of hard, grey limestones, or marly limestones, in beds 0.2 to 0.6 m thick, and light-grey, thin-bedded calcareous marls. The beds in the lower, 2 to 3 m thick part of the unit are bioturbated and yield *M. labiatus* (SCHLOTHEIM). The boundary interval between the Lower and Middle Turonian is placed at the appearance of a *M. labiatus* population, that is characterized by a more extensive inventory of characters than the populations in the eastern sections. In the 1.0 m thick interval above (SatrI-89 to SatrI-91) *hercynicus*-like forms occur. Both the inoceramids and the co-occurring ammonites, represented by rare *Phylloceras* (*Hypophylloceras*) sp., *Gaudryceras* sp., *N.* (*Eubostrychoceras*) sp., and ?*Lewesiceras* sp., are limited mainly to the uppermost 0.1 to 0.2 m of these beds. The ammonite assemblage occurring in the following horizon B, beds 95 and 96, is markedly different from that found in the eastern part of the Barranca. Here, beside *Sciponoceras bohemicum* (FRITSCH) and *Sciponoceras* sp., *Pachydesmoceras* sp., *Phylloceras* (*Hypophylloceras*) sp., *Gaudryceras* sp., and ?*Prohauericeras* sp. also occur. Inoceramids are rare, being represented only by two specimens of *M. hercynicus* and *M. subhercynicus*. Horizon B serves as a correlation horizon in the Satrustegui area and probably represents an equivalent of the *turoniense*/*hercynicus* Event of the Izurdiaga section. The ammonite assemblage in this event at Satrustegui is taxonomically markedly impoverished, with the exception of *Sciponoceras*, in comparison with those of the eastern sections, a feature which is generally found throughout the Middle Turonian.

Unit C: The topmost part of the section is developed as bioturbated, nodular weathered limestones. These limestones represent different stages of hardground development between a nodular chalks and an incipient hardground in the KENNEDY & GARRISON (1975) classification. True hardgrounds, with mineralised upper surfaces, borings and bio-encrustation, were not observed. The 0.6 m thick incipient hardground represented by bed Satr-98 in the Satrustegui II section shows slight glauconitic pigmentation of the nodular parts. Fossils are rare in this incipient hardground.

Integrated biostratigraphy

The Flysch à boules Formation of the eastern Barranca ranges stratigraphically from Middle to Upper Cenomanian. At Satrustegui, macrofossils are scarce and single finds of *Eucalycoceras*? sp. and *Hemiaster* sp. do not allow a more precise dating of the succession than Cenomanian in general. Moreover, neither macrofossils nor microfossils allow the position

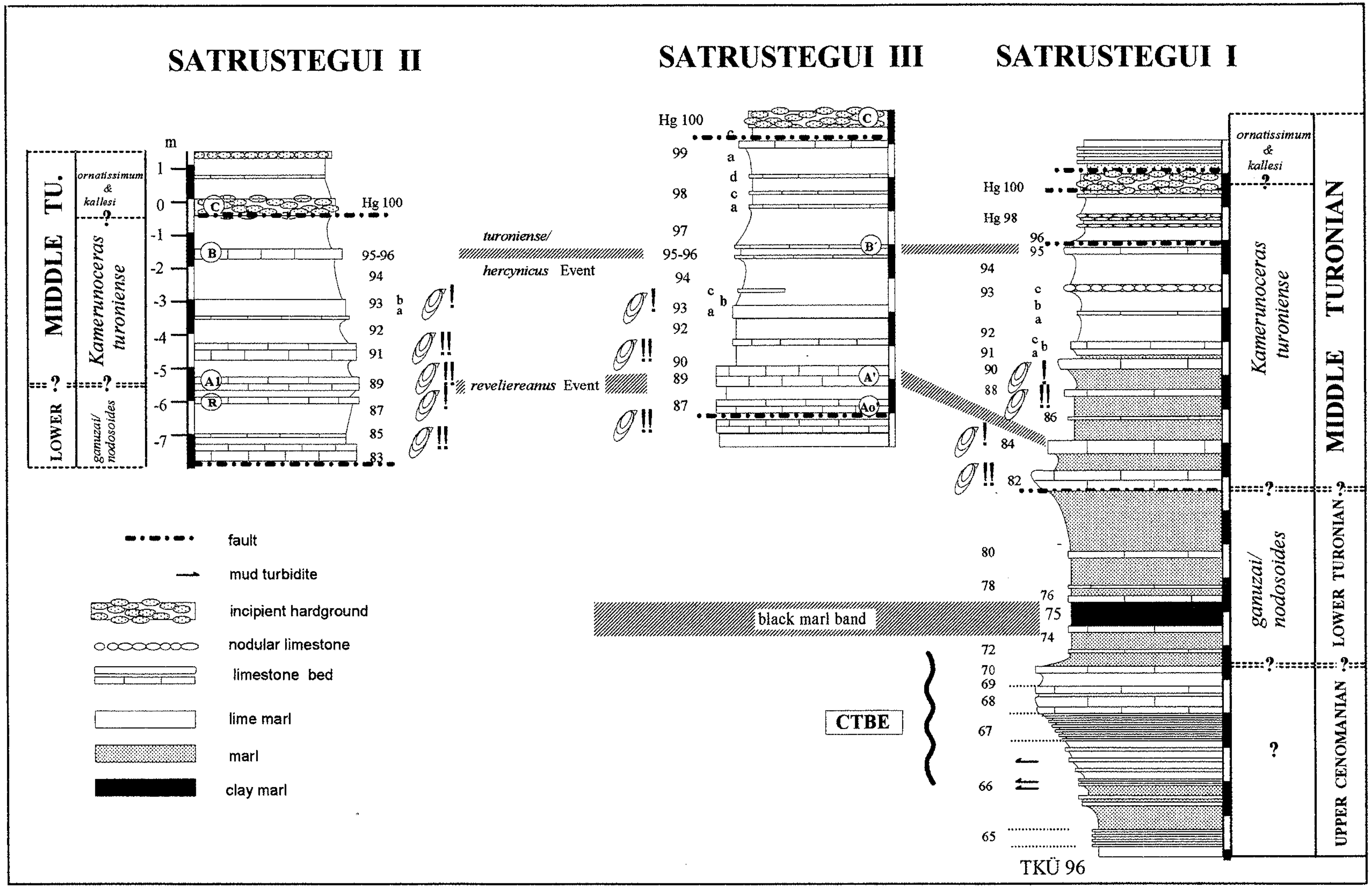


Fig. 9 Inter-correlation of the Satrustegui sections

of the Cenomanian/Turonian boundary to be indenfied.

Unit A2 belongs, however, to the Lower Turonian. Based on foraminifera, bed 73 already has to be placed in the *Helvetoglobotruncana helvetica* Zone. Consequently, the black marl horizon (bed 75) belongs to the *ganuzai/nodosoides* Zone of the ammonite zonal scheme. This dating corresponds well to that of the black marl in the Iturmendi section (Text-fig. 10), which likewise lies in the *helvetica* Zone.

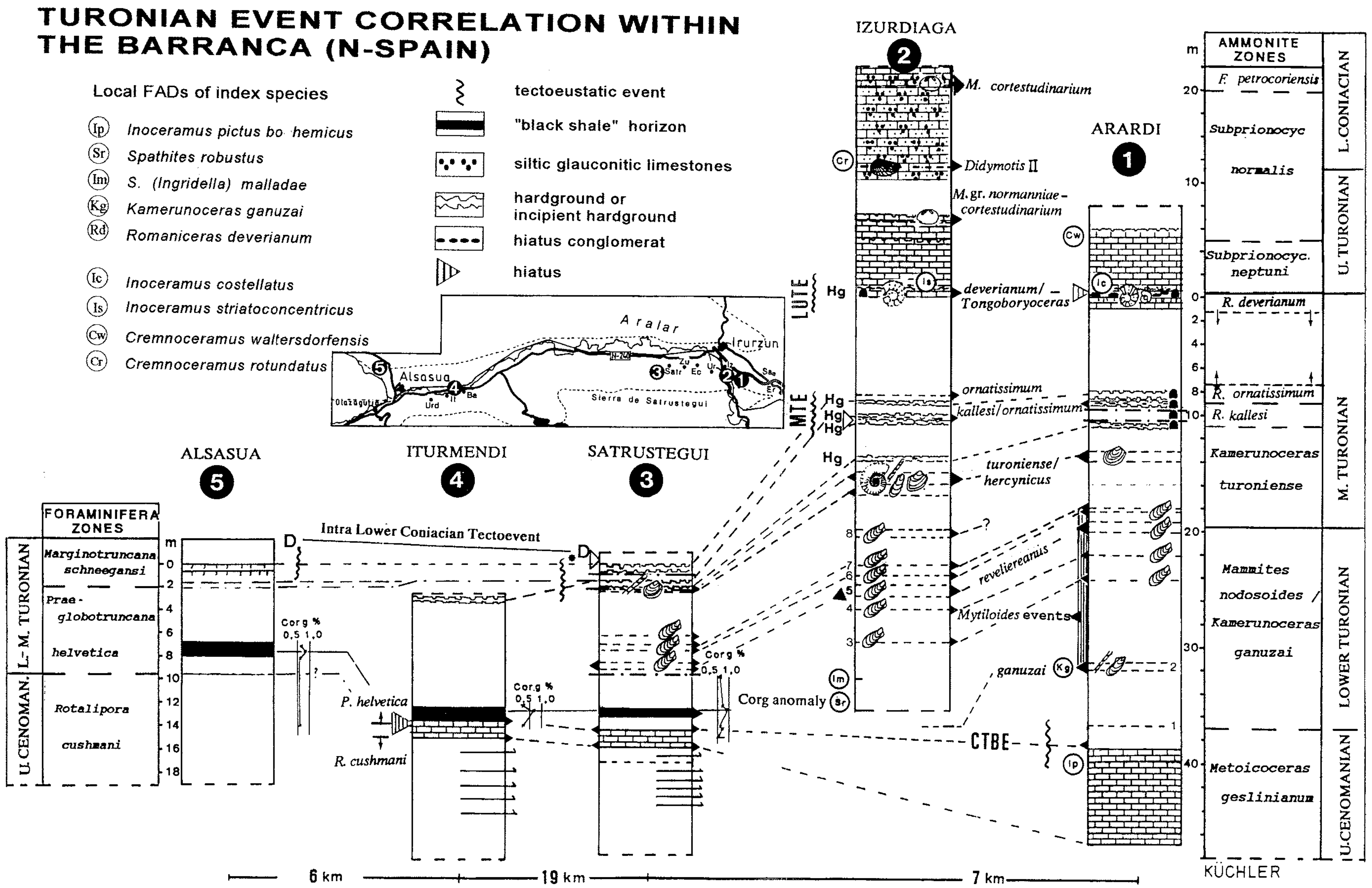
In the Satrustegui I section, the 9 to 10 m thick interval of the succession occurring above the main fault belongs to the Middle Turonian on the basis of the inoceramid – ammonite assemblage. The fauna is composed mainly of inoceramids, concentrated within the basal 2 to 3.5 m of the interval. Ammonites are relatively rare. There is a quantitative predominance of planktonic forms, compared to the assemblages in the Arardi/Izurdiaga sections. Stratigraphically important forms were collected mostly by KÜHN (1982) from his A1 and A2 horizons and probably from only one interval corresponding to that between beds 85 and 91c. Accurate placing of KÜHN's material is, however, not possible. According to the re-examination of this material, it mostly comprises *Kamerunoceras* sp., *Kamerunoceras* cf. *turoniense* and *Spathites* (*Jeanrogericeras*) sp. together with rare *Pachydesmoceras* sp., *Lewesiceras* sp., *Sciponoceras* sp., *S. bohemicum*, *N.* (*Eubostrychoceras*) aff. *matsumotoi*, *Ph.* (*Hypophylloceras*) sp. and *Fagesia* sp. Compared with the eastern sections, this assemblage together with the co-occurring inoceramids, indicates the upper *turoniense* Zone. In the planktonic foraminiferal zonation it still corresponds to the *helvetica* Zone (LAMOLDA, *pers. comm.*).

Bed SatrI-82 is characterized by the common occurrence of *M.* ex gr. *labiatus*. The inoceramid population (from KÜHN's collection) is represented by forms with a mixture of the morphological characters of both *labiatus* and *subhercynicus*, as well as morphotypes with characteristics of *mytiloides*, *subhercynicus*, *labiatus* and *pictus* (SEIBERTZ, *pers. comm.*). *M. labiatus* occurs commonly, while typical representatives of *M. subhercynicus* (SEITZ) are rare. In addition to a single specimen of the ammonite *Fagesia* aff. *catinus* (MANTELL), a large population of inoceramids was collected from bed SatrI-88. According to SEIBERTZ (*pers. comm.*), the inoceramids are represented mostly by juveniles of *Inoceramus cuvieri* SOWERBY and much rarer *M.* cf. *mytiloides* (MANTELL) and *M. subhercynicus*. WALASZCZYK (*pers. comm.*, 1995) referred these forms to *M.* ex gr. *labiatus* – *mytiloides* and to *M. subhercynicus*. A microfaunal sample from the marl directly above the incipient hardground Hg-100 was dated, according to ZANDER (*pers. comm.*), as *Marginotruncana schneegansi* foraminiferal Zone. The incipient hardgrounds of the Satrustegui sections equates with the hardgrounds in the middle part of the Arardi and Izurdiaga sections. The latter were assigned to the upper *K. turoniense* and *R. ornatissimum* zones of the Middle Turonian.

At Satrustegui, upper Lower Coniacian marls follow discordantly and a short distance above the hardground series. The contact is marked by a stratigraphical gap comprising the Upper Turonian and basal Lower Coniacian. The discordance and hiatus are traceable westwards through the Alsasua section in Navarra (ZANDER 1988) to the Ucuma/Eguino section in Alava (WOLZ 1985).

Events: their lateral changes and correlation within the Barranca

In a classic sense events are short-lived geological processes, *e.g.* gravity mass flows, turbidites, tempestites, which happen during a period of only a few hours or days, and which occur repeatedly with an interval between 100 and many thousand years (*compare* EINSELE 1993). These event beds seem to be controlled by the authogenic processes within the sedimentary basin. On the other hand, some of them can be confined to the allogenic, cyclic processes, such as climate or sea-level changes. The thick and widely distributed mud flows and mega-breccias are mainly caused by sea-level fall down to below the shelf edge (EINSELE 1993). Turbiditic sequences commonly occur, in sequence stratigraphic terms, within the lowstand deposits, but also can occur in other system tracts and likewise in a continuously prograding delta succession. The position of tempestites in the shallow-water sequences of 3rd order or higher is, according to EINSELE (1993), less clear. The origin of sandy



Event correlation within the Barranca; east-west transect from eastern, swell located (Arardi and Izurdiaga) to basinal (Iturmendi and Alsasua) sections in the west; the latter sections investigated microstratigraphically by ZANDER (1988) tempestites seem to be caused by the simultaneous building of the coast and wave erosion, *e.g.* during the late highstand and early lowstand.

The event stratigraphy developed by ERNST & *al.* (1983) in the Cenomanian and Turonian of NW Germany additionally refers to the so-called stratigraphical events, classified into eustato-, eco-, tephro-, litho-, phylo-, and oxic/anoxic events, and interpreted as genetically distinct. In contrast to pure sedimentological events, the origin of stratigraphical events involved markedly longer periods, up to several tens of thousand years. Stratigraphical events can be treated, however, as comparatively short-lived and isochronous horizons, that of markedly shorter duration than the standard ammonite zones which, in the Turonian for example had a duration of between 400 000 and 500 000 years (*see* ROBASZYNSKI & *al.* 1990, HANCOCK 1991). The genesis of an event is usually multi-causal and a sharp distinction of the particular event-types is usually impossible. The origin of events is highly complex, involving the interaction of a multiplicity of factors, as emphasised by KAUFFMAN (1986). In his high resolution event stratigraphy developed for the Western Interior Cretaceous he distinguished physical, chemical, thermal and biological events. Among the most common events he listed are tuffs, mass flow deposits, oxygen overturns, desalination events (caused by giant storms in the shallow basins), boundaries of the MILANKOVITCH cycles, mass mortalities, and mass extinction events. The application of event stratigraphy here permits stratigraphical resolution far below the interval of a biozone with an average duration of 50 000 years.

The event stratigraphical scheme presented here for northern Spain (*see also* ERNST & KÜCHLER 1992) was developed independently of the north German scheme (*see* ERNST & *al.* 1983, WOOD & *al.* 1984, KAPLAN 1986) and of the event succession later established for the Santander area (WILMSEN & *al.* 1996, WIESE 1997).

The event types, described below, are used in the sense of ERNST & *al.* (1983), and are defined here as relatively thin intervals in a dm to m scale commonly characterized often by a succession or a bundling of subordinate, short-lived phenomena. In the Turonian of northern Spain, these subordinate, minor events are represented mostly by ammonite or inoceramid accumulations. These are referred to here as bio-events with, at the moment, no genetic interpretation.

KAUFFMAN (1986) listed among the possible causes of the bio-events, rapid extinctions, immigrations, changes in population size and colonisations. However, distinction between the biologically caused events and the events caused by physical or chemical phenomena is rather difficult as both types can grade one another.

In addition, the first and last appearances of biostratigraphic index taxa, at species or subspecies level are described as bioevents. In event stratigraphical terms such an interpretation is not followed here. The record of a species or subspecies in a particular area depends on many different factors controlling dispersal, as well as on fossilisation and sedimentary processes, so that the observed distribution and stratigraphical range may reflect only a part of the hypothetical total range. However, most local range records are incomplete and the first and last appearances in different sections are hardly ever isochronous.

In their original paper ERNST & *al.* (1983) indicated the inter-relation between the bio- (eco-) events and relative changes of sea-level. Under the term eustatic-event they united both, negative (regressive) and positive (transgressive) sea-level fluctuations, giving a set of criteria for their recognition. The distinction between transgressive and regressive eustato-events will be followed here, as far as possible. Those sea-level changes that are interpreted as the result of plate tectonic movements, are referred to here as tecto-eustatic events. Many tectonic processes (culmination of active phases) take place within a million years, some even, within a few tens of thousands of years. The accompanying changes in the bathymetric and sedimentary conditions take place very rapidly. Most of the tecto-eustatic events thus correspond well to the sequence boundaries (in the sense of HAQ & *al.* 1987). Some of these tecto-events, correlatable throughout Europe were already referred to by ERNST & KÜCHLER (1992). The position of bio-events within a 3rd order sea-level cycle was recently shown clearly by WIESE (1997) and WILMSEN (1997). Events crossing structural highs, so-called overlapping events, coincide with maximum flooding surfaces and represent the primary isochronous correlation horizons within areas that are strongly differentiated into swells and basins. The state of the art of the microfacies and sequence stratigraphical studies in the Barranca do not allow for any comprehensive interpretation at the moment. Consequently, the present paper is limited to a description of the event beds, their phenotypic characteristics, faunal composition and lateral changes in respect of the basin configuration. The event succession is shown within an already high resolution biostratigraphical scheme, allowing direct dating (*see* Text-fig. 10). The Turonian succession was first worked out in the condensed sections of the outer shelf of the Barranca and then recognized and tested within the sections of the Estella area.

Oceanic Anoxic Event

The oceanic anoxic event (OAE) is clearly manifested in the Satrustegui section in bed 75 which is referred here to as the black marl band. In general, it is a more extended, 1.1 to 2.2 m thick interval of calcareous marls, marls or clayey marls with a slightly increased TOC (=total organic carbon) content. In the Barranca (Text-fig. 10), the black marl band is traceable from the Satrustegui section, where in bed 75 it reaches maximum 0.91% TOC, 19 km towards the west to the cemetery section of ZANDER (1988), 500 m north of Iturmendi (TOC = 0.65%). The horizon is expressed in the Alsasua section (road cutting on the N-240 2.2 km north of Alsasua), 25 km distant, by an horizon in argillaceous marl with a slightly increased C_{org} content (TOC = 0.83%) (*see* Text-fig. 11). To the east, the equivalent level in the Arardi section still shows *ca.* 0.45% TOC.

In comparison with C_{org} content of the Bonarelli Event, Italy, deposited in *ca.* 1 km depth on the continental margin, with TOC values between 11.8 and 23.0%, or with the English Black Band with 1.0 to 1.5% values, or with the 1.2 to 2.8% TOC values in the black shales of Wunstorf, Germany (*compare* SCHLANGER & *al.* 1987), the black marl band of the Barranca does not display a significant C_{org} content. However, the black marl band of the Barranca does not correspond stratigraphically to those in Italy or England. The latter two are placed in the Upper Cenomanian – Lower Turonian *Whiteinella archaeocretacea* Interval Zone, while the horizon in the Barranca, according to ZANDER (1988, p. 35), belongs to the *Helvetoglobotruncana* [*Praeglobotruncana*] *helvetica* Zone of the upper Lower Turonian. GRÄFE (1994) quoted a

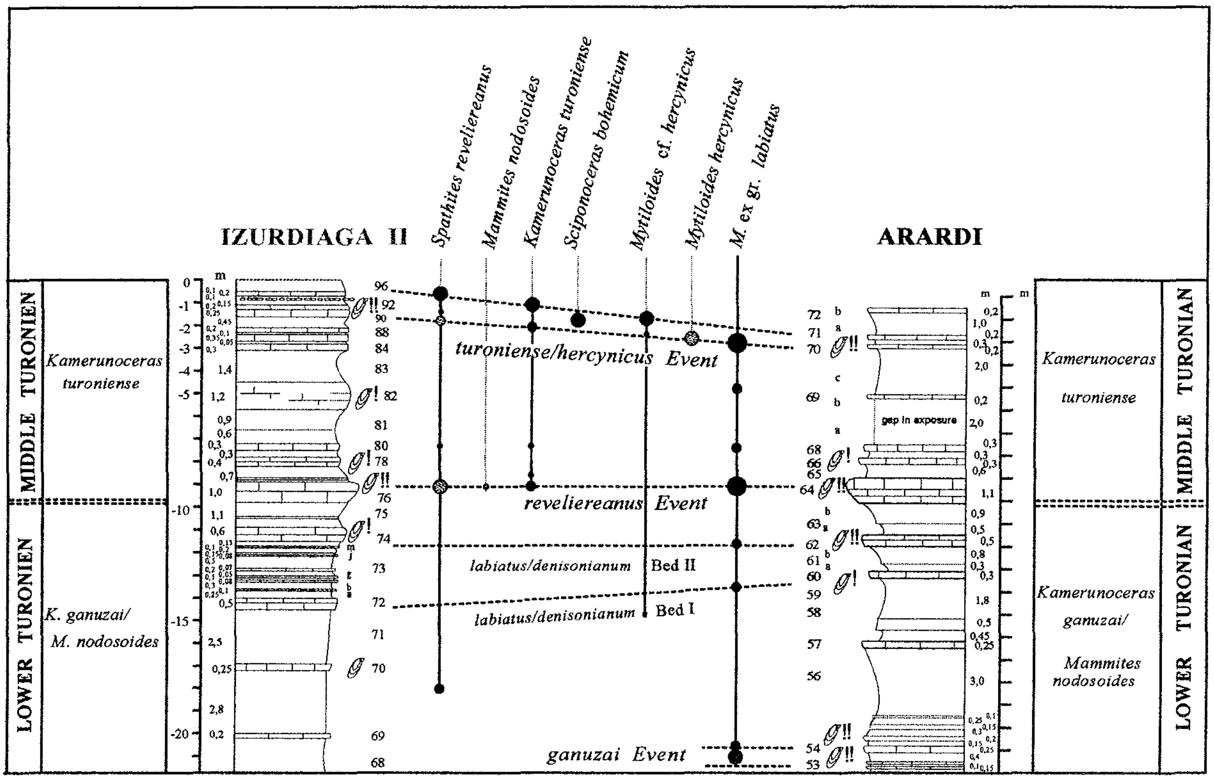


Fig. 11. Correlation of the *reveliereanus* and *turoniense/hercynicus* events between the Arardi and Izurdiaga II sections; stratigraphical ranges of selected ammonite and inoceramid forms

similar stratigraphical position for genetically equivalent deposits in the Province of Alava (GRÄFE 1994).

Kamerunoceras ganuzai Event

Actually, this event represents a bundle of closely in time spaced subordinate events, i.e. several ammonite and inoceramid layers, occurring in a restricted stratigraphical interval (*see* Text-fig. 3). It lies in the middle part of the *ganuzai/nodosoides* Zone of the upper Lower Turonian and takes its name from the ammonite species *Kamerunoceras ganuzai* (WIEDMANN), which first become common at this horizon and locally dominates the fauna. In addition to an abundance-acme of ammonites the event is characterized by a second, locally developed *Mytiloides*-acme. The first *Mytiloides*-acme, represented by the *Mytiloides* I Event, is missing in the Barranca probably as the result of faulting.

In northern Spain the *ganuzai* Event has been recognized up to now in Navarra, namely in the Arardi section and near Ganuza in the Estella area. The base of the ganuzai Event is the first correlation horizon between both areas. In the eastern Barranca the *ganuzai* Event is absent near Izurdiaga and Satrustegui as a result of tectonics. The event, in the form of a fossil accumulation is also not traceable to the western Barranca. In the Arardi section, the event, developed as 1.1 m thick limestone/marl alternation, is characterized by an ammonite assemblage dominated by *S.* cf. *bohemicum*. In contrast to the Estella area, the index taxon, *K. ganuzai* is much less common. Its occurrence is limited to the basal limestone bed, where it co-occurs with *S.* cf. *bohemicum*, *M. mytiloides* and representatives of the *M. labiatus* group. In the upper part of the event, occur several horizons with *S.* cf. *bohemicum* and *M. labiatus*, while an abundance-maximum of diverse *Mytiloides* species found at the top of the succession. In addition to the predominant *M. labiatus* and *M.* aff. *hercynicus* the assemblage also contains rare *M.* aff. *duplicostatus* and *M.* aff. *mytiloides*.

Spathites reveliereanus Event

The event is marked by an acme of representatives of the ammonite genus *Spathites*, primarily *S.* (*Jeanrogericeras*) *reveliereanus* (COURTILLER). It lies in the transition between the *ganuzai/nodosoides* (=*Mammites nodosoides*) and the *Kamerunoceras turoniense* zones and is associated with yet another *Mytiloides*-acme. In the Izurdiaga and Arardi sections, the event is marked by a frequency maximum of *Mytiloides labiatus* within a 1 m thick limestone bed at the top of a thickening upward sequence (*see* Text-fig. 11). This level is most probably condensed in the eastern Barranca, yielding only a comparatively sparse ammonite fauna (mainly juvenile *S. reveliereanus*), compared with the rich faunas of the Ganuza section in the Estella Basin. The horizon represents a local overlap of late forms of *M. nodosoides* (*M.* cf. *nodosoides*) and the first *K. turoniense*.

At Satrustegui, in a more basinward position, the event is marked similarly by a *M. labiatus*-acme (Text-figs 7-8), but ammonites are extremely scarce and mostly represented by gaudryceratids and phylloceratids. Near Satrustegui, the m thick marly limestone horizon developed in the more the eastern sections passes into a double limestone bed, each with a *Mytiloides* layer.

Kamerunoceras turoniense/Mytiloides hercynicus Event

This event comprises an event-bundle, which in one extreme is characterized by a mass-occurrence of ammonites (particular kamerunoceratids, sciponoceratids, and spathitids) and in the other by the highest frequency maximum of *Mytiloides hercynicus*. It lies in the middle part of the *K. turoniense* Zone. It comprises essentially two limestone beds with an intervening marly interval, in a total thickness of 0.7 to 0.8 m. It mainly yields inoceramids, and thus defined, is traceable from the marginal swell sections of Arardi and Izurdiaga over 7 km towards the west to the more distal, basinword Satrustegui section (Text-figs 9-10). In the fomer sections the *turoniense/hercynicus* Event contains a relatively diverse ammonite fauna (*see* Text-figs 5, 11). The associated inoceramid fauna for the first time contains unequivocal *M. hercynicus,* as well as late *M. labiatus*, with the latter dominating in the Barranca, while in the Estella area the inoceramids are represented exclusively by *M. hercynicus* and *M.* cf. *hercynicus* (Text-fig. 18). The typical development of the event is exemplified by the Izurdiaga I and II sections (Text-figs 4, 5) where a succession of characteristic fossil accumulations is observed:

Just below the event lies a 0.6 m thick interval, composed of two limestone beds separated by a thin marl seam, which contains a fauna mainly composed of ammonites and dominated by *Kamerunoceras turoniense*. The mostly completely preserved steinkerns of *K. turoniense* represent the ribbed, *salmuriense* type (Pl. 7, Fig. 2). The event beds (IzII-93 to IzII-96 and IzI-42 to IzI-46) are characterized either by the predominance of *Sciponoceras* or by the occurrence of inoceramids. These occur in accumulations at the top of the limestone beds or within the marly beds. The lower 0.4 to maximally 0.75 m of the event interval contain a diverse ammonite assemblage, comprising *Kamerunoceras turoniense, K. ganuzai, Spathites reveliereanus*, *Spathites* sp., *Pachydesmoceras denisonianum*, *Pachydesmoceras* sp., *Fagesia* aff. *catinus*, *Sciponoceras* cf. *bohemicum*, and *N.* (*Eubostrychoceras*) sp. The ammonites occur mostly within the marly beds and are accompanied by *M. labiatus* and subordinate *M. hercynicus*. Within the marls there is an intercalated allochthonous nodular limestone bed (packstones with "calcisphere" wackestone intraclasts) with fragmentary, large-sized *K. turoniense* and also pachydesmoceratids. The former are strongly tuberculate and represent inflated forms of the *turoniense* type (Pl. 7, Fig. 3). Large-sized *Pleurotomaria* are also a striking feature. This rich allochthonous fauna represents a taphonomical trap giving an insight into the ammonite fauna of the unexposed proximal facies. The event-bundle terminates in a limestone bed with *M. hercynicus* and *Sciponoceras* sp. In the Arardi section, to the east, (Text-fig. 3) the equivalent interval, 0.7 m thick, is represented by two limestone beds (Ar-70 and Ar-71), with *Mytiloides* ex gr. *labiatus* and subordinate *M. hercynicus*. The impoverished ammonite fauna consists of a few juvenile spathitids. In more distal positions, *i.e.* in the Satrustegui sections (Text-figs 6-8), one can observe a clear lateral change in the ammonite fauna, compared with that of the marginal swell sections, towards more pelagic forms and a predominance of pachydesmoceratids. The sparse ammonite fauna is represented by *Sciponoceras* sp., *S. bohemicum*, *Pachydesmoceras* sp., *Phylloceras* (*Hypophylloceras*) sp., *Gaudryceras* sp., and ?*Prohauericeras* sp. Rare inoceramids (*M. hercynicus* and *M. subhercynicus*) also occur.

MTE (Middle Turonian Event)

This is an eustatic, transgressive event at the boundary of the *Romaniceras kallesi* and *Romaniceras ornatissimum* ammonite zones, or at the boundary of the *Helvetoglobotruncana helvetica* and *Marginotruncana schneegansi* foraminiferal zones. The event lies within a series of pelagic hardgrounds that occur throughout the Barranca, from Izurdiaga to Alsasua (*see* Text-fig. 10) (ZANDER 1988) and represent reduced sedimentation of the *R. kallesi* and *R. ornatissimum* zones. In the eastern Barranca the MTE is clearly expressed by a thin, 0.05 to 0.10 m thick horizon with intraclasts, which lies in the *R. ornatissimum* Zone, within a series of erosionally truncated *Thalassinoides* hardgrounds (Text-fig. 5). The intraclast horizon, locally called the *kallesi/ornatissimum* Event, yields reworked ammonites of both zones, indicating a small hiatus.

Romaniceras ornatissimum Acme

In the Izurdiaga section, *Romaniceras ornatissimum* occurs commonly in an about 3 m thick interval in the lower part of the *R. ornatissimum* Zone (middle Middle Turonian). In the Arardi section the equivalent interval is lacking due to a tectonic gap, and in the Satrustegui section it is absent because of a stratigraphical gap. The *R. ornatissimum*-acme probably represents an eco-event of the highstand systems tract.

LUTE (Lower Upper Turonian Event)

This is a tectonic event of inter-regional importance that probably comprises several short-term events, which in northern Spain falls in the lower Upper Turonian (*Subprionocyclus neptuni* Zone). In swell sections, the LUTE is recorded by one or more hiati in the interval between the upper *deverianum* and upper *neptuni* zones (Text-fig. 3). It is expressed by conspicuous shallow marine hardgrounds with a locally intercalated transgressive conglomerate (Arardi section) and re-worked ammonites or, in more distal position (Izurdiaga section), an ammonite horizon (*deverianum/rhodanicum* Bed) (Text-fig. 5) with Middle and Upper Turonian ammonites, primarily desmoceratids. The pre-LUTE beds in the Izurdiaga section and, particularly, at Arardi document a polyphase hardground development.

The succession starts with a *Thalassinoides* firmground, succeeded by a glauconitized hardground, and terminated by phosphatization and partial colonisation by oyster-like bivalves and serpulids. The succession represents a shallowing-upward cycle or a phase of active tectonic uplifting.

The conglomerate from the Arardi section forms a thin horizon of bored and phosphatized flat pebbles with glauconitic crusts and encrusting organisms (oysters and serpulids). It is followed by a 0.1 m thick horizon penetrated by phosphatized and glauconitized *Thalassinoides* burrows and terminating in a hummocky hardground. This horizon yields numerous phosphatized and reworked ammonite steinkerns, mainly juvenile *Tongoboryceras*, corroded echinoid tests (*Conulus subrotundus*), as well as rare inoceramids and other bivalves. In a more basinward position (*e.g.* Izurdiaga section) an ammonite horizon occurs within the hardground sequence containing predominantly *R. deverianum* and *Romaniceras* sp., together with *Puzosia* sp., *Puzosia muelleri* and *Tongoboryoceras* sp.

Micraster ex gr. normanniae-cortestudinarium Event

The first abundance-maximum of *Micraster* ex gr. *normanniae – cortestudinarium* lies at the base of the herein introduced *C. waltersdorfensis* Zone. Because of stratigraphical gaps, this event is recognizable in the Barranca only at Izurdiaga (bed IzI-97) (Text-fig. 5).

Ammonite/Inoceramid zonation in the Barranca

The biostratigraphy of the Lower and Middle Turonian of the Barranca is based primarily on ammonites, and partly on inoceramids.

The correlation with the scheme established by WIEDMANN (1960, 1965, 1979a, b) for northern Spain is indirectly possible only in the upper Middle Turonian (from the *Kamerunoceras turoniense* Zone up to the *Romaniceras deverianum* Zone). The ammonite species used by that author in the zonation of the Upper Cenomanian and Lower Turonian, are Tethyan or endemic forms,

SUBSTAGES	France	Spain	Europe	SUBSTAGES
LOWER CONIACIAN	*Forresteria petrocoriensis*	*Forresteria petrocoriensis*	*Forresteria petrocoriensis*	LOWER CONIACIAN
UPPER TURONIAN	*Subprionocyclus neptuni*	*waltersdorfensis/ germari*	*Subprionocyclus neptuni*	UPPER TURONIAN
		Subprionocyclus neptuni		
	Romaniceras deverianum	*Romaniceras deverianum*	*Collignoniceras woollgari*	MIDDLE TURONIAN
MIDDLE TURONIAN	*Romaniceras ornatissimum*	*Romaniceras ornatissimum*		
	Romaniceras kallesi	*Romaniceras kallesi*		
	Kamerunoceras turoniense	*Kamerunoceras turoniense*		
LOWER TURONIAN	*Mammites nodosoides*	*Kamerunoceras gamuzai/ Mammites nodosoides*	*Mammites nodosoides*	LOWER TURONIAN
	hiatus	hiatus	*Watinoceras coloradoense*	
UPPER CENOMANIAN	*Neocardioceras juddii*	unnamed	*Neocardioceras juddii*	UPPER CENOMANIAN
	Metoicoceras geslinianum	*Metoicoceras geslinianum*	(unnamed *Thomasites* fauna)	
			Metoicoceras geslinianum	

Fig. 12. Comparison of European Upper Cenomanian-Lower Coniacian ammonite schemes and positions of formally used substage boundaries; after AMEDRO & *al.* (1982) and ROBASZYNSKI & *al.* (1982) for France, KÜCHLER (this work) for northern Spain, and KENNEDY (1984 b,1985); the Spanish ammonite zonation, established by WIEDMANN (1960, 1965, 1979a), is discussed further on (*see also* Text-fig. 17)

that are mostly absent in Navarra, while some of his zonal indices appear markedly earlier than formerly assumed. Consequently, his zonation cannot be applied to the Barranca.

The *ganuzai/nodosoides* Zone, introduced here for the upper Lower Turonian does not correspond to the *Schindewolfites ganuzai* Zone established by WIEDMANN (1960, 1965, 1979a) in the Estella area and subsequently used for the Lower Turonian of northern Spain. WIEDMANN treated the local range of *S. ganuzai* as an equivalent of his regional zone TU-IV, *i.e.* the Zone of *Ingridella malladae* and *Schindewolfites* spp., which was, on the other hand, perceived as the upper part of the *Mammites nodosoides* Zone (*compare* WIEDMANN & KAUFFMAN 1978, WIEDMANN 1979b, KENNEDY 1985). The restudy of WIEDMANN's type locality demonstrates that his *ganuzai* Zone corresponds to the upper part of the *ganuzai/nodosoides* Zone. In the Estella region the species is known only from the Lower Turonian, apart from a questionable find reported by LAMOLDA & *al.* (1989), together with *Romaniceras kallesi*. It ranges, however, into the lower Middle Turonian in the Barranca, where it co-occurs with *K. turoniense*. In the *ganuzai/nodosoides* Zone, *K. ganuzai* is in general rather rare, while it is relatively common in the following zone.

The collignoniceratids, especially *Collignoniceras woollgari* (MANTELL), the index ammonite species for the base of the Middle Turonian in north-west European sections (*see* Text-fig. 12) are extremely rare in this interval in the Barranca and in northern Spain in general. As in France, this species first appears very much later. In consequence, the application of the standard ammonite zonation for the Middle Turonian of NW Europe (*sensu* WRIGHT KENNEDY & *al.* 1982 and KENNEDY 1984b, 1985; *compare also* HANCOCK 1991), *i.e.* the recognition of a *C. woollgari* Zone in the sections of northern Spain is not possible. On the other hand, marked faunal similarities in the Lower Turonian and particularly in the Middle Turonian between northern Spain and the French Turonian type regions (Touraine and Saumurois) enable the application of the refined zonation of AMÉDRO & *al.* (1982) based on the *Kamerunoceras – Romaniceras* lineage. The French ammonite zonation, comprising the *K. turoniense*, *R. kallesi*, *R. ornatissimum*, and *R. deverianum* zones (*see* Text-fig. 12), is readily applicable in the Barranca and in the Estella area (*compare* KÜCHLER & ERNST 1989), as well as in the Santander region (WIESE 1995, 1997). This is particularly the case with the *K. turoniense* Zone, because of the widespread and common occurrence of the index taxon. In the basal part of the zone *K. turoniense* co-occurs with late *M. nodosoides*, while at the top of the zone transitional forms to *R. kallesi* are found.

The biostratigraphical zonation of the Upper Turonian in the Barranca, because of the rarity of ammonites, has had to be based on the similarly rare inoceramids. Through faunal comparison with the Estella area, with its rich ammonite fauna, the zonation of the Barranca can be correlated indirectly with the NW German zonal schemes, both that based on ammonites (*see* KAPLAN 1986, 1988) and that based on inoceramids (KÜCHLER & ERNST 1989, Text-figs 7-8).

The Cenomanian/Turonian boundary interval

The topmost Cenomanian and basal Turonian, in the sense of the currently applied ammonite biostratigraphy, are missing in the Barranca. The Upper Cenomanian *Metoicoceras geslinianum* Zone cannot so far be proved by means of ammonites. This zone is, however, suggested by a single find of *Inoceramus pictus bohemicus* LEONHARD from the top part of the Cenomanian limestones – calcareous marl alternations in the Arardi section, since this species, according to TRÖGER (1989) and WIEDMANN & *al.* (1989) has its main occurrence interval in the *M. geslinianum* and *Neocardioceras juddii* zones.

There is also no evidence so far of the presence of the *N. juddii* and *Watinoceras coloradoense* zones, or their Iberian equivalents, *i.e.* the *Vascoceras gamai*, *Fallotites subconciliatus* and *Paramammites*? *saenzi* zones, *sensu* WIEDMANN. The interval is characterized by the hiatus widely recorded in Europe at the Cenomanian/Turonian transition, which was already recognized in the western Barranca by RAMIREZ DEL POZO (1971) by means of planktonic foraminifera. ZANDER (1988) was able to determine the extent of hiatus precisely in the Iturmendi section. The gap here, probably of the same extent as near Alsasua, comprises the upper part of the *Rotalipora cushmani* Zone, characterized normally by solely occurring *R. cushmani*, as well as the entire *Whiteinella archaeocretacea* Zone. According to ZANDER (1988), the *cushmani* Zone is followed directly by the upper Lower Turonian

Helvetoglobotruncana helvetica Zone. A gap, with a more or less similar stratigraphical range is also postulated, based on the available fossil data, for the eastern Barranca. The first evidence for the Turonian there is provided by transitional forms between *Inoceramus* and *Mytiloides* in the Arardi section, with unequivocal Early Turonian ammonites occurring in a few metres higher.

