Maastrichtian molluscan biostratigraphy and extinction patterns in a Cretaceous/Tertiary boundary section exposed at Zumaya, Spain

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ABSTRACT

Ammonites and inoceramid bivalves were stratigraphically collected from lower and upper Maastrichtian units in continuous exposure along the seacoast near Zumaya, Spain. Three ammonite tell zones can be recognized: (1) a lower zone correlative with parts of the Globotruncana gasuerri planktonic foraminiferal zone and characterized by numerous inoceramids among three different species as well as Pachydiscus neubergeri, a noded Baculites, Polyptychoceras sipho, and Hauerioceras renida; (2) a middle zone that has no inoceramids but that has Pachydiscus fresvillensis and P. neubergeri and is correlative with the lower parts of the Abathomphalus mayaroensis Zone (planktonic foraminiferal) and (3) an upper zone that has P. colligatus and is correlative with the upper parts of the A. mayaroensis Zone. These three tell zones may be the basis for a Tethyan, facies-wide ammonite zonation of the Maastrichtian. The four main components of the fossil record at the Zumaya section show differing range characteristics with respect to the Cretaceous/Tertiary (K/T) boundary exposed in this section. The inoceramids disappear at the top of the lower Maastrichtian, except for the small enigmatic form Tenoipteria, which has a restricted range in the uppermost levels of the Cretaceous. Ammonites range upward to levels approximately 10 m below the boundary. Most larger planktonic forams and many nannofossil species disappear within several centimetres of the boundary. Echinoid fossils range up to, and possibly across, the K/T boundary. The Zumaya section is thus characterized by apparently nonsynchronous or graded extinctions of most of its fossil content.

INTRODUCTION

The stratigraphic section exposed along the seaciffs near Zumaya, Spain, includes a well-exposed Cretaceous/Tertiary (K/T) boundary. This is one of the few K/T boundary sections that contain macrofossils as well as microfossils. Our study suggests an ammonite and inoceramid bivalve biostratigraphy of the Maastrichtian Stage and provides new data about the timing of macrofossil extinctions in this region of Europe during the K/T transition.

HISTORICAL BACKGROUND

The Maastrichtian Stage of the Cretaceous System was loosely defined by Dumont (1850) on the basis of faunas and localities in chalk facies of eastern Holland, and its boundaries were a matter of dispute. In many respects the stratotype section, today considered to be the E.N.C.I. quarry in Limbourg, Holland, and nearby reference sections such as Kronsmoor and Hemmoor were unfortunate choices. The problem is twofold. First, the sections are incomplete in that none contains a Maastrichtian/Paleocene boundary. The Campanian/Maastrichtian boundary is present in these sections but is difficult to define on macrofaunal evidence (Jeletzky, 1951; Schmid, 1967; Surov, 1982). Second, and perhaps of greater importance, is the problem posed by the nature of the facies and faunas composing the stratotypes. The stratotype sections are chalks, deposited in a boreal biogeographic province. The nature of the rock and its setting strongly influenced the suite of animals inhabiting this area and tends to make the enclosed stratotype fauna quite provincial in nature. Because of these two factors, correlation with nonchalk facies and faunas is difficult. Tethyan faunas of more equatorial areas, for instance, contain few or no co-occurring faunal elements.

Although the problems of establishing a refined Maastrichtian biostratigraphy have long been known to Cretaceous biostratigraphers, the need for more reliable subdivision of the Maastrichtian Stage has recently become of interest to a wider segment of the scientific community. The K/T boundary coincides with one of the most pronounced faunal turn-
overs known in the geologic record, a turnover that affected both terrestrial and marine faunas. The now well-known iridium anomalies that can be found in virtually every K/T boundary section have led to the hypothesis of an extraterrestrial cause for these marine and terrestrial extinctions (Alvarex et al., 1980, 1984, and references therein). Unfortunately, most complete K/T boundary sections are in the deep sea and thus accessible only through deep-sea drilling programs; in most cases the drilling methodology excludes information about macrofossil stratigraphic ranges and abundances. Information about the ranges of larger fossils must come from terrestrial Maastrichtian Stage stratigraphic sections, which have proved to be scarce and usually incomplete.

