Occurrence of the belemnite *Actinocamax plenus* in the Cenomanian of SE France and its significance

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The Late Cenomanian belemnite *Actinocamax plenus* is recorded from the Tethyan Realm for the first time, from les Lattes in the Alpes de Haute-Provence, southeastern France. This exceptionally southerly occurrence of the species is coincident with a cold temperature event, the Plenus Cold Event, registered by oxygen isotope data from southeast England. The record of *A. plenus* from les Lattes enables a precise correlation to be made with the Plenus Marls of the Anglo-Paris Basin.

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Introduction

The region of la Foux and les Lattes, in the commune of Peyroules, Alpes de Haute-Provence, affords some of the most accessible and fossiliferous Cenomanian exposures in the eastern part of the Vocontian Basin (Fig. 1). The total Cenomanian succession in the area is in excess of 350 m in thickness (Donze & Thomel 1972, Thomel 1993). It contains a significant percentage of coarser clastic material (silt, fine sand), several glauconitic horizons, and was deposited in shallower water towards the eastern margin of the Vocontian Basin. The higher part of the Cenomanian is particularly well exposed in badland ravines 1 km east of les Lattes (Fig. 1). During a visit to this section in August 1990, ASG discovered a bed high in the Cenomanian containing frequent belemnites *(Actinocamax plenus)* and an abundant benthic fauna including various elements characteristic of Bed 4 of the Plenus Marls in the Anglo-Paris Basin (= Wessex-Paris Basin) (Jefferies 1962, 1963), but previously unknown in southern Europe. These fossils include the serpulid tube *Hamulus* sp. and the bivalve *Oxytoma seminudum* (Dames), species which, together with *A. plenus* itself, were classified by Jefferies (1962) as a North Boreal faunal group. He interpreted these species as migrants from the north and east, indicative of a cooler climatic phase. The occurrence of this North Boreal fauna at les Lattes extends its distribution southwards by nearly 600 km.

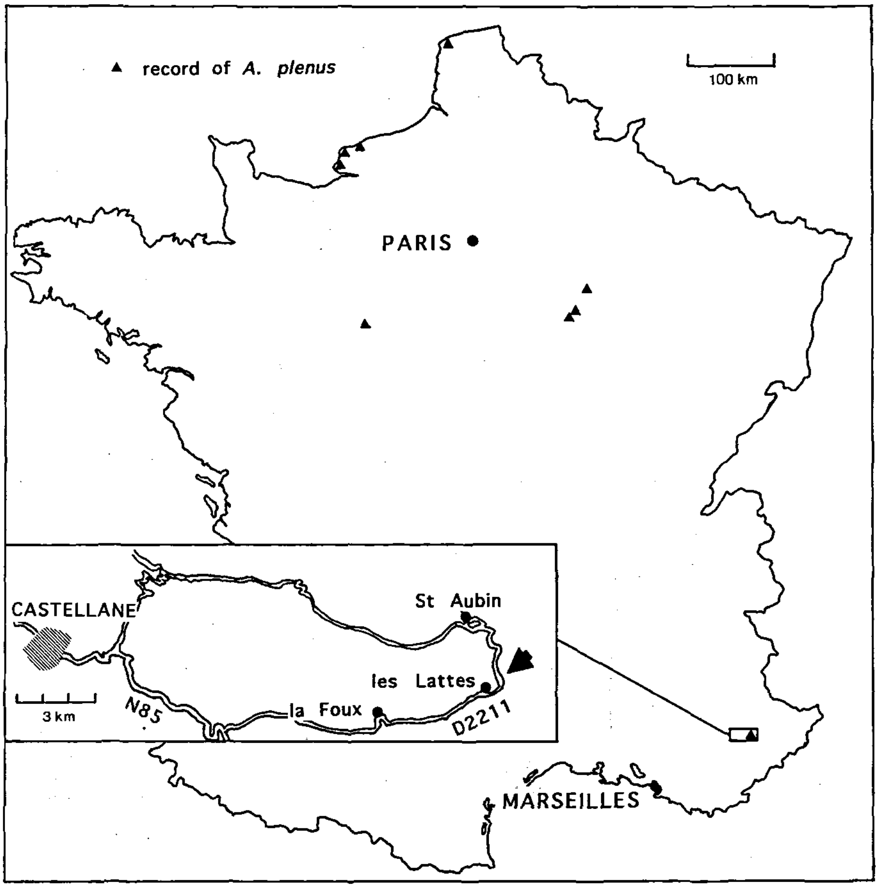
Because this fauna is of considerable interest, the section was logged and sampled in detail (Fig. 2). The presence of a positive $\delta^{13}C$ excursion in the Late Cenomanian is widely known elsewhere (e.g. Gale et al. 1993), so stable oxygen and carbon isotope analyses (bulk carbonates) were run by J. Cartlidge at Oxford University. It appears that the succession at les Lattes can be correlated on a bed scale with the Plenus Marls of the Anglo-Paris Basin.