Kamerunoceras ganuzai/Mammites nodosoides Zone

The base of the zone is defined by the first appearance of the small-sized, spinose acanthoceratid *Kamerunoceras ganuzai* (WIEDMANN). This species occurs relatively commonly in the Lower and in the lower Middle Turonian of northern Spain. At Ganuza, its type locality, according to LAMOLDA & *al.* (1989), *K. ganuzai* appears simultaneously with *Mammites nodosoides* (SCHLÜTER). Because of the extreme rarity of the latter species in northern Spain, particularly in Navarra, at least in the lower part of its range, the *ganuzai/nodosoides* Zone is proposed as an equivalent of the international *M. nodosoides* Zone. In the Barranca (Arardi section) *K. ganuzai* appears for the first time in the so-called *ganuzai* Event which, in comparison with the FAD of this species at Ganuza, in the *kossmati* Event (*compare* Text-figs 14, 16), lies in the middle part of the zone. In the Arardi section (Text-fig. 3), *K. ganuzai* (Pl. 5, Figs 9-10) occurs in the *ganuzai* Event together with *Sciponoceras* cf. *bohemicum* (FRITSCH) (Pl. 5, Figs 5-6). An extremely rare ammonite fauna was found in the basal, 4 m thick part, of the Izurdiaga II section (which is not the base of the zone), comprising *Spathites* (*J.*) *robustus* (WIEDMANN) (*see* Pl. 5, Fig. 7a-b), *Choffaticeras quaasi* (PERON) (*see* Pl. 9, Fig. 8a-b), *Pachydesmoceras* sp., and *Spathites* (*J.*) *reveliereanus* (COURTILLER). Slightly higher appears *Spathites* (*Ingridella*) *malladae* (FALLOT) (*see* Pl. 5, Fig. 8a-b), and still higher *K. ganuzai*. The topmost part of the zone is characterized by a sole occurrence of *Pachydesmoceras denisonianum* (STOLICZKA)(*see* Pl. 6, Fig. 1a-b) and *Spathites* (*J.*) *reveliereanus* (COURTILLER).

Kamerunoceras turoniense Zone

The base of this zone is defined here by the first occurrence of *K. turoniense* (D'ORBIGNY) (*see* Pl. 6, Fig. 2; Pl. 7, Figs 2-5). This definition differs from that given by ROBASZYNSKI & *al.* (1990) for Tunisia, defined by the last appearance of *Mammites nodosoides*. The base of the zone is additionally marked by common *Spathites reveliereanus* (*see* Pl. 6, Figs 4, 6) and late forms of *Mammites* cf. *nodosoides* (*see* Pl. 6, Fig. 5). The lower part of the zone is dominated by *S. reveliereanus*, *Sciponoceras bohemicum* and *Pachydesmoceras denisonianum*. In the upper part, in the proximal areas (Arardi and Izurdiaga sections), the zone is characterized by a rich and taxonomically diverse ammonite fauna dominated by kamerunoceratids (*K. turoniense* and *K. ganuzai*) and spathitids (*S. reveliereanus*). In distal areas the ammonite assemblage is dominated by *P.* cf. *denisonianum*. Co-occurring forms are *S. bohemicum*, *S.* cf. *bohemicum*, rare *Nostoceras* (*Eubostrychoceras*) aff. *matsumotoi* (COBBAN) (*see* Pl. 7, Figs 6, 8-9), and *N.* (*Eubostrychoceras*) sp., *Placenticeras* aff. *cumminsi* CRAGIN (*see* Pl. 7, Fig. 1), *Cibolaites molenaari* COBBAN & HOOK (*see* Pl. 6, Fig. 7), *Fagesia* aff. *catinus* (MANTELL), *Puzosia* cf. *planata* (BAYLE), and *Neoptychites cephalotus* (COURTILLER). In distal deposits *Gaudryceras* sp., *Phylloceras* sp., *Phylloceras* (?*Hypophylloceras*) sp., ?*Lewesiceras* sp., and *Tetragonites* sp. appear.

Romaniceras kallesi Zone

Both this zone and the succeeding *R. ornatissimum* Zone are extremely condensed in the eastern Barranca. In the Arardi section the presence of the *kallesi* Zone is presumably indicated by *Romaniceras* aff. *kallesi* (ZÁZVORKA) (*see* Pl. 8, Fig. 2) and fragmentarily preserved *Romaniceras* cf. *kallesi* in a single horizon. Near Izurdiaga the zone is 2.1 m thick, but the index species is extremely rare below the *kallesi/ornatissimum* Event. Its range there overlaps with that of *K. turoniense*.

Romaniceras ornatissimum Zone

The index species *Romaniceras* (*Yubariceras*) *ornatissimum* (STOLICZKA) (*see* Pl. 8, Figs 1 and 3) is only locally common. At Izurdiaga, it is found together with *R. kallesi* in an 3.5 to 4 m thick interval, but it has not so far been found in the Arardi section. In the latter section, the presence of the zone is indicated by the first appearance of *Tongoboryceras* sp., accompanied there by ?*Kamerunoceras* sp. and *Puzosia* sp.

Romaniceras deverianum Zone

The index species was reported from the Izurdiaga section by KÜCHLER & ERNST (1989), thereby proving the presence of the zone in the Barranca. Accompanying forms are represented by *Tongoboryceras* sp., *Pachydesmoceras denisonianum*, *Puzosia* sp., and *Puzosia curvatisulcata* CHATWIN & WITHERS. However, the position of the base of the zone in the Izurdiaga section, defined by the FAD of the index taxon is questionable, since there is a 7.4 m thick interval without unequivocal *R. deverianum* and without any other stratigraphically important ammonites. *R. deverianum* (*see* Pl. 8, Fig. 4) appears for the first time in the *deverianum/rhodanicum* Event at the top of the zone. In the Arardi section the so-called *deverianum/rhodanicum* pebble bed contains already a mixed ammonite association composed of Middle and Upper Turonian forms, but without *R. deverianum*. The *R. deverianum* Zone is indicated only by the presence of *Tongoboryceras rhodanicum* (ROMAN & MAZERAN), occurring here associated with *Puzosia* sp. and juvenile *Tongoboryceras* sp.

Subprionocyclus neptuni Zone

The presence of the zone is documented in the Barranca by single finds of *Baculites undulatus* D'ORBIGNY (*see* Pl. 8, Fig. 5) and *Neocrioceras* (*Schlueterella*) cf. *multinodosum* (SCHLÜTER), together with *Inoceramus costellatus* WOODS and *Mytiloides striatoconcentricus* (GÜMBEL) in a single horizon in the Arardi section. Such an association is typical for the *neptuni* Zone. The index taxon of the zone, *S. neptuni* (GEINITZ) and also *Subprionocyclus* ex gr. *neptuni – hitchinensis*, are lacking in the Barranca, most probably because of the more distal location of this area.

Cremnoceramus waltersdorfensis Zone

The base of the zone is defined by the FAD of *C. waltersdorfensis* (ANDERT) in the *Micraster* ex gr. *normanniae-cortestudinarium* Event at Izurdiaga. The zone is documented only by scarce and poorly preserved inoceramids. Besides the nominate species *Inoceramus websteri* sensu WOODS also occurs. Despite the rarity of ammonites the zone is assumed to correspond approximately to the *Prionocyclus germari* Zone of authors.

STANDARD SECTIONS IN THE ESTELLA AREA

Near the villages of Ganuza and Ollogoyen, about 10 km west of Estella, are found several sections, which have been intensively studied for decades, and regarded as standard sections for the Turonian in northern Spain. Multidisciplinary investigations supplying important data were undertaken by WIEDMANN (1960, 1965, 1979a), WIEDMANN & KAUFFMAN (1978), LAMOLDA & *al.* (1981), SCHWENTKE & WIEDMANN (1985), LAMOLDA & PROTO-DECIMA (1986), LAMOLDA & *al.* (1989), KÜCHLER & ERNST (1989), LOPEZ (1990, 1992a, b, d), SANTAMARIA (1991, 1992, 1995) and LAMOLDA & PERYT (1995).

The Ganuza section provides a continuous succession across the Cenomanian-Turonian boundary developed in silty limestone facies. Compared to the English Eastbourne and Dover sections or the American Pueblo section, the Ganuza section represents the most expanded and complete boundary succession according to LAMOLDA & PERYT (1995). Near Ganuza, the exposures extend up into the Middle Turonian (*Romaniceras kallesi* Zone). Near Ollogoyen, an exceptionally thick succession of Middle Turonian to upper Upper Turonian (*R. deverianum* Zone up to the *Cremnoceramus waltersdorfensis/Prionocyclus germari* Zone) is exposed, albeit not reaching the Turonian/Coniacian boundary (*see* KÜCHLER & ERNST 1989).

To the south the Estella area is limited by the Villasana de Mena-Estella Diapir Zone and to the east by the Estella-Dax Diapir Zone. During the Late Cretaceous the area was situated in the south-easternmost part of the Navarro-Cantabrian zone of intra-shelf basins, within a halfgraben or oblique-slip-fault basin, with the greatest subsidence at its southern margin (WIEDMANN 1979a, REITNER & WIEDMANN 1982). During the Cenomanian and Turonian the Estella Basin was characterized by a high subsidence and sedimentation rate with the resulting accumulation of a 1200 m thick succession. During the Middle and Late Turonian the whole area lay in the mid-shelf, with predominantly open-marine, partly neritic conditions. Accumulation and subsidence rates were in equilibrium at least in the Late Turonian. The distribution of the benthonic foraminifera and the composition of the assemblages, *i.e.* lack of shallow marine or extreme deep-water indices, indicates, according to LAMOLDA & PROTO-DECIMA (1986, Text-fig. 3), a not particularly deep environment.

Ganuza Section (upper Cenomanian to Middle Turonian, *kallesi* Zone)

The Ganuza section (*see* Text-figs 13-14) is composed of the three investigated exposures, *i.e.* Ganuza IV (GZ), Ganuza I (GA) and Ganuza II (GI), located west of the national road Ollobaren – Ganuza, south and south-west of the village of Ganuza. The thickness of the exposed Turonian in the composite Ganuza/Ollogoyen standard section is about 230 m, of which 130 m are exposed close to Ganuza.

Ganuza IV (GZ)

Location: Topographical map Metauten, sheet 140-13, 1:10 000, R=570.940, H=4.727.450.

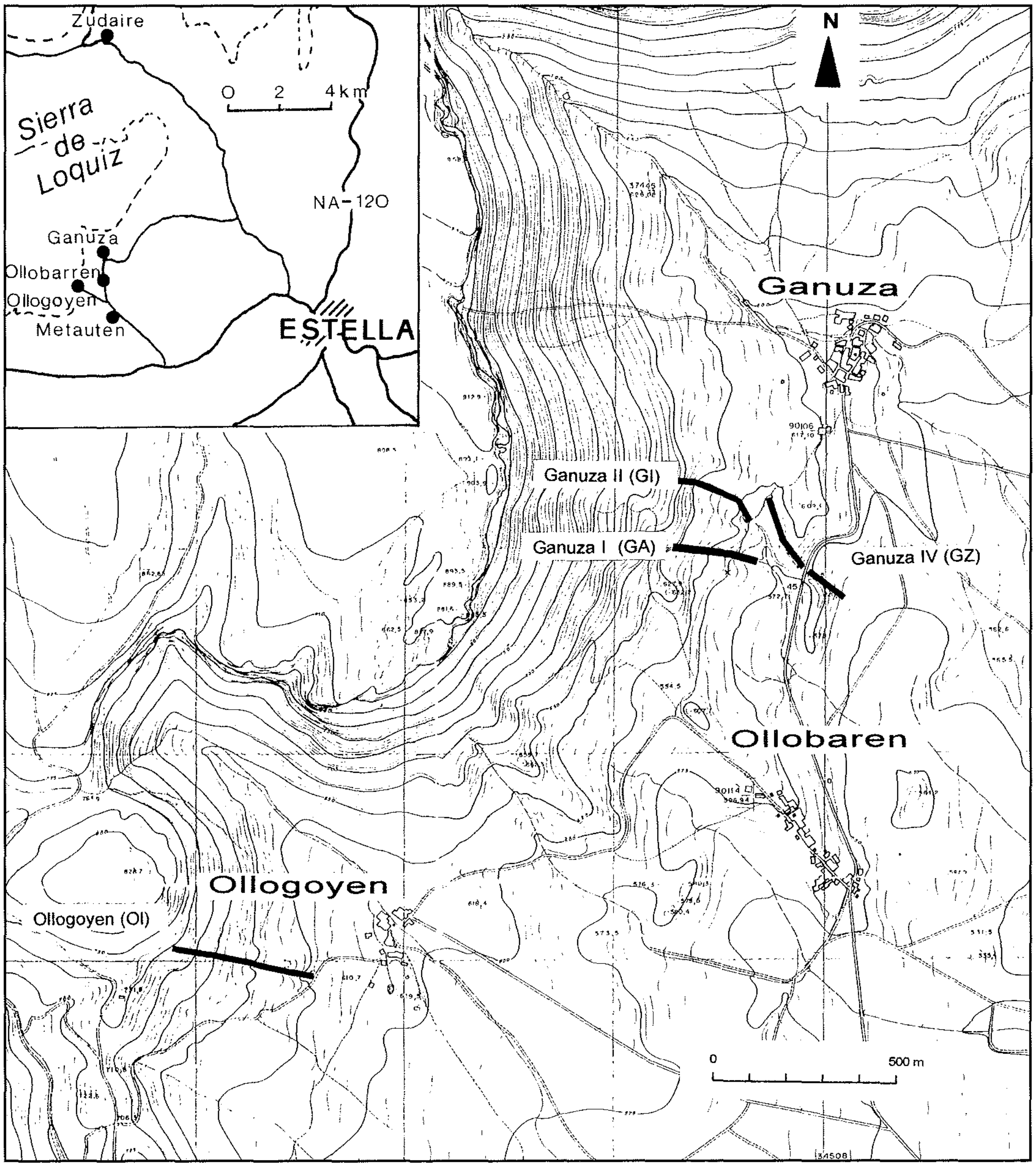


Fig. 13 Location of the Ganuza and Ollogoyen sections, 10 km west of Estella

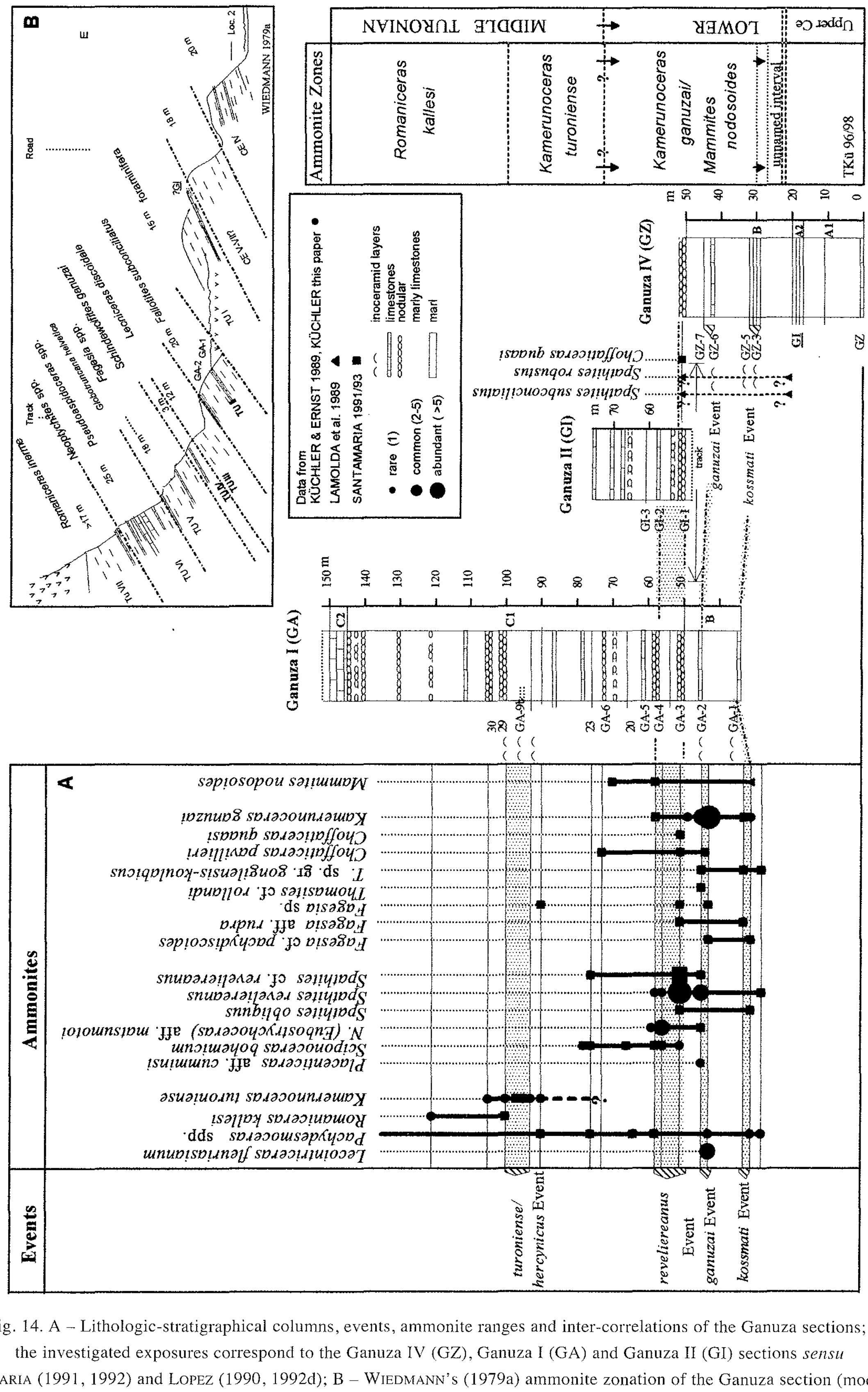
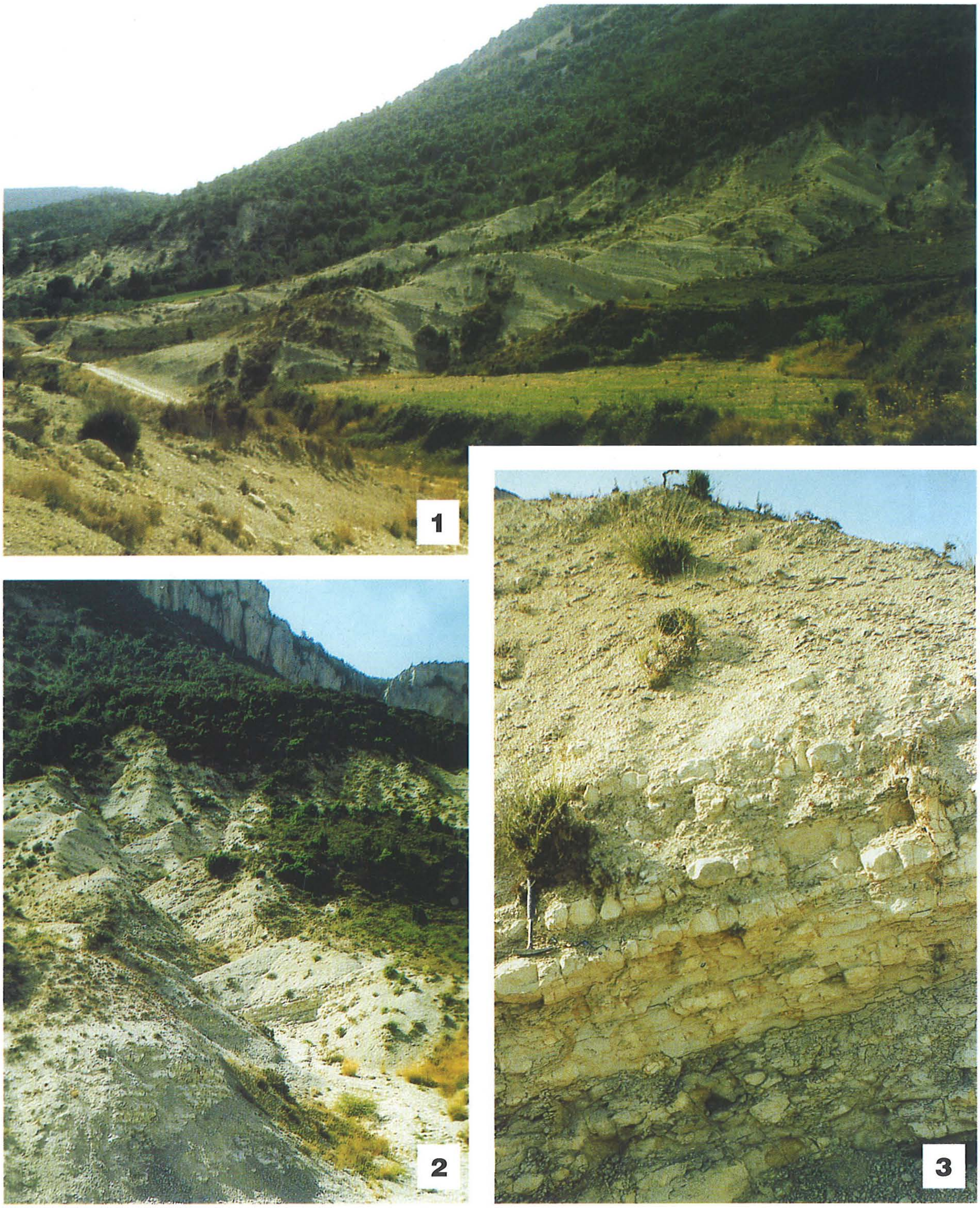


Fig. 14. A – Lithologic-stratigraphical columns, events, ammonite ranges and inter-correlations of the Ganuza sections; the investigated exposures correspond to the Ganuza IV (GZ), Ganuza I (GA) and Ganuza II (GI) sections *sensu* SANTAMARIA (1991, 1992) and LOPEZ (1990, 1992d); B – WIEDMANN's (1979a) ammonite zonation of the Ganuza section (modified)



Lower-Middle Turonian succession near Ganuza

1 – Ganuza II (GI) section; view from N to S; exposed is a succession from the upper Lower Turonian (*ganuzai/nodosoides* Zone) up to higher Middle Turonian (*ornatissimum* Zone); the top limestones of unit C2 are covered up to the Middle Coniacian limestones (cliffs of the Sierra de Santiaga de Loquiz) by talus; **2** – Erosional channel of the Ganuza I (GA) section; visible the GA-3 and GA-4 beds (interval of the *reveliereanus* Event) exposed west of the track Ganuza-Ollogoyen; **3** – Close-up view of the GA-4 limestones marked in Fig. 2

The interval comprising the Upper Cenomanian through the Lower Turonian starts *ca.* 600 m south of the centre of Ganuza, east of the national road, with a succession marked as GZ. It corresponds to the GZ section of LAMOLDA & *al.* (1989) and to the Ganuza IV (GZ) of SANTAMARIA (1991, Text-fig. 10). The bed numbering used here is adopted from that of the latter author. The top of the section is situated *ca.* 350 m SSW of Ganuza, within the track leading to the Church.

Ganuza I (GA)

Location: Topographical map Metauten, sheet 140-13, 1:10 000, R=570.750, H=4.727.440

The composite Ganuza section continues in an erosional gully, above the track, *ca.* 600 m SSW of the centre of Ganuza. The exposure Ganuza I starts with a *ca.* 1 m thick, massive, hard limestone/marl alternation (GA-1) some metres below the track. The succeeding beds (GA-2) may correspond to the *ganuzai* Event. LAMOLDA & *al.* (1989) referred to this exposure as the GA section and SANTAMARIA (1991, 1992) as Ganuza I (GA). In my opinion, it ranges from the upper Lower Turonian (*ganuzai* Event, *ganuzai/nodosoides* Zone) up to the upper *Romaniceras kallesi* Zone of the Middle Turonian.

Ganuza II (GI)

Location: Topographical map Metauten, sheet 140-13, 1:10 000, R=570.820, H=4.727.560

This section comprises the same stratigraphical interval as the Ganuza I (GA) section and is situated about 100 m north of it. The beds continue above the track in an another erosional gully. This section corresponds to the Ganuza II (GI) section of SANTAMARIA (1991, 1992) and LOPEZ (1990b, 1992d).

The Ganuza II (GI) section is very important for regional correlations and comparison of previously published data of LOPEZ & SANTAMARIA (1992) and MARTINEZ & *al.* (1996) who used an lower Turonian *Choffaticeras quaasi* Zone. The basal beds of this section were incorrectly assigned to the basal Turonian (*Choffaticeras quaasi* Zone or *quaasi* Association; SANTAMARIA 1992). Even taking other biostratigraphical data from the literature into consideration, *e.g.* the reported local appearances of *Spathites* (*J.*) *robustus* (WIEDMANN) and *Spathites subconciliatus* (CHOFFAT) (assigned to the *Watinoceras coloradoense* Zone by LAMOLDA & *al.* 1989, Text-fig. 2 in the same section), there is no evidence for an Lower Turonian in this particular part of the section. The faunal association suggests WIEDMANN's TU-III Zone (zone with *Leoniceras discoidale*). Referring to WIEDMANN (1979a, Text-fig. 10), this interval above the track lies actually in his TU-III Zone, which does not correspond to his basal Turonian.

Lithostratigraphy

With slight modification of the notation of the units (*see* Text-fig. 14), the descriptions here are taken from LAMOLDA & *al.* (1989). Accordingly in the whole Ganuza/Ollogoyen section, nine lithological units are distinguished. These comprise, in ascending order A1, A2, B, C1, C2 (Ganuza); D, E1, E2, F (Ollogoyen). Microfacies analyses were carried out *i.a.*, by SCHWENTKE & WIEDMANN (1985) and the reader is referred to this paper.

Unit A1: From the GZ beds, up to GI, is exposed a 16 m thick marly succession with intercalations of thin limestone beds or limestone/marl alternations. Based on foraminifera, the marls are referred to the Upper Cenomanian – *Rotalipora cushmani* Zone (LAMOLDA & *al.* 1989).

Unit A2: The marls of unit A1 are followed by a 4 m thick unit of closely-spaced limestone/marl alternations with thin-bedded limestones. According to LAMOLDA & *al.* (1989) these beds are the top part of the *cushmani* Zone.

This Upper Cenomanian alternation in terms of foraminifera and referred to by LAMOLDA & *al.* (1989) as GI-1, is renamed herein GI in order to distinguish it from the GI-1 beds of SANTAMARIA (1991) (and the use in ammonite terms by LAMOLDA & *al.* 1989), which are upper Lower Turonian. The alternation GI crops out some metres above the Ollobaren-Ganuza road. The lower 2.5 m of the unit corresponds in its appearance to the so-called flysch à boules (CIRY & MENDIZABAL 1949). This, as in the Barranca, is developed as a succession of dm thick calcareous marls and 0.1 m thick limestones. According to SCHWENTKE & WIEDMANN (1985, p. 13) some of the limestones are turbidites.

The upper 1.5 m of the unit are developed more uniformly and the beds compare in both thickness and appearance with the topmost part of the Upper Cenomanian *pictus* Limestone of the Barranca

(Iturmendi and Satrustegui sections, *compare* Text-fig. 6 and Pl. 2).

Unit B: In the 30 m thick interval between GI and GA-3 clay-rich marls are developed with intercalations of hard limestone beds (0.2 m) and about 1.0 m thick limestone/marl alternations of the ?topmost Cenomanian – Lower Turonian (Text-fig. 14A).

According to LAMOLDA & *al.* (1989) the Cenomanian/Turonian boundary is placed at the boundary between *R. cushmani* and *Whiteinella baltica* (=*W. archaeocretacea*) zones and lies *ca.* 2 m above the lithofacies boundary (*see* Text-fig. 14). Up to the *Mytiloides kossmati* Event (GZ-3 to GZ-5 interval *sensu* SANTAMARIA 1991, or to GI-3 *sensu* LAMOLDA & *al.* 1989) the succession is only very poorly exposed. This interval yielded no ammonites. On the other hand LOPEZ (1992d, Text-fig. 31) cited many beds with inoceramids from this interval, corresponding to his *Mytiloides submytiloides* associations. About 10 m above GI, within unit GZ-3 (*see* Text-fig. 14) lies the base of the *Mammites nodosoides* Zone as defined by SANTAMARIA (1991) and LAMOLDA & *al.* (1989). Similarly SCHWENTKE & WIEDMANN (1985) report, probably from the same level, a rich fauna of ammonites and inoceramids. Unit B corresponds to zones TU-I to TU-II, *sensu* WIEDMANN (1979a, Text-fig. 10) (*see also* Text-fig. 14B), though according to him, TU-I Zone is devoid of ammonites.

Unit C1: In an erosional gully above the Ganuza – Ollobaren track up to 100 m thick dark grey clay-rich marls are exposed. In their lower part there occur many m-thick horizons with nodular calcareous marls, nodular limestones and accumulations of limestone nodules, the origin of which is closely associated with *Thalassinoides* burrows. In the middle part of the unit dm-thick limestone beds or m-thick, closely spaced limestone/marl alternations predominate. The upper part of the unit is again more calcareous, with occurrence of m-thick parts with accumulations of calcareous nodules. Unit C1 stratigraphically comprises an interval from the *ganuzai*/ *nodosoides* Zone to the *Romaniceras kallesi* Zone. This unit includes the upper part of unit B and part of unit C of LAMOLDA & *al.* (1989).

Unit C2: In the top part of the Ganuza I section occur a *ca.* 5 m thick unit of thick-bedded limestones, which still belongs in the *R. kallesi* Zone. The unit is much better accessible south of Ollogoyen, at the village cemetery. It is composed there of m-thick intervals with light grey marly limestones and calcareous marls, with intervening marl seams and m thick, thin-bedded marls. The harder alternations weather in a nodular manner, and exhibit a yellow colour. In the upper part of the exposure sporadic inoceramids and ammonites occur.

Ollogoyen Section (Middle Turonian to Upper Turonian, *waltersdorfensis*/*germari* Zone)

Location: Topographical map Metauten, sheet 140-13, 1:10 000, R=569.750, H=4.726.570

The exposed succession starts with Middle Turonian strata (*Romaniceras ornatissimum* Zone), *ca.* 200 m west of Ollogoyen, south of a field road. In the more northerly located erosional gully the lowest exposed bed is bed O1-102 (*sensu* LAMOLDA & *al.* 1989) (Pl. 4, Fig. 2) This bed corresponds to the top of the TU-VII (the zone with *Romaniceras inerme*) of LAMOLDA & *al.* (1989, Text-fig. 11). In the erosional gully, adjacent to the former and some metres to the west, LAMOLDA & *al.* (1989) began the numbering of the beds with O1-101, numbering only the limestones. However, *ca.* 10 m of marls occur below the base of their section. The church at Ollogoyen stands on the Middle Turonian limestones (unit C2).

Lithostratigraphy

The Ollogoyen section exposes a *ca.* 100 m thick succession, extending up into the upper Upper Turonian *Cremnoceramus waltersdorfensis*/ *Prionocyclus germari* Zone (Text-fig. 15).

Unit D: The unit is represented by a monotonous, *ca.* 58 m thick, alternation of m thick dark-grey clay rich marls and marls with beds of calcareous nodules or continuous dm-thick limestone beds (0.15 to 0.3 m).

Unit E1: This conspicuous unit, 1.5 m thick, is composed in part of distinctly bedded limestones (Turonian-Coniacian boundary bed of LAMOLDA & *al.* 1981, Text-fig. 11). Unit D is succeeded with sharp contact, by two 0.4 m thick limestone beds. Higher up follows a slightly arenitic limestone (0.06-0.09 m). The topmost part of the unit is composed of a 0.5 m thick limestone bed with nodular appearance.

Unit E2: Above the limestones of the preceding unit, a 15 m thick succession of clay-rich marls is again developed with sporadic intercalations of thin beds of calcareous nodules or nodular limestones.

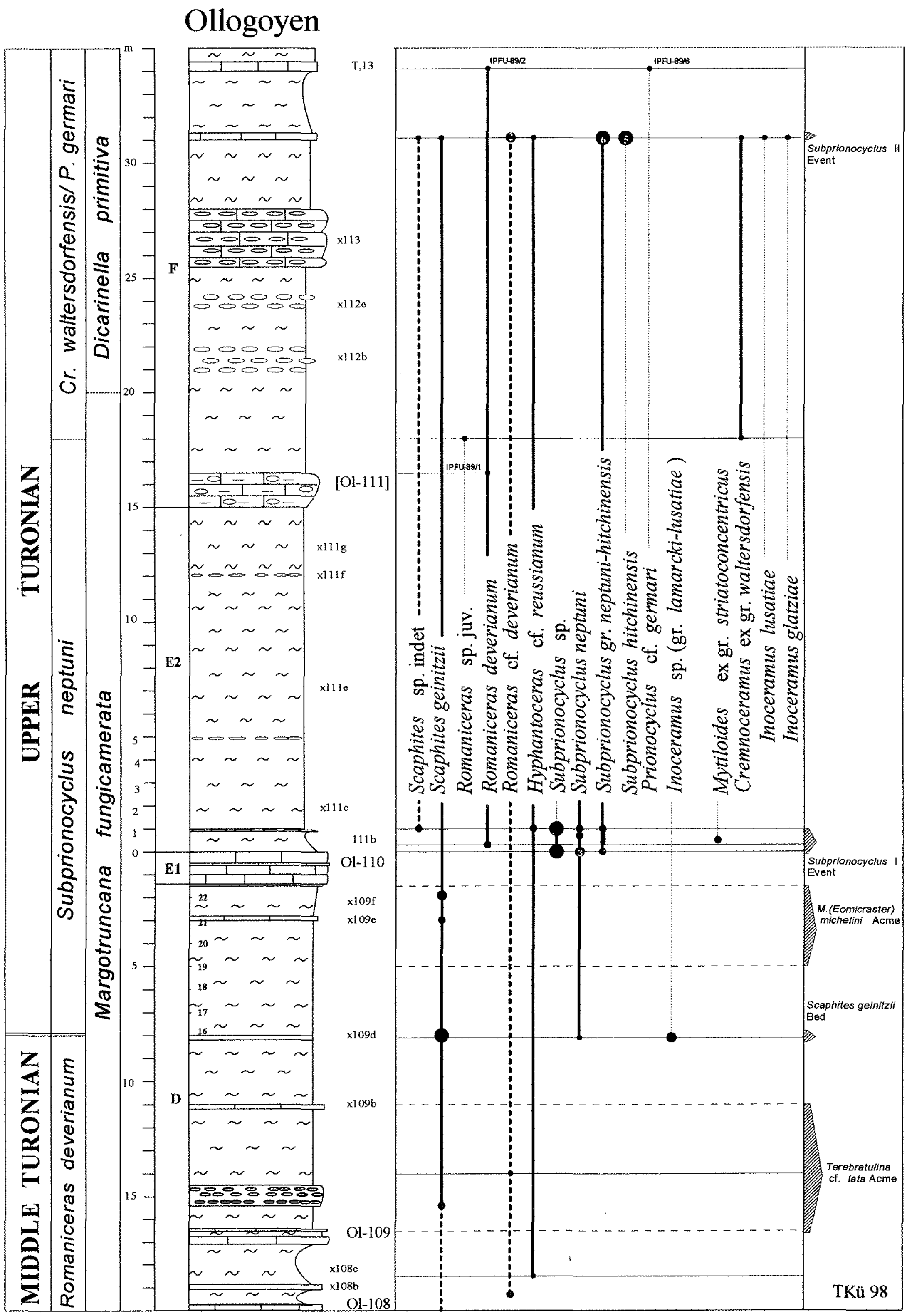


Fig. 15. Uppermost part of the Ollogoyen section (*modified after* KÜCHLER & ERNST 1989); litho-, bio- and event stratigraphy in the uppermost Middle and Upper Turonian; local ranges of ammonites and inoceramids; microbiostratigraphy *after* LAMOLDA & PROTO-DECIMA (1986)

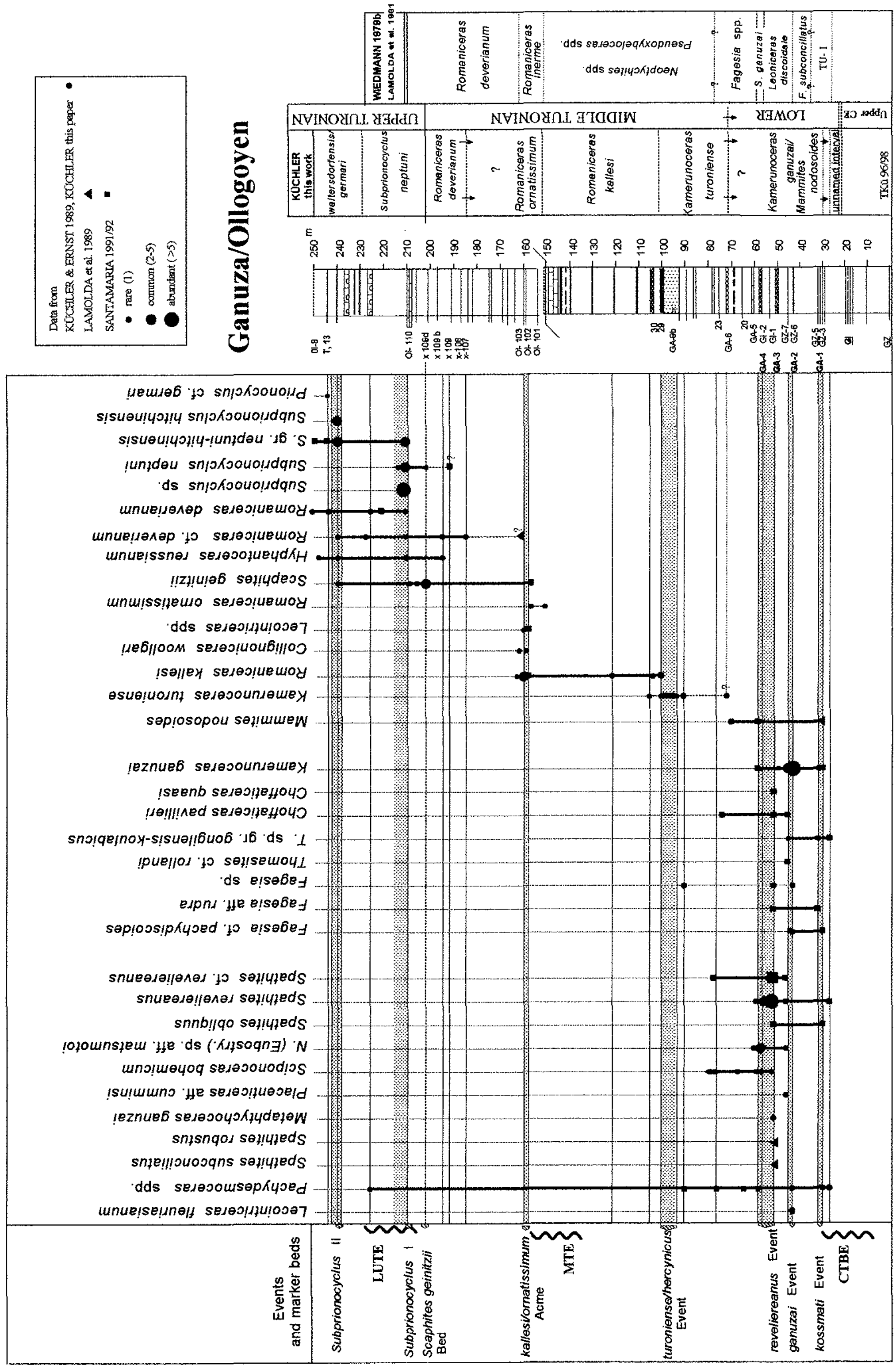
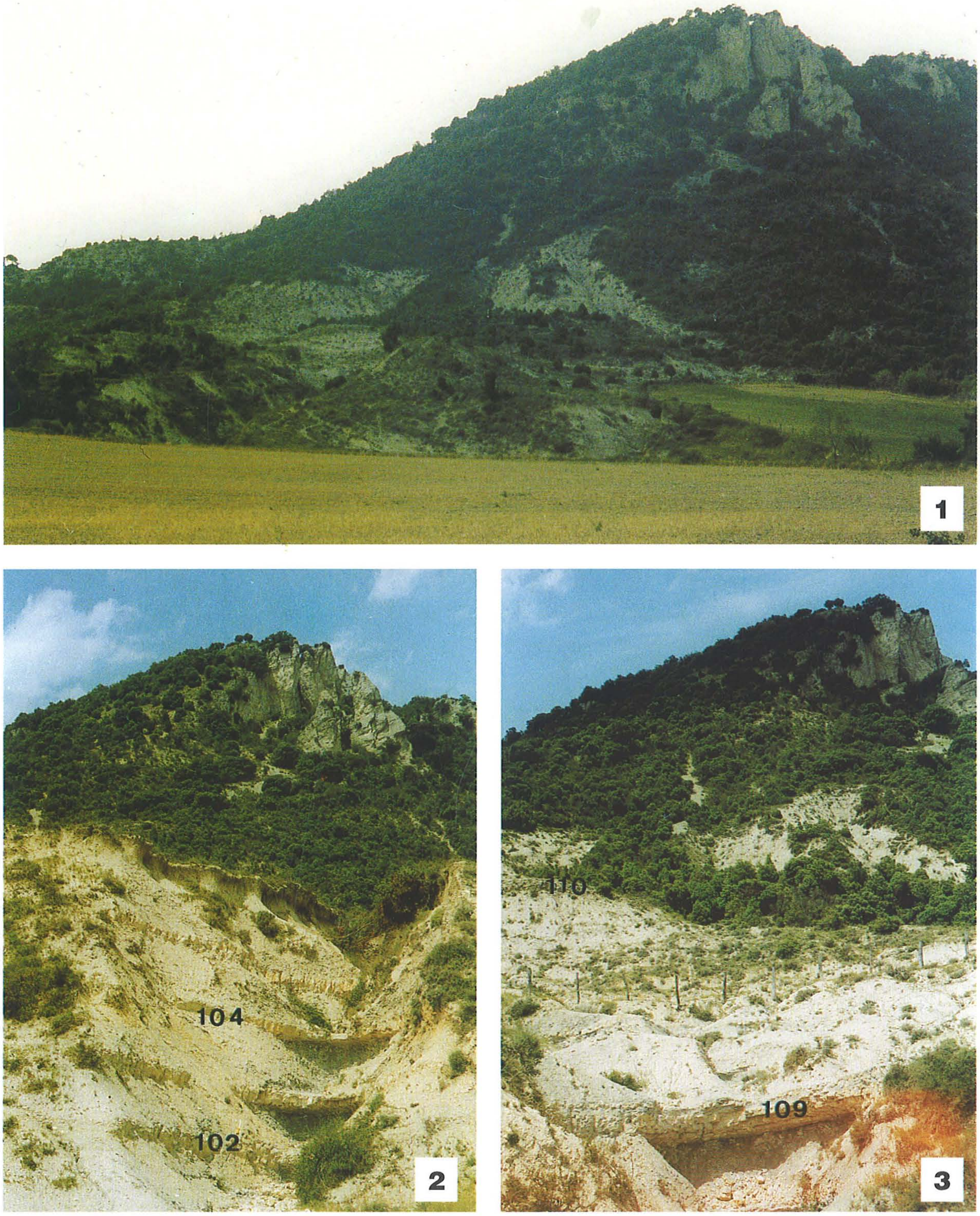


Fig. 16. Lithological-stratigraphical column of the composite Ganuza/Ollogoyen standard section, with events, vertical ranges and relative abundance of ammonites; additional data after KÜCHLER & ERNST (1989, Text-fig. 2), LAMOLDA & *al.* (1989, Text-fig. 2), and SANTAMARIA (1991, Text-figs 7, 10, 13); the Ollogoyen section corresponds to OL and OLLO of SANTAMARIA (1991, 1992) and LOPEZ (1990, 1992d)



Middle- Upper Turonian succession of the Ollogoyen section (*compare* Text-figs 15-16)

1 – General view W-E; **2** – Close-up view of the lower part of section (Middle Turonian; *Romaniceras ornatissimum* Zone); bed Ol-102 corresponds to the top of zone TU VII of WIEDMANN (*in* LAMOLDA & *al*. 1981); **3** – Close-up view of the middle part of the section with beds Ol-*108b; Ol-109 (*Romaniceras deverianum* Zone) and beds Ol-110 (Upper Turonian, *Subprionocyclus neptuni* Zone), the latter visible in the middle part of the right side

Unit F: The 20 to 25 m thick unit is dominated by m-thick horizons of clay-rich limestones, beds with calcareous nodules and nodular limestones, alternating with clay-rich marls.