In large part because of the relatively few land-based K/T boundary sections available for study, paleontological study of the timing of extinctions in the marine and terrestrial realm has lagged behind the geochemi-

Figure 2. Measured stratigraphic section (in metres) showing position of ammonites and inoceramid bivalves. Fossil occurrences are marked by short horizontal line; if more than one occurrence of a given taxon was recorded at that horizon, exact number of specimens is listed to left of line. Total number of occurrences for each taxon is tabulated at bottom of column. Ranges of diagnostic planktonic forms are shown between stratigraphic column and ammonite range charts.
cal and magnetostratigraphic studies of the K/T boundary. The ranges of fossils from the Zumaya section and from other nearby coeval sections exposed along the coast of the Bay of Biscay provide new information about Maastrichtian biostratigraphy and the K/T extinctions.

STRATIGRAPHIC SETTING

The Zumaya section (Fig. 1) is part of a thick sequence of upper Mesozoic and lower Cenozoic strata that crop out along the northern coast of Spain. It is part of the Basque-Cantabrian Basin of northern Spain (Wiedmann et al., 1983). Most of the stratigraphic sections in the central region of this basin are composed of turbidites; megafossils are usually rare. During deposition of the Maastrichtian part of the section, however, regional regression led to a change of facies patterns. During the early Maastrichtian, turbidite deposition in the region between San Sebastian and Bilbao gave way to deposition of pelagic and hemipelagic marls and limestones. Turbidite deposition recommenced in the early Tertiary.

The Maastrichtian section exposed near Zumaya is approximately 800 m thick (Lamolda et al., 1981). The upper 200 m are composed of limestones and marls. Megafossils, as well as a diverse microfossil assemblage, can be found in the upper marl and limestone unit.

The stratigraphic section measured for this study (Fig. 2) consists of about 240 m of interstratified limestone, marl, and calcarenitic sandstone. Two principal lithofacies are an interbedded limestone/marl lithofacies and a purple marl lithofacies. Stratigraphic alternation of these lithofacies form large-scale couplets about 50 m thick (Fig. 2; see Mount and Ward, 1986, for a paleoenvironmental analysis).

The limestone/marl lithofacies (Fig. 3a) consists of interstratified thin- to medium-bedded, light-gray micritic limestones and thin- to thick-bedded, dark-gray marls. Thin-bedded calcarenitic sandstones occur sporadically throughout this facies. The sandstones have well-developed basal scours and incomplete Bouma sequences. The purple marl lithofacies consists of grayish-red to dark-purple, thick-bedded marls interstratified with thin-bedded marls and thin-bedded calcarenitic sandstones (Fig. 3b).

Both the limestone/marl lithofacies and the purple marl lithofacies are dominated by helicoidal and arculate Zoophycus traces, and there are lesser amounts of Planolites, Scolica, Thallasinoides, Chonarioides, and Rhostoecorallium. In addition, both lithofacies contain abundant pelagic and benthic foraminifera, spicules, echinoderm plates, and coccolithophorids.

The general stratigraphy of the area has been described by Wiedmann (1964) and Lamolda et al. (1981). Herm (1963) and Hillebrandt (1965) have studied the succession of foraminifera in the Cretaceous and lower Tertiary parts, respectively, of the section; Kapellos (1974) and Percival and Fisher (1977) have examined the record of calcareous nannoplankton. The iridium anomaly at the K/T boundary near Zumaya has been described by Alvarez et al. (1980); the general geochemistry has been described by Smit and ten Kate (1982).

The section dips to the east at approximately 40° and is well exposed. Because of the dip of the beds and lack of cover, large bedding planes are exposed along the beach; this allows excellent opportunities for fossil collection.

BIOSTRATIGRAPHY

Herm (1963) reported the presence of the planktonic foramin zone Globorutunicata falloisi (lower Maastrichtian), G. gunosseri (lower to upper Maastrichtian), and Abathomphalus mayenteri (upper Maastrichtian). The lowest zone of the Tertiary, represented by Eugubina eugubina, has also been identified at the Zumaya seacoast section (Smit and ten Kate, 1982).