Description of the section

The section described below is situated 1 km northeast of the small village of les Lattes, 100–200 m east of D2211 (Fig. 1). The section comprises badland slopes and gullies cut in marls of Late Cenomanian age which are overlain by a precipitous scarp of marly limestones of Late Cenomanian and Early Turonian age. Only the middle part of the succession is described here (Fig. 2). It is not certain exactly how the succession described here relates to that given by Thomel (1993) for the la Foux-les Lattes region.

Unit 1. – Silty marls (only top 4 m shown on Figure 2) containing thin beds (0.1–0.2 m) of firmer marlstone; these contain diffuse carbonate concretions, and a single 0.1 cm bed of fine sandstone which shows hummocky cross-stratification (HCS) and is probably a turbidite. Indeterminate ammonites.

Fig. 1. Map of France showing localities yielding *Actinocamax plenus* and the region between Castellane and les Lattes (inset). The arrow indicates the locality for the section and material described herein. Note the northerly occurrences of *A. plenus* in the Anglo-Paris Basin.



Unit 2. – 1.07 m of intensely bioturbated, glauconitic, sandy marl; the lower 0.15 m comprises streaks of laminated, glauconitic sand. The upper glauconitic unit has a burrowed omission surface at the base. No fossils.

Unit 3. – 4.6 m silty marls containing abundant small lenticular carbonate concretions set in poorly defined beds, and numerous small finger-like white and grey flints, possibly replacing sponges. The fauna includes oysters and echinoids (*Discoides* sp. and *Stereocidaris* sp.). The ammonites *Metoicoceras geslinianum* (d'Orbigny) and *Worthoceras* sp., and the bivalve *Inoceramus pictus* (J. Sowerby) were found in concretions within the highest metre.

Unit 4. – 0.88 m of glauconitic, sandy silt with a omission surface at the base, piped into the underlying silty marls in *Thalassinoides* burrows. This bed contains frequent specimens of *Actinocamax plenus*, and a diverse calcitic fauna of bivalves, brachiopods and serpulids. Aragonitic fossils, preserved as composite moulds, are rarer and include the ammonites *M. geslinianum* and *Sciponoceras gracile* (Shumard). This assemblage includes species diagnostic of Jefferies' Bed 4 of the Plenus Marls in the Anglo-Paris Basin (*Hamulus* sp., *A. plenus* and *Oxytoma seminudum*). The belemnites are described in detail below.

Unit 5. – 5.3 m of silty and sandy, grey marls containing numerous layers (5–10 cm thick) of lensoid carbonate concretions in more or less well defined beds.

Unit 6. – 1.25 m prominent weathering, grey, sandy limestone containing three levels of poorly defined carbonate concretions.

Unit 7. – 0.9 m of dark grey, sandy marl.

Unit 8. – Only 2.2 m shown in Fig. 2. Poorly bedded grey sandy limestones containing bryozoans.