Ammonite zonation in the Estella Aarea

Because of bad exposure conditions and, as mentioned already by LAMOLDA & *al.* (1989), the rarity of macrofossils in the uppermost Cenomanian to lowermost Turonian part of the investigated Ganuza IV (GZ) section, a stratigraphical interpretation of this interval can be made only on the basis of literature data.

No reference is made here to some sections located north of Ganuza which, according to LOPEZ (1990) and SANTAMARIA (1991) should expose the lowermost Turonian, and were unknown to me at the time of my own studies. However, the interpretations of LAMOLDA & *al.* (1989), defining the base of the Lower Turonian with the ammonite zone of *W. coloradoense* or that of SANTAMARIA (1991, 1992) with his *Ch. quaasi* Zone at the base of the Ganuza II (GI) section, respectively, contrast with the data presented within this work.

According to WIEDMANN's ammonite scheme the uppermost Upper Cenomanian of northern Spain is divided into three zones (in ascending order): *Metoicoceras geslinianum*, *Vascoceras gamai* and *Fallotites subconciliatus* zones (*see* SCHWENTKE & WIEDMANN 1985). The two latter zones are endemic (KAPLAN & *al.* 1984, p. 329) and are regarded as an equivalent of the *Neocardioceras juddii* Zone by WIEDMANN & *al.* (1989, Tab. 2).

The stratigraphical succession of the intensively studied Ganuza section, corresponding to Ganuza IV (GZ) of the Spanish authors, starts with *Mytiloides* frequency-maxima, particularly of *M. kossmati*, associated with *Kamerunoceras ganuzai* (WIEDMANN).

According to LAMOLDA & *al.* (1989), this level corresponds to the level of first appearance *of* of *M. nodosoides* (SCHLÜTER) and, consequently, to the base or the lower part of the *M. nodosoides* Zone and thus to the upper Lower Turonian. Eight ammonite associations have been recognized within the composite Ganuza/Ollogoyen section, separated, in part, by several m-thick intervals with few ammonites. The range charts showing the local stratigraphical distribution of ammonites (*see* Text-figs 14, 16) are based on new bed by bed collections, supplemented by previously published data based on KÜCHLER & ERNST (1989) and SANTAMARIA (1991, 1992).

It proved extremely difficult to use the data provided by WIEDMANN (1962b, 1965, 1979a), WIEDMANN & KAUFFMAN (1978) and LAMOLDA & *al.* (1981) and to recognize their zones in the field. These papers contain faunal lists and thickness data for the various zones, but no detailed graphic sections or range charts. Moreover, the thickness data for individual zones are so discrepant, that some of the zones can be correlated only approximately with the zonal scheme presented here. This problem particularly concerns zones TU-II through TU-VI, *sensu* WIEDMANN & KAUFFMAN (1978), corresponding to zones TU-III through TU-VI in the formal scheme of WIEDMANN (1965).

Reference to, and the correlation of the different zonal schemes presented by LAMOLDA & *al.* (1989), KÜCHLER & ERNST (1989) and SANTAMARIA (1991) was possible only through restudy of the sections and a re-evaluation of the published columns directly in the field.

With the exception of the controversial topmost Cenomanian to lowermost Turonian zones (*see* discussion below) and an unnamed interval, seven ammonite zones are distinguished in the studied sections. The positions of the zonal boundaries as here defined are presented in Text-fig. 17 against the schemes of WIEDMANN (1979a) and LAMOLDA & *al.* (1981).

Metoicoceras geslinianum Zone

According to LAMOLDA & *al.* (1989), the upper 1.5 m or 1.0 m of the alternation GI comprises the topmost part of the *R. cushmani* foraminiferal Zone and the lower part of the *W. archaeocretacea* Zone. The record of *M. geslinianum* (D'ORBIGNY) places this interval within the *geslinianum* Zone according to SCHWENTKE & WIEDMANN (1985, p. 13).

Vascoceras gamai or Neocardioceras juddii Zone

This and the overlying Turonian zone of *W. coloradoense* are controversial and in my opinion not recognizable in the studied Ganuza section.

Despite a complete Cenomanian/Turonian boundary succession (*see also* SCHWENTKE &

WIEDMANN 1985; LAMOLDA & PERYT 1995), according to WIEDMANN & KAUFFMAN (1978) the *Vascoceras gamai* Zone (equivalent of the *N. juddii* Zone), known from other sections in northern Spain, is not present here.

However, SANTAMARIA (1991) reported a single loose specimen of *Neocardioceras* sp. from a Cenomanian exposure (GA-IV), 1 km east of Ganuza. He correlated this so-called "association with *Neocardioceras* sp." with the north European *juddii* Zone.

Watinoceras coloradoense Zone

According to MARTINEZ (*in* LAMOLDA & *al.* 1989, p. 154, Text-fig. 2) the *N. juddii and W. coloradoense* zones are indicated by the occurrence of *Spathites subconciliatus* (CHOFFAT) at the top of GI-1 as well as by *Spathites* (*J.*) *robustus* (WIEDMANN) which occurs immediately above. He postulated the presence of the Early Turonian *coloradoense* Zone solely on the occurrence of the latter species in the Ganuza II (GI) section. However, the base of the Turonian was incorrectly placed at Ganuza (*see* Text-fig. 14A and discussion above). Moreover, *S. robustus* is, at least in the Barranca, known to range up into the middle part of the *ganuzai*/ *nodosoides* Zone, *i.e.* into the upper Lower Turonian, where it cooccurs with *Choffaticeras quaasi*.

unnamed interval with rare ammonites

This is a 4 m thick interval below the *kossmati* Event which according to SANTAMARIA (1991) yields *Spathites* sp., *Spathites* (*J.*) *reveliereanus*, *Thomasites* ex gr. *gongiliense – koulabicus* and *Pachydesmoceras denisonianum* (STOLICZKA). It probably ought to be referred to the upper Lower Turonian *K. ganuzai*/*M. nodosoides* Zone.

Kamerunoceras ganuzai/Mammites nodosoides Zone

The base of the zone can be drawn only in the Ganuza IV (GZ) section. It approximately corresponds to the GZ-3 horizon of SANTAMARIA (1991, Text-fig. 10) where, according to LAMOLDA & *al.* (1989), *M. nodosoides* first appears. It is also possible that the base of the zone lies some metres deeper, as mentioned above. *P. denisonianum* and *K. ganuzai* (*see* Pl. 9, Figs 1-4,6) were found in the basal part. The specimen figured by SANTAMARIA (1991, Pl. 4, Fig. 1) as *Kamerunoceras puebloense* (COBBAN & SCOTT) is also a *K. ganuzai* (compare Pl. 9, Figs 1-4,6). Consequently, I define the base of the zone at the simultaneous entrance of both index species.

In the vicinity of Ganuza, a 10 to 15 m thick interval between the *kossmati* Event and the *ganuzai* Event is characterized by common small-sized *Kamerunoceras*. The ammonite association additionally consists of spathitids, mainly *S. reveliereanus*, and, according to SANTAMARIA, of *Fagesia* aff. *rudra* (STOLICZKA) and *Fagesia* cf. *pachydiscoides* SPATH). *Placenticeras* aff. *cumminsi* CRAGIN, *Lecointriceras fleuriausianum* (D'ORBIGNY) and *Choffaticeras* sp. first occur at the level of the *ganuzai* Event.

A second association is known from the 10 m thick interval above the *ganuzai* Event, up to the lower part of the *reveliereanus* Event. The association is characterized by rare choffaticeratids [*Ch. quaasi* (PERON), *Ch. pavillieri* (PERVINQUIERE)] and representatives of the genus *Fagesia* (*F. pachydiscoides*, *F. thevestensis* and *F.* aff. *rudra*) but is dominated by spathitids [*S. reveliereanus*, *S.* cf. *reveliereanus*, and rare *S. obliquus* (KARRENBERG)]. This interval may correspond to the *Leoniceras discoidale* Zone (TU-III) of WIEDMANN (1979b).

Spathites reveliereanus dominates in the 14 m interval between GA-3 and GA-4 (= *reveliereanus* Event) where it is associated with *Nostoceras* (*Eubostrychoceras*) aff. *matsumotoi* COBBAN. The higher part of this interval is additionally characterized by a heteromorph ammoniteamonite assemblage, comprising *Metaptychoceras ganuzai* WIEDMANN, *Sciponoceras bohemicum* (FRITSCH) and *N.* (*E.*) aff. *matsumotoi*. Rare *M. nodosoides*, *M.* cf. *nodosoides* as well as *K. ganuzai* also occur.

The interval between the top of the *reveliereanus* Event and the first *K. turoniense* yields *Sciponoceras bohemicum*, *Pachydesmoceras* spp. (mostly *P. denisonianum*), *M. nodosoides* and *S.* cf. *reveliereanus*. The *Schindewolfites ganuzai* Zone *sensu* WIEDMANN as well as the *Fagesia* spp. Zone established by WIEDMANN & KAUFFMAN (1978) probably fall in this interval (Text-fig. 16). WIEDMANN (1960, 1965, 1979a) reports a 15 m thick (later 18 m) interval with *Fagesia* from the Ganuza section. The accompanying forms comprise *Parapuzosia gaudama* (FORBES), *Jeanrogericeras binicostatum*

(PETRASCHECK) (=*S. reveliereanus*), *Eubostrychoceras indicum* (STOLICZKA) (=? *N.* (*E.*) aff. *matsumotoi*), and *Metaptychoceras ganuzai*.

Kamerunoceras turoniense Zone

Field data gathered together with M. LAMOLDA, R. MARTINEZ and G. LOPEZ, S. SANTAMARIA, and G. ERNST, reveal that the index taxon first appears in the Ganuza section *ca*. 14-17 m above the *reveliereanus* Event in the GA-6 horizon. It occurs sporadically up to horizon GA-10, and is somewhat more common in GA-9 (*see* Pl. 10, Fig. 1).

The *K. turoniense* Zone probably more or less corresponds to the zone of *Neoptychites* spp. and *Pseudoaspidoceras* spp. *sensu* WIEDMANN & KAUFFMAN (1978). According to WIEDMANN (1965, 1979a) this zone was supposed to be characterized by *Pseudoaspidoceras armatum* (PERVINQUIERE) and *Pseudoaspidoceras salmuriense* (COURTILLER). KENNEDY & WRIGHT (1979) referred both species to *K. turoniense* (D'ORBIGNY). According to WIEDMANN (1979a, p. 176) other associated forms include *Kamerunoceras* cf. *inaequicostatus* (WIEDMANN), *S.* cf. *reveliereanus* and *Fagesia superstes* (KOSSMAT).

Romaniceras kallesi Zone

The zone is used here in the original sense of AMÉDRO & BADILLET (1978) and of ROBASZYNSKI & *al*. (1982), and not in the sense of SANTAMARIA (1991, 1992). Its lower boundary is defined by the FAD of the index species, and in the Ganuza section it comprises a *ca*. 50 m thick interval with relatively few ammonites.

Based on a single loose find of *R. kallesi* by SANTAMARIA (1991, Text-fig. 7), and my own collections in 1997, this species enters in the nodular unit directly above the *turoniense*/*hercynicus* Event (Ganuza I section, Text-figs 14 and 16), and ranges up at least into the bedded limestones of unit C2.

From my own *in situ* collected material another specimen of *R. kallesi* (*see* Pl. 10, Fig. 8) is from a level *ca*. 20 m above the *turoniense*/*hercynicus* Event. The entry of *Romaniceras ornatissimum* (STOLICZKA) marks the upper boundary of the zone. On the other hand, the broadly interpreted *kallesi* Zone of SANTAMARIA embraces an interval corresponding in the presented scheme to the *kallesi*, *ornatissimum*, *deverianum* zones and almost the whole *neptuni* Zone *sensu* KÜCHLER & ERNST (1989) (*see* Text-fig. 17). Near Ganuza in the basal part of the *kallesi* Zone there is a m-thick overlap interval of *K. turoniense* and *R. kallesi*.

Romaniceras ornatissimum Zone

The *R. ornatissimum* Zone as used here corresponds to WIEDMANN's *Romaniceras inerme* Zone (WIEDMANN 1979a, p. 175, Text-fig. 10; WIEDMANN & KAUFFMAN 1978, p. III4). The base of the zone, defined by the FAD of the index taxon, lies in the Ganuza section within, or a short distance above, the limestone unit at the top of the exposed succession (*compare* LAMOLDA & *al*. 1989, Text-fig. 2).

In the Ollogoyen section, the *ornatissimum* Zone is *ca*. 10 m thick (WIEDMANN 1979a; LAMOLDA & *al*. 1981, p. 32, Text-fig. 11) and was reported to contain *R. ornatissimum* [*R. ornatissimum* form C = *R. inerme* (DE GROSSOUVRE) *sensu* WIEDMANN], *R. kallesi* [= *Proromaniceras pseudodeverianum* (JIMBO) *sensu* WIEDMANN] and *Pachydesmoceras* cf. *linderi* (DE GROSSOUVRE). SANTAMARIA (1991, Text-fig. 13) listed *R. ornatissimum* and *Romaniceras* sp. nov. (=*Romaniceras navarrense* SANTAMARIA 1995) from the base of the zone, as well as *Lecointriceras* sp., *R. kallesi* and *Scaphites* cf. *diana* WRIGHT higher up-section, between Ol-100 and Ol-102. According to my own data, the ranges of *R. ornatissimum* and *R. kallesi* overlap in the interval Ol-102 to Ol-104. Rare *C. woollgari* (MANTELL) (*see* Pl. 10, Figs 6-7) and *Lecointriceras* sp. also occur in this interval. *C. woollgari* was also listed by LAMOLDA & *al*. (1989, Text-fig. 2). SANTAMARIA (1992) later referred this specimen to *Collignoniceras* cf. *boreale* (WARREN). The other finds of *C. woollgari*, from the lower part of the section, reported by LAMOLDA & *al*. (1989), were neither confirmed nor supplemented by SANTAMARIA (1991). Consequently, the *woollgari* Zone of LAMOLDA & *al*. (1989) is invalid.

Romaniceras deverianum Zone

The base of the zone, as well as its thickness, are not as yet adequately understood in Navarra, particularly in the Estella Area area and require further investigation. According to LAMOLDA & *al*. (1981), the base of the zone lies about 50 m below the prominent limestone bed OL-22

(=Ol-110), *i.e.* at a level that most probably corresponds to bed Ol-104 *sensu* LAMOLDA & *al.* (1989). According to LAMOLDA & *al.* (1981, p. 32), *Romaniceras* cf. *deverianum* (D'ORBIGNY), *R. ornatissimum*, *Collignoniceras* sp., *Puzosia* cf. *planulata* (SOWERBY) and *P. denisonianum* (STOLICZKA) occur within this zone.

The basal part of the zone contains only rare ammonites, and consequently the position of the lower boundary of the zone as given by LAMOLDA & *al.* (1981) could not be confirmed. SANTAMARIA (1991, 1992) took the base of the zone significantly higher, at the top of the *neptuni* Zone, or even higher, in the lower part of the *normalis* Zone (as defined by KÜCHLER & ERNST 1989, Text-fig. 2). It must be emphasised that the specimens of *R. deverianum*, figured by KÜCHLER & ERNST (1989) and by SANTAMARIA (1991), actually come from high levels of the Ollogoyen section. The specimen figured here (Pl. 11, Fig. 6), however, comes from the *Subprionocyclus* I Event (Ol-*111b), directly above OL-110 (=Ol-22). An additional, small specimen, referred to as *R.* cf. *deverianum*, was found 28 m down-section in bed Ol-107a, and *ca.* 20 m below the base of the *neptuni* Zone. From these records it follows that the thickness of the *deverianum* Zone in Ollogoyen, reported by WIEDMANN, is questionable.

Ammonites are again more common about 16 m below the prominent Ol-110 limestone bed. Here juvenile *Romaniceras* sp. and *R. ?deverianum* occur together with *S.* cf. *geinitzii* D'ORBIGNY and *Hyphantoceras reussianum* (D'ORBIGNY).

Subprionocyclus neptuni Zone

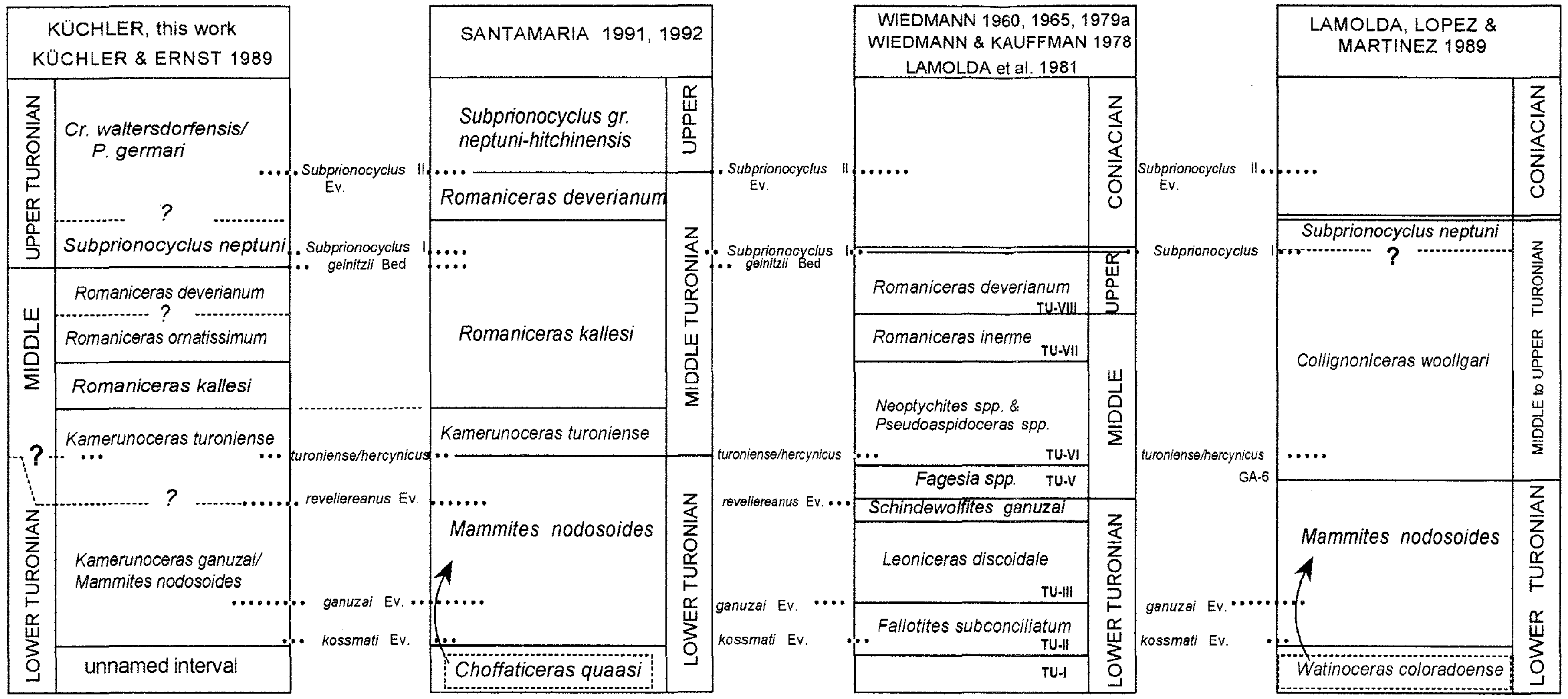
In northern Spain, the zone was proved in the Ollogoyen section (KÜCHLER & ERNST 1989) by a rich *Subprionocyclus* fauna. The base of the zone is now taken at the herein designated *S. geinitzii* Bed (bed Ol-109d), about 8 m below the level previously taken as the boundary, at the top of Ol-110. The first *Subprionocyclus neptuni* (GEINITZ) (Pl. 11, Fig. 8) associated with *Scaphites geinitzii* (Pl. 11, Fig. 7) occurs in this bed, together with poorly preserved inoceramids, tentatively (TRÖGER, *pers. comm.*) referred to the *Inoceramus lamarcki* or *Inoceramus lusatiae* group.

The zone is characterized by a *Subprionocyclus* – *Scaphites* – *Romaniceras* assemblage comprising *S. neptuni*, *S.* ex gr. *neptuni – hitchinensis*, *S. geinitzii*, *R. deverianum*, juvenile *Romaniceras* sp., and *Hyphantoceras* sp. Inoceramids are rare, and restricted to single finds of *Mytiloides* ex gr. *striatoconcentricus* from the *Subprionocyclus* I Event (Text-fig. 15).

The *neptuni* Zone as defined here corresponds to the upper part of the *kallesi* Zone of SANTAMARIA (1991, 1992).

Cremnoceramus waltersdorfensis/Prionocyclus germari Zone

In the Ollogoyen section, KÜCHLER & ERNST (1989) postulated an equivalent of the *Subprionocyclus normalis* Zone, based on a single specimen of *Prionocyclus* cf. *germari* (REUSS) and sporadic occurrences of *Cremnoceramus waltersdorfensis* (ANDERT). This zone was adopted and re-interpreted by GRÄFE & WIEDMANN (1993) and GRÄFE (1994) for northern Spain. At Ollogoyen, the base of the zone was indirectly defined by the first appearance of *C. waltersdorfensis*, approximately 17 m above bed Ol-110 (KÜCHLER & ERNST 1989). Unfortunately, the inoceramid material (determined by E. SEIBERTZ) is represented by very poorly preserved specimens and consequently the lower part of the zone remains uncertain. The ammonite fauna in this zone is nearly identical to that in the underlying *neptuni* Zone. It consists of *Subprionocyclus neptuni, S. hitchinensis* (BILLINGHURST), *S.* gr. *neptuni-hitchinensis*, *Romaniceras deverianum*, *R.* cf. *deverianum*, *Scaphites geinitzii* and *Hyphantoceras reussianum*, as well as juvenile specimens of *Hyphantoceras*. *Prionocyclus* cf. *germari* first appears 3 m above the *Subprionocyclus* II Event, associated with *R. deverianum*. The latter species (*see* Pl. 11, Fig. 3) ranges considerably higher, up to bed Ol-*8 (Text-fig. 16 not figured here). From a higher part of the section, his Ollogoyen (Ol II) section (not treated in this work), LOPEZ (1990b) reported an inoceramid assemblage with rare *Mytiloides incertus incertus* (JIMBO), *Mytiloides labiatoidiformis* (TRÖGER), *M.* cf. *labiatoidiformis*, and *M.* aff. *carpathicus* (SIMIONESCU). The assemblage was later referred by him to the upper Upper Turonian *Inoceramus frechi* Zone (*compare* LOPEZ 1992d, Text-fig. 29). This appears to correspond broadly to Zone 19 of TRÖGER (1989), and, consequently to the *normalis* Zone *sensu* KAPLAN (1986, 1988) thus supporting the origi-



Correlation of the ammonite schemes hitherto applied to the Ganuza/Ollogoyen standard section, by means of event stratigraphy; the zonations of WIEDMANN (1960, 1965, 1979a), WIEDMANN & KAUFFMAN (1978) and LAMOLDA & *al.* (1981), is only roughly completed due to the lack of precise, original presentation; the *Choffaticeras quaasi* Zone, *sensu* SANTAMARIA (1991, 1992), and the *Watinoceras coloradoense* Zone, *sensu* LAMOLDA & *al* (1989), represent the uppermost Lower Turonian *ganuzai/nodosoides* Zone nal interpretation of KÜCHLER & ERNST (1989). The *normalis* Zone *sensu* KÜCHLER & ERNST (1989) is herein renamed the *Cremnoceramus waltersdorfensis/Prionocyclus germari* Assemblage Zone. Its base is defined tentatively at the FAD of *C. waltersdorfensis*.

It is assumed that the Spanish *waltersdorfensis/germari* Zone corresponds entirely or in part to the *Prionocyclus germari* Zone of KAPLAN & KENNEDY (1994) in Germany, and embraces an interval referred to the *deverianum* Zone, as well as to the *Subprionocyclus* ex gr. *neptuni-hitchinensis* Zone or Association by SANTAMARIA (1991, 1992). The base of latter author's *S.* ex gr. *neptuni – hitchinensis* Zone (bed T.13) lies below the *Subprionocyclus* II-Event of this paper (*compare* Text-fig. 17). Recent records of *Prionocyclus germari*, *M. incertus* and *Mytiloides scupini* in the Santander area (WIESE 1996, 1997) confirm the existence of the *normalis* (=*germari*) Zone there, as previously postulated by KÜCHLER & ERNST (1989). It should be noted in this context that WIESE (1997) erected a *M. incertus/P. germari* Assemblage Zone which was inferred to equate with the *germari* Zone of northern Germany.

Event stratigraphy in the Estella area

The event stratigraphical scheme presented here is the first proposed for the Ganuza/ Ollogoyen standard section. It enables not only a better correlation of particular sections near Ganuza but also reveals the discrepancies between the hitherto applied biostratigraphic subdivisions (*see* Text-fig. 17).

The events consist of ammonite and/or inoceramid accumulations that can be correlated with those of the Barranca (*see* Text-figs 18-19). A continuity of particular horizons over a distance of 34 km is demonstrable. Because of the more complete and very much thicker successions of the Estella area, compared to those of the Barranca (230 m against 56 m), the event horizons or event sets may extend over several metres, and consequently not so well defined and easily recognizable as in the latter area. The events also show considerable differences in the faunal content and diversity, depending mainly on the different palaeogeographical position of the two areas (outer shelf in the case of the Barranca, and middle shelf position in the case of the Estella area), as well as the resulting differences in bathymetry and temperature.

In the Estella area, the stratigraphical gap at the Cenomanian – Turonian boundary has not been recognized, and there are no black marls or black clays. According to LAMOLDA & PERYT (1995), dysaerobic conditions in the topmost part of the *cushmani* Zone are recognizable by changes in the benthonic foraminiferal assemblages, displayed by a temporary disappearance of some taxa and their substitution by others. According to those authors, such conditions persisted until the early *Whiteinella archaeocretacea* Zone.

As indicated by the occurrence of the *Mytiloides* I Event (=*kossmati* Event), the Lower Turonian is more complete in the Estella area than in the Barranca. The *ganuzai*, *revelgiereanus*, and *turoniense/hercynicus* events are important for the correlation between both areas (Text-fig. 18). The timing of the tectonically-induced Lower Upper Turonian Event (LUTE), documented in the Barranca by a shallowing upward phase with associated marked lithological changes and hiati, has now been established in Ollogoyen section. The LUTE is marked here by short-term, probably multi-phase redepositional events between the *Scaphites geinitzii* bed at the base of the *neptuni* Zone and the level of *Subprionocyclus* ex gr. *neptuni-hitchinensis* mass-occurrence in the *Subprionocyclus* I Event. Strong subsidence of the basin was compensated by a high sedimentation rate and consequently there was no major difference in the bathymetric position.

Mytiloides I Event (=Mytiloides kossmati Event)

The horizon is a *ca.* 2.6 m thick succession developed between GZ-3 and GZ-5 in the Ganuza IV section, comprising alternating thin-bedded (0.1 m) limestones and clayey, several dm-thick marls. The topmost three beds are very rich in inoceramids, represented by *Mytiloides labiatus*, *M.* m.f. *mytiloides/labiatus*, *M.* m.f. *labiatus/kossmati*, *M. kossmati*, and *M.* cf. *hercynicus*. Including additionally the data of LOPEZ (1990b) and also those of LAMOLDA & *al.* (1989), who reported an abundance of *M. goppelnensis*, a younger synonym of *M. kossmati* (WALASZCZYK 1992, *see also* HARRIES & *al.* 1996) at this level, the assemblage is dominated by *M. kossmati* (HEINZ). In the Estella area, this

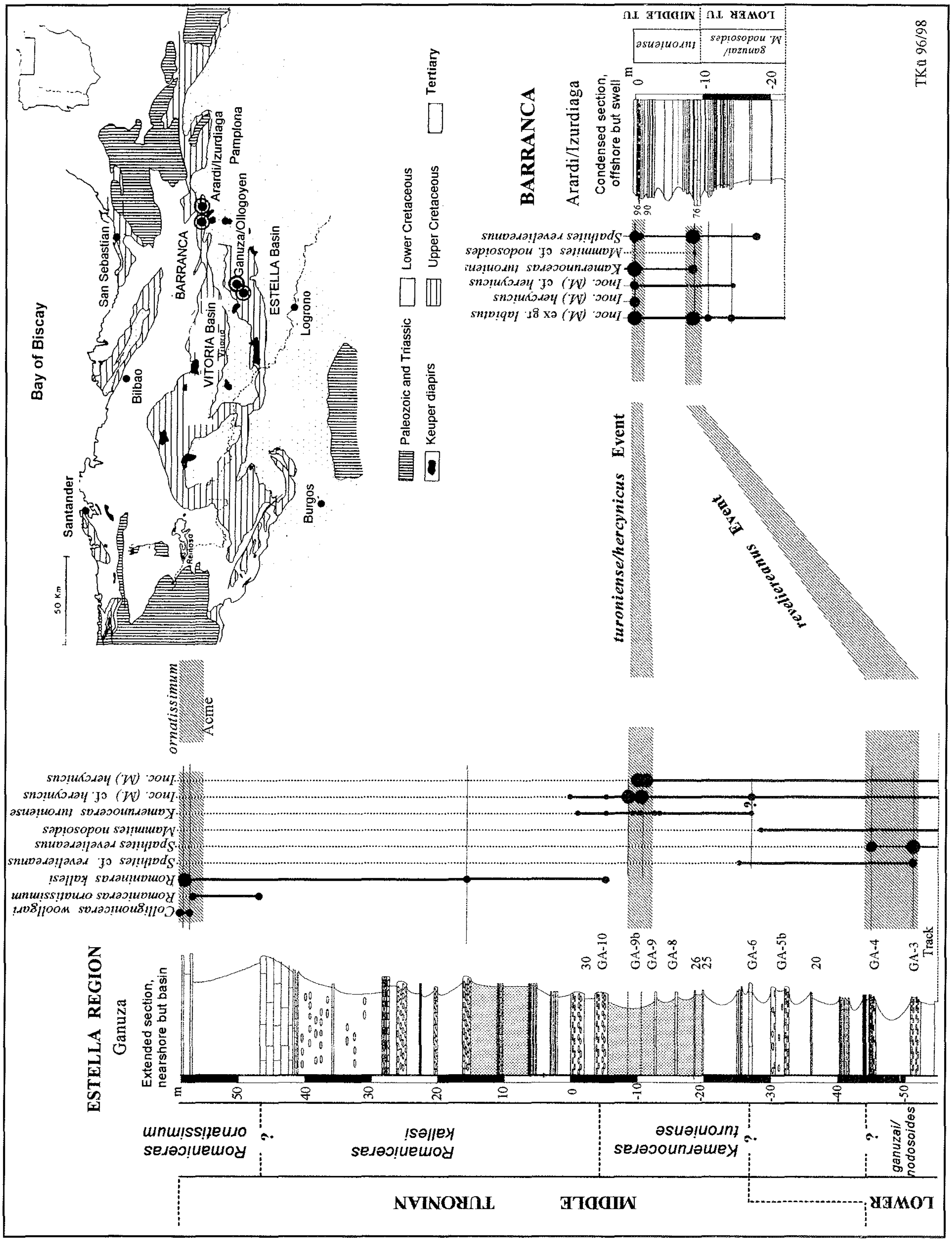


Fig. 18. Ammonite/inoceramid assemblages within the *reveliereanus* and *turoniense/hercynicus* events in outer- (Barranca) to mid-shelf positions (Estella region)

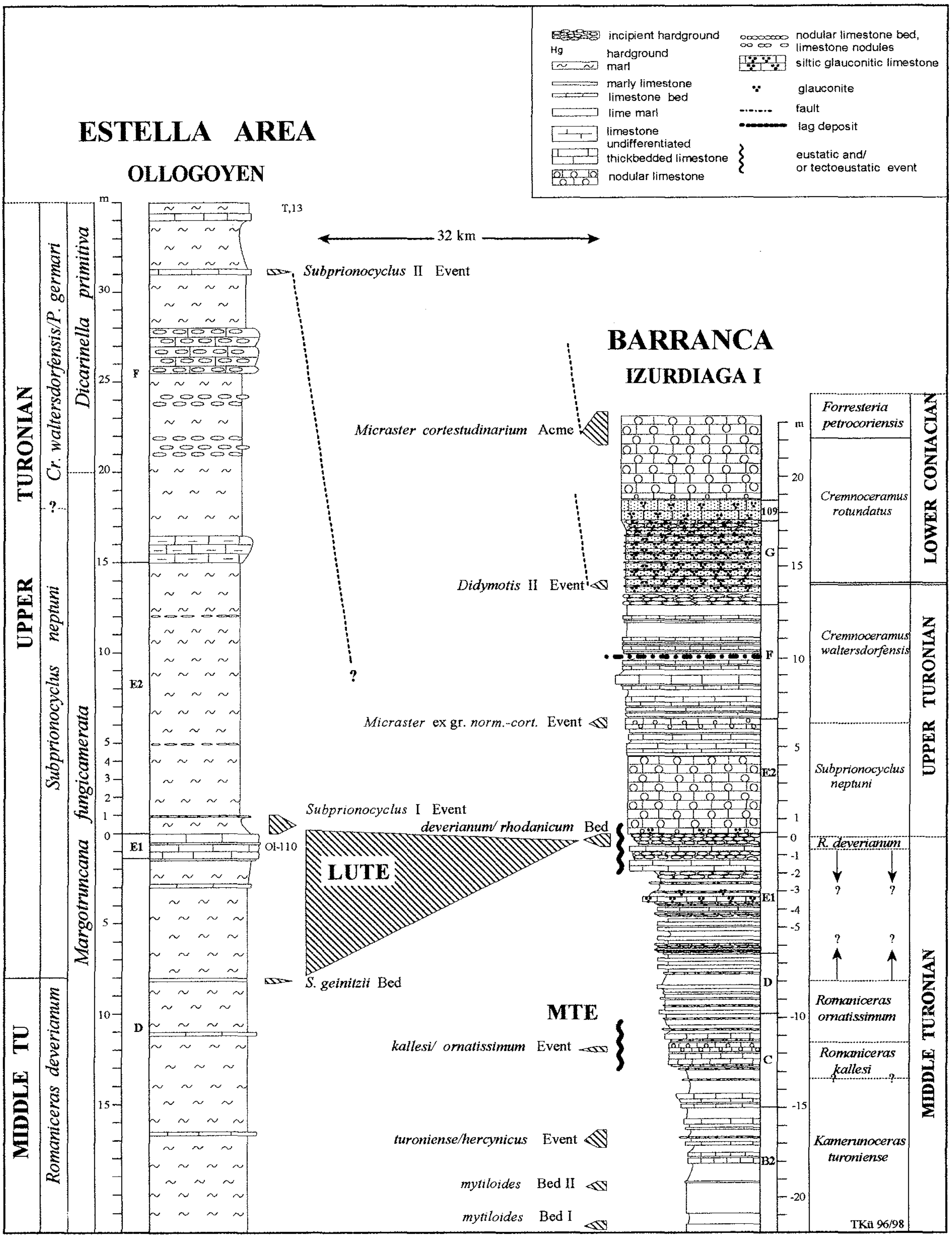


Fig. 19. Middle Turonian to Lower Coniacian event successions and correlation of the LUTE (lower Upper Turonian) Event between the Estella area and the Barranca

lowest *Mytiloides* mass-occurrence falls in the basal or at least lower part of the *Kamerunoceras ganuzai/Mammites nodosoides* Zone, as indicated by the FADs of the zonal indices in this event.

Kamerunoceras ganuzai Event

This event is located stratigraphically in the basal part of the 2.2 m thick interval between GZ-6 and GZ-7, as distinguished by SANTAMARIA (1991, Text-fig. 10). In contrast to the Barranca, the horizon here yields a more diverse ammonite fauna. The lower 0.5 m, composed of alternating 0.1 m thick marls and marly limestones, are particularly fossiliferous.

The second limestone bed includes a level with sporadic inoceramids, comprising *M.* cf. *labiatus*, *M.* ex gr. *labiatus*, *M. mytiloides*, *M.* cf. *hercynicus*, and *M.* m.f. *labiatus/kossmati*. The ammonites are dominated (up to 50% of the assemblage) by *Kamerunoceras ganuzai*. The assemblage also includes *Spathites reveliereanus* (19%), *Lecointriceras fleuriausianum* (6%), *Fagesia* sp. (13%), *Choffaticeras* sp. (6%), and *Placenticeras* aff. *cumminsi* (6%). The latter three genera indicate a stronger Tethyan or warm-water faunal influence in the Estella area. About 1.5 m above the alternation a marly limestone bed yields a second frequency-maximum of *K. ganuzai* associated with *P.* aff. *cumminsi*. A similar ammonite association, comprising *K. ganuzai* (= *Kamerunoceras puebloensis* COBBAN *sensu* SANTAMARIA), *Fagesia pachydiscoides*, *Fagesia* sp., *Pachydesmoceras linderi* (DE GROSSOUVRE), *Lecointriceras fleuriausianum*, and *Choffaticeras pavillieri*, was also reported by SANTAMARIA (1991, 1992) in these beds.

Spathites reveliereanus Event

In the Ganuza I (GA) and Ganuza II (GI) sections, the *reveliereanus* Event spans an interval several metres thick. The succession is composed of nodular calcareous marls or layers of calcareous nodules (GI-1 to GI-2, and GA-3 to GA-4 respectively), separated by a some m-thick marly horizon (*see* Text-figs 14, 18). In contrast to the equivalent level in the Barranca (Text-fig. 11), medium-sized spathitids are common, while the rather sparse inoceramids are more diverse. The latter are represented by *Mytiloides mytiloides*, *M.* cf. *mytiloides*, *M.* ex gr. *labiatus*, and *M.* m.f. *labiatus/kossmati*, with a dominance of *M. mytiloides* and *M.* cf. *mytiloides* (*see also* LOPEZ 1990, Text-fig. 11). LOPEZ also listed *M. transiens* (SEITZ) and commoner *M.* cf. *transiens*. The ammonite fauna is composed mainly of *S. reveliereanus*, juvenile forms of *Spathites* and *Mammites*, and *N.* (*Eubostrychoceras*) aff. *matsumotoi*. *Spathites obliquus* (KARRENBERG), *Spathites robustus*, and *Spathites subconciliatus* occur rarely (LAMOLDA & *al.* 1989). Fagesiids are common, while sciponoceratids and choffaticeratids are rare.