Ammonites and inoceramid bivalves occur sporadically in the lime-

Figure 3. Diagnostic lithologies of Cretaceous part of section. a: Limestone/marl lithofacies; note packs for scale. b: K/T boundary. Maastrichtian purple marl lithofacies on right; Danian nannofossil limestones on left. Approximately 20 m of section shown in photo.

stone and marl sections. Whereas inoceramids are locally abundant in both limestones and marls of the lower part of the Zumaya section, ammonites are more rare. Ammonites are most abundant in the marls; the massive limestones are least fossiliferous, and preserved ammonites are generally large. During this study, 252 ammonites were collected or noted. This number is a reflection of time on the outcrop; because of access problems during high tide, field work was limited to about four hours per day. Quarrying of the marls was the most productive means of acquiring ammonite specimens. The preservation of the body fossils is poor. All of the ammonites are laterally compressed casts, without external shell. Suture patterns are usually not preserved. The most commonly encountered ammonites are usually less than 10 mm in diameter, an indication that juveniles as well as larger immature or mature ammonites were accumulating within the same depositional environment. There was no evidence of dwarfing higher in the section; the single largest specimen collected (Pachydiscus colligatus, 32-cm diameter) was among the stratigraphically highest of all ammonites collected.

Three intergradational faunal associations of ammonites can be discerned (Fig. 2). These three units could perhaps be defined as zones on the basis of further collecting and refinement of taxon ranges. The lowest is a diverse fauna extending upward from the base of the measured section to the first thick shale unit. This fauna is characterized by Pachydis-
cas neubergicus (ss), Haueri ceras sp., Guadryceras lunenburgensis, Saghalinites wrighti(?), an indeterminate baculitid characterized by frequent nodes on the sides of the shell, and numerous phylloceratids and diplomoceratids. This interval, which coincides with the upper parts of the G. ganserti Zone of Herr (1963), also contains mass occurrences of Inoceramus pteroides, Playaceramus gr. cycloides, and Inoceramus (Endoceras) aff. baradini. The foraminiferal fauna was considered by Herr to represent the highest part of the lower Maastrichtian. Both the ammonite and inoceramid fauna are also characteristic of the lower Maastrichtian (Birkeland, 1979, 1982). The base of the upper Maastrichtian, marked by the first occurrence of the foraminifer A. mayaroensis, also coincides with the complete disappearance of true inoceramids in the Zumaya section.

The ammonite fauna of the lower part of the upper Maastrichtian contains many of the same faunal elements as the lower section, including far-ranging phylloceratids such as Hypophyloceras sp. and Phyllopa chyceras forbesianum and diplomoceratids such as Glyptoceras aff. subcompressum and Diplomoceras cylindricum. New ammonites include Pachydiscus fresvillensis and a distinct subspecies of P. neubergicus that has fewer umbilical ribs but more ventral ribs than the lower Maastrichtian forms. This fauna extends upward in the section to a point about 50 m below the boundary.

The youngest fauna is located in the highest 50 m of the stratigraphic section; some of its elements occur only within the highest 20 m. At about 50 m below the boundary are found numerous ornamented ammonites of very small size (5–10 mm), assignable to the family Kossmatitaceae. At least two different taxa are present. The small size and crushed nature of the fossils make specific identification impossible. At about 20 m below the boundary, the very evolved ammonites Vertebrilites kayei and Pachydiscus colligtatus first appear. The latter is the more common, and it ranges higher in the section than any other ammonite. P. colligtatus replaces P. neubergicus (?) and shows no range overlap with the older latter species. Also fairly common in this part of the section is the bivalve Tenopteria, which according to Dhondt (1979, 1983) is characteristic of the uppermost Maastrichtian.

The stratigraphically highest ammonite was collected 12.5 m below the boundary. Although the remaining part of the Cretaceous section was well exposed and vigorously searched and quarried, no younger ammonite specimens were recovered. Other megafaunis, however, such as echinoids (Stegastes [??] sp.) and Tenopteria sp., were found to range higher in the section than the ammonites, even to the boundary. A single fragment of possible cephalopod origin was collected at a level 1 m below the boundary; if a cephalopod, this specimen could be either an ammonite or a nautiloid. Nautiloids have been recovered in both the underlying Cretaceous and overlying Tertiary parts of the Zumaya section.