Kamerunoceras turoniense/ Mytiloides hercynicus Event

In the Ganuza I section (Text-fig. 18) this stratigraphic event extends over 13 m from bed GA-9 to bed GA-10. The basal 0.3 m thick, shell-detrital limestone bed (GA-9), with *Mytiloides hercynicus* and *M.* cf. *hercynicus*, is followed by a *ca.* 7.0 m thick clayey marl (GA-9b) with two inoceramid horizons yielding *M. hercynicus* and *M.* cf. *hercynicus*. The overlying unit consists of *ca.* 2 m thick horizons of nodular limy marls or nodular limestone beds (bed 29 and 30) with a 1.6 m thick marly bed in between. These beds, as well as the two overlying ones, also yield inoceramids. LOPEZ (1990, Text-fig. 11) also listed *M.* cf. *hercynicus* also from the topmost part of this event-bundle and for several metres above. *M. labiatus*, dominant within the *turoniense/hercynicus* Event in the Barranca is missing here. Ammonites are very rare and of extremely low diversity. *K. turoniense* occurs sporadically, namely the compressed ribbed type *salmuriense*, but it is practically restricted to this interval. *P. denisonianum* is similarly rare.

Romaniceras kallesi/R. ornatissimum Event

This event lies in the *ornatissimum* Zone and is represented by an acme of romaniceratids above the m-thick limestone unit C2. In the basal part of the Ollogoyen section *R. kallesi* dominates also over *R. ornatissimum* while the associated fauna is composed of *Collignoniceras woollgari*, *Lecointriceras boreale*, *Lecointriceras* sp. and *Scaphites geinitzii*.

Scaphites geinitzii Bed

In the Ollogoyen section (Text-figs 15, 19) this very thin horizon, represented by a hard clayey marl, coincides with the FAD of *Subprionocyclus neptuni*, and is characterized by common *S. geinitzii*. It most probably lies at the base of the *S. neptuni* Zone, or at least in the basal part of this zone, and consequently in the basal part of the Upper Turonian.

Subprionocyclus I Event

This event is marked by a frequency maximum of *Subprionocyclus* spp., namely *S. neptuni* and *S.* ex gr. *neptuni-hitchinensis* but mainly specifically indeterminate specimens. In the Ollogoyen section (Text-fig. 15) it lies within a *ca.* 1.0 m thick interval (Ol-*111b), directly above bed Ol-110 (*after* LAMOLDA & *al.* 1989) or Ol-22 (after LAMOLDA & PROTO-DECIMA 1986). Ammonites are concentrated at three levels; in the topmost 0.03-0.05 m of Ol-110, as well as 0.3 m and *ca.* 1.0 m higher. *S. neptuni* and *S.* ex gr. *neptuni-hitchinensis* co-occur with rare *R. deverianum*, *Scaphites* sp. and *Hyphantoceras* cf. *reussianum*. The rare inoceramids are usually poorly preserved and therefore indeterminable, apart two specimens referred to *Mytiloides* ex gr. *striatoconcentricus*.

Subprionocyclus II Event

The second *Subprionocyclus* acme-horizon, where the genus comprises up to 70% of the ammonite assemblage, is located stratigraphically within the *normalis* Zone (*sensu* KÜCHLER & ERNST 1989), or the *Prionocyclus waltersdorfensis/germari* Zone as used here (Text-fig. 15). It lies about 31 m above limestone bed Ol-110 and about 3 m below bed T. 13 of SANTAMARIA (1991).

The ammonite association, beside *Subprionocyclus* ex gr. *neptuni-hitchinensis* and *S. hitchinensis* comprises *Romaniceras* cf. *deverianum*, *H.* cf. *reussianum*, *S. geinitzii*, and *S.* cf. *geinitzii*. Bed T. 13 corresponds to the level of the stratigraphically lowest occurrence of *Prionocyclus* cf. *germari*. In and above T. 13, SANTAMARIA (1991) still found representatives of the *neptuni – hitchinensis* group.

SUMMARY AND DISCUSSION OF THE BIOSTRATIGRAPHICAL RESULTS

Lower Turonian

According to the proposal of the Second International Symposium on the Cretaceous Stage Boundaries in Brussels 95, the base of the Turonian should be drawn at the FAD of the ammonite species *Watinoceras devonense* WRIGHT & KENNEDY (*see* BENGTSON 1996). At Ganuza, LAMOLDA & PERYT (1995) defined the base of the Turonian in terms of nannoplankton with the appearance of *Quadrum gartneri* PRINS, a level falling within the *Whiteinella archaeocretacea* foraminiferal zone. However, the base of the Turonian could not be recognized by means of ammonites.

WIEDMANN's zones introduced for the Lower Turonian of the Estella area (*see* WIEDMANN 1979a, Text-fig. 10), are largely unusable. This is also the case with the *Choffaticeras quaasi* Zone introduced by SANTAMARIA (1991, 1992) for the basal Turonian, and with the *Watinoceras coloradoense* Zone of LAMOLDA & *al.* (1989).

In the Estella area, *Kamerunoceras ganuzai* and *Mammites nodosoides* appear more or less simultaneously, at a much lower stratigraphical level than assumed by WIEDMANN, and already in his *Fallotites subconciliatus* Zone. An association with *Choffaticeras* spp. first occurs in the middle part of the *ganuzai/nodosoides* Zone. This part corresponds to WIEDMANN's *Paramammites*? *saenzi/Leoniceras discoidale* (or *Leoniceras discoidale*) Zone. Only above its appearance levels and in the middle part of the *ganuzai/nodosoides* Zone as introduced here, an association with *Choffaticeras* spp., corresponding to WIEDMANN's *Paramammites*? *saenzi/Leoniceras discoidale* Zone (or *Leoniceras discoidale* Zone) can be observed. In the Ganuza sections, WIEDMANN's zones from TU-II through TU-IV lie within the range of *K. ganuzai* and *fide* LAMOLDA & *al.* (1989) also in the range of *M. nodosoides* (*see* Text-fig. 16). Similarly, the *Ch. quaasi* Zone, or better, *quaasi* Assemblage of SANTAMARIA (1991) is incorrectly stratigraphically placed below the *M. nodosoides* Zone in Ganuza. In my opinion, this is the result of an incorrect interpretation of the Ganuza II (GI) section, which is located not below, but above, the GZ section, and consequently lies already above the FAD of *M. nodosoides* (*see* SANTAMARIA 1991, Text-fig. 10).

The only specimen of *Ch. quaasi* (PERON) in the GI section (Text-fig. 14) therefore comes from the middle part of the *ganuzai/nodosoides* Zone, well above the *ganuzai* Event. This corresponds to its first occurrence in the Barranca. The *ganuzai/nodosoides* Zone is treated here as the

Spanish equivalent of the European *nodosoides* Zone, which at Ganuza, at least, comprises the upper part of the *F. subconciliatus* Zone, as well as WIEDMANN's *L. discoidale* and *Schindewolfites ganuzai* zones. The widespread and relatively common *K. ganuzai* represents a much better index species than *M. nodosoides* in northern Spain. The latter, at least within the lower part of its range, is relatively rare in Navarra.

Middle Turonian

The FAD of the ammonite species *Collignoniceras woollgari* (MANTELL) was proposed (BENGTSON 1996) as the base of the Middle Turonian. This definition is, however, not suitable for northern Spain, where MANTELL's species is rare. Moreover, *C. woollgari* appears diachronously in different regions. Thus according to the data in this paper, it appears no lower than the *Romaniceras ornatissimum* Zone in the Estella area, while in France it is reported already from the upper part of the *turoniense* Zone.

This is the reason why WIEDMANN (1979b, Table 2) recognized an equivalent of the *woollgari* Zone in northern Spain, *i.e.* his *Collignoniceras* sp. Zone, only above the *K. turoniense* Zone (=Zone with *Neoptychites cephalotus*). The *Collignoniceras* sp. Zone of WIEDMANN corresponds, in the scheme presented here, to the *R. kallesi* and *R. ornatissimum* zones. Records of *C. woollgari* lower in the Turonian can be attributed to incorrect determinations. Consequently, *C. woollgari* does not match the requirements for a boundary marker of the Middle Turonian in northern Spain.

The base of the Middle Turonian is defined here with the FAD of *K. turoniense*. In the condensed sections of the Barranca, this species first appears within the *S. reveliereanus* Event, co-occurring with *M.* cf. *nodosoides* and with *S. reveliereanus*. In the more complete and more expanded successions of the Estella area, it seems to appear higher, where it is common for the first time within the *turoniense/hercynicus* Event.

With reference to the situation in France and northern Germany, *C. woollgari* has its FAD at the level of the *hercynicus* Event (ERNST & *al.* 1983), corresponding to the *turoniense/hercynicus* Event recognized here. Its FAD thus falls within the upper part of the *turoniense* Zone. Consequently, the French *turoniense* Zone (*sensu* AMÉDRO & BADILLET 1982) comprises both the upper Lower Turonian and the basal Middle Turonian, rather than (as previously postulated) only the lower part of the *woollgari* Zone. It is clear that *K. turoniense*, as already suggested by KENNEDY & WRIGHT (1979), COBBAN (1983) and ROBASZYNSKI & *al.* (1990), appear as low as Lower Turonian *M. nodosoides* Zone in the southern faunal province. In northern Spain the base of the *K. turoniense* Zone, defined by the FAD of the zonal index, thus falls within the *M. nodosoides* Zone of the northern European scheme.

Contrary to the view of SANTAMARIA (1991, 1992), it is possible to distinguish *Romaniceras kallesi*, *R. ornatissimum* and *R. deverianum* zones, above the *K. turoniense* Zone in the Middle Turonian of the composite Ganuza/Ollogoyen succession.

Upper Turonian

During the Second International Symposium on Cretaceous Stage Boundaries in Brussels, 95, no formal proposal was made regarding the base of the Upper Turonian. Apart from criteria based on ammonites, namely the FAD of *R. deverianum* or *S. neptuni*, an alternative proposal was to place the boundary at the FAD of the inoceramid species *Inoceramus costellatus* WOODS (*see* BENGTSON 1996). The FAD of *I. costellatus* lies close to that of *S. neptuni*. In Westphalia, the base of the Upper Turonian is taken at the *costellatus/plana* Event (*sensu* ERNST & *al.* 1983) which marks the FAD of *I. costellatus* (*see* KAPLAN 1986). KAPLAN & KENNEDY (1994) showed that the FAD of *S. neptuni* lay 4 m above the *costellatus/plana* Event. The two FADs are thus situated very close to one another, so that the new boundary criterion closely approximates to the most widely used boundary criterion in the sense of HANCOCK & *al.* (1977), *i.e.* at the base of the *S. neptuni* Zone.

In Spain (WIEDMANN 1960, 1965, 1979b; KÜCHLER & ERNST 1989) and in France (*e.g.* AMÉDRO & *al.* 1982) this boundary was commonly (in the traditional sense of DE GROSSOUVRE 1889) placed at the FAD *of* of *R. deverianum* (D'ORBIGNY). According to KENNEDY & *al.* (1986) *R. deverianum* co-occurs with *C. woollgari* in the Paris Basin, while according to AMÉDRO & *al.* (1982) in France it ranges up only to the FAD of *S. neptuni*.

In northern Spain, *R. deverianum* appears considerably lower than the FAD of *S. neptuni* (*fide* WIEDMANN *in* LAMOLDA & *al.* 1981) and ranges, in the Estella area, up to the topmost Upper Turonian, where it is recorded in association with *S. neptuni* in the *neptuni* Zone, and with *Prionocyclus* cf. *germari* in the *normalis* Zone (*i.e. waltersdorfensis*/*germari*) Zone (KÜCHLER & ERNST 1989).

In the Santander area, *R. deverianum* occurs likewise in a stratigraphically narrow interval below the FAD of *S. neptuni*, where it overlaps with *S. neptuni*, up to a high level in the *neptuni* Zone (*see* WIESE & KÜCHLER 1995, WIESE 1997). Furthermore in the Ollogoyen section *R. deverianum* was actually found mainly in the *neptuni* Zone (*see* KÜCHLER & ERNST 1989, SANTAMARIA 1992, and this paper). All these reports completely refute HANCOCK's (1991) statement that "nobody has ever found *R. deverianum* in the *S. neptuni* Zone of the Turonian as used here" as well as show the renewed ignoring of data by some members of the Subcommission, who assume that (*in* BENGTSON 1996) "The main problem lies, however, in the fact that the relative position of the FOs of the two species are uncertain, as they rarely co-occur". Contrary to the former view (*see* KÜCHLER & ERNST 1989) and in an approach towards the proposal of the Brussels Symposium, the base of the Upper Turonian is placed here at the FAD of *S. neptuni* (*see also* WIESE & KÜCHLER 1995), the definition which had already been used by LAMOLDA & *al.* (1989). In the Ollogoyen section there is an interval, below the FAD of *S. neptuni*, in which *R. deverianum* co-occurs with *H.* cf. *reussianum* and *S. geinitzii*, allowing a *R. deverianum* Zone to be distinguished in the topmost Middle Turonian.

The Upper Turonian of northern Spain may be divided into two ammonite zones, namely, the *S. neptuni* and *Prionocyclus germari* zones. In the Estella area, the *neptuni* Zone, as here defined, comprises the upper part of the *kallesi* Zone of SANTAMARIA (1991, 1992). In addition the topmost Turonian can also be treated as a *Cremnoceramus waltersdorfensis*/*Prionocyclus germari* Assemblage Zone.

The Spanish *waltersdorfensis*/*germari* Assemblage Zone is defined at the FAD of the inoceramid species *C. waltersdorfensis* (ANDERT) which in the Barranca appears around the *Micraster* ex gr. *normanniae-cortestudinarium* Event. It is assumed that the Spanish interval corresponds entirely to the German *Prionocyclus germari* Zone of KAPLAN & KENNEDY (1994).

In Germany, on the other hand, *C. waltersdorfensis* was first recorded by some authors (WOOD & *al.* 1984; KAPLAN 1986, 1988; KAPLAN & KENNEDY 1994, KAUFFMAN & *al.* 1996) in the uppermost part of the *P. germari* Zone, in an interval referred to as the *C. waltersdorfensis* Zone. This zone lies immediately beneath the Turonian/Coniacian boundary and ranges from the *Didymotis* II Event to the FAD of *Cremnoceramus rotundatus* (TRÖGER *non* FIEGE) in the German Salzgitter-Salder section (*see* KAUFFMAN & *al.* 1996).

However, KELLER (1982, p. 38; Text-fig. 17) reported one of the lowest German records of *C. waltersdorfensis* from the base of his *Subprionocyclus* aff. *normalis* Zone in the Sack Syncline (Sack I section). There, *fide* KELLER (1982), the species occurred rarely, in association with *S.* aff. *normalis*, between a tuff-layer and an abundance-maximum of *Micraster* ex gr. *leskei*/*cortestudinarium*. This *Micraster* acme is interpreted herein as an equivalent of the *Micraster* Event *sensu* ERNST & *al.* (197883). TRÖGER (1989, Text-fig. 2) also reported *C. waltersdorfensis* together with *M. incertus* and *M. labiatoidiformis* in Zone 19, which equates with the *M. labiatoidiformis* Zone *sensu* WOOD & *al.* (1984), *i.e.* above the *Hyphantoceras* Event and below the base of the *normalis* Zone (*sensu* KAPLAN 1988). The base of the *normalis* Zone, lying below the *Micraster* Event, corresponds more or less to the base of the *Inoceramus* aff. *frechi* Zone, now renamed the *Mytiloides scupini* Zone (*see* WALASZCZYK & TRÖGER 1996). On the other hand, the base of the *germari* Zone (which replaces the *normalis* Zone) is defined by the FAD of *Prionocyclus germari*, 3 m above the *Micraster* Event (KAPLAN & KENNEDY 1994). Recently, HORNA & WIESE (1997) reported *C. waltersdorfensis* in the lowermost part of the "Grauweiße Wechselfolge" in the Hoppenstedt section. There, the species occurs within the *scupini* Zone at a level correlatable to the lower part of the *germari* Zone (WIESE, *pers. comm.* 1998).

Taking these data from Germany into consideration, the FAD of *C. waltersdorfensis* seems to be in a similar stratigraphical position in northern Spain. In the Barranca, *C. waltersdorfensis* first appears around an abundance peak of advanced *Micraster* of the *normanniae-cortestudinarium* group, *i.e.* a time-equivalent of the German *Micraster* Event. In the Estella area, the latter is not developed, but *C. waltersdorfensis* occurs between an equivalent of the German *Hyphantoceras* Event and the FAD of *Prionocyclus* cf. *germari*.

In northern Spain, furthermore, the *waltersdorfensis/germari* Zone embraces an interval referred to as the *Romaniceras deverianum* Zone as well as to the *Subprionocyclus* ex gr. *neptuni-hitchinensis* Zone of SANTAMARIA (1991, 1992). Despite the fact, that *Mytiloides scupini* was not found during this investigation, the zone may also correspond to the *Mytiloides scupini/Prionocyclus germari* Assemblage Zone of WIESE (1997).

EVENTS; REGIONAL AND INTER-REGIONAL CORRELATION

Mytiloides kossmati Event

Because of the dominance of *Mytiloides kossmati* (HEINZ), the lowest *Mytiloides* Event recognized in the Estella area is called the *M. kossmati* Event. Based on its stratigraphical position, it can be correlated with the *Mytiloides* Event *sensu stricto* of authors. This event is interpreted as the first evolutionary burst of the genus *Mytiloides* above the Cenomanian/Turonian boundary (the first *Mytiloides*, e.g. *Mytiloides hattini* ELDER, occur already in the topmost Cenomanian). According to HARRIES & KAUFFMAN (1992) the *Mytiloides* Event is associated with the peak – highstand facies, at a time of maximum flooding. It is assumed that this burst was additionally favoured by the ending of the Oceanic Anoxic Event II (KAUFFMAN 1986) and/or the ending of the synsedimentary tectonics (ERNST & *al.* 1992, DAHMER & *al.* 1986, HILBRECHT & DAHMER 198694) connected with the Cenomanian Turonian Boundary Event (CTBE).

This *Mytiloides*-acme possesses a nearly world-wide record, and is noted at the boundary between *Watinoceras coloradoense* and *Mammites nodosoides* zones, or in the basal part of the latter zone, from Germany (ERNST & *al.* 1983, KAPLAN 1986), England (HANCOCK 1989, p. 574), as well as from thc Western Interior (KAUFFMAN 1986, KENNEDY & COBBAN 1991). From northern Spain, it was already indirectly reported by WIEDMANN & KAUFFMAN (1978), LAMOLDA & *al.* (1989) and LOPEZ (1990). This *Mytiloides*-acme thus seems to be nearly isochronous. However, the composition of the inoceramid populations at species level in this event differ markedly, probably for ecological reasons. Thus, in Germany (*see* DAHMER & *al.* 1986) and similarly also in Colorado, Western Interior, it is dominated by *Mytiloides mytiloides*. In the studied Spanish sections the dominant form is *M. kossmati*. At Pueblo/Colorado, according to KENNEDY & COBBAN (1991) (*see also* BENGTSON 1996) the first *Mytiloides* abundance peak (the *Mytiloides* Event of BIRKELUND & *al.* 1984) is recorded from within the *nodosoides* Zone.

Kamerunoceras ganuzai Event

It is defined as an abundance-maximum of *K. ganuzai*, associated with another *Mytiloides*-acme, in the middle part of the upper Lower Turonian *ganuzai/nodosoides* Zone. It is so far known only from Navarra, where it provides the first isochronous horizon between the Barranca and the Estella area. In the Santander area, the stratigraphical interval with the inferred position of the *ganuzai* Event falls in a hiatus that extends up into the *Kamerunoceras turoniense* Zone (*see* WIESE 1997).

Spathites reveliereanus Event

As in the case of the *ganuzai* Event, the *reveliereanus* Event, represented by an acme-occurrence of spathitids (including the index species, *S. reveliereanus*) has so far been recognized only in the Barranca and the Estella area (Text-fig. 18). It is situated at the base of the *K. turoniense* Zone. However, similar acme-occurrences of *Spathites* are also known from France (*see* AMÉDRO & HANCOCK 1985, Text-fig. 2) (*see* Text-fig. 20) but their event character and stratigraphical position require further study. The combination of the *reveliereanus* Event with yet another *Mytiloides*-acme suggest that it might be an equivalent of the so-called 3rd *Mytiloides* Event in northern Germany.

Middle Turonian Event (MTE)

This event was probably induced by regional tectonism in the Middle Turonian. In the Arardi and Izurdiaga sections of the Barranca, it is expressed by the *kallesi/ornatissimum* Event, a bed of hiatus concretions and reworked ammonites within a hardground series in the Middle Turonian *ornatissimum* Zone. The exact horizon of the *kallesi/ornatissimum* Event has not so far been established in the more expanded Ganuza/Ollogoyen section.

In northern Spain the event seems to be slightly diachronous. Near Santander, it is apparently earlier and documented by the so-called *kallesi* Event (*sensu* WIESE 1995), which falls into the upper part of the *kallesi* Zone. WIESE (1995) described a m-thick succession of glauconitic limestones and glauconite marls in proximally located sections, the topmost bed of which forms a *Thalassinoides* hardground.

The *kallesi* Event represents a mass-occurrence of the index taxon, as well as of large *Pachydesmoceras* cf. *denisonianum*, *Puzosia* sp., *Neoptychites cephalotus* and *Spathites reveliereanus*. The sedimentary characteristics and the preservation of the fauna indicate, as in the Barranca, low sedimentation rates and reworking. WIESE & WILMSEN (*in press*) interpret the *kallesi* Event as a fossil accumulation during a sea-level highstand. In this context, it can be explained as generated by a low sedimentation rate and/or condensation (WIESE 1995).

Kamerunoceras turoniense/Mytiloides hercynicus Event

This event lies in the upper part of the *K. turoniense* Zone. In northern Spain it is expressed by a mass-occurrence of ammonites, particularly of *Sciponoceras bohemicum*, *Kamerunoceras* spp. and *Spathites* spp. This characteristic and often high diversity assemblage is well documented in condensed, outer shelf sections, situated in marginal parts of submarine swell (Text-fig. 18). The associated

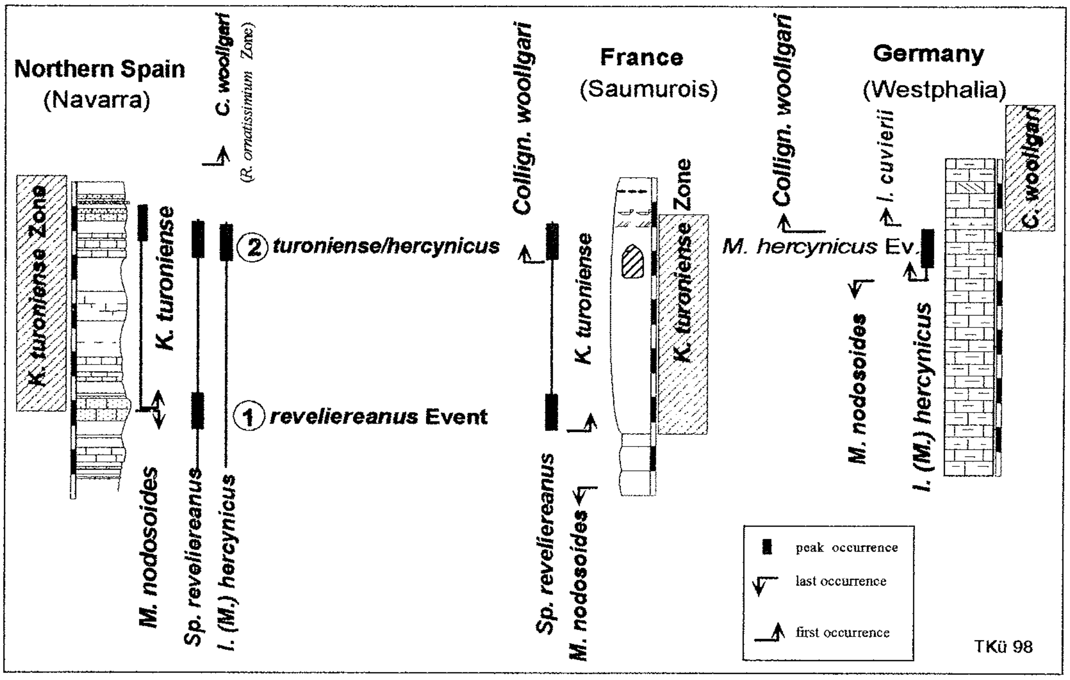


Fig. 20. The position of the *reveliereanus* and *turoniense/hercynicus* events within the local ranges of *Kamerunoceras turoniense* in northern Spain and in France and calibration of the local FADs of *Collignoniceras woollgari* and the local LADs of *Mammites nodosoides* in northern Spain, France, and north-western Germany by using these events as more or less isochronous marker horizons; as *C. woollgari* enters the interval around the *hercynicus* Event in north-western Germany, and in the same position (*turoniense/hercynicus* Event) in France, this level is of importance for an inter-basinal correlation and can aid, as an isochronous marker, for calibration of different biostratigraphic frameworks. In northern Spain, *C. woollgari* appears delayed in the *Romaniceras ornatissimum* Zone, this means one ammonite zone later. The base of the Middle Turonian, defined at the FAD of *C. woollgari* (BENGTSON 1996), would approximate the position of the Spanish *turoniense/hercynicus* Event

inoceramids are dominated by *Mytiloides labiatus* (SCHLOTHEIM). Towards more proximal sections with thick sedimentary successions, due to high accumulation rates (*e.g.* Estella Basin) and more basinward, bathymetrically deeper positions (*e.g.* Satrustegui), the ammonite frequency markedly decreases. In the latter case, the decrease is probably attributable to a reduction in the preservation potential of the ammonites. In the same directions, the ratio between *M. labiatus* and *M. hercynicus* also changes with an increasing dominance of the latter species.

The *turoniense/hercynicus* Event is, moreover, the highest level of common occurrence of *M. hercynicus* or similar forms. Above this event, there are only sporadic occurrences of forms referable to *M.* cf. *hercynicus*.

According to ERNST & KÜCHLER (1992), the *turoniense/hercynicus* Event of northern Spain corresponds to the *hercynicus* or *subhercynicus* Event, *sensu* ERNST & *al.* (1983) of northern Germany. The latter event lies in the basal part of the *apicalis/cuvieri* Zone and, in basinal sections, is recorded by an acme of the index inoceramid. The *hercynicus* Event is recorded from several sections in both Lower Saxony and Westphalia. In Westphalia, KAPLAN (1986) reported the lowest *Collignoniceras woollgari* from this level. This species is widely distributed but of rare occurrence in this area. However, in the marginal deposits of the Haarstrang, *C. woollgari* is common, associated with *Sciponoceras bohemicum*, *Neocrioceras multinodosum*, *Lewesiceras peramplum* (MANTELL), and *Collignoniceras carolinum* (D'ORBIGNY).

In my opinion, this event is also recognizable in France, where it likewise corresponds to the FAD of *C. woollgari*, whereas in northern Spain *C. woollgari* appears well above this level, together with *Romaniceras kallesi* and *R. ornatissimum* (Text-fig. 20). In France and in Spain the LAD of *S. reveliereanus* is in the level of the *turoniense/hercynicus* Event or a short distance above. In Germany, the first *Inoceramus apicalis* and *I. cuvierii* appear more or less simultaneously in the *hercynicus* Event.

In France the *turoniense/hercynicus* Event can be recognized at Saumur (Saumurois) and near Taillebourg (Charante) in Aquitaine. In my opinion, it lies in the uppermost 4.8 m of unit C of the Tuffeau de Saumur in the quarry of Trésorerie, south-east of Saumur (*compare* ROBASZYNSKI & *al.* 1982, p. 131, Text-figs 3 and 5-6). From that level were recorded about 124 ammonite specimens referred to *Lewesiceras peramplum* (46% of the collection), *S. reveliereanus* (25%) and *K. turoniense* (15.3%), with subordinate *Neoptychites cephalotus*, *Spathites combesi* and *Lecointriceras costatum*. The species *C. woollgari*, which has its FAD at this level, belongs, according to KENNEDY & *al.* (1982) to the subspecies *C. woollgari woollgari* sensu COBBAN & HOOK (1980), an early form characteristic of the basal *C. woollgari* Zone. Thus, the base of the *woollgari* Zone and, consequently, the base of the Middle Turonian, lies in the upper part of the French *Kamerunoceras turoniense* Zone. The associated inoceramid fauna (from Saumur) is dominated by *M. mytiloides* and *M. labiatus*, with subordinate *M. hercynicus*, which is very characteristic of this interval (*see* ROBASZYNSKI & *al.* 1982, Text-fig. 5).

The other French section in which a *turoniense/hercynicus* Event can be inferred is the 57 motorway cutting near Taillebourg, described by AMÉDRO & HANCOCK (1985, Text-fig. 2) and interpreted by them as extending from the *Mammites nodosoides* to the *R. kallesi* Zone. In my opinion, both the *reveliereanus* Event and the *turoniense/hercynicus* Event were exposed in this section which, therefore, spanned only the *turoniense* and *kallesi* zones. The *ca.* 2 m thick interval of the *turoniense* Zone, sensu AMÉDRO & HANCOCK (1985) is here interpreted as the *turoniense/hercynicus* Event, recorded by a marked acme of *Spathites reveliereanus*, associated with *C. woollgari*, rare *K. turoniense* and *Neoptychites cephalotus*. On the other hand, the 1.0 m thick interval the 5 m and 6 m marks in their section, which yields an abundance-maximum of *S. reveliereanus*, associated with rare *M. nodosoides*, is interpreted here as the *reveliereanus* Event. It is inferred to correspond with the 2.5 m thick bed d of Unit C of the quarry La Trésorerie more or less simultaneously near Saumur, which is assigned to the basal *turoniense* Zone.

Lower Upper Turonian Event (LUTE)

This event is interpreted here as a tectonic event with inter-regional importance. Its culmination falls within the *neptuni* Zone and comprises a set of tectonic activities that can be dated to fall between the time-equivalents of the

German *costellatus/plana* Event (basal Upper Turonian) and the *Hyphantoceras* Event (*sensu* ERNST & *al.* 1983). It was, most probably, caused by increasing tiltblock-halfgraben tectonics within the Basco-Cantabrian Region.

In the Barranca, the LUTE is expressed by tectonic uplift of the most eastern part, *i.e.* the area between Sarasate and Urrizola, which generated turbidite sequences as well as extended hiati by reworking in that interval. Contemporaneously, the Estella area was affected by continuing subsidence, and here the LUTE is marked only by an increase in the number of turbidites in the interval between the *geinitzii* Bed and the *Subprionocyclus* I Event. Similar, time-equivalent, tectono-sedimentary events were also noted by WIESE (1997) in the North Cantabrian Basin (northern Cantabria, Spain), and may be expressed by the tuffs in the north German sections.

Scaphites geinitzii Bed

This event marks the FAD of *Subprionocyclus neptuni* in the continuous section of the Estella area. Because of its bio- and event stratigraphical position, it is inferred to correlate with the level of the German *costellatus/plana* Event *sensu* ERNST & *al.* (1983), which was named after the echinoid *Sternotaxis plana* and the inoceramid *I. costellatus*. The FAD of the latter index species was suggested as a basal boundary marker for the Upper Turonian (BENGTSON 1996). This marker-horizon was originally interpreted as an ecoevent but, in condensed north-west German sections, it is associated with a period of condensation and reworking. It has, consequently, to be interpreted in a wider, inter-regional, context. In marginal positions (*e.g.* Barranca), the Spanish *geinitzii* Bed, falls in a hiatus induced by the LUTE (Text-fig. 18) and it is expressed by the *deverianum/rhodanicum* Event.

Subprionocyclus I Event

In a middle shelf position, this event is characterized by the first abundance peak of *Subprionocyclus* spp. together with rare *Scaphites* sp. indet, *R. deverianum* and *Hyphantoceras* cf. *reussianum* (Text-Fig. 15). Inoceramids (*Mytiloides* ex gr. *striatoconcentricus*) are extremely rare. The faunal composition and stratigraphical position of the event within the *neptuni* Zone suggest that it may equate with the *Hyphantoceras* Event established by ERNST & *al.* (1983) in Germany. The lithological and faunal features of this latter event, were described from section in Lower Saxony (ERNST & *al.* 1983, WOOD & *al.* 1984, DAHMER & ERNST 1986) and from the Münsterland Cretaceous Basin (KAPLAN 1988, 1991). The *Hyphantoceras* Event can be recognized throughout central Europe.

In northern Spain, the inferred equivalent of the *Hyphantoceras* Event has so far been found only in the continuous Ollogoyen section. From this section, it is traceable to the Izurdiaga and Arardi sections in outer shelf, albeit occupying local swell positions with stratigraphically condensed successions. At Izurdiaga, two events, the *geinitzii* Bed and the *Subprionocyclus* I Event, are probably condensed and expressed by the so-called *deverianum/rhodanicum* Event. This event yields an ammonite assemblage with *R. deverianum*, *Romaniceras* sp., *Puzosia* sp., *Puzosia muelleri* and *Tongoboryceras* sp. in a distal position. Towards the swell, in the more proximal Arardi section it is expressed by reworking. The conglomerate above the hardground (Ar-89) consists of glauconitized and phosphatized flat pebbles as well as phosphatized ammonites, particular small-sized *Tongoboryceras* spp. The faunal composition, *i.e.* the presence of single *I. costellatus, Neocrioceras* (*Schlueterella*) cf. *multinodosum* and *Baculites undulatus*, indicates the base of the *neptuni* Zone as well as a higher level in the *neptuni* Zone. It is suggested that this level corresponds to both the *costellata/planus* and the *Hyphantoceras* Event in German sense. The *deverianum/rhodanicum* Event of the Arardi section, on the other hand, correlates with the so-called *deverianum* Event *sensu* WIESE (1997) in the Santander area, Cantabria, which lies in the lower part of the neptuni or *neptuni/deverianum* Assemblage Zone *sensu* WIESE (1997).

Coniacian – Santonian

In the western Barranca, the Coniacian is relatively homogenous and developed in marly or calcareous marl facies. Between Satrustegui and Alsasua, the lowermost part of Lower Coniacian is missing. South of Iturmendi, ZANDER (1988) reported a thickness of about 300 m for the

Coniacian, of which *ca*. 100 m were Lower Coniacian, developed in marly facies, and the remaining 200 m were Middle Coniacian, characterized by calcareous marls. ZANDER (op. cit.) interpreted these sediments as shallow shelf deposits. Further to the west, south of Olazagutia, at least in the lower part of the *Dicarinella concavata* foraminiferal Zone (Middle to Late Coniacian) the foraminiferal associations reflected a deeper outer shelf position.

At Olazagutia, the Santonian reaches a maximum thickness of *ca*. 230 m in the Quarry of the Cements Portland S.A. Cantera de Margas (KANNENBERG 1985, and Text-fig. 28B). GRÄFE (1994), however, gives a Santonian thickness of only 140 m for the same quarry, where he recognized the Lower Santonian (upper part of the *Dicarinella concavata* Zone) and the Upper Santonian *Dicarinella asymetrica* foraminiferal Zone. According to that author the benthonic foraminiferal associations of the *asymetrica* Zone suggested deposition in a deeper basin at about 500 m depth.

Toward the east, in the direction of Irurzun, the thicknesses of both the Coniacian and Santonian decrease rapidly and the facies changes from marly sediments towards a calcareous, glauconitic facies (*see* Text-fig. 27). While near Zuazu the Coniacian and Santonian still reach a thickness of about 200 and 100 m respectively, the thickness of both stages at Izurdiaga is reduced to *ca*. 248 m as a result of condensation and hiati. Tectonic movements of the Ilsede Subhercynian Phase *sensu* STILLE (1924) caused uplift structures and led, in the eastern Barranca, to strong facies differentiation towards a structural high, which is well documented by the sections between the villages of Urrizola and Sarasate. The succession of thick-bedded limestones and alternations of limestones and calcareous marls in this area is referred to the Izurdiaga Group, which is described in more detail below.

LITHOSTRATIGRAPHY OF THE CONIACIAN AND SANTONIAN OF THE EASTERN BARRANCA

Izurdiaga Group (Upper Turonian – ?Upper Santonian)

The type locality of the Izurdiaga Group is the village of Izurdiaga, situated *ca*. 1.5 km south of Irurzun (Text-fig. 1). RADIG (1973) already used the name Izurdiaga Limestones for the succession of limestone and alternations of limestone and calcareous marls exposed at this locality, and he suggested a Coniacian – Santonian age. This interpretation was followed later by DEGENHARDT (1983) who made a detailed lithostratigraphical study of the type section situated east of the Alsasua – Pamplona railway. He, however, defined his base of the Izurdiaga Limestones considerably deeper than RADIG, at a level that is here placed within the Middle Turonian.

At Izurdiaga (*see* Text-fig. 27), the Izurdiaga Group shows an internal threefold subdivision. DEGENHARDT (1983) recognized the following units which are, in ascending order the Lower Izurdiaga Limestones, the Intermediate Marl and the Upper Izurdiaga Limestones. This subdivision, derived from the topographic features near Izurdiaga, was also applied to the exposures east and west of the type locality by KÜHN (1982) and KÜCHLER (1983). However, the significant facies changes, *i.e.* decrease of thicknesses towards the east (Text-fig. 27), as well as the absence of several sub-units of the Izurdiaga Group due to hiati, were not fully recognized at that time. Consequently, each author interpreted and subdivided the Izurdiaga limestones differently.

At the type locality the Izurdiaga Group is about 260 m thick. In the present paper, it is divided (in descending order) into three formations:

(i) Upper Izurdiaga Limestone Formation.
(ii) Zuazu Formation
(iii) Lower Izurdiaga Limestone Formation

The terms Lower and Upper Izurdiaga Limestones, used informally by DEGENHARDT (1983), KÜHN (1982) and KÜCHLER (1983), are herein given formal formation status, albeit with revised definitions and limits. The newly introduced Zuazu Formation (herein) based on the sections at Zuazu, rather than on those at Izurdiaga, includes at the base the up to 30 m thick *Sternotaxis* Marls, which were previously termed the *Zwischenmergel* (Intermediate Marls) by KÜHN (1982). At Zuazu a second marly unit, the *Micraster* Marls, is separated from the *Sternotaxis* Marls by a unit of alternating calcareous marls and limestones. At the type locality for the Izurdiaga Group, the *Sternotaxis* Marls and part of the overlying unit are missing at an hiatus, and here the marls unit above the Lower Izurdiaga Limestones correspond to the *Micraster* Marls of the complete Zuazu section.

The stratotype Zuazu Formation extends from a level within the upper Lower Coniacian *Peroniceras subtricarinatum* Zone to a level within the Middle Santonian *Texanites quinquenodosus* Zone. The contact with the overlying Upper Izurdiaga Limestone Formation can be observed in the section south of Zuazu; at Izurdiaga the contact has not yet been accurately identified because of the lack of detailed studies. However, it is placed at a distinct limestone boundary, *i.e.* at the base of bed IzI-153 (*see* Text-fig. 27).

Distribution: In its characteristic topographic expression as a range of scarps, the Izurdiaga Group is limited to the eastern part of the Barranca. This chain of hills, composed of almost vertically dipping beds, strikes in a NNW – SSE direction and accompanies the Sierra de Satrustegui from Izurdiaga to Ecay. The range is also a part of the Sandaña-Sollaondi Anticline (KÜCHLER 1983), the northern flank of which is cut out west of Sarasate by the Irurzun – Larumbe Fault. Near Ecay, the Izurdiaga Group is cut off by a N-S trending fault. In the area west of Zuazu – Satrustegui, the Izurdiaga Group is intensively folded and divided into blocks by transverse faults.

Toward the west, the Zuazu Formation and the Upper Izurdiaga Limestone Formation of the Izurdiaga Group become more marly, simultaneously increasing in thickness and grading laterally into the so-called Barranca Member and in the Olazagutia Formation *sensu* AMIOT (1982).

Stratigraphical position of the Izurdiaga Group: Contrary to previous opinions of RADIG (1973), KÜHN (1982), DEGENHARDT (1983) and KÜCHLER (1983), the lower boundary of the Lower Izurdiaga Formation, as here defined, lies in the lower Upper Turonian *Subprionocyclus neptuni* Zone. The formation extends up into the upper Lower Coniacian. The Zuazu Formation starts in the upper part of the *Peroniceras subtricarinatum* Zone. The Upper Izurdiaga Formation is unsatisfactorily worked out at the moment, but it starts in the Middle Santonian *Texanites quinquenodosus* Zone and probably extends up into the Upper Santonian.

Lower Izurdiaga Formation

The Formation consists of m-thick, nodular limestones and alternations of thinly bedded limestones with intercalated marls. Seven, in part strongly glauconitic subunits can be recognized locally. In the type locality at Izurdiaga, the formation is *ca.* 42 m thick (Text-figs 5, 27). At Arardi, where it is rather poorly exposed it reaches a thickness of *ca.* 31 m. At these two localities, as well as at Urrizola and Ecay, the formation forms a significant step in the landscape.

Type locality – Izurdiaga: At Izurdiaga (*see* Text-fig. 4) the base of the formation is defined by the appearance of the harder nodular limestones of unit E2, the limestone bed of which is marked by a hardground (IzI-92). This level corresponds to the boundary between the *deverianum* and *neptuni* zones (Middle to Upper Turonian).

The Lower Izurdiaga Limestone Formation is composed of seven lithological units. However, only the lower four units (up to bed IzI-109a), were investigated in detail. The description of the remainder of the succession and the lithological subdivision are taken from DEGENHARDT (1983, pp. 45-48).

Unit E2: This unit, 5.0 m thick, is composed of limestones ("calcisphere" packstones and echinoid debris packstones) with cm-thick intercalations of calcareous marls. The limestone beds are in part incipient hardgrounds (*sensu* KENNEDY & GARRISON 1975).

Unit F: This unit consists of a 7 m thick succession of mainly nodular limestones ("calcisphere" packstones), of variable thickness, and with intercalations of thin-bedded calcareous marls.

Unit G: This unit is about 5.0 m thick and consists of a glauconitic alternation of thin-bedded calcareous marls to marls (wacke-, pack- and grainstones) and nodular (0.1-0.2 m) limestones. This unit includes the Turonian – Coniacian boundary, which is situated in the glauconitic marl of bed IzI-105d.

Unit IzI-109a: This unit, *ca.* 1.1 m in thickness, is a highly glauconitic, silty biomicritic wackstone to packstone. Its thickness rapidly decreases westwards, so that in Urrizola W section, it is only 0.6 m thick (Text-fig. 27).

Unit IzI-109: This is a *ca.* 8.0 m thick unit, composed of nodular limestones, separated by thin horizons of calcareous marls.

Unit IzI-(110-112): The *ca.* 5 m thick unit is composed of bedded limestones, producing a negative topographic feature.

Unit IzI-114: This is a 11.5 m thick unit of poorly bedded limestones.

Reference section – Arardi: (Text-fig. 3): The base of the formation is again marked by a limestone bed with a hardground at its top. At Arardi, however, this bed is succeeded by an horizon of hiatus concretions (Ar-90). The basal bed is followed by a poorly exposed alternation of 0.3 to 0.4 m thick limestones and marls (0.1 m). The upper part of these *ca.* 31 m thick limestones is eroded or overgrown.

Zuazu section: In this section, which, in contrast to the Izurdiaga and Arardi sections represents a more distal situation, the equivalents of the Lower Izurdiaga Formation are represented by a *ca.* 43 m thick alternation of light grey, platy, up to m-thick calcareous marls and nodular, 0.1-0.2 m thick marly limestones of the Upper Coniacian *Peroniceras subtricarinatum* Zone.

Zuazu Formation

The Zuazu Formation was defined south of the village of Zuazu (Text-fig. 1). It consists of light calcareous marls, dark marls and intercalated light, nodular limestones. It reaches a maximum thickness of approximately 180 m.

Type locality Zuazu: Details of the stratotype Zuazu Formation are given later in this chapter, by a description of the localities Zuazu B and C (*see* Text-figs 21-22).

Izurdiaga section (Text-fig. 27): Near Izurdiaga, the Zuazu Formation overlies the Lower Izurdiaga Formation (unit 114) with a hiatus, comprising the so-called *Sternotaxis* Marls (Text-figs 21, 27, and DEGENHARDT 1983, Text-fig. III3). The *ca.* 8.0 m thick Unit 120 probably represents Member B (subunit B2) of Zuazu. It starts with a conglomerate of limestone pebbles and is mainly composed of an alternation of nodular limestones and calcareous marls of varying thickness.

Unit 120 is followed by the overgrown *ca.* 29 m thick Intermediate Marl (Iz-123), correlated here with the *Micraster* Marls (Member C) of Zuazu (*compare* Text-fig. 21). The upper part of the Izurdiaga section was not investigated in this study.

The next unit is a *ca.* 57 m thick succesion (Iz-124 to Iz-153), composed of m-thick, hard, nodular calcareous marls, intercalated in softer calcareous marls with, in the basal and middle part, intercalations of thin, glauconite calcareous marls.

Upper Izurdiaga Formation

Based on the investigation of the sections near Zuazu, the threefold division of the Izurdiaga Group is maintained, despite the fact that already at its type locality, and still further to the east, this subdivision becomes less clear because of the increasing extent of the hiati and rapid lateral facies change. This means that there is an amalgamation of the formations in this direction.

Type locality – Izurdiaga (Text-fig. 27): At Izurdiaga, DEGENHARDT (1983) placed the base of the Upper Izurdiaga Limestones immediately above the so-called Intermediate Marl, i.e. at a much lower level than that adapted here (base of IzI-153). However, his section is very useful because it is extremely detailed.

The Upper Izurdiaga Formation (Text-fig. 27) starts with a *ca.* 40 m thick unit of hard, in the upper part of well bedded, limestones, containing, according to DEGENHARDT, two pebble – beds in its topmost 6 m. The *ca.* 1.0 m thick top bed (Iz-162) is strongly glauconitic.

The succeeding unit is *ca.* 85 m thick. The lowest part consists of a marly interval of *ca.* 4.0 m. These are followed by harder, nodular calcareous marls, alternating with up to m-thick, softer calcareous marls. There are also some 1.0 to 2.0 m thick weakly to highly glauconitic beds. The topmost part of the unit is developed as 14-15 m thick interval of nodular, harder calcareous marls or nodular marly limestones, which become increasingly glauconitic upwards.

Zuazu: Near Zuazu, the Upper Izurdiaga Formation already begins to resemble the rhythmically bedded at least 85 m thick, limestone/marl succession of the western Barranca as seen in the Olazagutia quarry, and referred herein to the Olazagutia Formation (Text-fig. 28B) of AMIOT (1982).

SELECTED SECTIONS OF THE EASTERN BARRANCA

Zuazu B and Zuazu C (upper Lower Coniacian – Middle Santonian)

Location

(a) Zuazu B section (Text-fig. 21): Topographical map Ecay 114-12, 1:10 000, R=591.830, H=4.750.970; base of the section about 650 m south of the exit from Zuazu.
(b) Zuazu C (Text-fig. 22): Topographical map Ecay 114-12, 1:10 000, R=591.740, H=4.750.740; base of the section about 850 m south of Zuazu.

General remarks

South of the small village of Zuazu/Araquil there are several natural exposures. The beds dip gently at a low angle and comprise a normal succession, ranging stratigraphically from the Lower Coniacian to the Middle Santonian. The locality names Zuazu A and Zuazu B are taken from KÜHN (1982), who investigated the succession for the first time in this area. He dated it broadly as Coniacian and gave only a rather rough presentation of the sections.

At Zuazu, the Lower Izurdiaga Formation comprises a unit of calcareous marls and therefore no longer forms a positive features. The land rises gently towards the south, but with the onset of the limestones of the Santonian Upper Izurdiaga Formation, a scarp feature attaining a considerable altitude (*ca.* 700 m) is developed. The basal Coniacian, indicated at Izurdiaga by the *Cremnoceramus rotundatus* and *Forresteria petrocoriensis* zones, is missing at Zuazu. The Zuazu B section starts in the upper Lower Coniacian *Peroniceras subtricarinatum* Zone (Text-fig. 21), as indicated by the presence of *Peroniceras subtricarinatum* (D'ORBIGNY), *Cremnoceramus deformis* (MEEK), and *C. crassus* (PETRASCHECK) The succession is overthrust onto limestones of presumed Santonian age, so that the Coniacian succession is limited tectonically.

Up to the middle 1980s, the Zuazu B section was comparatively well exposed. Later, however, its upper part was destroyed by a newly constructed field road. The beds of the Zuazu B section dip almost vertically (80-90°). The exposure is limited by a fault zone.

The investigation of the Zuazu sections was supplemented by a second exposure, the Zuazu C section (Text-fig. 22), situated on a small elevation between the two brooks, *ca.* 850 m south of Zuazu. The base of the Zuazu C section lies south of the fault zone at an altitude of 540 m.The beds dip 30 to 40° to SE.

In the area between Ecay and Satrustegui the Coniacian reaches *ca.* 200 m in thickness, with a particularly thick upper Lower Coniacian reaching alone *ca.* 150 m. The Santonian attains a thickness of about 100 m, but only its lower part has been investigated in detail.

The upper Lower Coniacian is characterized by small hiati. A major hiatus occurs in the Coniacian/Santonian boundary interval. This hiatus is designated here by the term ULSE (=Upper Lower Santonian Event). The upper Lower Santonian or Middle Santonian (*Texanites quinquenodosus* Zone) discordantly overlies strata belonging to the Upper Coniacian *Protexanites bourgeoisi* Zone, the latter corresponding to the lower part of the Upper Coniacian *Paratexanites serratomarginatus* Zone *sensu* KENNEDY (1984a).

Lithostratigraphy

The illustrated succession of the Zuazu B section, *ca.* 97 m in thickness, starts about 4 m below the base of the Zuazu Formation (0 m level in Text-fig. 21). The whole of the Lower Izurdiaga Formation, *ca.* 43 m thick at Zuazu, is not shown. The boundary between the Lower Izurdiaga Formation and the Zuazu Formation is exposed about 630 m south to south-east of Zuazu. It is characterized there by a distinct lithological change from marl-limestone alternations to weakly lithified, dark marls. To the west, these marls are deeply incised by a brook that flows parallel to the strike of the beds.

Lower Izurdiaga Formation: Near Zuazu, distal equivalents of the Lower Izurdiaga Limestones overlie probable Santonian limestones at a tectonic contact. Above the contact, an up to 1.6 m thick limestone bed pinches out to the west and

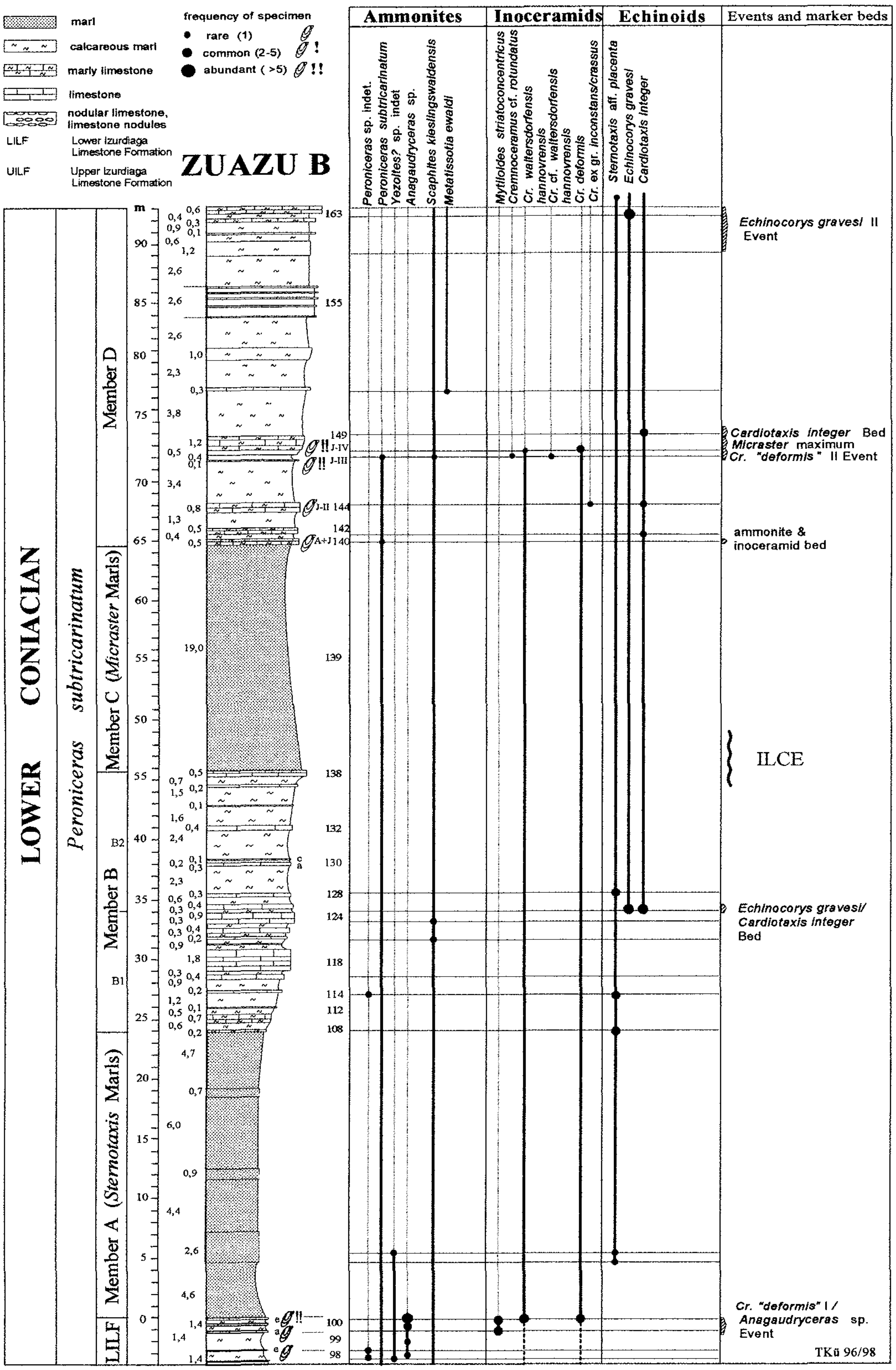


Fig. 21. Zuazu B section; litho-, bio- and event stratigraphy in the Lower Coniacian (*Peroniceras subtricarinatum* Zone); local ranges of ammonites, inoceramids and echinoids, the latter group without the *Micraster*, the most abundant taxa throughout the section

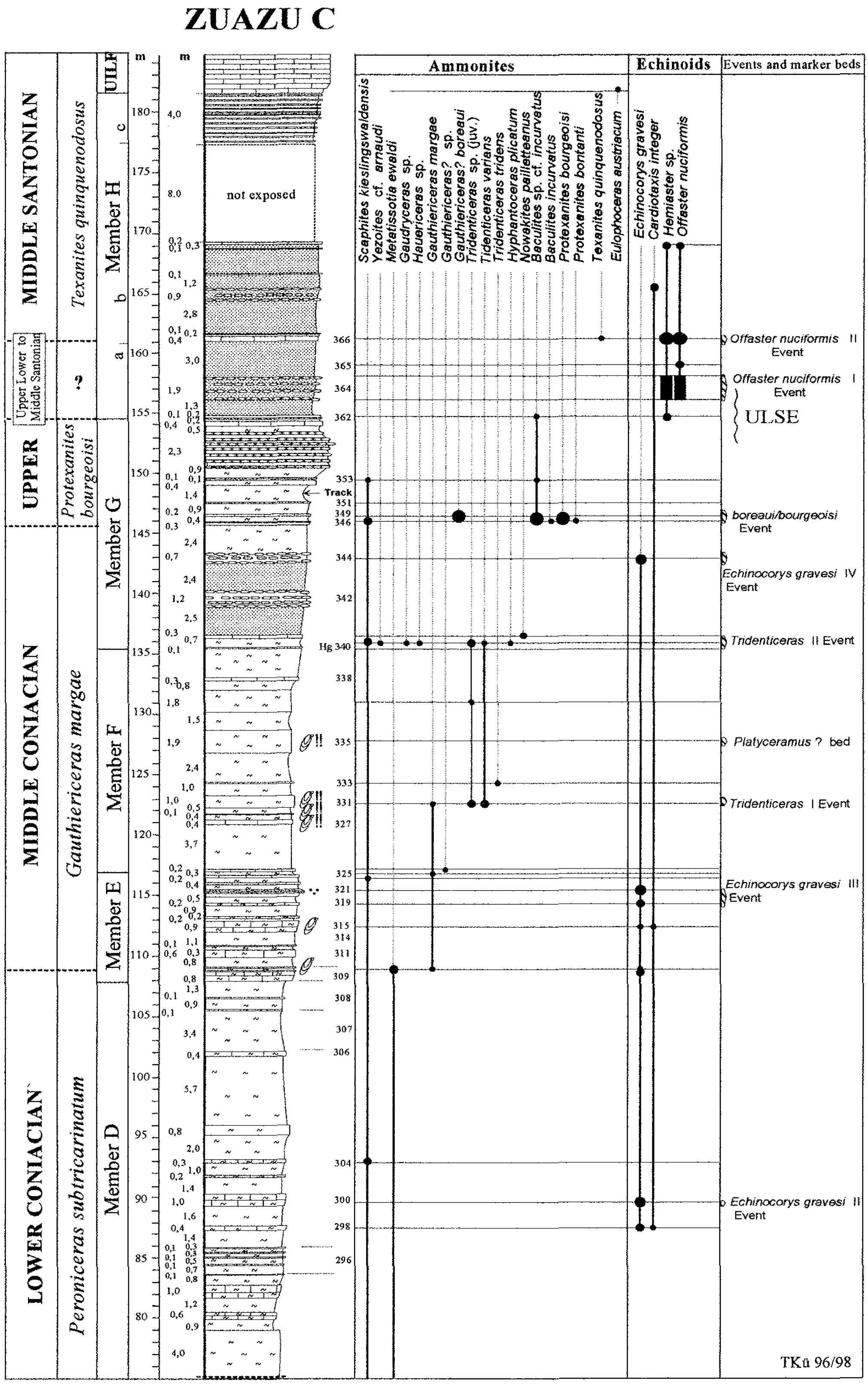


Fig. 22. Zuazu C section; litho-, bio- and event stratigraphical subdivisions of the Lower Coniacian to Middle Santonian succession; vertical ranges of selected macrofossil groups; the echinoids presented without the most abundant *Micraster* genus

east, rendered conspicuous by its yellowish weathering colour, as well as by the limonitised concretions on its upper surface.

The Lower Izurdiaga Formation is composed of a *ca*. 43 m thick alternation of light grey, platy, up to m-thick calcareous marls and nodular, *ca*. 0.1-0.2 m thick marly limestones. Groups of limestone beds together with single dm-thick calcareous marls build topographic ribs, on average 1.4 m thick. At least the upper part of the formation at Zuazu may be referred to the upper Lower Coniacian *Peroniceras subtricarinatum* Zone.

Zuazu Formation: The Zuazu Formation is composed of eight lithological units, characterized (in ascending order) below (Text-figs 21-22).

(viii) *Offaster* Marls (= Member H)
(vii) Nodular limestone Unit (= Member G)
(vi) Calcareous marl Unit (= Member F)
(v) *gravesi* Limestone/calcareous Marl alternation (= Member E)
(iv) Spongiolithic calcareous Marls (= Member D)
(iii) *Micraster* Marls (= Member C)
(ii) Calcareous marl/Marly limestone Unit (= Member B)
(i) *Sternotaxis* Marls (= Member A)

Sternotaxis Marls (= Member A): The *Sternotaxis* Marls correspond to the Intermediate Marl of KÜHN (1982) and have a thickness of about 24 m at Zuazu. The member, composed of dark grey brittle marls (4.4 to 6.0 m) with thin intercalations of harder, platy marlstones, overlies the Lower Izurdiaga Formation with a slight angular unconformity. The unit takes its name from the occurrence of the large-sized *Sternotaxis* aff. *placenta* AGASSIZ. *Micraster* ex gr. *cortestudinarium* is, however, much more common.

Calcareous marl/Marly limestone Unit (= Member B): This unit, 22 m thick, is bipartite. Its lower, 10 m thick part (ZuB-108 to 124) called B1, represents a thickening upward sequence, composed of dm-thick calcareous marls and well-bedded dm to m-thick limestones. The upper part, B2, is dominated by calcareous marls, with m-thick beds, and with intercalations of well-bedded, dm-thick limestones. The top bed ZuB-138, 0.5 m thick, is a useful marker horizon.

Micraster Marls (= Member C): This unit is a 19 m thick interval, of grey marls, characterized by the abundance of the echinoid *Micraster*. The marls pass gradually upwards into calcareous marls. About 14-15 m above the base of the unit sponges become common.

Spongiolithic calcareous Marls (= Member D): It is a *ca*. 41 m thick series of light grey, platy, calcareous marls weathering yellowish to dark grey, with intercalations of nodular, 0.1 to 0.3 m thick marly limestones. The calcareous marls sometimes build more resistant, up to m-thick beds, which form topographic steps and ribs. The beds ZuB-155 (=ZuC-296), comprising five, closely-spaced thin limestone beds, is recognizable as far as Satrustegui and may be used as a marker horizon. The characteristic feature of the whole unit is the abundance of siliceous sponges.

gravesi Limestone/calcareous Marl alternation (= Member E): This 8 m thick succession (ZuC-309 to ZuC-325) is composed of 0.1-0.2 m thick limestones or marly limestones and calcareous marls with upward decreasing bed thicknesses. These are sporadic, m-thick intervals of harder calcareous marls. The limestone bed ZuC-321 is slightly glauconitic. The member is characterized by the common occurrence of *Echinocorys gravesi*.

Calcareous marl Unit (= Member F): This 20 m thick unit (ZuC-326 to ZuC-340) is composed of light grey, platy calcareous marls, rich in *Micraster* spp. and sponges. The sponges are represented by cup- or mushroom-shaped as well as branching forms. Layers of large-sized, thin-shelled inoceramids are characteristic. The member terminates in a hardground (ZuC-340).

Nodular limestone Unit (=Member G): This 20 m thick unit forms a positive topographic feature. Its lower part is composed of up to m-thick, more resistant intervals consisting of several closely spaced layers of limestone nodules separated by dark grey calcareous marls (2.5 m). In contrast, the upper, *ca*. 5.0 m of the unit comprises an alternation of closely-spaced (0.1-0.2 m) calcareous marls and nodular, marly limestones. The marly limestones have a characteristic yellowish weathering colour. Near Zuazu, the unit starts in the upper part of the *margae* Zone and extends up to the top of the *Protexanites bourgeoisi* Zone.

This member probably corresponds to that exposed in the road section at the pass towards the Urbasa, south of Alsasua (*compare* ZANDER 1988) and to the Upper Coniacian alternation exposed in the Olazagutia quarry.

Offaster Marls (=Member H): In its lower part, the unit consists of dark grey marls to calcareous marls in a thickness of *ca.* 6 m. Intercalated in the marls are sporadic, m thick beds of limestones nodules. Above follows light grey marls *ca.* 8 m-thick, with sporadic intercalations of thin limestones. The index echinoid *Offaster nuciformis* ERNST is common over an interval of *ca.* 15 m. The top part of the unit is composed of a *ca.* 4 m thick closely spaced alternation of dark grey marls (0.1 m) and 0.05-0.08 m thick nodular, marly limestones, as well as beds of limestone nodules.

Upper Izurdiaga Formation: At Zuazu, a succession of thick bedded limestones, referred to the Upper Izurdiaga Formation, forms the next significant step in the landscape.

Fauna and biostratigraphy

Irregular echinoids: The succession at Zuazu is extraordinarily rich in irregular echinoids. The dominant genus *Micraster* exhibits many acme-occurrences. However, these have not been incorporated into the event stratigraphic framework, nor have ranges of indicated taxa been given, because a detailed taxonomic treatment of this group has not yet been carried out.

Echinocorys gravesi (DESOR) and *Cardiotaxis integer* (AGASSIZ) have long stratigraphic ranges, but in contrast to *Micraster*, they show acme-occurrences only in a few distinct beds. *Echinocorys* has four acme-occurrences, each of which is characterized by different morphotypes and sizes.

The genus *Sternotaxis*, represented by *Sternotaxis* aff. *placenta* (AGASSIZ) is limited to the middle part of the Lower Coniacian *Peroniceras subtricarinatum* Zone, while *Hemiaster* ranges from the Middle Coniacian *Gauthiericeras margae* Zone up to the Middle Santonian. The genus *Offaster*, with the species *Offaster nuciformis*, first appears in an stratigraphically uncertain interval between the upper Lower and the lower Middle Santonian.

Ammonites: The Coniacian succession of Zuazu is of considerable biostratigraphical importance, on the one hand because of the co-occurrence of inoceramids and ammonites and, on the other hand because of ammonite assemblages that show great similarities to those of the French type region of the Coniacian. This permits a calibration of biostratigraphical frameworks between these two areas. Additionally, the Barranca may be considered as a direct stratigraphical link between the French localities and the Spanish Burgos area with its local zones (WIEDMANN 1960, 1965, 1979b), which could not hitherto be correlated with those of the regions to the north.

The upper Lower Coniacian yields a low-diversity *Scaphites – Peroniceras* assemblage, with tissotiids occurring extremely rarely in the highest part of the substage. The ammonite diversity increases in the Middle Coniacian, where the ammonite fauna is characterized by a *Scaphites-Tridenticeras-Gauthiericeras* assemblage. The diversity decreases again in the Upper Coniacian, being characterized by the genera *Protexanites*, *Gauthiericeras*, *Baculites* and *Scaphites*.

Inoceramids: The inoceramids discussed here were determined by C. J. WOOD (Croydon, UK) and I. WALASZCZYK (Warsaw). *Mytiloides striatoconcentricus* ranges up to the upper part of the *Peroniceras subtricarinatum* Zone, in the Ecay E section up to the *Echinocorys gravesi* II Event. Representatives of the *Cremnoceramus waltersdorfensis* group disappear already earlier, in the *deformis* II Event (*see* Zuazu B section). The *Cremnoceramus erectus – deformis* lineage and *C. crassus* first appear together with *Peroniceras subtricarinatum*, in the lower part of the *Peroniceras subtricarinatum* Zone within the Lower Izurdiaga Formation at Zuazu (not figured). Late cremnoceramids as well as *P. subtricarinatum* were still found in the *Gauthiericeras margae* Zone, in the Zuazu A section just below above the *Tridenticeras* II Event.

In the *subtricarinatum* Zone, inoceramids occur in the topmost 4.2 m of the Lower Izurdiaga Formation, between beds ZuB-98 and ZuB-100e, and in the basal part of Member D of the Zuazu Formation, between beds ZuB-140 and ZuB-148 (*see* Text-fig. 21).

In the basal part of the *G. margae* Zone, inoceramids occur between beds ZuC-309 and ZuC-321. Layers of thick-shelled inoceramid fragments (probably *Platyceramus*? sp.) are abundant in an interval between beds ZuC-327 to ZuC-331, around the *Tridenticeras* I Event (Text-fig. 22). Single finds from bed ZuC-331 may represent *Inoceramus* cf. *percostatus* MÜLLER or forms close to *Cremnoceramus* aff. *inconstans* according to TRÖGER (*pers. comm.*).

Event stratigraphy

The exposures around Zuazu yield a sequence of marker-beds that have potential for regional correlation within the Barranca. Additionally, some of these events can be shown to have an interbasinal importance as they permit a precise dating and correlation of major tectono-sedimentary events, related to relative sea-level changes (for discussion *see* further below).

deformis I/Anagaudryceras sp. Event: This event is defined as an event-set, characterized by the common occurrence of the two eponymous taxa, the inoceramid *Cremnoceramus deformis* and a specifically indeterminate *Anagaudryceras*, at its top. At Zuazu, the event set comprises a 1.4 m thick interval of calcareous marls with 0.1-0.2 m thick intercalations of nodular limestones. Small *Mytiloides striatoconcentricus* are concentrated in two limestone beds at the base and at the top. *Micraster* sp. is abundant in the basal, 0.8 m part, of the event. Throughout the interval ammonites are common, particularly *Anagaudryceras* sp.

gravesi/integer Bed: This is a local acme-occurrence of *Cardiotaxis integer* and *Echinocorys gravesi*, found in bed ZuB-125, which is a 0.3 m thick calcareous marl. This bed and the underlying 0.9 m thick limestone serve as marker horizons for correlation of the exposures around Zuazu.

deformis II Event: This inoceramid-rich horizon lies *ca*. 8 m above the base of Member D. It yields *Cremnoceramus* cf. *rotundatus* as well as poorly preserved *C. waltersdorfensis hannovrensis* and *C.* cf. *waltersdorfensis hannovrensis*. The inoceramid abundance varies markedly over a lateral distance of only a few metres. As in the Ecay E section (Text-fig. 24). There is an abundance maximum of *Micraster* ex gr. *cortestudinarium* above the *deformis* II Event.

Cardiotaxis integer Bed: At Zuazu, this *Cardiotaxis*-rich horizon is located above the *deformis* II Event and *Micraster*-acme event-bundle.

Echinocorys gravesi II Event: The second *gravesi* maximum lies *ca*. 18.7 m above the *Cardiotaxis integer* Bed, around a 0.6 m thick horizon (ZuB-163; = ZuC-300).

gravesi III Event: The *gravesi* III Event is characterized by two distinct maxima of *Echinocorys gravesi* within an interval of 1.1 m (ZuC-319 to ZuC-321), the latter being accompanied by a *Micraster*-acme. The event lies at the top of the Member E.

Tridenticeras I Event: It is a *ca*. 1.0 m thick, calcareous marl (ZuC-331) with an accumulation of large undetermined inoceramids. It is characterized by the abundance of almost exclusively heteromorph ammonites of the genus *Tridenticeras* (juvenile *Tridenticeras* sp., *Tridenticeras varians*). This level marks the local FAD of the genus *Tridenticeras*.

Platyceramus? Bed: It is a prominent plaster of large inoceramids within a 1.9 m thick calcareous marl bed (ZuC-335).

Tridenticeras II Event: This is a fossiliferous interval (ZuC-340a) between a nodular limestone and a marly limestone bed. The lower of these beds is a 0.1 m thick incipient hardground. The intervening marl (*ca*. 0.3 m), as well as the higher limestones, are both very fossiliferous, yielding abundant inoceramids and an ammonite fauna dominated by tridenticeratids and scaphitids. The assemblage comprises *Scaphites kieslingswaldensis*, *Yezoites* cf. *arnaudi*, *Gaudryceras* sp., *Hauericeras* sp., *Tridenticeras varians*, *T. tridens*, *T.* sp., and *Hyphantoceras plicatum*.

Echinocorys IV Bed: The fourth *Echinocorys gravesi* maximum is recognized around bed ZuC-344.

boreaui/bourgeoisi Event: This event is defined by the abundance maxima of the two eponymous ammonites *?Gauthiericeras boreaui* and *Protexanites bourgeoisi* as well as *Baculites incurvatus* within a 0.7 m thick interval (ZuC-346 to ZuC-349). The event interval consists of two limestone beds and a calcareous marl between. The lower limestone bed yields siliceous sponges, and the second (ZuC-349) is additionally characterized by bivalves.

Offaster nuciformis I Event: It is a level of a mass occurrence of irregular echinoids of the genera *Offaster* and *Hemiaster*, in a stratigraphically uncertain position between the upper Lower and lower Middle Santonian. Near Zuazu, of the genus *Hemiaster* is more common than the eponymous *Offaster nuciformis* within the 1.9 m thick interval (ZuC-364) of dark grey marls and nodular limestones.

Offaster nuciformis II Event: The second *Offaster*-acme (*nuciformis* II Event) lies *ca.* 3.0 m above the first one in a *ca.* 0.7 m interval. It coincides in Zuazu with the first record of *Texanites* cf. *quinquenodosus* (REDTENBACHER).

Zuazu A (Middle Coniacian, *margae* Zone)

Location and remarks

Erosional gully 350 m south of Zuazu/Araquil, west of the track leading to the Sierra de Satrustegui (Topographical map Ecay 114-12, 1:10 000, R= 591.750, H= 4.751.220).

Text-fig. 23 shows the upper part, *ca.* 13 m in thickness, of a 100 m thick Coniacian succession investigated previously by KÜHN (1982, p. 48, Text-fig. 33). The beds are overthrust and dip northeast 30°.

The base of the measured section is taken at a nodular, marly limestone bed (ZuA-200) that forms a conspicuous rib in the gully. The interval from bed ZuA-200 to ZuA-205 correspond to the beds Az1 to B500 *sensu* KÜHN (1982) and falls in the Middle Coniacian *margae* Zone.

Lithology

In the gully, grey blue, platy marls to calcareous marls are exposed with intercalated layers of limestone nodules. In the upper part of the section four marly limestone beds are developed, one of which, bed ZuA-205a represents the lateral equivalent of hardground Hg340 (*Tridenticeras* II Event) of the Zuazu C section (Text-fig. 22).

Fauna

Siliceous sponges: Siliceous sponges occur commonly throughout the entire section.

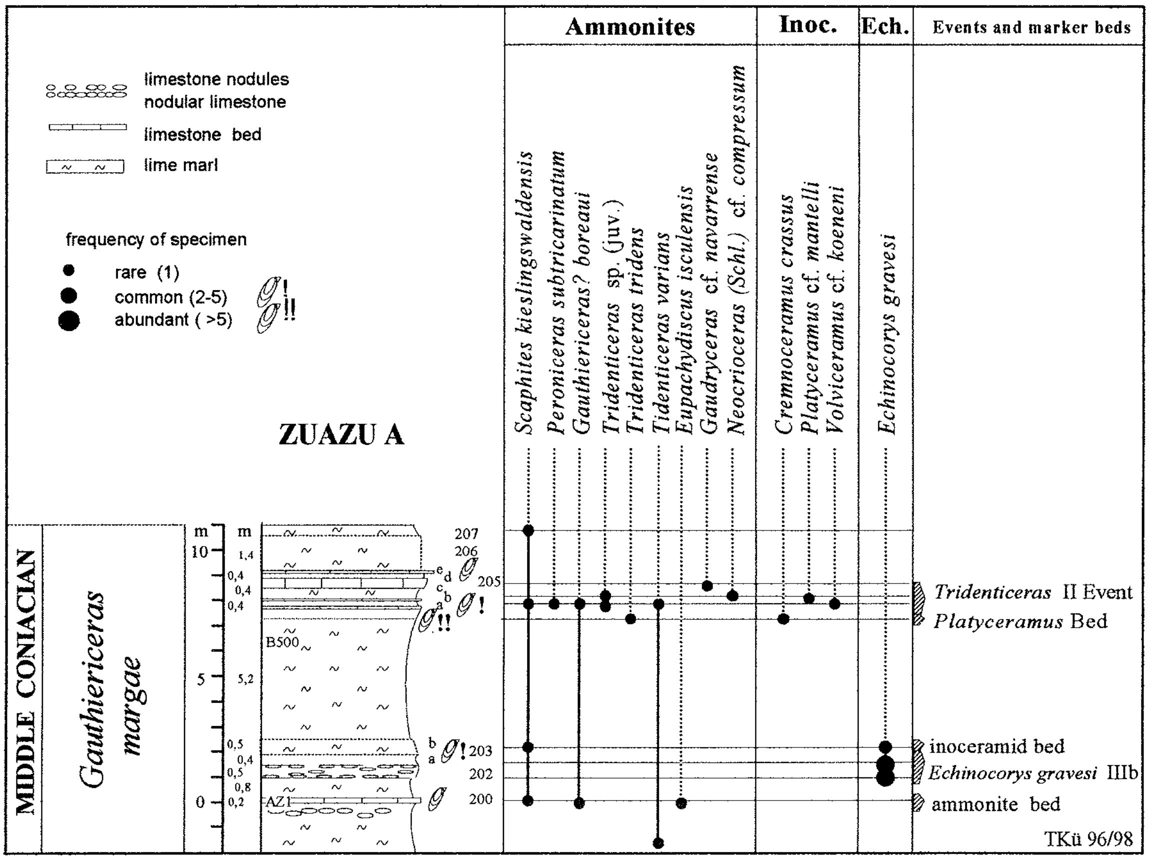


Fig. 23. Zuazu A section; lithology, bio- and event stratigraphy in the Middle Coniacian *Gauthiericeras margae* Zone

Echinoids: Among irregular echinoids, *Micraster* dominates the echinoid fauna. *Echinocorys gravesi* occur only in the two, closely spaced beds in the lower part of the section

Inoceramids: The upper part of the section is characterized by beds with large-sized inoceramids (probably *Platyceramus*), associated with late *Cremnoceramus*. In bed ZuA-205 a single specimen of *P. ?mantelli* MERCEY was found. WALASZCZYK (*pers. comm.* 2/95) determined two additional specimens from bed B500 and from ZuA-205 as *Cremnoceramus crassus* (PETRASCHECK) and *Volviceramus* cf. *koeneni* (G. MÜLLER) respectively. This is the first record of *Volviceramus koeneni* from Spain.

Ammonites: Ammonites, with the exception of *Scaphites kieslingswaldensis* are limited to distinct beds. Characteristic forms of the *margae* Zone comprise *Gauthiericeras*? *boreaui* (DE GROSSOUVRE), *Tridenticeras varians* (SCHLÜTER) and *Tridenticeras tridens* (SCHLÜTER). There are also single finds of *Eupachydiscus isculensis* (REDTENBACHER), *Peroniceras subtricarinatum* and *Neocrioceras* (*Schlueterella*) cf. *compressum* KLINGER.

Event stratigraphy

Ammonite bed: This is a *ca.* 0.2 m thick, nodular limestone bed (ZuA-200), which yields *Gauthiericeras? boreaui*, *Scaphites kieslingswaldensis* and *Eupachydiscus isculensis*.

Echinocorys gravesi IIIb Event: About 0.8 m above the ammonite bed, there is a *ca.* 1.0 m thick interval (ZuA-202 to ZuA-203a) with abundant small-sized, and followed by large-sized *Echinocorys gravesi*. There is also a *Micraster*-acme.

Inoceramid bed: This bed is characterized by large, thin-shelled inoceramids, directly above the *gravesi* maximum.

Platyceramus Bed: A conspicuous bed of large, thin-shelled platyceramids, intercalated within calcareous marls, about 0.4 m below the *Tridenticeras* II Event.

Tridenticeras II Event: This event represents an accumulation of ammonites with abundant gauthiericeratids and tridenticeratids. Inoceramids are represented by *Cremnoceramus deformis* and *Platyceramus ?mantelli*. As in the Zuazu C section, a limestone with a firmground and pyrite concretions is developed immediately beneath.

Ecay E (Lower Coniacian, *Peroniceras subtricarinatum* Zone)

Location

Calcareous marl rib (Text-fig. 24) about 200 m east of the village Ecay (Araquil) (Topographical map Ecay 141-12, 1: 10 000, R=593 000, H=47 51 350).

General remarks

Upper Cretaceous strata, from the Upper Cenomanian to the upper Lower Campanian are sporadically exposed in a N-S trending section (Text-figs 1, 27). The Izurdiaga Group forms three conspicuous NW-SE ridges that are abruptly truncated to the west at a NNE – SSW fault. Locally, its thickness is reduced to about 200 m by several NNE – SSW faults, running almost parallel to the strike. A major fault brings Cenomanian Flysch à boules into tectonic contact with the Lower Izurdiaga Formation (Text-fig. 27).

The Lower Izurdiaga Formation forms the northernmost scarp in the landscape. It reaches a thickness of *ca.* 60 m and consists of an alternation of hard limestones and calcareous marls, dipping at 80° towards the south. Because the lower part of the formation is tectonically disturbed and the upper 25 metres are to some extent overgrown detailed investigation proved difficult. Approximately 200 metres to the east, the highest part of the succession yielded an ammonite-inoceramid assemblage similar to that of the *deformis*/*Anagaudryceras* Event of Zuazu, thus indicating the *Peroniceras subtricarinatum* Zone. *Micraster* spp. occurs commonly throughout the entire section.

The Lower Izurdiaga Formation is probably overlain by the *Sternotaxis* Marls. This member of the Zuazu Formation is poorly exposed and also tectonically reduced (*compare* Text-fig. 27).

Litostratigraphy

Spongiolithic calcareous Marls (Member D): The second distinct elevations east of Ecay consists of

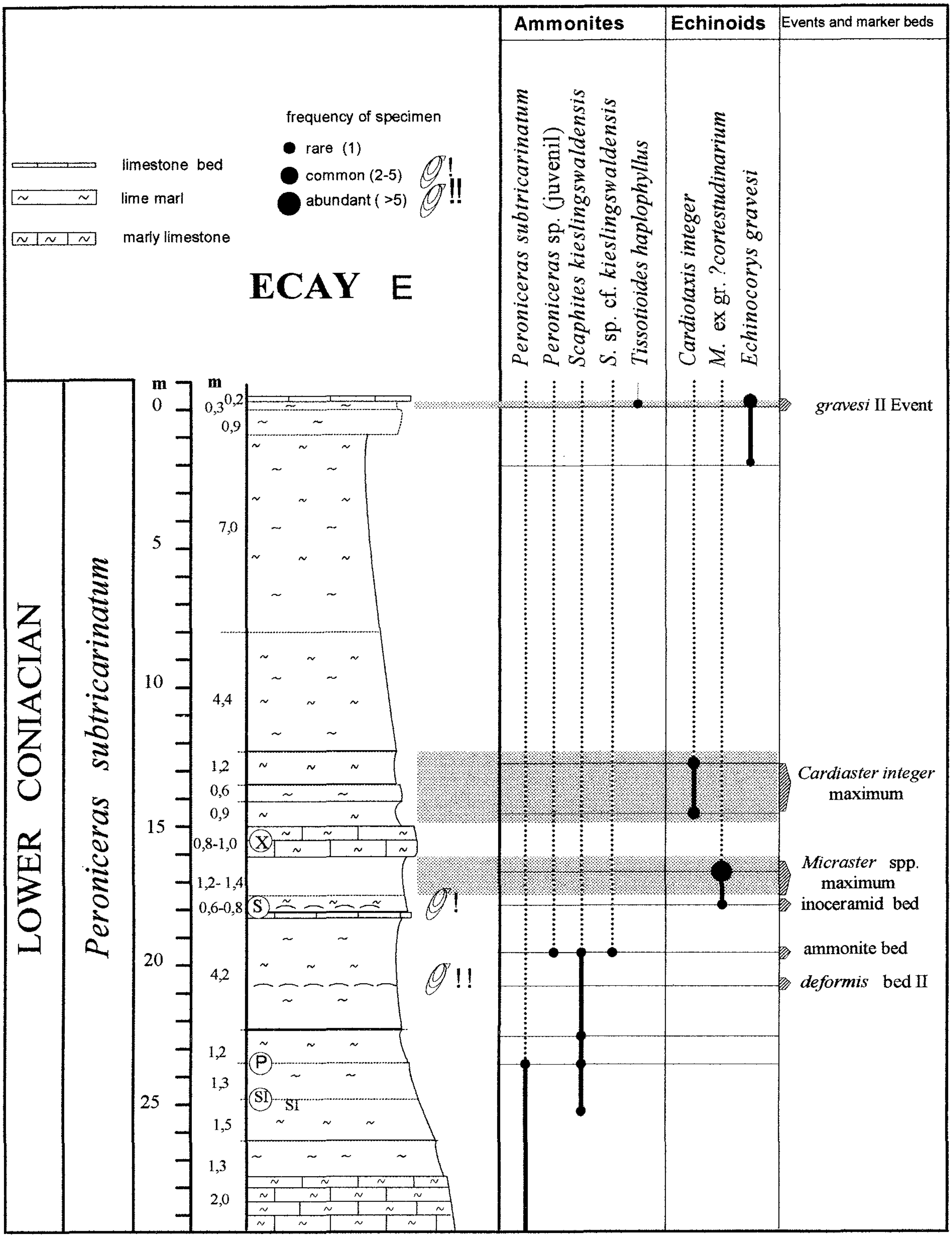


Fig. 24. Ecay E section; lithology, macrofossil occurrences and event stratigraphy in the Early Coniacian *Peroniceras subtricarinatum* Zone

light grey, platy calcareous marls. They are well exposed over an interval of *ca.* 30 m in the figured section (Text-fig. 24). The calcareous marls, characterized by abundant siliceous sponges, include a few 0.1 m thick, nodular intercalations of hard marly limestones. The more resistant parts of the calcareous marls, form distinct steps in the field. For further subdivision the event occurrences of *Cardiotaxis integer* and *Echinocorys gravesi* were used.