**IMPLICATIONS FOR THE K/T EXTINCTION**

At Zumaya, the disappearance of the inoceramids and parts of the lowest ammonite fauna coincides with the lower–upper Maastrichtian boundary as determined by foraminifera (the base of the A. mayaroensis foran Zone). This faunal turnover occurs at a major lithological change. The uppermost parts of the lower Maastrichtian at Zumaya are composed of a thick limestone-marl lithofacies. This lithofacies is rich with inoceramids, which on some bedding planes occur as pavements. The basal part of the upper Maastrichtian is composed of the purple marl lithofacies. Although ammonites are numerous in these purple marls, extensive searching yielded no inoceramids.

The highest ammonite fauna, located in the upper 40 m of section, first appears in the limestone-marl lithofacies that is somewhat similar to the upper part of the lower Maastrichtian. At about 20 m below the K/T boundary, this lithology changes to the purple marl lithofacies characteristic of the upper Maastrichtian, which is the last occurrence of large ammonites. In this upper 20 m both the richness and abundance of the ammonite species drop markedly and reach 0 at 12.5 m below the boundary, even though other megafaunis (the bivalve Tenopteria and burrowing echinoids) can be recovered from stratigraphic horizons extending up to the K/T boundary. Because the purple marl lithofacies yields the richest concentrations of ammonites elsewhere in the Cretaceous part of the Zumaya section, the disappearance of the ammonites within this part of the section, immediately before the K/T boundary, is enigmatic. Collection failure also seems an unlikely reason for the lack of ammonites in the highest 12 m of the Zumaya Cretaceous section. Exposure of strata is continuous immediately beneath the boundary. About 30 hours were spent searching the upper 15 m of the section and included observation of bedding planes as well as the quarrying and disaggregation of strata on the outcrop. The field evidence from the Zumaya section suggests that ammonite extinction rates exceeded origination or introduction rates, beginning in the late Maastrichtian and accelerating as the Cretaceous came to a close (Fig. 4). Ammonites appear to have been completely ex-
distinct, or at least very rare, prior to deposition of the K/T boundary in this section.

In addition to the Zumaya section, we were able to study stratigraphic sections at Sopelana, a seacoast exposure located about 70 km west of Zumaya. This section is lithologically similar to the Zumaya section, but thinner; like Zumaya, it contains a well-preserved K/T boundary. According to Lamolda (1983), the *A. mayaroensis* Zone is 55 m thick, in contrast to a thickness of this zone of approximately 120 m at Zumaya. As at Zumaya, the last inoceramids are found at the top of the lower Maastrichtian. Ammonites are also fairly common at Sopelana; the youngest ammonite we collected (*Phyllopectyctes sp.* occurred 20 m below the K/T boundary.

The timing of the final extinction of the ammonites remains uncertain. Birkelund (1979) listed nine species reaching the K/T boundary at Stevns Klint, Denmark. It is clear, however, that the Fish Clay horizon at Stevns Klint is unconformable, and some Cretaceous strata are missing. At Mons Klint, located more centrally in the Danish Basin, the K/T is conformable, and at this section the last ammonites are found several centimeters below the boundary (T. Birkelund, 1986, personal communication). At least at Zumaya, and perhaps in other sections as well, local extinctions of the ammonites appear to have occurred prior to the K/T boundary event which so markedly affected the plankton. The extinction of the true inoceramids occurred even earlier, at the end of the early Maastrichtian.

The apparent extinction of the ammonites prior to the end of the Cretaceous in the Bay of Biscay region may very well be a local event caused by changes in the local environment and hence may be of little use in making larger generalizations about the timing and causes of the terminal Cretaceous extinctions. On the other hand, the extinction pattern at Zumaya may be a first glimpse at a very different mode of extinction in a more tropical, Tethyan environment, as compared to our current information based largely on boreal faunas and facies.

**REFERENCES CITED**


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**ACKNOWLEDGMENTS**

Supported by SFB 55, Tübingen University. We benefited from discussions with Jim Kennedy and Annie DhoNT and from field assistance by Martin Lendahl.