Fauna and biostratigraphy

Ammonites: The ammonite association is dominated by scaphitids and peroniceratids [*Peroniceras subtricarinatum* (Pl. 12, Fig. 4), *Peroniceras* sp. (juveniler)], with the occurrence and abundance of *Scaphites kieslingswaldensis* LANGENHAN & GRUNDAY being directly linked to the sponge facies. Ammonites occur mainly, albeit not commonly, in the lower third of the section. (Text-fig. 24) *Tissotioides haplophyllus* (REDTENBACHER) (Pl. 13, Figs 1-2) appears in the upper part of the section.

The section represents an interval in the upper Lower Coniacian *subtricarinatum* Zone, comparable to the interval from ZuB-140 to ZuB-163 of Zuazu (*compare* Text-fig. 21).

Inoceramids: Finely-ribbed forms occur, needing detailed determination.

Echinoids: The echinoid fauna is represented by *Micraster* ex gr. *cortestudinarium*, *Cardiotaxis integer*, and *Echinocorys gravesi*.

Event stratigraphy

deformis bed II: The large inoceramids of this bed have not got yet been determined. However, the position of this bed, *ca.* 5.4 m below the *Cardiotaxis integer* maximum, indicates that it equates with the *Cremnoceramus deformis* Event II of Zuazu B.

Ammonite bed: This is a level with juvenile *Peroniceras* sp. and *Scaphites kieslingswaldensis*.

Inoceramid bed III: Small, finely-ribbed inoceramids, possibly *Mytiloides striatoconcentricus* characterizes this horizon.

Micraster-acme: This is a 1.2 m thick interval between the S and X horizons characterized by abundant, small-sized *Micraster* ex gr. ?*cortestudinarium*. The *Micraster* acme is traceable 1.4 km towards the east to the Urrizola W exposure (*see* Text-fig. 27) as well as to Zuazu B (ZuB-149).

Cardiotaxis integer Maximum: *Cardiotaxis integer* occurs abundantly within a *ca.* 2.7 m thick interval.

gravesi II Event: As at Zuazu and at Urrizola W (*see* Text-fig. 27), this *Echinocorys* bed similarly follows the *Cardiotaxis* Event.

INTEGRATED BIOSTRATIGRAPHY

Definition of the stage and substage boundaries

Turonian/Coniacian boundary

The base of the Coniacian is defined by the FAD of *Cremnoceramus rotundatus* (*sensu* TRÖGER *non* FIEGE) (KAUFFMAN & *al.* 1996). In northern Spain, the boundary, thus defined, approximates to the level of the so-called *Didymotis* II Event (KÜCHLER & ERNST 1989, WIESE 1997), in a similar manner to the situation at the proposed boundary stratotype section in the Salzgitter-Salder limestone quarry in northern Germany (WOOD & *al.* 1984, KAUFFMAN & *al.* 1996). In the Barranca, a comparatively complete, but condensed Turonian/Coniacian boundary interval is exposed only near Izurdiaga (Text-fig. 5). Throughout the Barranca, the basal Lower Coniacian is missing due to tectonic and stratigraphical gaps. At Izurdiaga, the boundary interval is marked by an equivalent of the *Didymotis* II Event, characterized by an only cm-thick bivalve accumulation, with the index inoceramid appearing only a few cm higher.

Lower/Middle Coniacian boundary

Following the proposal of the Brussels Symposium, September 1995, the base of the Middle Coniacian is defined by the FAD of *Volviceramus koeneni* (G. MÜLLER) (KAUFFMAN & *al.* 1996).

In northern Spain, this boundary is marked by the entry of the *Platyceramus mantelli* group, approximately at the same level as the first *Gauthiericeras margae* (SCHLÜTER) and the last peroniceratids (*compare* KÜCHLER & ERNST 1989). This boundary agrees with that in Germany, which is taken at the entry of volviceramids (*compare* TRÖGER 1989). The German Middle Coniacian inoceramid assemblage additionally inlcudes *Platyceramus* of the *mantelli* group, which can occur together with volviceramids at the same horizon (TRÖGER 1981) [other elements of the assemblage includes *Inoceramus frechi* FLEGEL, *I. kleini* MÜLLER and *I. percostatus* MÜLLER (TRÖGER 1989)]. In Central Europe the FAD of volviceramids coincides with that of *Gauthiericeras margae* (*see* TRÖGER 1981, 1989). The occurrence of volviceramids in northern Spain has recently become known, whereas the *Platyceramus mantelli* group is widely distributed in this region. The first record of *Volviceramus* cf. *koeneni* from Zuazu is thus of particular biostratigraphical importance, since its occurrence there is coincident with a *Platyceramus* cf. *mantelli*-acme.

Middle/Upper Coniacian boundary

The basal boundary marker of the Upper Coniacian proposed on a preliminary bases at the Brussels Symposium (KAUFMANN & *al.* 1996), i.e. *Magadiceramus subquadratus* (SCHLÜTER), is lacking in the eastern Barranca, while scarce occurrences are quoted from the western Barranca (*see* LOPEZ 1996, GALLEMI & *al.* 1997). Its distribution seems to be facies-dependent, occurring mostly in marls or silty marls. However, it is also possible that its absence in the eastern Barranca is due to the hiatus, spanning the upper Upper Coniacian and lower Lower Santonian. Consequently, the base of the Upper Coniacian in the Barranca is defined at the first occurrence of an ammonite assemblage, dominated by *Protexanites bourgeoisi* (D'ORBIGNY)(Text-fig. 22). Compared with France, the more or less simultaneous first appearance of *Protexanites bontanti* (DE GROSSOUVRE) at that level may indicate the presence of the *Paratexanites serratomarginatus* Zone *sensu* KENNEDY (1984a). Today, the latter zone is placed in the Upper Coniacian (KAPLAN & KENNEDY 1994).

Coniacian/Santonian boundary

The FAD of *Cladoceramus undulatoplicatus* (ROEMER) was proposed as the primary basal boundary marker for the Lower Santonian (LAMOLDA & HANCOCK 1996). Due to the inferred, continuous succession across the Coniacian/Santonian boundary interval, and the associated inoceramid fauna, the Olazagutia quarry was proposed by ERNST (*in* SCHULZ & *al.* 1984) as an international boundary stratotype (BIRKELUND & *al.* 1984, LAMOLDA & HANCOCK 1996). This quarry "Cantera de Margas" or "Cantera Egibil", of the Cementos Portland S.A. is located on the northern edge of the Sierra de Urbasa, south of Olazagutia (Text-fig. 28).

KANNENBERG (1985) gave the first detailed measurement of the succession (Text-fig. 28B) and reported the stratigraphically lowest *Cladoceramus undulatoplicatus* from a level 1.0 m below his fossil horizon LA3. This is a comparatively narrow stratigraphical interval with a first acme-occurrence of the index-species, here named the *undulatoplicatus* I Event. Recently, four levels of inoceramid concentrations over a maximum interval of 1.3 m have been distinguished within this horizon (GALLEMI & *al.* 1997, PONS & *al. in prep.*). The lowest record of *Cl. undulatoplicatus* has now been proved 5.5 m below the *undulatoplicatus* level 4 of PONS & *al.* (*in prep*). *Cl. undulatoplicatus* level 4 is assumed to correspond to the top of the *undulatoplicatus* I Event.

Lower/Middle Santonian boundary

The extinction of *Cladoceramus undulatoplicatus* was suggested as a possible datum for the base of the Middle Santonian (LAMOLDA & HANCOCK 1996).

At Olazagutia, this datum is uncertain and controversial (*see* KANNENBERG 1985, GALLEMI & *al.* 1997) because the range of *Cl. undulatoplicatus* has not been worked out in detail. In this paper, the local FAD of *Texanites* of the *quinquenodosus-gallicus* group is proposed as a provisional marker for this boundary in the Barranca sections. As in the French Corbières (KENNEDY & *al.* 1995) *Texanites* first occurs far above the total range of *Cl. undulatoplicatus*.

Middle/Upper Santonian boundary

The FAD of the crinoid *Uintacrinus socialis* GRINNELL was suggested as a possible datum for the base of the Upper Santonian (LAMOLDA & HANCOCK 1996). It has not yet been reported from northern Spain.

In this paper, the base of the Upper Santonian is provisionally defined at the FAD of *Cordiceramus muelleri* (PETRASCHECK). As *Cordiceramus muelleri* is common both in Cantabria (OPPERMANN 1996) and at Olazagutia (KANNENBERG 1985), the FAD of this species is considered as a reasonable boundary marker for the base of the Late Santonian in northern Spain. In north-west Europe, the FAD of *Cordiceramus muelleri* (PETRASCHECK) and its occurrence falls into the *Sphenoceramus pinniformis* Zone according to SEITZ (1961) or in the inoceramid Assemblage Zone 28 and Zone 29 *sensu* TRÖGER (1989), respectively. According to TRÖGER (1989), this corresponds to the *Uintacrinus* [*socialis*] Zone or *Gonioteuthis westfalica-granulata* to *G. granulata* Zone, respectively. The definitions of the base of the Upper Santonian at the FAD of *Cordiceramus brancoiformis* (SEITZ) (LOPEZ 1992d, MARTINEZ & *al.* 1996) or at the FAD of *Eupachydiscus isculensis* REDTENBACHER (MARTINEZ & *al.* 1996), respectively, appear not to be appropriate, because the first species is rare in Spain, and occurs already in the Middle Santonian (TRÖGER 1989), while the second is known already from the Coniacian of the Barranca.

Ammonite/Inoceramid zonation of the Barranca

The biostratigraphical subdivision of the Coniacian in the working area is based mainly on ammonites, with the additional incorporation of inoceramid data. By contrast, due to their scarcity, subdivision of the Santonian by means of ammonites is very coarse, with inoceramids giving a better resolution (Text-fig. 25).

The Coniacian ammonite succession and the composition of the assemblages shows affinities to those of assemblages from the French type localities in Touraine and Aquitaine (*see* further below)(Text-figs 25, 28B). Therefore, with some modifications, the Coniacian subdivision proposed by KENNEDY (1984a, b; 1985), into *Forresteria petrocoriensis*, *Peroniceras tridorsatum*, *Gauthiericeras margae* and *Paratexanites serratomarginatus* zones, can be applied (*see* Text-figs 21-27). However, there are significant differences between KENNEDY's 1984-1985 scheme and that in this paper, particularly in respect of the positions of the substage boundaries and the assignment of the ammonite zones to particular substages. The boundaries of the Coniacian substages used here are based on the proposals previously given by KÜCHLER & ERNST (1989), which correspond to the proposals given by the Subcommission on Cretaceous Stratigraphy in Brussels 1995 (Kauffamn & *al.* 1996)

The subdivision of the Santonian of the Barranca by means of ammonites is based on preliminary data from the Olazagutia quarry. Following a still unnamed interval which comprises the Upper Coniacian and Lower Santonian, a middle Santonian zone of *Texanites quinquenodosus* and an upper Santonian *Jouaniceras hispanicum*/*Scalarites cingulatum* Zone can be recognized (Text-fig. 28B). The latter zone show affinities to the so-called *Texanites gallicus* and *Placenticeras paraplanum* subzones of the French Corbières (KENNEDY & *al.* 1995). *Placenticeras polyopsis*, used as index for a broad Santonian zone in the Corbières, is known from Olazagutia in amateur collections but not from any specimen collected in situ.

The Santonian succession of Olazagutia (Text-fig. 28B), 220 m in thickness, can be subdivided into three inoceramid zones (KÜCHLER & OPPERMANN, *in prep.*). These are (in ascending order): a lower *Cladoceramus undulatoplicatus* Partial Range Zone (=PRZ), a middle *Platyceramus cycloides* PRZ and an upper *Cordiceramus muelleri* PRZ. An *Endocostea baltica* Zone, as recognized in Cantabria (OPPERMANN 1996), was not recognized at Olazagutia, albeit *Endocostea* cf. *baltica* (BÖHM) is known to occur (LAMOLDA & *al.* 1981). This may be, however, caused by the broad fossil record.

Cremnoceramus rotundatus Interval Zone

The base of the zone is taken at the FAD of the *Cremnoceramus rotundatus-erectus-deformis* lineage which, in the Barranca, is established by a single record of *C. rotundatus*. Its upper limit is taken at the entry of unequivocal Coniacian ammonites. The zone comprises a 8 m thick interval with rare (or absent) inoceramids and ammonites and is so far recognized only in the Izurdiaga section.

Forresteria petrocoriensis Zone

Until recently, in terms of ammonite biostratigraphy, the base of the Coniacian was taken at the

Stage	Aquitaine,Touraine KENNEDY, 1984a;1985,1987 Ammonite Zones		Corbières area KENNEDY, BILOTTE & MELCHIOR 1995 Ammonite Subzones				Barranca KÜCHLER, this paper Ammonite Assemblages and Zones	Barranca KÜCHLER, this paper Inoceramid Assemblages and Zones
SANTONIAN	*Placenticeras polyopsis*	UPPER	*polyopsis*	*Placenticeras paraplanum* -- ?	UPPER		*Jouaniceras hispanicum/ Scalarites cingulatum*	*Cordiceramus muelleri*
		MIDDLE		*Texanites gallicus*	M.		*Texanites quinquenodosus*	*Platyceramus cycloides*
		LOWER		*Nowakites carezi*	LOWER		unnamed interval	*Cl. undolatoplicatus*
UPPER CONIACIAN	*Paratexanites serratomarginatus*				UPPER CO.		? ? ?	no record
					UPPER CO.	*bourge.*	*Protexanites bourgeoisi* AS	*I.* cf. *percostatus*
	Gauthiericeras margae				MIDDLE CO.	*margae*	*Tridenticeras varians* AS	*Platyceramus* sp. cf. *mantelli* *Volviceramus* cf. *koeneni* *Cremnoceramus crassus*
					MIDDLE CO.	*margae*	*Gauthiericeras margae* AS	no record
MIDDLE CONIACIAN	*Peronioceras tridorsatum*				LOWER CONIACIAN	*subtricarinatum*	*Metatissotia ewaldi/ T. haplophyllus* AS	*Cr.* gr. *deformis/erectus* *Cr.* gr. *inconstans/crassus*
					LOWER CONIACIAN	*subtricarinatum*	*P. subtricarinatum* AS	*Cremnoceramus hannovrensis* *Cr.* cf. *rotundatus* *M. striatoconcentricus*
LOWER CONIACIAN	*Forresteria petrocoriensis*				LOWER CONIACIAN		AS *Forresteria petrocoriensis*	no record
					LOWER CONIACIAN		unnamed interval	*Cremnoceramus rotundatus*

TKü96/98

Fig. 25. Coniacian – Santonian ammonite and inoceramid subdivisions of the Barranca compared with the ammonite zonation applied in France

FAD of the genus *Forresteria*, in particular *Forresteria* (*Harleites*) *petrocoriensis* (COQUAND) (BIRKELUND & *al.* 1984, KENNEDY 1984a). However, although this species occurs in France and in Westphalia/Germany, it is rare in most of the rest of Europe. Furthermore, in stratigraphically complete and well investigated sections, its FAD is located well above the level of the *Didymotis* II Event (*compare* CECH 1989, KAPLAN 1986, KAPLAN & KENNEDY 1994) and the intervening interval, since it provides no new ammonite taxa remains uncharacterized.

This is also true for northern Spain, where the first evidence of the *F. petrocoriensis* Zone was provided by a single record of *Forresteria* (*Harleites*) sp. from the Izurdiaga section (KÜCHLER & ERNST 1989). The FAD of the index taxon falls within an acme of *Micraster* ex gr. *cortestudinarium* occurring 8 m above the *Didymotis* II Event. Besides *Forresteria* (*Harleites*) sp., only a single specimen of *Scaphites* sp. is known from the zone. Furthermore, the first unequivocal *F. petrocoriensis* was found stratigraphically even higher, in the *Peroniceras subtricarinatum* Zone of Villanueva de Araquil. The zone is thus still very poorly documented in the Barranca.

Peroniceras subtricarinatum Zone

The base of the zone is defined by the FAD of *Peroniceras subtricarinatum* (D'ORBIGNY). Neither in the Zuazu nor in the Izurdiaga section, can the base of the zone be precisely placed, due to gaps in exposure or hiati.

Near Zuazu, *P. subtricarinatum* first appears in the Lower Izurdiaga Formation, 24 m below the *deformis* I/*Anagaudryceras* sp. Event (Text-fig 27). It is biostratigraphically significant that *P. subtricarinatum* appears simultaneously with *Cremnoceramus deformis* (MEEK) and earlier than *Peroniceras* (*Peroniceras*) *tridorsatum* (SCHLÜTER). *P. subtricarinatum* occurs much more commonly than *P. tridorsatum* and is, therefore, of better use for biostratigraphic zonation. The co-occurrence of *P. subtricarinatum* and *C. deformis* has also been reported from the Liencres area, Cantabria (WIESE 1997). It is also biostratigraphically important that the FADs of *Metatissotia ewaldi* (VON BUCH) in Zuazu B and *Tissotioides haplophyllus* (REDTENBACHER) in Ecay E (Text-fig. 24) are located in the upper part of the *subtricarinatum* Zone.

Following KÜCHLER & ERNST (1989) the *P. subtricarinatum* Zone is taken here to define the upper Lower Coniacian. The concept of a *Peroniceras bajuvaricum* Zone, introduced by them for the middle part of the Lower Coniacian in the Barranca, is abandoned here, because *P. subtricarinatum* appears much earlier in the stratigraphical record than previously suggested.

Near Zuazu, three subunits with a distinct faunal composition can be recognized within the *subtricarinatum* Zone (*see* Text-figs 21-22). The lowest subunit up to the top of the *deformis* I/*Anagaudryceras* sp. Event is characterized by the occurrence of rare *P. subtricarinatum* and *Peroniceras* sp. indet. Only just below this event, peroniceratids appear more commonly and are associated with ?*Yezoites* sp. and *Anagaudryceras* sp. The hardground succession of Villanueva de Araquil to the northwest of Zuazu (*see* KÜCHLER & ERNST 1989, Text-Fig. 5), especially the interval immediately above Hg3, additionally yielded *Forresteria* cf. *petrocoriensis*, *Forresteria nicklesi* (DE GROSSOUVRE), *Peroniceras* cf. *bajuvaricum* (REDTENBACHER), *Scaphites kieslingswaldensis*, *Tongoboryceras* cf. *hancocki* KENNEDY, *Scaphites* sp. indet as well as *Diplomoceras* sp.

Near Zuazu and Ecay (Text-figs 21-22, 24), the middle subunit is characterized by a *Peroniceras*-*Scaphites* association, composed of abundant *S. kieslingswaldensis*, rare *Peroniceras subtricarinatum*, the first *Peroniceras* (*Peroniceras*) *tridorsatum* (SCHLÜTER)(from the not figured part of Satrustegui section) as well as *Nostoceras* (*Eubostrychoceras*) sp. The latter species is known from rare single specimens from the Ecay and Satrustegui exposures.

In the upper subunit (from the *deformis* I/*Anagaudryceras* sp. Event upwards, *see* Text-figs 21-22, 24, 27), *Metatissotia ewaldi* (VON BUCH), *Metatissotia* sp. indet and *Tissotioides haplophyllus* (REDTENBACHER) appear.

Gauthiericeras margae Zone

The base of the zone is defined at the FAD of *Gauthiericeras margae* (SCHLÜTER). In the Zuazu C section (Text-fig. 22), it lies 7 m below the *Echinocorys gravesi* III Event, where the zonal index is found associated with *Metatissotia evaldi* Near Zuazu, the zone reaches a thickness of about 40 m.

The *margae* Zone contains a more diverse ammonite fauna than the underlying *subtricarinatum* Zone. As in France, the zone is characterized by the appearance of various gauthiericeratids. *G. margae* is extremely rare, and so far is known only from three, badly preserved specimens. Locally, it ranges up to the *Tridenticeras* I Event.

Tridenticeras tridens (SCHLÜTER) and *Tridenticeras varians* (SCHLÜTER) appear in the middle part of the zone and range up to the *Tridenticeras* II Event. This middle part (Text-figs 23-24) is characterized by a rich *Tridenticeras-Scaphites* fauna with *S. kieslingswaldensis*, *Gauthiericeras? boreaui* (DE GROSSOUVRE), *Eupachydiscus isculensis* (REDTENBACHER), *Neocrioceras* (*Schlueterella*) cf. *compressum* KLINGER, *Gaudryceras* cf. *navarrense* WIEDMANN, *Hauericeras* sp. and *Yezoites* cf. *arnaudi* (DE GROSSOUVRE). Furthermore, *Hyphantoceras plicatum* (D'ORBIGNY), so far known only from France and Germany, is proved for the first time from northern Spain. *Peroniceras subtricarinatum* ranges up to the *Tridenticeras* II Event of the Zuazu A section (Text-fig. 23).

Protexanites bourgeoisi Zone

SANTAMARIA (1992) defined the base of the zone at the FAD of *Protexanites bourgeoisi* (D'ORBIGNY). This zone is used in northern Spain in view of the rarity or complete lack of *Paratexanites serratomarginatus* (REDTENBACHER) (*see also* SANTAMARIA 1991, 1992). By faunal comparison it correlates with the lower part of the *P. serratomarginatus* Zone *sensu* KENNEDY(1984a).

In Navarra, the base of the zone is characterized by an acme of the zonal index *Protexanites bourgeoisi* as well as *Gauthiericeras? boreaui*. KENNEDY (1984a) and KENNEDY & *al.* (1995) remarked that the first appearance of *P. bourgeoisi* was already in the topmost part of the underlying *margae* Zone, where it was extremely rare. However, the co-occurrence of *P. bourgeoisi* with *P. serratomarginatus* and *Protexanites bontanti* is, at least in France, a good indication of the *serratomarginatus* Zone. *P. bourgeoisi* occurs very commonly in this interval in France. Near Zuazu (Text-fig. 22), *P. bourgeoisi* occurs associated with *P. bontanti* (rare) and *S. kieslingswaldensis* in the *boreaui/bourgeoisi* Event, together with *Gauthiericeras*? *boreaui* and *Baculites incurvatus* DUJARDIN. The equivalent Upper Coniacian, *Magadiceramus subquadratus* Zone, has not so far been recognized in the eastern Barranca.

Texanites quinquenodosus Zone

The base of the Zone is defined at the FAD of *T. quinquenodosus*. Compared to the Zuazu section (Text-fig. 22), where *T. quinquenodosus* first occurs at the level of the second *Offaster nuciformis* Event and apparently above the FAD of *Cl. undulatoplicatus*, its occurrence at Olazagutia (Text-fig. 28B) seems to be extremely high in the stratigraphical record. At Olazagutia, representatives of the *T. quinquenodosus-gallicus* group first occur around the "yellow bank" (= bed 68) of KANNENBERG (1985). The zone is represented by a scarce fauna, comprising *Neocrioceras* (*Schlueterella*) *compressum* and *Glyptoxoceras souqueti* COLLIGNON.

Jouaniceras hispanicum/Scalarites cingulatum Zone

The zone is defined as an assemblage zone of the nominate index ammonites in the Olazagutia Quarry (Text-fig. 28B). Its base should be marked by the FAD of *Scalarites cingulatum* (SCHLÜTER). *S. cingulatum* is known to occur in northern Europe in the Lower Campanian (SCHLÜTER 1872, KENNEDY & KAPLAN 1995). In northern Spain, it occurs significantly earlier, in the Upper Santonian *Cordiceramus muelleri* inoceramid, or *Dicarinella asymetrica* foraminiferal, Zone, respectively. *Jouaniceras hispanicum* (WIEDMANN) occurs already in the Middle Santonian (GISCHLER & *al.* 1994) and probably ranges up into the Lower Campanian (KÜCHLER, *in prep.*).

At Olazagutia, the lowest records of both index species come approximately from bed 138-139 (level minus 14 *sensu* KANNENBERG 1985) (Text-fig. 28B). They are common around bed K167. Above this horizon of glauconitic calciturbidites, *S. cingulatum* dominates the assemblage. *Glyptoxoceras* sp. 1, smooth baculitids and *Gaudryceras mite* VON HAUER also occur. A single find of *Boehmoceras krekeleri* (WEGNER), somewhat higher in the succession, indicates Upper Santonian in terms of ammonite biostratigraphy. Where well dated, it occurs in the *Marsupites/granulata* Zone of Westphalia/Germany (*see* SCHÖNFELD 1985, KENNEDY & CHRISTENSEN 1993).

Discussion and correlations of Coniacian subdivisions

Zonation of Coniacian type regions, France

Ammonites are comparatively scarce in the Coniacian of France. KENNEDY (1984a) summarised the lithostratigraphy and faunal succession of four regions in France, (1) the Aquitaine, (2) a small area in the Touraine of the southern Paris Basin, (3) the surroundings of Dieulefit (Drôme), and (4) the Beausset (Var) near Marseilles. Based on historic data as well as on his new field investigations he recognized the following sequence of ammonite zones (in ascending order): *Forresteria* (*Harleites*) *petrocoriensis* Zone, *Peroniceras tridorsatum* Zone, *Gauthiericeras margae* Zone, and *Paratexanites serratomarginatus* Zone. This zonation is based on scarce material and mainly unproved historical data and it is difficult to recognize the zonal sequence in the field (KENNEDY 1984a, p. 25).

Forresteria petrocoriensis Zone: *F. petrocoriensis* is the first ammonite appearing in the Aquitaine. According to KENNEDY (1984a), it occurs at various localities and marks the base of the Coniacian in the type region. With the exception of *Scaphites* cf. *meslei* DE GROSSOUVRE [=*S. kieslingswaldensis*] no other ammonite species was found in situ. Although extensive museum material exists from the Dordogne, apart from *F. petrocoriensis*, only single specimens of *Metatissotia desmoulinsi* (DE GROSSOUVRE), *M. nodosa* (HYATT) and ?*M. nanclasi* (DE GROSSOUVRE) are known to occur.

Peroniceras tridorsatum Zone: In Aquitaine, the appearance of diverse peroniceratids marks the base of the *tridorsatum* Zone. The zonal fauna consists of *Peroniceras* (*Peroniceras*) *tridorsatum* and other *Peroniceras* (*Peroniceras*) species [*P.* (*P.*) *westphalicum* (VON STROMBECK), *P.* (*P.*) *lepeei* (FALLOT), *P.* (*P.*) *dravidicum* (KOSSMAT), *P.* (*P.*) *subtricarinatum*] with rare *P.* (*Zuluiceras*) *bajuvaricum*. KENNEDY (1984, 1985) also reported ?*Onitshoceras ponsianum* (DE GROSSOUVRE), *Tongoboryceras hancocki*, *Placenticeras fritschi* (DE GROSSOUVRE), *Forresteria* (*Harleites*) *nicklesi*, *Tissotia redtenbacheri* (DE GROSSOUVRE), *Metatissotia slizewiczi* (DE GROSSOUVRE), *Metatissotia ewaldi*, *Metatissotia nodosa* (HYATT), *Tissotioides haplophyllus*, *Scaphites meslei*, *Yezoites* [*Otoscaphites*] *arnaudi* (DE GROSSOUVRE) and nodose baculitids.

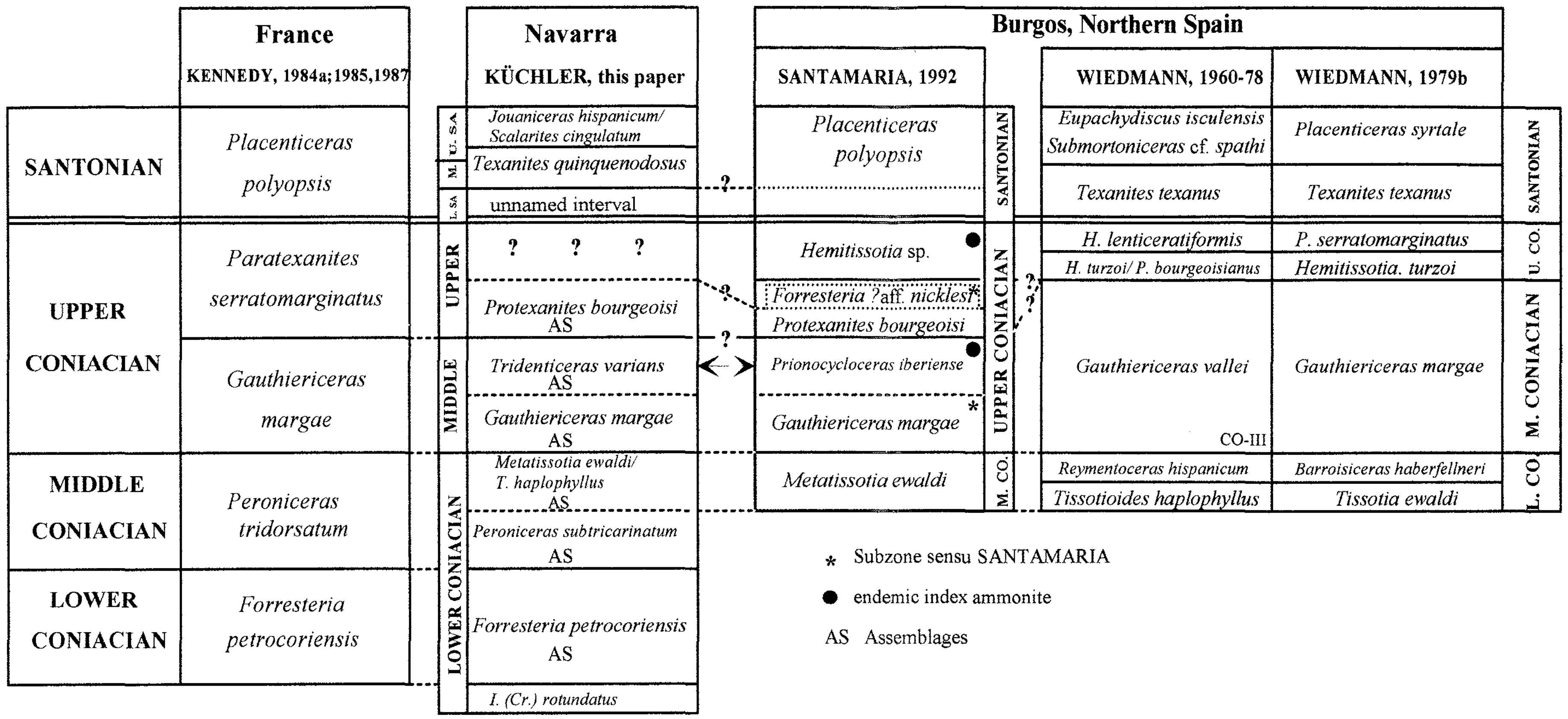
Gauthiericeras margae Zone: The base of the zone is marked by the appearance of *Gauthiericeras margae* and *Gauthiericeras nouelianum* (D'ORBIGNY). *Protexanites bourgeoisi* enters within the zone. Additional elements of the assemblage are ?*G. boreaui* (DE GROSSOUVRE), *Baculites incurvatus* DUJARDIN and *Tridenticeras* sp.

Paratexanites serratomarginatus Zone: The base of the zone is defined by the appearance of *Paratexanites serratomarginatus*. *Protexanites bourgeoisi*, *Protexanites bontanti*, *Placenticeras semiornatum* (D'ORBIGNY), *Phlycticrioceras trinodosus* (GEINITZ) and *Baculites incurvatus* also occur. *Protexanites bontanti* is restricted to this zone, while *Protexanites bourgeoisi* occurs relatively commonly (KENNEDY 1985).

Intra-Spanish comparison (Barranca and Burgos region)

In establishing the so-called standard zonal scheme for northern Spain, WIEDMANN (1979b) based his data mainly on sections investigated in the Province of Burgos (WIEDMANN 1960, 1962, WIEDMANN & KAUFFMAN 1978)(Text-fig. 26). The ammonite fauna of this area is dominated in the Coniacian by the four genera *Tissotioides*, *Metatissotia*, *Hemitissotia* and *Prionocycloceras*. These genera, however, are extremely rare or absent in the Barranca. In the latter region, the most common genus is *Scaphites*, which occurs associated with *Peroniceras*, *Gauthiericeras* and *Tridenticeras*. Thus, both areas differ markedly in their ammonite assemblages and in the abundance of particular genera. These faunal differences, resulting from ecological or paleogeographical factors, have hitherto hindered the correlation of the ammonite zonation of the Burgos successions and those applied in France (KENNEDY 1984a) and in the Barranca (KÜCHLER & ERNST 1989), respectively.

The re-investigation of WIEDMANN's standard sections by SANTAMARIA (1991, 1992) and their detailed description have facilitated correlations between these regions. In this context, the Barranca represents an intermediate faunal



Biostratigraphical correlation between France and northern Spain and comparison of the ammonite zonations or ammonite associations (AS) between the Barranca and the Burgos area assemblage between those of France and the mostly endemic one of the Burgos region. This permits an interbasinal comparison and correlation of the ammonite zonations between the above mentioned areas. A tentative correlation diagram is presented here in Text-fig. 26.

For the Barranca a modified version of the French zonal scheme of Kennedy (1984a) was applied (see Text-fig. 25). The *Forresteria petrocoriensis* Zone has so far been documented in the Barranca by single records of *Forresteria* (*Harleites*) sp. indet and *Scaphites* sp. indet. This is succeeded by an upper Lower Coniacian *Peroniceras subtricarinatum* Zone (corresponding to the French *P. tridorsatum* Zone), comprising a lower subtricarinatum and a higher *Metatissotia ewaldi*/*Tissotoides haplophyllus* assemblage, a Middle Coniacian *Gauthiericeras margae* Zone, comprising a lower *margae* amd a higher *Tridenticeras varians* assemblage; and an Upper Coniacian *Protexanites bourgeoisi* Zone (corresponding in part to the French *Paratexanites serratomarginatus* Zone) comprising a sole *bourgeoisi* assemblage.

For the Burgos area SANTAMARIA (1991, 1992), contrary to WIEDMANN (1979b), used the following zonation:

(iv) *Hemitissotia* sp. Zone
(iii) *Protexanites bourgeoisi* Zone (with an included *Forresteria*? aff. *nicklesi* marker horizon, the so-called *Forresteria*? aff. *nicklesi* Subzone)
(ii) *Prionocycloceras iberiense* Zone (with a *Gauthiericeras margae* Subzone in the basal part)
(i) *Metatissotia ewaldi* Zone

The ammonite succession in the Burgos area starts with a *Metatissotia ewaldi-Tissotioides haplophyllus* Assemblage, with subordinate peroniceratids and rare *Tissotioides hispanicus* WIEDMANN. The *M. ewaldi* Zone of SANTAMARIA (1991, 1992) (approximating to WIEDMANN's zones CO-I and CO-II), comprises an interval between the FAD of the index species and that of *G. margae*. It agrees very well with the stratigraphical position of the *M. ewaldi*/*T. haplophyllus* Assemblage in the Barranca. Compared with the Burgos region, where SANTAMARIA quoted 25 specimens of *M. ewaldi* alone and 30 specimens of *T. haplophyllus*, both forms are extremely rare in the Barranca.

This assemblage falls stratigraphically into the upper part of the *Peroniceras subtricarinatum* Zone or *P. tridorsatum* Zone of KENNEDY (1984a), respectively. That means, as already suggested by KENNEDY (1985) and KÜCHLER & ERNST (1989), that the Zone CO-II with *T. haplophyllus* of WIEDMANN (1979b) does not represent the basal unit of the Coniacian in northern Spain. Moreover, the greater part of the Lower Coniacian in the Burgos region, i.e. the *F. petrocoriensis* Zone as well as the lower part of the *P. subtricarinatum* Zone, is missing. In the Barranca, the Lower Coniacian succession is more complete.

Based on the Burgos region, SANTAMARIA (1992) defined a second ammonite zone at the FAD of the endemic species *Prionocycloceras iberiense* (BASSE). However, as he includes in the zone a 5 m interval below the FAD of the zonal index, that was characterized almost exclusively by *G. margae*, this zonal scheme is inherently illogical. He interpreted this interval as a subzone of *G. margae*, within the *iberiense* Zone and suggested that the *iberiense* Zone corresponds to the base of WIEDMANN's Zone CO-III (=*Gauthiericeras vallei* or *G. margae* Zone, respectively). *P. iberiense* is accompanied by *Prionocycloceras turzoi* (KARRENBERG) in the upper part of this zone (Text-fig. 26).

This fauna also shows similarities to that of the *G. margae* Zone of the Barranca, which is characterized by two ammonite assemblages, a lower *G. margae* Assemblage, with rare occurrences of the index-taxon, and a higher *Tridenticeras varians* Assemblage, dominated by *Scaphites* spp. and *Tridenticeras* spp. Although the ammonite genus *Prionocycloceras* has not been recognized in the Barranca, the first occurrence of *Tridenticeras* spp. permits a comparison with the Burgos area. *Tridenticeras tridens* first occurs in the upper part of the *iberiense* Zone of SANTAMARIA (1992), *i.e.* at a level that can be inferred to correlate with that of the *Tridenticeras* assemblage in the Barranca. This species was first described by WIEDMANN (1962), from the same Burgos section, although he reported it from his stratigraphically obviously higher *Hemitissotia turzoi* Zone (CO-IV), thereby giving the species a longer range.

The first occurrences of *T. tridens* and *T. varians* in northern Spain also permit correlation with their first occurrences in Westphalia, NW Germany

(KAPLAN & KENNEDY 1994). As in northern Spain, both species appear in the upper part of the *margae* Zone and range into the *serratomarginatus* (=*bourgeoisi*) Zone. However, discrepancies are encountered in trying to correlate the first appearances of *Tridenticeras* to France, since KENNEDY & *al.* (1995) record *T. varians* there from as low as the upper *tridorsatum* Zone.

The succeeding interval, both in the Barranca as well as in the Burgos region, is characterized by the abundance of protexanitids, mainly *Protexanites bourgeoisi*. In agreement with SANTAMARIA (1992), this interval should be referred to as the *P. bourgeoisi* Zone. The first and more or less simultaneous appearance of *Protexanites bontanti* at this level, by comparison with the French Coniacian, may indicate the presence of the *Paratexanites serratomarginatus* Zone *sensu* KENNEDY (1984a).

For the Upper Coniacian of the Burgos region, SANTAMARIA (1992) introduced a *Hemitissotia* sp. Zone, with its base marked by the FAD of *Hemitissotia turzoi* KARRENBERG. This zone clearly equates with the *H. turzoi* Zone of WIEDMANN (1979b). According to SANTAMARIA (1991), differences in the definition of the zonal boundaries justified the erection of this new zone. However, as he never defined or discussed the base of his *Hemitissotia* sp. Zone, the *H. turzoi* Zone of WIEDMANN (1979b) should be maintained. The virtually exclusive occurrence of the endemic zonal index, associated with the endemic *Hemitissotia dullai* (KARRENBERG), and their abundance, characterize the sections investigated by SANTAMARIA (1992). The *Hemitissotia* sp. Zone embraces, according to SANTAMARIA (1991), the zones CO-IV and CO-V (*Hemitissotia lenticeratiformis* Zone) *sensu* WIEDMANN (Text-fig. 26). At the moment, there is no direct correlation of the *H. turzoi* Zone to the Barranca and it may well be possible that this zone, or the upper part of the *serratomarginatus* Zone, respectively, fall within a hiatus near Zuazu. Near Olazagutia on the other hand, the succession seems to be continuous, because WIEDMANN (1979a, p. 180) reported *H. turzoi* and LOPEZ (1996) the Upper Coniacian inoceramid zonal index *Magadiceramus subquadratus subquadratus* from the base of the Olazagutia Quarry. Unfortunately, these records relate to loose material, which cannot be placed stratigraphically.

EVENTS; REGIONAL AND INTER-REGIONAL CORRELATION

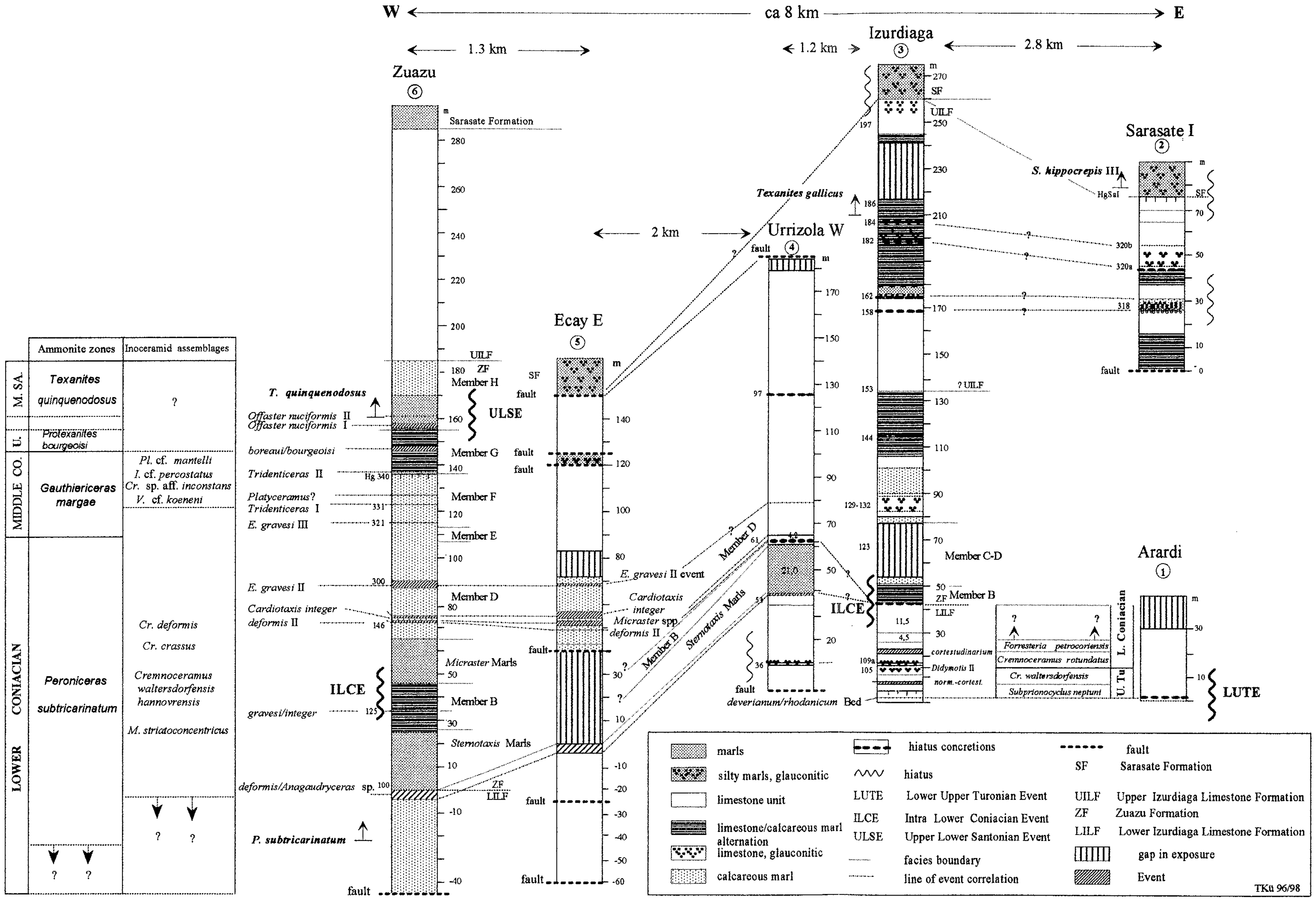
Didymotis II-Event

The *Didymotis* Event of the Barranca is inferred to represent an equivalent of the *Didymotis* II Event *sensu* ERNST & *al.* (1983), which characterizes the Turonian/Coniacian boundary interval. The event is recorded from a single locality (Izurdiaga), where it is combined with a marked facies change from predominantly calcareous marls to shallow marine carbonates with high siliciclastic and glauconite content. Faunistically, it is documented by an acme-occurrence of various bivalves, in particular *Spondylus*, and it is restricted to an interval of only a few centimetres. This poor bivalve fauna contains *Cremnoceramus waltersdorfensis* and rare *Didymotis*, typical of the *Didymotis* II Event elsewhere. *C. rotundatus* appears only a few cm higher.

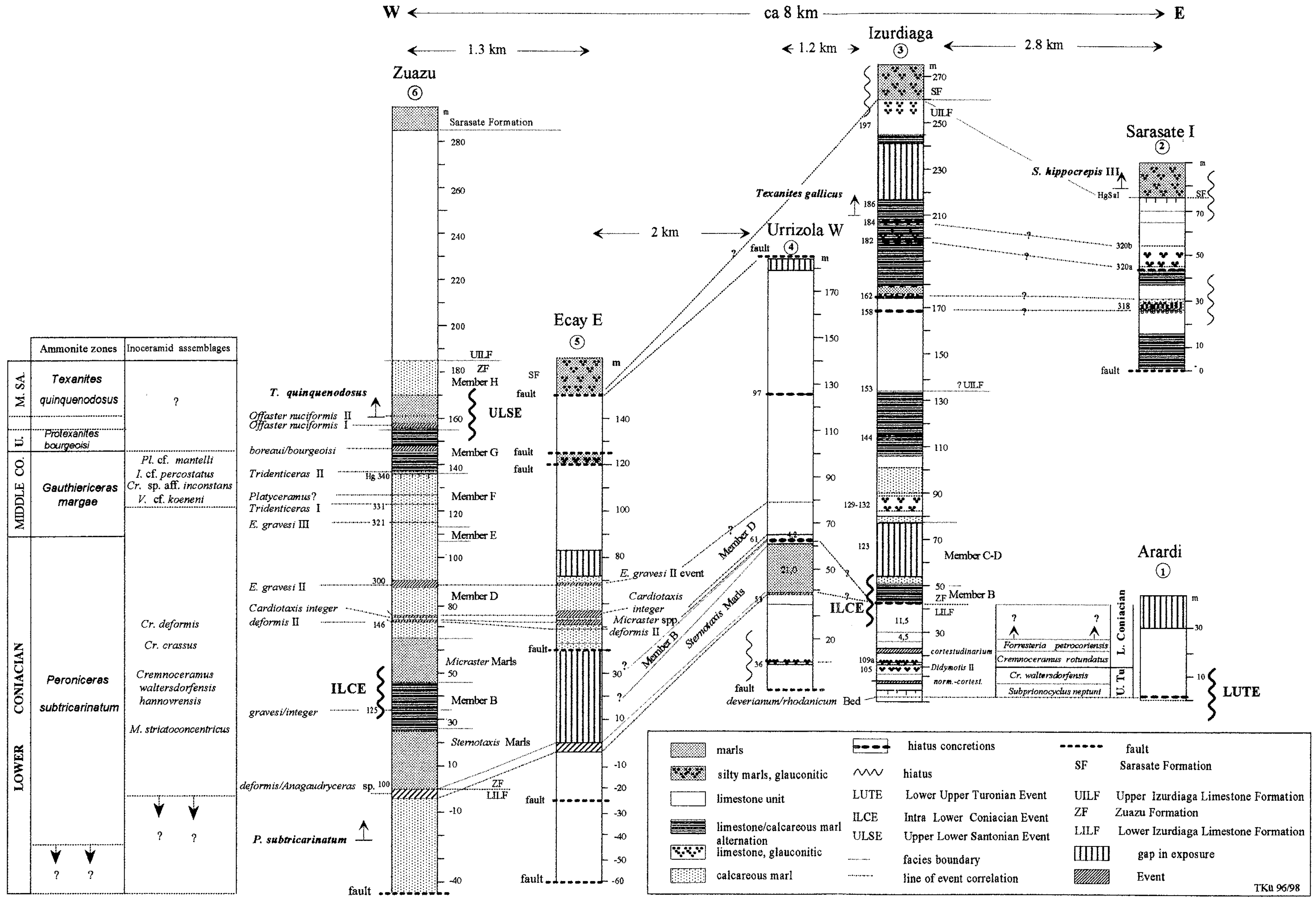
In Germany (ERNST & *al.* 1983) and the Czech Republic (CECH 1989) this event is situated some distance above another *Didymotis*-acme in the Upper Turonian, the so-called *Didymotis* I Event. In Cantabria, northern Spain, both events were reported from exposures around Liencres (KÜCHLER & ERNST 1989, WILMSEN & *al.* 1996, WIESE 1997) as well as from other localities in northern Cantabria (WIESE 1997). As reported by KÜCHLER & ERNST (1989), the *Didymotis* II Event at Liencres lies about 24 m above the lower *Didymotis* I Event and contains an inoceramid fauna with *C. waltersdorfensis*, *C. rotundatus*, and *Inoceramus ernsti* HEINZ together with *Micraster leskei* (DESMOULINS) and *Micraster* of the *praecursor-normanniae-cortestudinarium* lineage.

Micraster ex gr. cortestudinarium Acme

A distinct acme of *Micraster* ex gr. *cortestudinarium* occurs in the lower part of the Lower Coniacian. In the Izurdiaga section, it begins about 6 m above the *Didymotis* II Event, in the boundary interval between the *rotundatus* and the *petrocoriensis* zones (beds IzI-109), and extends up to the top of bed IzI-114, 25 m above (*see* Text-fig. 27). The mass-occurrence of *Micraster* ex gr. *cortestudinarium* corresponds to the *Micraster*-acme found above the *Didymotis* II Event at Liencres, Cantabria



Event stratigraphical correlation within the Coniacian to Santonian of the eastern Barranca; the traverse from Zuazu to Sarasate shows strong facies differences, decreasing thicknesses and increasing hiati towards the east, indicating a paleo-high between Urrizola and Sarasate; for location of exposures see Text-fig. 28a



Event stratigraphical correlation within the Coniacian to Santonian of the eastern Barranca; the traverse from Zuazu to Sarasate shows strong facies differences, decreasing thicknesses and increasing hiati towards the east, indicating a paleo-high between Urrizola and Sarasate; for location of exposures see Text-fig. 28a

(KÜCHLER & ERNST 1989, Text-Fig. 6), the so-called *Micraster* limestone of WIESE (1997).

Cremnoceramus deformis/Anagaudryceras sp. Event

This event lies in the lower part of the *Peroniceras subtricarinatum* Zone. In a sequence stratigraphical context, it is associated with a late highstand system tract or a sequence boundary, as indicated by hardgrounds and/or condensation horizons in the Barranca. The event is associated with the first common occurrence of Coniacian inoceramids, *i.e.* of *Cremnoceramus deformis* (MEEK), and particularly of *C. waltersdorfensis hannovrensis* (HEINZ). The essentially Turonian form *Mytiloides striatoconcentricus* is also comparatively common. This level is recognizable in many localities within the eastern Barranca (Text-fig. 27), where it is characterized either by an abundance maximum of *Cremnoceramus* spp. and *Anagaudryceras* sp. or by a single *Cremnoceramus* layer. It probably corresponds to the hardground HG 3 (KÜCHLER & ERNST 1989, Text-Fig. 5) within the hardground succession near Villanueva de Araquil northeast of Zuazu. Just above HG 3, an association of *Cremnoceramus* spp. and ammonites occurs, similar as in the Zuazu B section. In addition to *Inoceramus ernsti* and *Mytiloides striatoconcentricus*, the inoceramid fauna comprises *C. waltersdorfensis hannovrensis* and *C. deformis*. The ammonite fauna is of higher diversity than at Zuazu, and is represented by *Forresteria* (*H.*) cf. *petrocoriensis*, *Forresteria* (*H.*) *nicklesi*, *Peroniceras* (*Z.*) cf. *bajuvaricum*, *Tongoboryoceras* cf. *hancocki* and *Scaphites kieslingswaldensis*. There is, again, a remarkable dominance of *Anagaudryceras* sp.

Echinocorys gravesi/Cardiotaxis integer Bed

A level with *Echinocorys gravesi* and *Cardiotaxis integer* is found in the middle of Unit B at Zuazu (*see* Text-fig. 21). It lies in the middle part of the *P. subtricarinatum* Zone. At Izurdiaga, this bed is missing, presumably due to the hiatus associated with the Intra Lower Coniacian Event (ILCE) which includes the lower part of member (Text-fig. 27). Near Villanueva de Araquil, hardground HG 4 represents this level (*see* KÜCHLER & ERNST 1989, Text-fig. 5).

Intra Lower Coniacian Event (ILCE)

In the Barranca, the ILCE represents a strongly marked tecto-eustatic event, which is inferred to correspond to the so-called Ilsede Phase, originally distinguished in north-west Germany (STILLE 1924, p. 152) and subsequently recognized throughout northern Europe (MORTIMORE & POMEROL 1997, MORTIMORE & *al.* 1988). It is assumed that the Ilsede Event was a multi-phase event starting in the Late Turonian. The ILCE, on the other hand, started in the Early Coniacian *Cremnoceramus deformis* Zone. This period is marked by large hiati of variable extent and angular unconformities at basin margins and on the top of tilted, uplifted blocks, which can be observed, from Izurdiaga to Alsasua, in a E-W traverse through the Barranca. Turbiditic sequences, grain-flows, debris-flows and slumps were deposited in the rim synclines of the uplifted structures in the Barranca and in the Vitoria Basin, Alava Province. The discontinuities are mostly succeeded by the so-called *Micraster* Marls (Member C of the Zuazu Formation), which belong to the *Peroniceras subtricarinatum* Zone. Locally, however, the hiati span a larger interval and the first sediments above the discontinuity surface are then the spongiolithic, calcareous marls of the Member D.

The E-W trending traverse (Text-figs 10, 27) from Izurdiaga to Alsasua and the evaluation of the duration of the observed hiati prove the generation of relief, caused by block-rotation as a result of the ILCE.

The onset of tectonic activity is indicated by turbidites occurring in the upper part of Member B of the comparable complete succession at Zuazu (*see* Text-fig. 21).

Towards the east (Text-fig. 27), the increasing hiati are indicated by the progressive development of erosional unconformities and/or conglomerates. At Urrizola, event stratigraphical correlation shows that parts of Zuazu Member D lie almost directly above bed UrW-61, the bed with 0.02-0.03 m, strongly glauconitic pebbles which probably belongs to the lower part of Member B. Compared with Zuazu, this bed reflects the absence of two lithological units, *i.e.* the upper part of Member B and also Member C (*Micraster* Marls). At Izurdiaga erosion has cut even deeper, to the top of the Lower Izurdiaga Limestone Formation. The conglomerate here is associated with amalgamation of two erosional

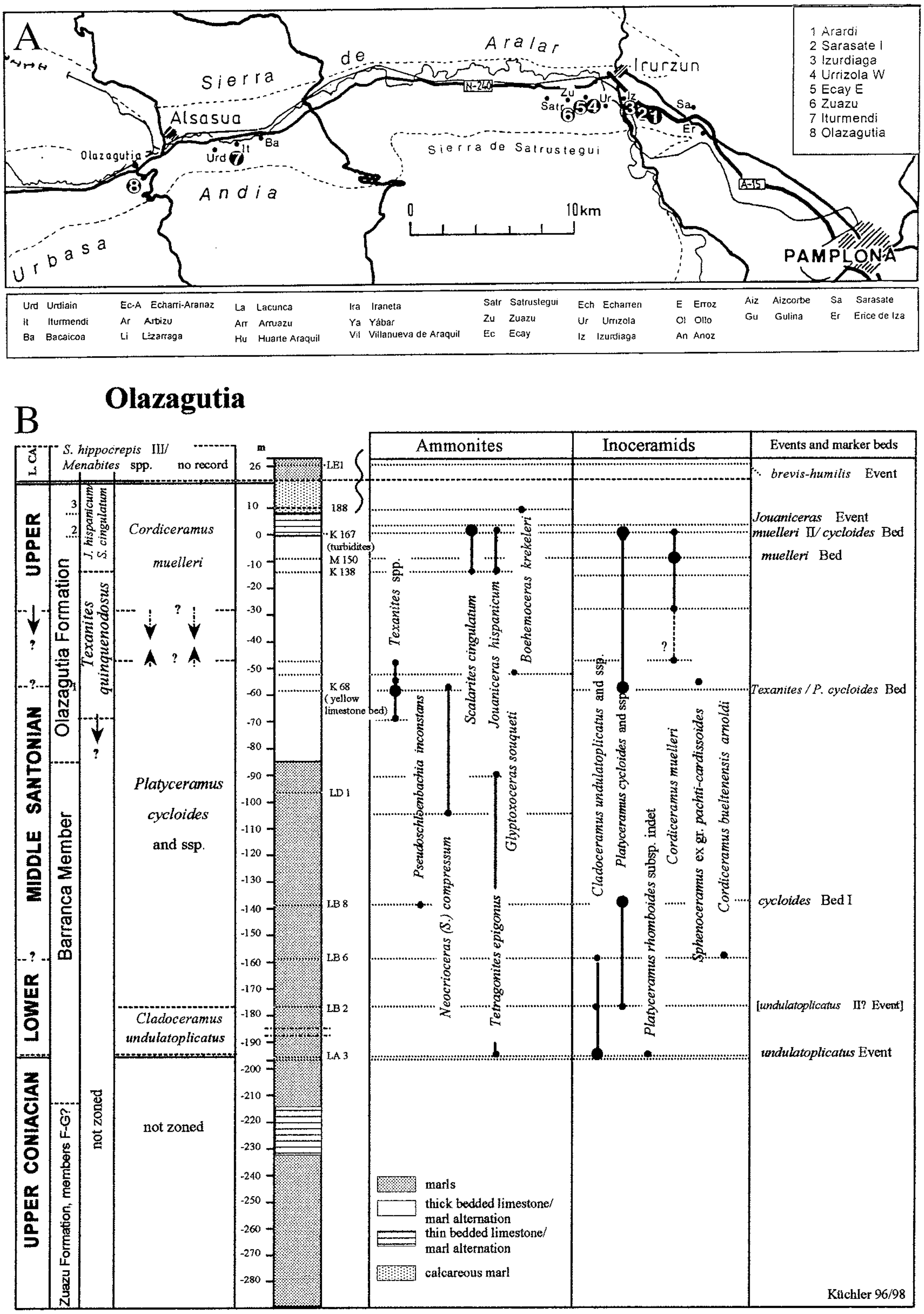
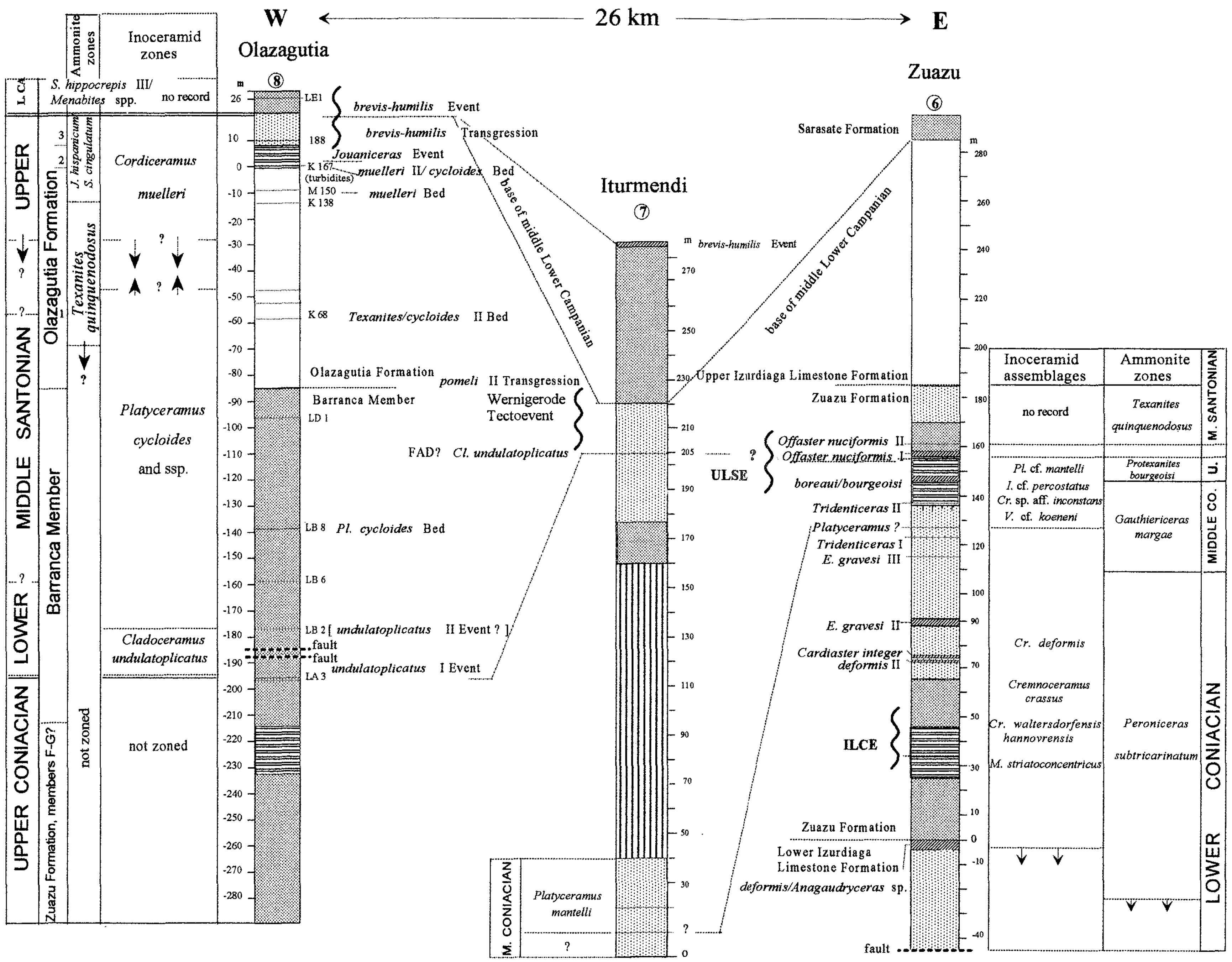


Fig. 28. A. Location of the investigated Coniacian to Santonian exposures within the Barranca
B. Cantera de Margas or Egibil quarry of the Cementos Portland S.A. near Olazagutia, the proposed Coniacian/Santonian boundary stratotype section; macrofossil distribution and provisional zonation; lithology simplified and modified after KANNENBERG (1985); macrofossil data after KANNENBERG (1985), LOPEZ 1990 and KÜCHLER (*in prep.*)



Eventstratigraphical correlation within the Coniacian and Santonian of the Barranca in an E – W transect from Zuazu through Iturmendi to Olazagutia; data based partly on ZANDER (1988) (for Iturmendi), KANNENBERG (1985) and LOPEZ (1990) (for Olazagutia); for explanation of lithology see Text-fig. 27, for location of the section Text-fig. 28

surfaces, which represent the interval from the *Sternotaxis* Marls and Member B up to Member D (for comparison *see* Text-fig. 21).

To the west of Zuazu, towards Olazagutia, the extent of the hiatus increases (Text-fig. 10). At Satrustegui and Alsasua, the *Micraster* Marls unconformably overlie a middle Turonian hardground succession belonging to the *Marginotruncana schneegansi* Zone (Text-fig. 10). The *Micraster* Marls near Alsasua are dated by *Dicarinella* aff. *primitiva* (DALBIEZ) and *D. concavata* (BROTZEN) as Lower Coniacian (lower part of the *Dicarinella concavata* Zone) (ZANDER 1988).

Further to the west, near Guevarra in Alava, turbidite fans (calcarenites) cut into a succession of basinal marls (ENGESER 1985). These turbidites were part of the Ariola Fan, probably generated by uplift of the nearby Aizgorri Massif, and shed in an eastern direction, into basin inclined to the east (ENGESER 1985). WOLZ (1985) showed that the fans extend towards the south-east (Araya section). The fans can be correlated to Eguino in Alava and according to inoceramids (*C. deformis*, *C. waltersdorfensis hannovrensis*) can be assigned to the upper Lower Coniacian.

Cladoceramus undulatoplicatus Events

The Lower Santonian *C. undulatoplicatus*-acme can be recognized in wide parts of Europe. In Spain, it is known from Navarra (KANNENBERG 1985, GALLEMI & al. 1997), Catalonia (CAUS & *al.* 1981) and Cantabria (OPPERMANN 1996, WILMSEN & *al.* 1996). As in northern Germany and England (BAILEY & *al.* 1984), the acme comprises several distinct levels or peak-occurrences. In the marginal situation of the eastern Barranca, the *undulatoplicatus*-acme is not preserved because of an hiatus embracing virtually the entire Lower Santonian.

Near Olazagutia, in the quarry of the Cementos Portland S.A, a continuous succession of marls and calcareous marls crosses the Coniacian/Santonian boundary interval. Two *Cladoceramus undulatoplicatus* maxima *ca.* 19-20 m apart were recognized by KANNENBERG (1985). The local FAD of *Cl. undulatoplicatus* was reported to lie *ca.* 1 m below the lowermost *Cladoceramus*-acme, referred to as the *undulatoplicatus* I Event herein. According to KANNENBERG (1985) and LOPEZ (1990), bed LA 3 contains *Cl. undulatoplicatus michaeli* (HEINZ), *Cl. undulatoplicatus undulatoplicatus* (RÖMER) and *Platyceramus rhomboides* ssp. indet. The second *Cladoceramus*-acme, based on loose specimens of *Cl. undulatoplicatus*, is inferred to lie in the LB 2 level, from which LOPEZ (1990) reported *Pl. cycloides ahsenensis* (SEITZ). Reinvestigation of the quarry and re-sampling of the horizon referred to the *undulatoplicatus* I Event shows that four levels of inoceramid concentrations can be distinguished over a maximum interval of 1.3 m (GALLEMI & *al.* 1997, PONS & *al.*, *in prep.*). The lowest occurrence of *Cladoceramus undulatoplicatus* has now been proved to be 5.5 m below the *undulatoplicatus* level 4 of PONS & *al.* (*in prep*). Level 4 of *undulatoplicatus* is assumed herein to correspond to the top of the *undulatoplicatus* I Event. The second *undulatoplicatus* maximum of KANNENBERG (1985) has not been proved.

Upper Lower Santonian Event (ULSE)

Near Zuazu (Text-fig. 22), this event is documented by a distinct lithological change from a nodular limestone-marl alternation to dark grey marls with *Offaster nuciformis*, associated with an hiatus. If the extinction level of *Cl. undulatoplicatus* is taken to define the base of the Middle Santonian (*see* LAMOLDA & HANCOCK 1996), the hiatus comprises parts of Upper Coniacian *serratomarginatus* Zone and parts of the Lower Santonian. Compared with the Olazagutia section (Text-fig. 28B), the beds rich in *Cl. undulatoplicatus* (LA3) sensu KANNENBERG (1985), are missing (*see* Text-figs 28-29).Consequently this event is stratigraphically younger than the interval with the *undulatoplicatus*-acmes in the Olazagutia Quarry.

Offaster nuciformis Events

Two event beds of *Offaster nuciformis* are recognized. They are characterized by the abundance of echinoids and occur in the more proximal sections in the eastern part of the Barranca some metres above the discontinuity surfaces of the ULSE (Text-fig. 22).

The *Offaster nuciformis* I Event is located *ca.* 1.5 m above the FAD of the eponymous species at Zuazu, and marks the first appearance of the genus *Offaster* in northern Spain. At Zuazu, the first event is represented by a *ca.* 1.9 m thick interval with *Hemiaster* sp., which is commoner than the index taxon (Pl. 13, Figs 10-12, 13-15). The upper *nuciformis* II Event, coincides with the local FAD of *Texanites* cf. *quinquenodosus*.

In Cantabria, northern Spain, *Offaster nuciformis* is known to occur within the total range of *Cl. undulatoplicatus* in the Soto de la Marina section (OPPERMANN 1996; KÜCHLER & OPPERMANN, *in prep*.). The only other reported occurrences outside northern Spain are from Groß Bülten/Germany, i.e. from the type locality of *Offaster nuciformis*, and from England, from the Santonian chalk of Kent and from the Haldon residual flint gravels (ERNST 1971). Its occurrence in Germany is placed by ERNST & SCHULZ (1974, p.17) in the upper Lower Santonian *coranguinum/westfalica* Zone. On the other hand, rare *Offaster* sp. were found together with *Hemiaster* sp. at Olazagutia, 14 m above the last known occurrence of *Cl. undulatoplicatus* (GALLEMI & *al.* 1997). Unfortunately, the total range of *Cl. undulatoplicatus* still is uncertain at this locality, because KANNENBERG (1985) reported the species as occurring at an even higher level (*see* Text-fig. 28B). Consequently, the events fall either in the higher part of the Lower Santonian, or in the Middle Santonian.

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PLATES 5 – 14

If not otherwise stated all figures are in natural size; the specimen abbreviations consist of (1) section symbol (*e.g.* Ar -Arardi; IzI – Izurdiaga I, SatrII – Satrustegui II, GZ – Ganuza IV (GZ), Ol – Ollogoyen, ZuC – Zuazu C) (2) bed number and (3) number of an individual from particular beds (*e.g.* Izurdiaga II section, bed number 93, specimen 4 = IzII-93/4). Asteriks and brackets are used for bed numbers which differ or are additional to those used by other authors in the Ganuza and Ollogoyen sections.

All specimens, including those labelled with IPFU and housed previously in the Institute für Paläontologie, Freie Universität Berlin, are currently housed in author's private collection.

Plate 5

Ammonites and inoceramids from the Lower Turonian of the Barranca/Navarra

Fig. 1 – *Inoceramus* sp., specimen Ar-52/3; Lower Turonian, ?*ganuzai/ nodosoides* Zone; Arardi

Fig. 2 – *Inoceramus pictus bohemicus* LEONHARD, specimen Ar-50/1; Upper Cenomanian, *geslinianum* Zone; Arardi

Figs 3-4 – *Sciponoceras* sp; Lower Turonian, ?*ganuzai/nodosoides* Zone; Arardi
3 – specimen Ar-52/1
4 – specimen Ar-52/2

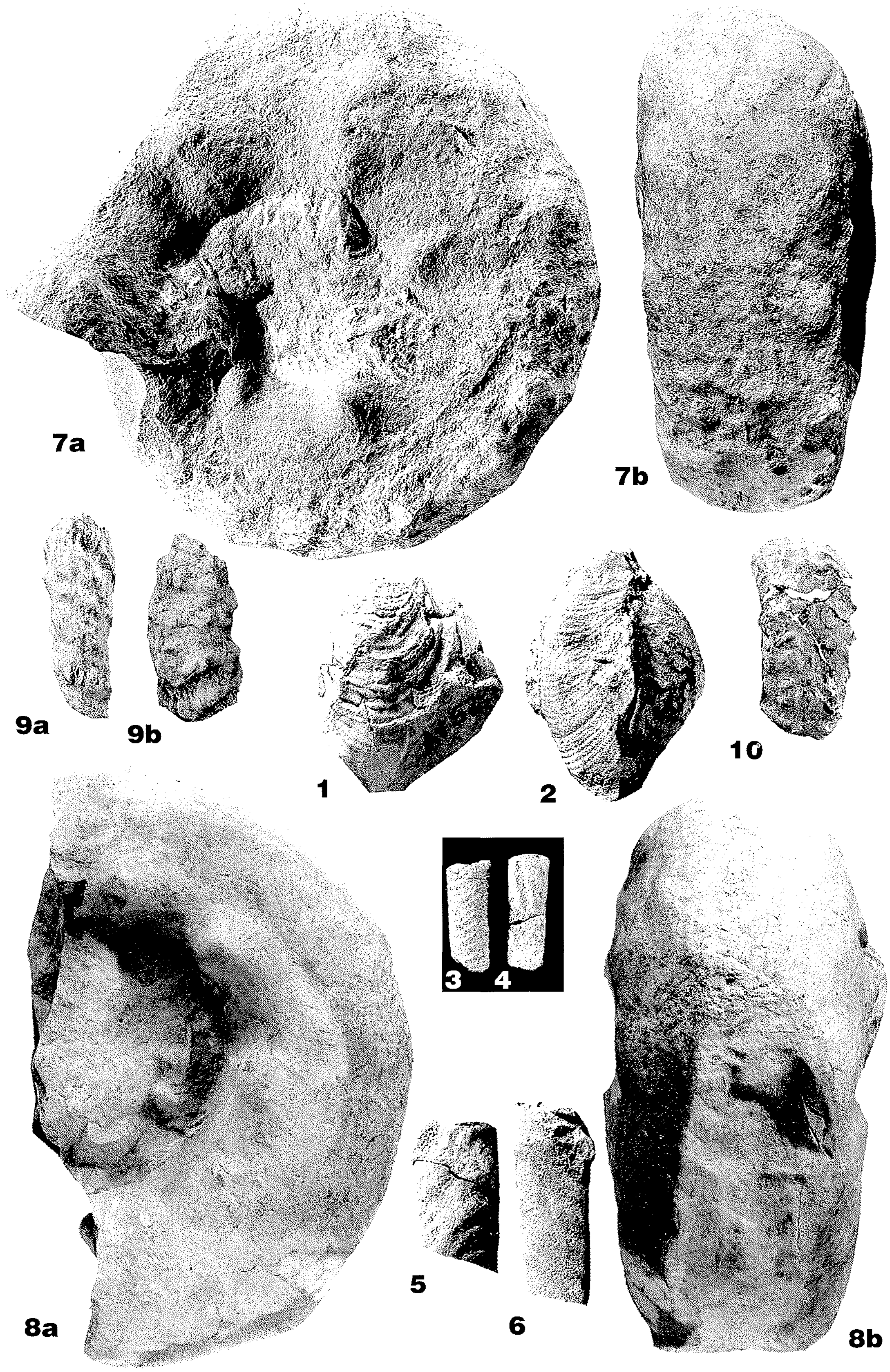
Figs 5-6 – *Sciponoceras* cf. *bohemicum* (FRITSCH); Lower Turonian, *ganuzai/nodosoides* Zone, *ganuzai* Event; Arardi
5 – specimen Ar-53/1
6 – specimen Ar-53/2

Fig. 7a-b – *Spathites* (*Jeanrogericeras*) *robustus* (WIEDMANN), specimen IzII-68/1; Lower Turonian, *ganuzai/nodosoides* Zone; Izurdiaga; b × 0.9

Fig. 8 – *Spathites* (*Ingridella*) *maladae* (FALLOT), specimen IzII-70/1; Lower Turonian, *ganuzai/nodosoides* Zone; Izurdiaga

Fig. 9 – *Kamerunoceras ganuzai* (WIEDMANN), specimen Ar-53b/1; Lower Turonian, *ganuzai/nodosoides* Zone, *ganuzai* Event; Arardi

Fig. 10 – *Kamerunoceras ganuzai* (WIEDMANN), specimen Ar-53a/1; Lower Turonian, *ganuzai/nodosoides* Zone, *ganuzai* Event; Arardi; × 1.42


7a
7b
9a
9b
1
2
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3
4
5
6
8a
8b

Plate 6

Ammonites from the Lower and Middle Turonian of the Barranca

Fig. 1 – *Pachydesmoceras denisonianum* (STOLICZKA), specimen Ar-(60/62)/1; Lower Turonian, *ganuzai/nodosoides* Zone; Arardi

Fig. 2 – *Kamerunoceras turoniense* (D'ORBIGNY), specimen Ar-60/2; basal mid-Turonian, base of the *turoniense* Zone, *reveliereanus* Event; Arardi, loose, probably from bed Ar-64

Fig. 3 – *Kamerunoceras ganuzai* (WIEDMANN); specimen Ar-68/2; Middle Turonian, *turoniense* Zone; Arardi

Fig. 4 – *Spathites (Jeanrogericeras) reveliereanus* (COURTILLER), specimen Ar-70/1; Middle Turonian, *turoniense* Zone, *turoniense/hercynicus* Event; Arardi

Fig. 5 – *Mammites* cf. *nodosoides* (SCHLÜTER), specimen Ar-64/3; base of the mid-Turonian, base of the *turoniense* Zone, *reveliereanus* Event; Arardi

Fig. 6 – *Spathites reveliereanus* (COURTILLER), specimen Ar-64/1; Lower Turonian, *ganuzai/nodosoides* Zone, *reveliereanus* Event; Arardi

Fig. 7 – *Cibolaites molenaari* COBBAN & HOOK, specimen IzII-82/1; Middle Turonian, *turoniense* Zone; Izurdiaga

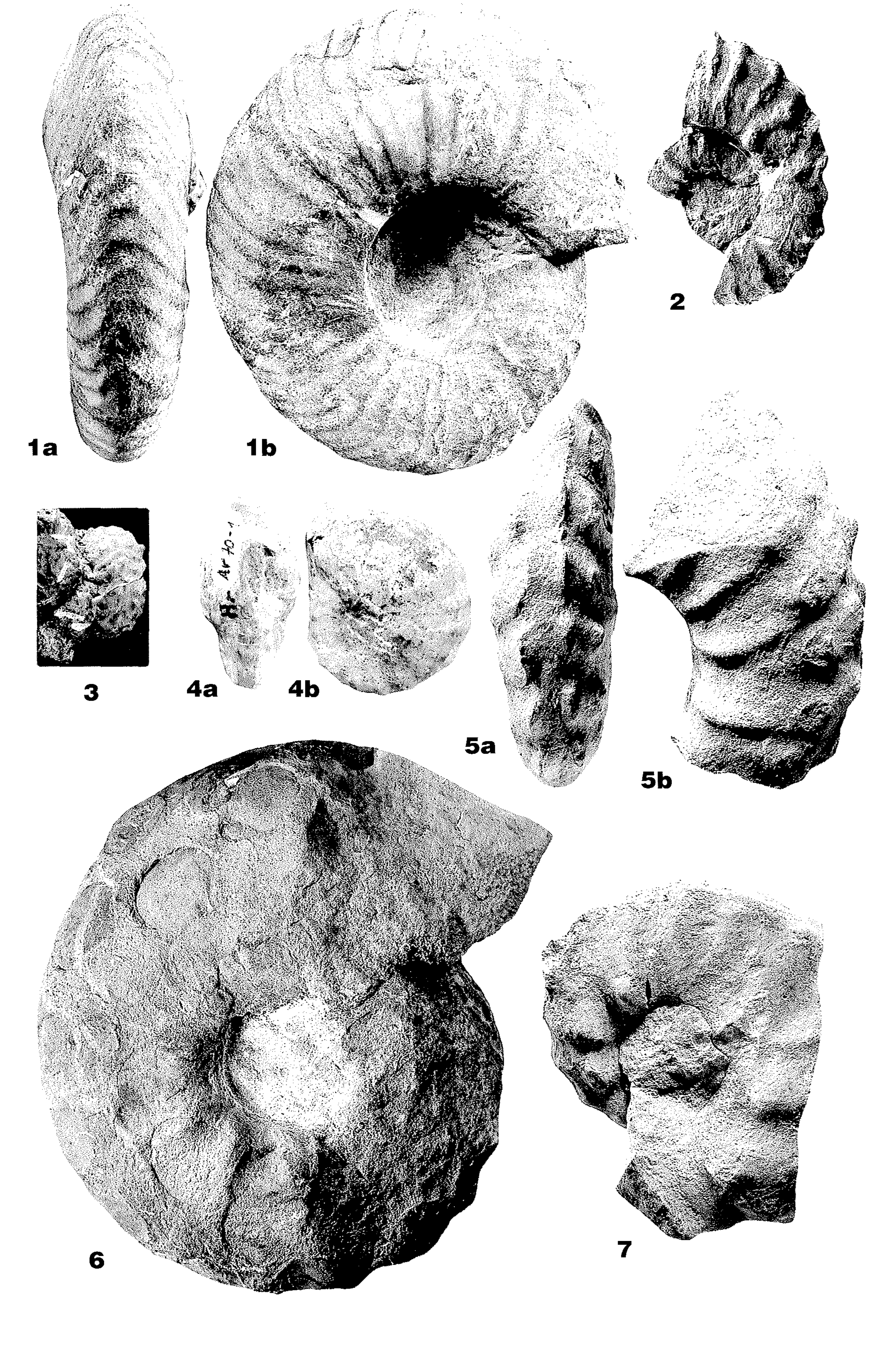
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Plate 7

Ammonites from the Middle Turonian of the Barranca and the Estella area/Navarra

Fig. 1 – *Placenticeras* aff. *cumminsi* CRAGIN, specimen IzII-93/1;. Middle Turonian, *turoniense* Zone, *turoniense/hercynicus* Event; Izurdiaga

Figs 2-5 – *Kamerunoceras turoniense* (D'ORBIGNY); Middle Turonian, *turoniense* Zone; Izurdiaga

2 – specimen IzI 46/1

3 – specimen IzII-(93/94)/2; *turoniense/hercynicus* Event

4 – specimen IzII-89-(7990)/2; immediately below the *turoniense/hercynicus* Event

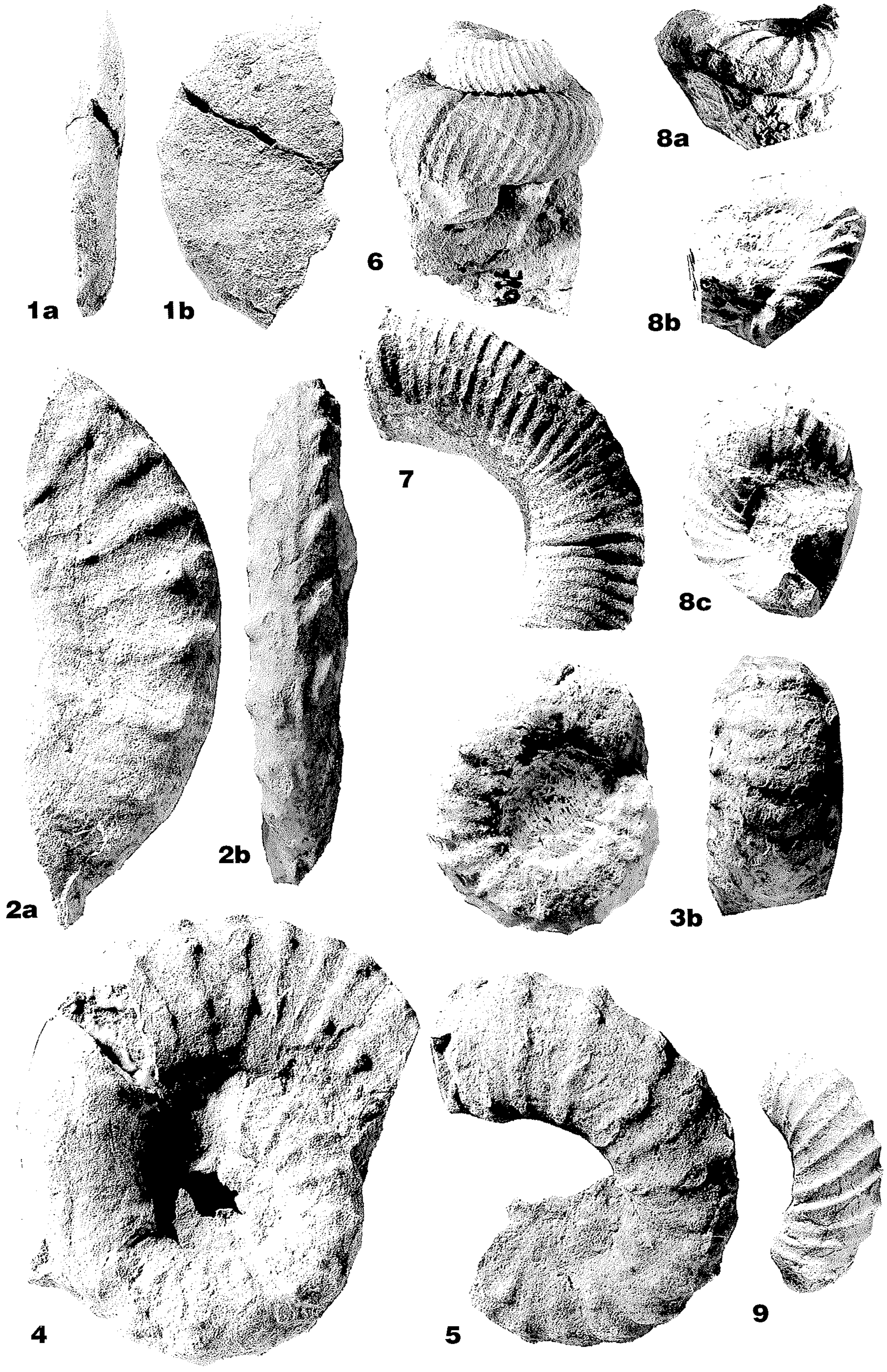
5 – loose specimen from the interval of the *turoniense/hercynicus* Event; Izurdiaga I

Fig. 6 – *Nostoceras* (*Eubostrychoceras*) aff. *matsumotoi* COBBAN, specimen IzI-36/1; Middle Turonian, *turoniense* Zone; Izurdiaga

Fig. 7 – *Nostoceras* (*Eubostrychoceras*) nov. sp., specimen IzII-94/7; Middle Turonian, *turoniense* Zone, *turoniense/hercynicus* Event; Izurdiaga

Fig. 8 – *Nostoceras* (*Eubostrychoceras*) aff. *matsumotoi* COBBAN, specimen SatrI-A1/16; uppermost Lower Turonian to Middle Turonian; Satrustegui

Fig. 9 – *Nostoceras* (*Eubostrychoceras*) aff. *matsumotoi* COBBAN, specimen GA-4(Ga-4+/1); Lower Turonian, *Spathites reveliereanus* Event; Ganuza I (GA) section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8c
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3b
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Plate 8

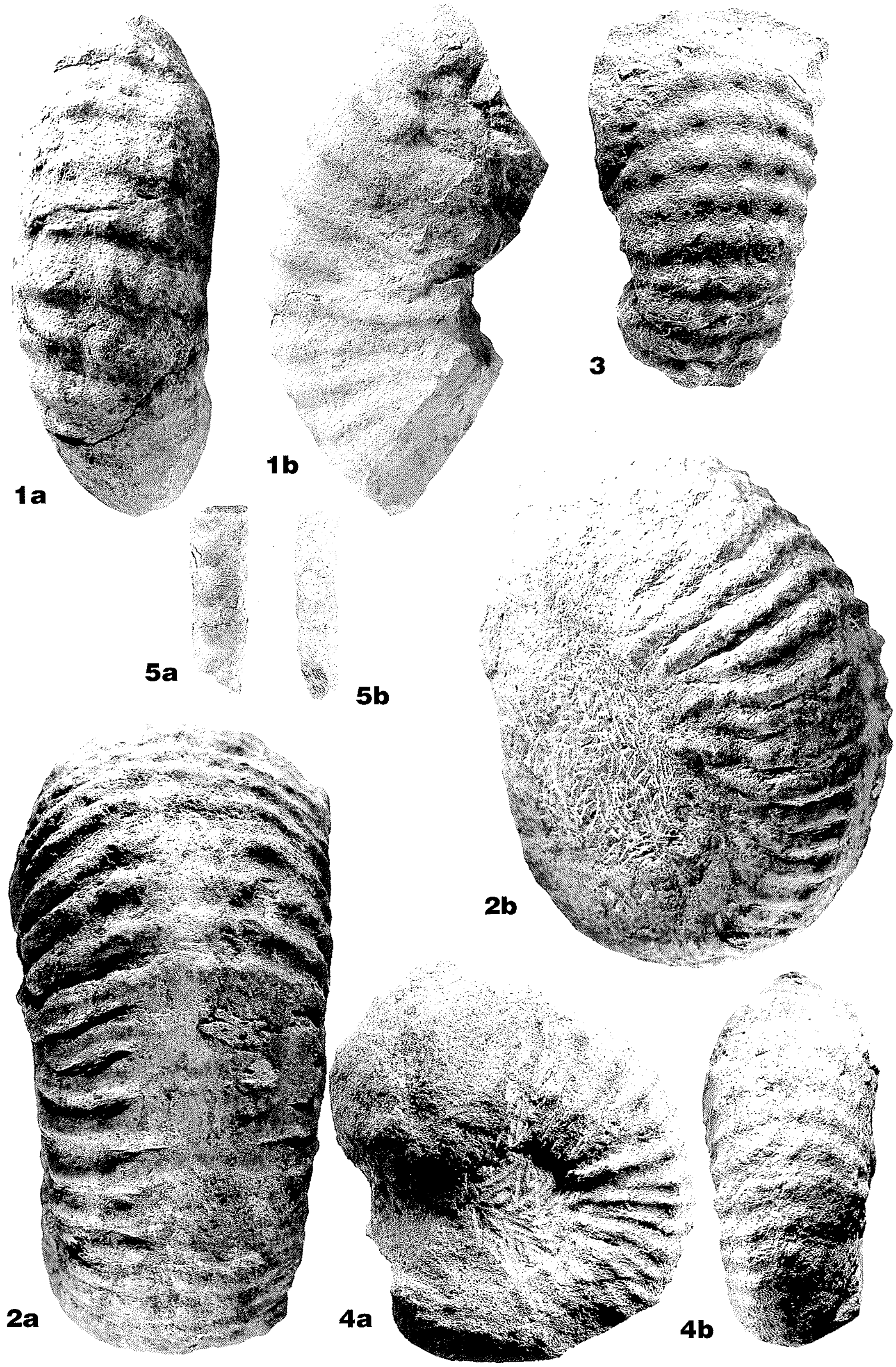
Ammonites from Middle Turonian of the Barranca

Figs 1, 3 – *Romaniceras ornatissimum* (STOLICZKA); Middle Turonian, *ornatissimum* Zone; Izurdiaga
1 – specimen IzI-71/2
3 – specimen IzI-67(4886)

Fig. 2 – *Romaniceras* aff. *kallesi* (ZÁSVORKA), specimen Ar-78/1; Middle Turonian, *kallesi* Zone, *kallesi/ornatissimum* Event; Arardi

Fig. 4 – *Romaniceras deverianum* (D'ORBIGNY), specimen IzI-93/1; Middle Turonian, *deverianum* Zone; loose below IzI-93; Izurdiaga

Fig. 5 – *Baculites undulatus* D'ORBIGNY, specimen Ar-90a/1; Upper Turonian, *neptuni* Zone, *deverianum/rhodanicum* Event; Arardi


1a
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2a
4a
4b

Plate 9

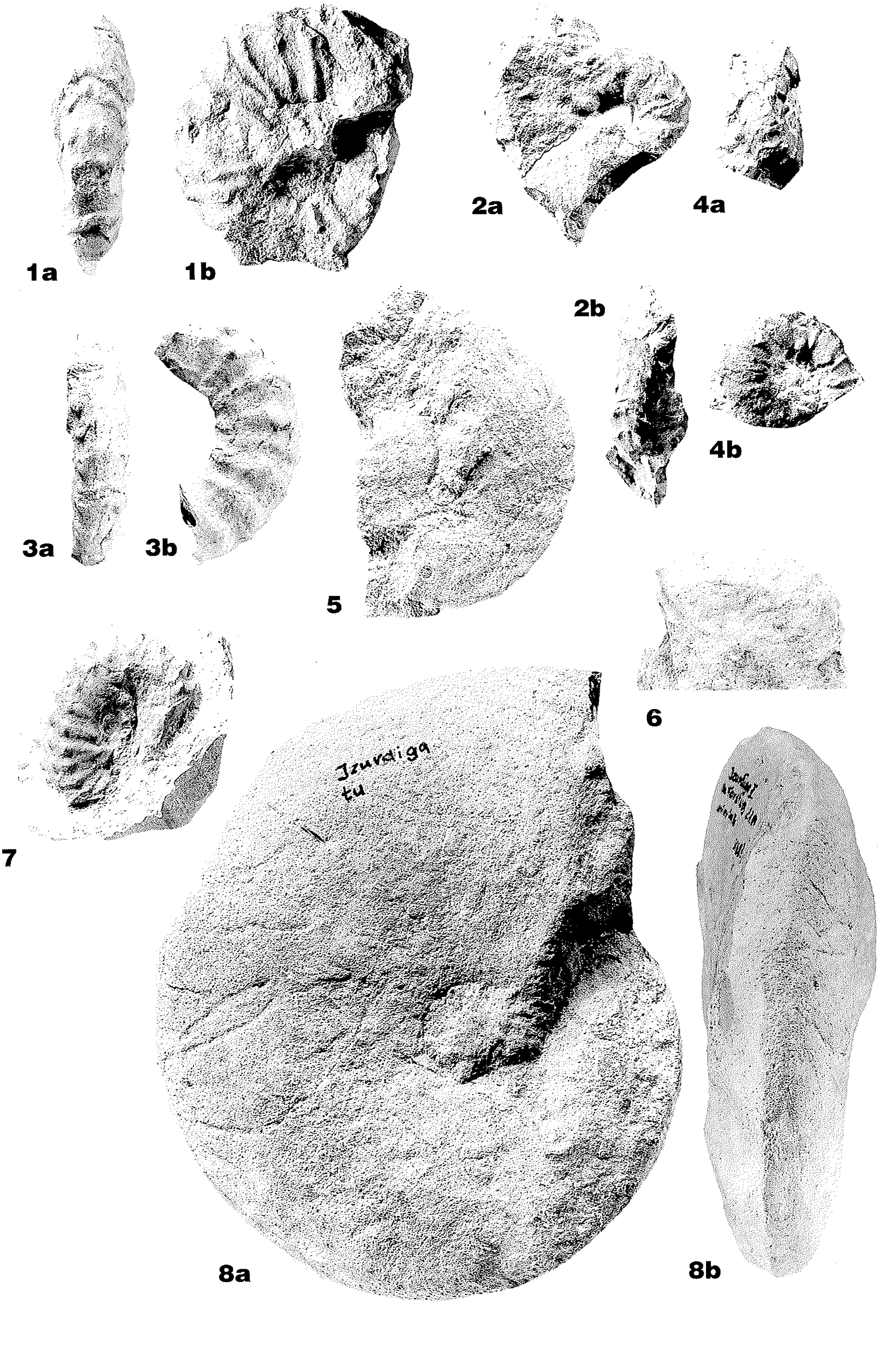
Ammonites from the Lower Turonian of the Estella area and the Barranca

Figs 1-4, 6 – *Kamerunoceras ganuzai* (WIEDMANN); Lower Turonian, *ganuzai/ nodosoides* Zone; Ganuza IV (GZ)
1 – specimen GZ-6 (Ga-2e/1); *ganuzai* Event
2 – specimen GZ-6 (Ga-2c-e/1); *ganuzai* Event
3 – specimen GZ-7 (Ga-2g/1); *ganuzai* Event; Fig. 3b is upside-down
4 – specimen GZ-6 (Ga-2c-e/2); *ganuzai* Event
6 – specimen Gz-3/1; *kossmati* Event

Fig. 5 – *Placenticeras* aff. *cumminsi* CRAGIN, specimen GZ-6 (Ga-2e/2); Lower Turonian, *ganuzai/nodosoides* Zone, *ganuzai* Event; Ganuza IV (GZ)

Fig. 7 – *Spathites* cf. *reveliereanus* (COURTILLER), specimen ?GI-2 (BI-3e); Lower Turonian, *ganuzai/nodosoides* Zone, topmost part of the *reveliereanus* Event; Ganuza II (GI)

Fig. 8 – *Choffaticeras quaasi* (PERON), specimen IzII-68-/2; Lower Turonian, *ganuzai/nodosoides* Zone; Izurdiaga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8a
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Plate 10

Ammonites and inoceramids from the Lower Turonian of the Barranca and Middle Turonian of the Estella area

Fig. 1 – *Kamerunoceras turoniense* (D'ORBIGNY), specimen GA-9b (Ga-8/2); Middle Turonian, *turoniense* Zone, *turoniense/hercynicus* Event; Ganuza I (GA)

Fig. 2 – *Romaniceras kallesi* (ZÁZVORKA), specimen ?Ol-103/1; Middle Turonian, *ornatissimum* Zone, base of the zone TuVIII *sensu* WIEDMANN (1979a); Ollogoyen

Fig. 3 – *Mytiloides hercynicus* (PETRASCHEK), specimen GA-9b (Ga-8/29); Middle Turonian, *turoniense* Zone, *turoniense/hercynicus* Event; Ganuza I (GA)

Fig. 4 – *Mytiloides kossmati* (HEINZ), specimen Ar-64 (unregistered); Lower Turonian, *ganuzai/nodosoides* Zone, *reveliereanus* Event; Arardi

Fig. 5 – *Spathites reveliereanus* (COURTILLER), specimen GA-(3/4)/1; Lower Turonian, *ganuzai/nodosoides* Zone, *reveliereanus* Event; loose between GA-3 and GA-4, Ganuza I (GA)

Figs 6-7 – *Collignoniceras woollgari* (MANTELL); Middle Turonian, *ornatissimum* Zone; Ollogoyen
6 – specimen Ol-(102/103)/1
7 – specimen Ol-(102/103)/2

Fig. 8 – *Romaniceras kallesi* (ZÁZVORKA), specimen GA-*11a/1; Middle Turonian, *kallesi* Zone; Ganuza I (GA), approximately 120 m level

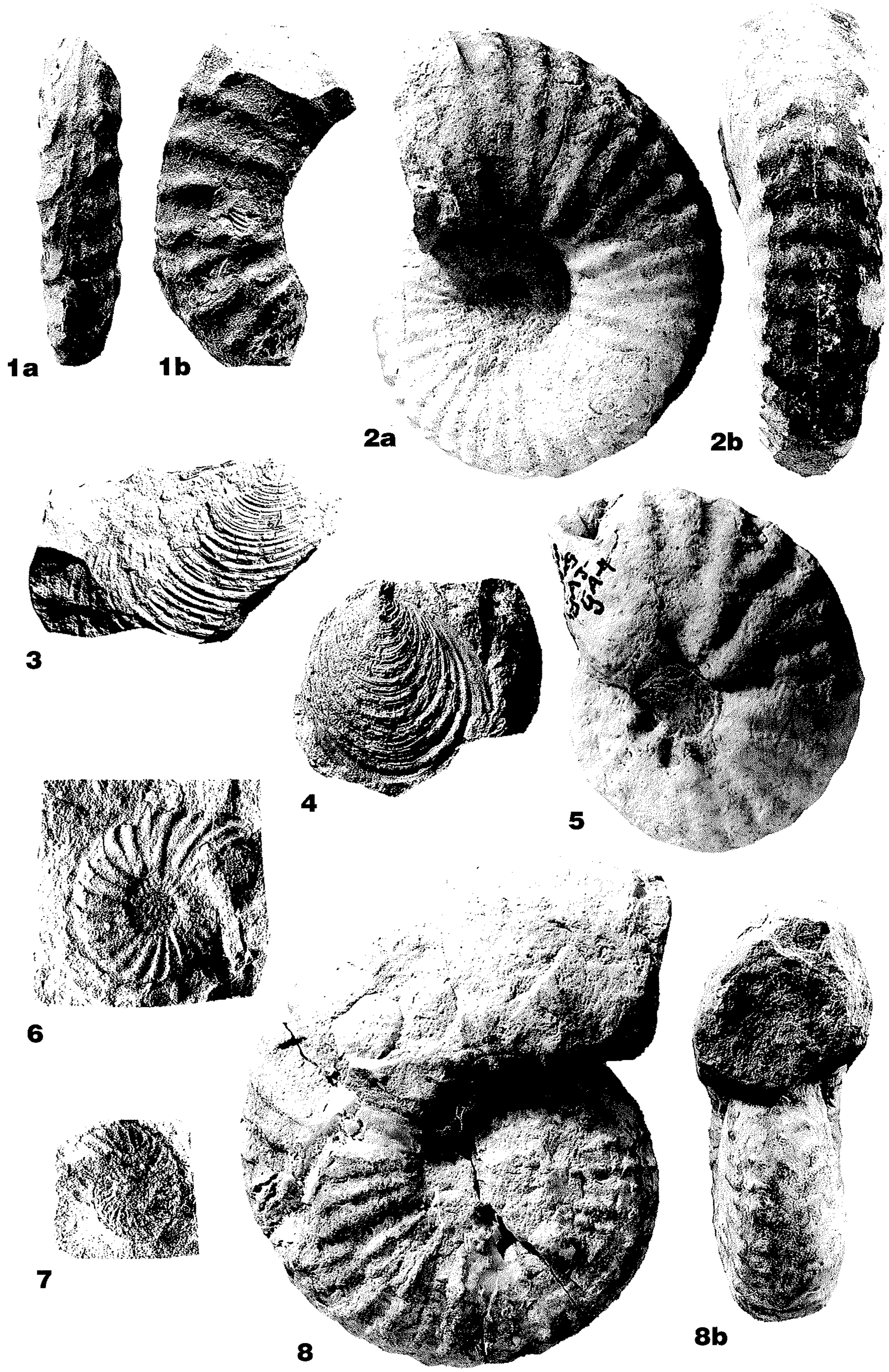
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Plate 11

Ammonites from the Upper Turonian of the Estella area

Figs 1-2 – *Subprionocyclus* ex gr. *neptuni-hitchinensis*; Upper Turonian; Ollogoyen

1 – specimen IPFU-GE 89/4 (cf. KÜCHLER & ERNST 1989, Pl. 2, Fig. 1); *waltersdorfensis/germari* Zone, *Subprionocyclus* II Event;

2 – specimen IPFU-GE 89/5 (cf. KÜCHLER & ERNST 1989, Pl. 2, Fig. 2); *neptuni* Zone, *Subprionocyclus* I Event (= bed Ol-110+1m)

Figs 3, 5-6, 10 – *Romaniceras deverianum* (D'ORBIGNY); Upper Turonian; Ollogoyen

3 – specimen Ol-*8/1; upper part of the *waltersdorfensis/germari* Zone, ca. 40 m-level of the Ollogoyen section.

5 – specimen IPFU-GE 89/1 (cf. KÜCHLER & ERNST 1989, Pl. 1, Fig. 1); *waltersdorfensis/germari* Zone, 16,5 m- level of the Ollogoyen section

6 – specimen Ol-*111b/1; *neptuni* Zone, Ollogoyen, *Subprionocyclus* I Event

10 – specimen IPFU-GE 89/2 (cf. KÜCHLER & ERNST 1989, Pl. 1, Fig. 2); *waltersdorfensis/germari* Zone, 3 m above *Subprionocyclus* II Event

Fig. 4 – *Prionocyclus* cf. *germari* (REUSS), specimen IPFU-GE 89/6 (cf. KÜCHLER & ERNST 1989, Pl. 2, Fig. 3); Upper Turonian, *waltersdorfensis/germari* Zone, 3 m above *Subprionocyclus* II Event at the 34 m-level of the section; Ollogoyen

Fig. 7 – *Scaphites geinitzii* D'ORBIGNY, specimen Ol-*109d/2; Upper Turonian, base of the *neptuni* Zone, *geinitzii* Bed; Ollogoyen

Fig. 8 – *Subprionocyclus neptuni* (GEINITZ), specimen Ol-*109d/1; Upper Turonian, base of *neptuni* Zone, *geinitzii* Bed; Ollogoyen

Fig. 9 – *Subprionocyclus* ex gr. *neptuni-hitchinensis*, specimen Ol-*111b/2; Upper Turonian, *neptuni* Zone, *Subprionocyclus* I Event; Ollogoyen

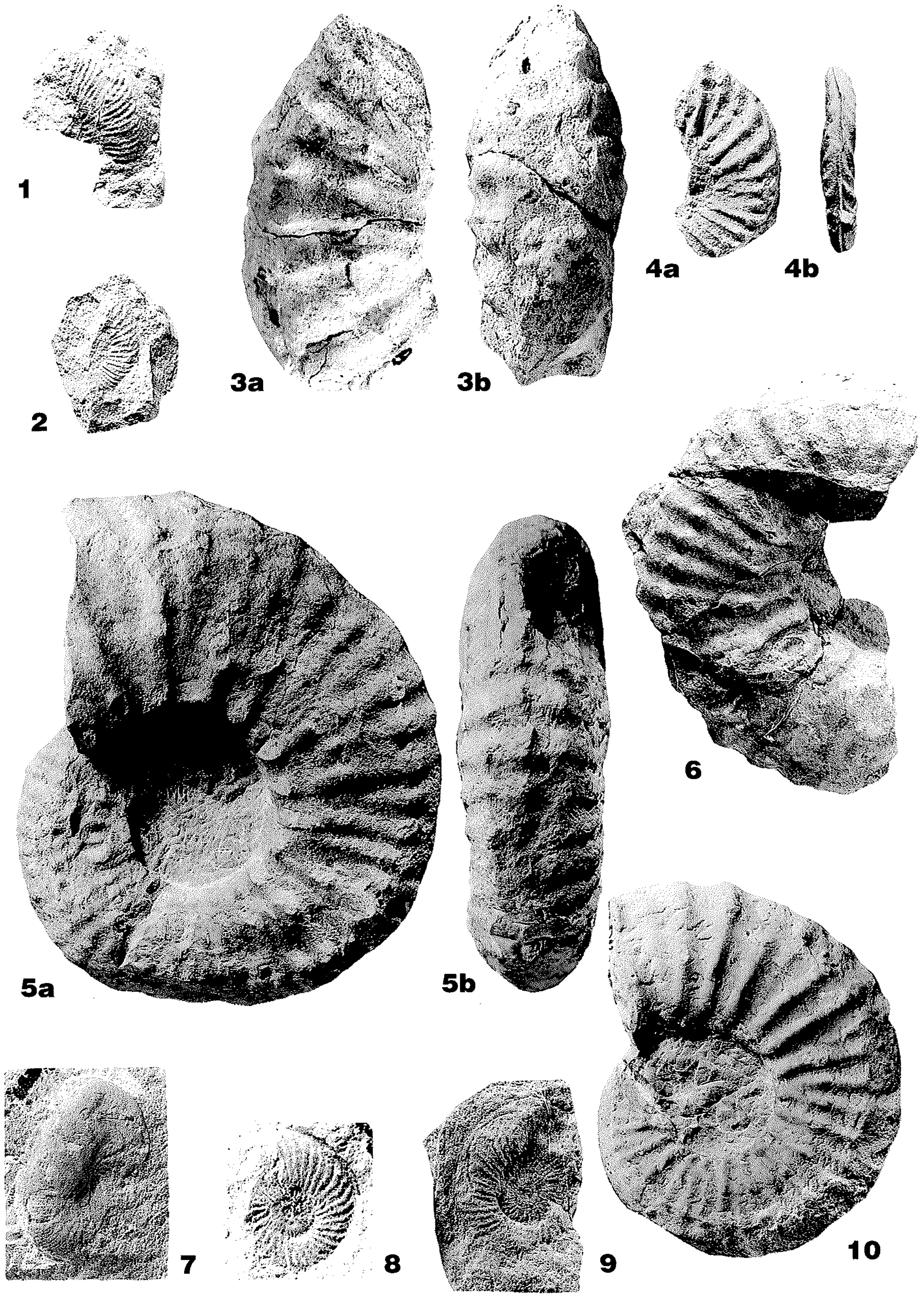

Plate 12

Ammonites from the Lower Coniacian of the Barranca

Fig. 1 – *Forresteria* (*Harleites*) sp., specimen IzI-109/1; Lower Coniacian, *petrocoriensis* Zone; Izurdiaga

Fig. 2 – *Forresteria* (*Harleites*) *nicklesi* (DE GROSSOUVRE), specimen IPFU-GE89/7 (cf. KÜCHLER & ERNST 1989, Pl. 2, Fig. 4); Lower Coniacian, *subtricarinatum* Zone; Villanueva de Araquil, HG3

Fig. 3 – *Peroniceras* (*Peroniceras*) *tridorsatum* (SCHLÜTER), specimen IPFU-GE 89/9 (cf. KÜCHLER & ERNST 1989, Pl. 2, Fig. 6); Lower Coniacian, *subtricarinatum* Zone; Satrustegui I, bed A3

Fig. 4 – *Peroniceras* (*Peroniceras*) *subtricarinatum* (D'ORBIGNY), specimen IPFU-GE 89/11 (cf. KÜCHLER & ERNST 1989, Pl. 3, Fig. 1); Lower Coniacian, *subtricarinatum* Zone; Ecay E, bed P

Fig. 5 – *Peroniceras* (*Zuluiceras*) cf. *bajuvaricum* (REDTENBACHER), specimen IPFU-GE 89/8 (cf. KÜCHLER & ERNST 1989, Pl. 2, Fig. 5); Lower Coniacian, *subtricarinatum* Zone; Villanueva de Araquil, 0.3 m above HG3,

Figs 6-7 – *Anagaudryceras* sp.; Lower Coniacian, *subtricarinatum* Zone; Zuazu,
6 – specimen ZuB-100e/1
7 – specimen ZuB-100e/2

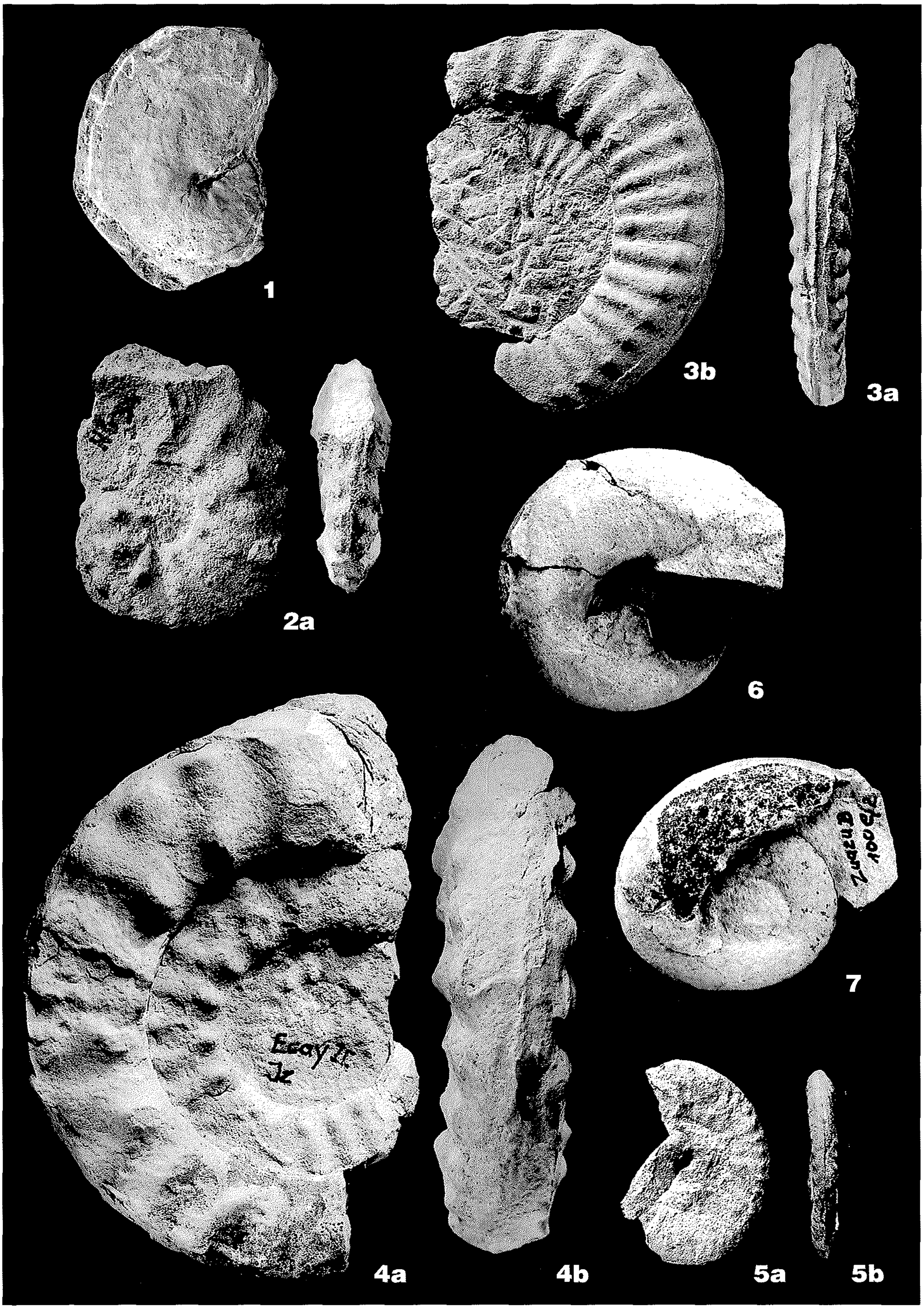
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Plate 13

Ammonites and echinoids from the Lower and Middle Coniacian of the Barranca

Figs 1-2 – *Tissotioides haplophyllus* (REDTENBACHER) EcE-(Ech.-B)/1; Lower Coniacian, *subtricarinatum* Zone, *Echinocorys gravesi* II Event; Ecay E, at the zero level of the section

Fig. 3 – *Nowakites pailletteanus* (D'ORBIGNY), specimen ZuC-340c/1; Middle Coniacian, *margae* Zone; Zuazu

Figs 4-5 – *Gauthiericeras margae* (SCHLÜTER), specimen ZuC (unregistered); Middle Coniacian, *margae* Zone; Zuazu

Fig. 6 – *Peroniceras subtricarinatum* (D'ORBIGNY), specimen ZuB-(bed 100 -12m)/1; Lower Coniacian, *subtricarinatum* Zone; 12 m below "*deformis*" I/*Anagaudryceras* sp. Event, Zuazu

Figs 7-8 – *Eupachydiscus isculensis* (REDTENBACHER), specimen ZuA-AZ1/1; Middle Coniacian, *Gauthiericeras margae* Zone, ammonite bed; Zuazu

Fig. 9 – *Protexanites bontanti* (DE GROSSOUVRE), specimen ZuC 346/1; Upper Coniacian, *bourgeoisi* Zone, *boreaui*/*bourgeoisi* Event; Zuazu

Figs 10-15 – *Offaster nuciformis* ERNST. Uppermost Lower Santonian or lowermost Middle Santonian, *nuciformis* Event I; Zuazu
10-12 – specimen ZuC-364/1
13-15 – specimen ZuC-364/2

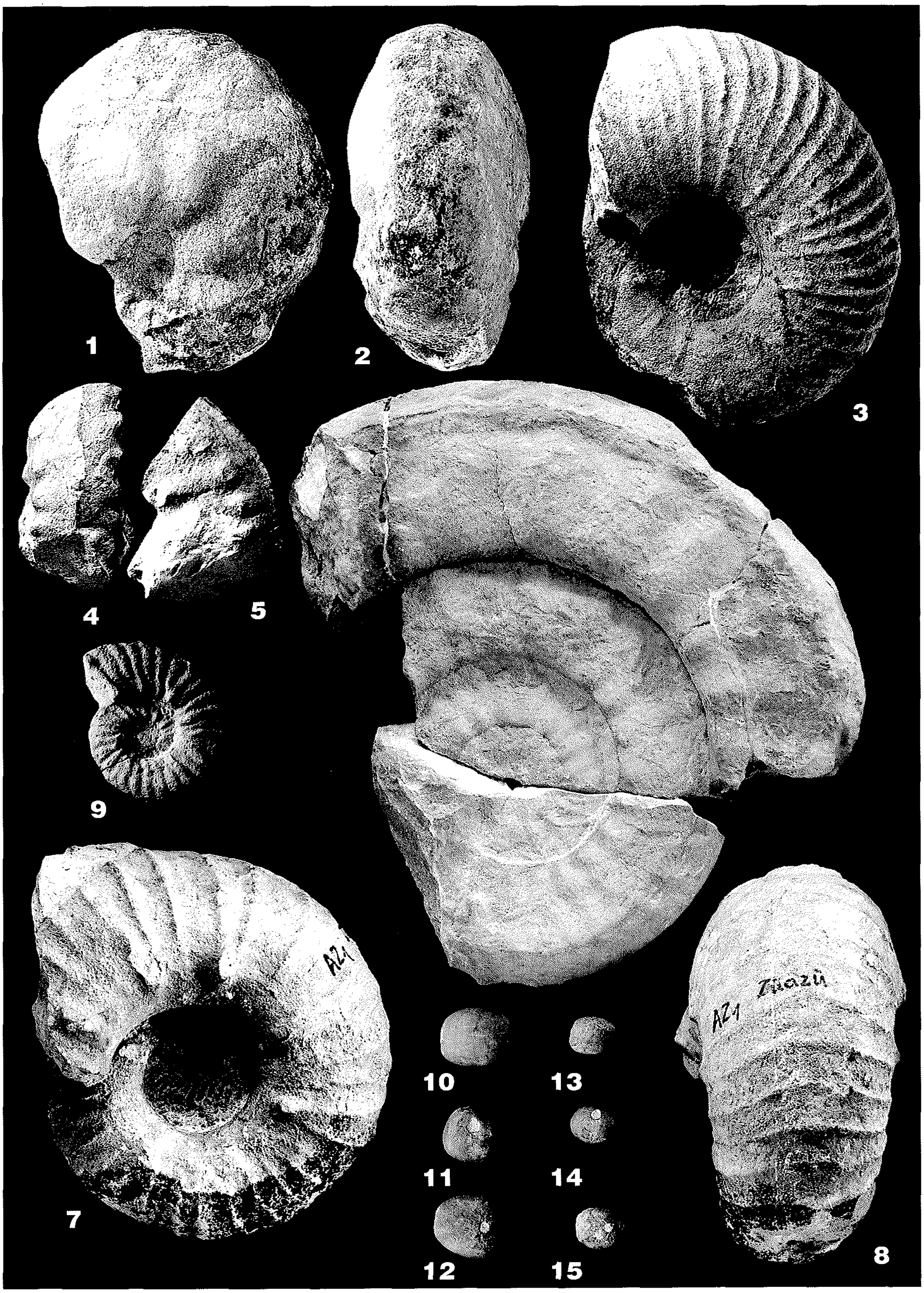
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Plate 14

Ammonites from the Middle Coniacian to Middle Santonian of the Barranca

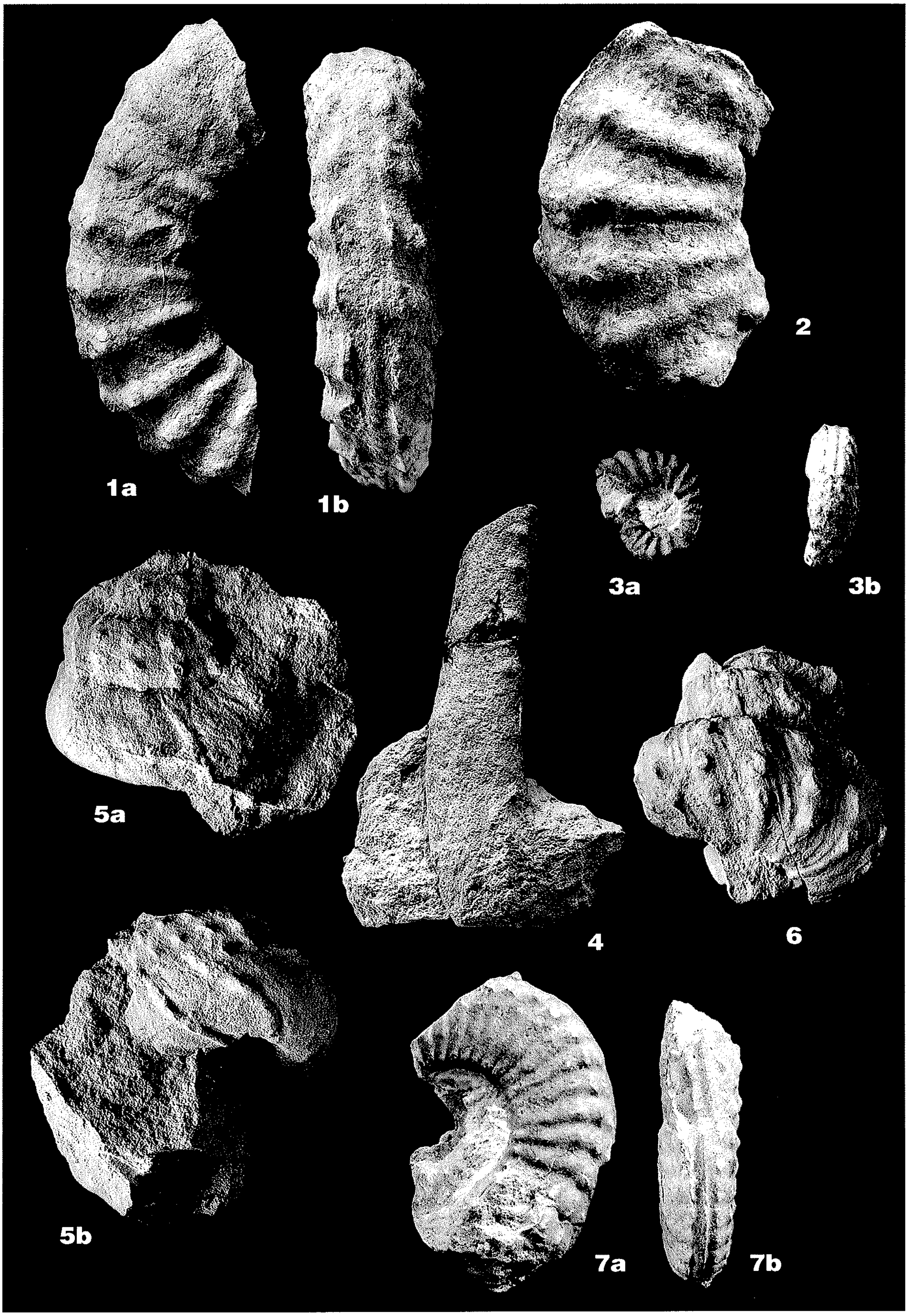
Figs 1-3 – *Protexanites bourgeoisi* (D'ORBIGNY); Upper Coniacian, *bourgeoisi* Zone, *boreaui/bourgeoisi* Event; Zuazu
1 – specimen ZuC-347/349/1; loose between beds 347 and 349
2 – specimen ZuC-348/2
3 – specimen ZuC-347/2

Fig. 4 – *Baculites incurvatus* DUJARDIN, specimen ZuC-348/1; Upper Coniacian, *bourgeoisi* Zone; Zuazu

Fig. 5 – *Tridenticeras varians* (SCHLÜTER), specimen ZuC-131/1; Middle Coniacian, *margae* Zone, *Tridenticeras* I Event; Zuazu

Fig. 6 – *Tridenticeras tridens* (SCHLÜTER), specimen ZuA-B 500/1; Middle Coniacian, *margae* Zone; loose, probably from within bed 204 (= bed B 500 *sensu* KÜHN 1983); Zuazu

Fig. 7 – *Texanites quinquenodosus* (REDTENBACHER), specimen ZuC-366/1; Middle Santonian, *quinquenodosus* Zone; Zuazu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