Carbon isotope stratigraphy

Samples were cleaned using 10% H_2O_2, followed by acetone and then dried at 60°C. They were then reacted with purified orthophosphoric acid at 90°C and

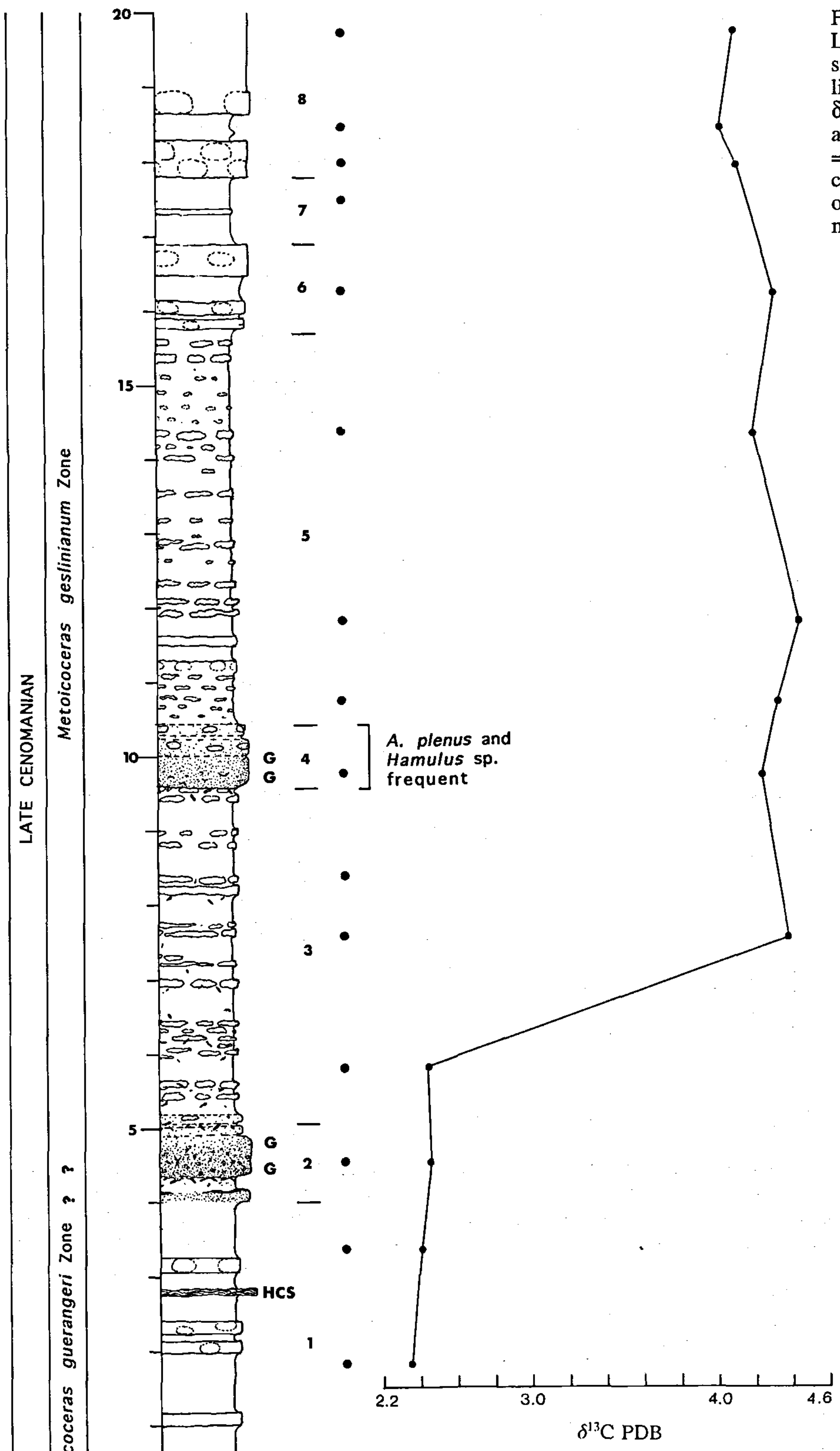
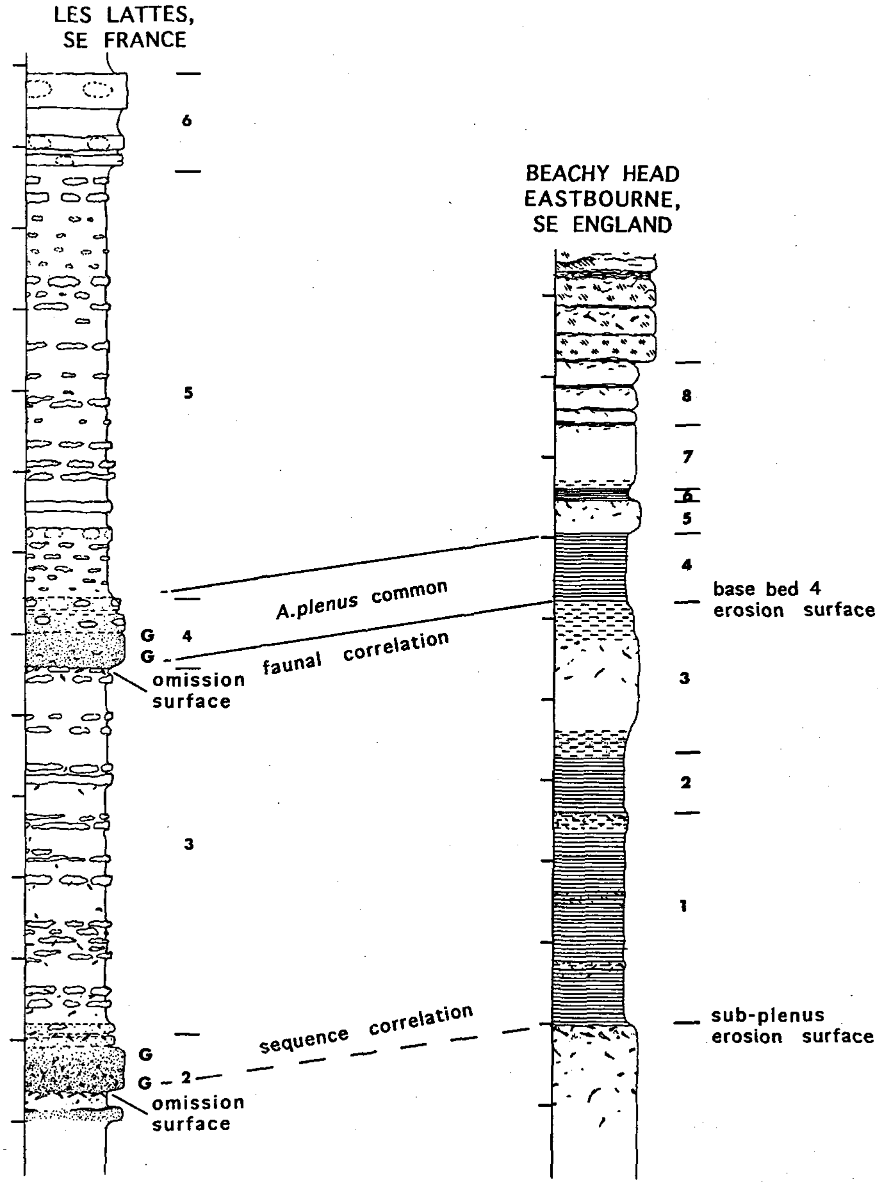


Fig. 2. Stratigraphy of the Late Cenomanian succession at les Lattes, with the lithological succession and $\delta^{13}C$ curve (bulk carbonate). G = glauconite; HCS = hummocky crossstratification. Scale on left of column in metres.

Fig. 3. Correlation between les Lattes (Haute-Alpes de Provence) and the Plenus Marls of the Anglo-Paris Basin (Eastbourne, southeast England). Faunal correlation is based on frequent occurrences of *A. plenus* (solid line), sequence correlation on the equivalence of the sub-plenus erosion surface with the omission surface at the base of Unit 2 at les Lattes. Scales in metres.



analysed on-line using a VG Isocarb device and Prism mass spectrometer at Oxford University by Julie Cartlidge. Corrections were applied and the results are reported using the usual notation, in ‰ deviation from the PDB (Pee Dee Belemnite) standard.

The four lowest samples analyzed show steady values of $\delta^{13}C$ with a low variance (2.376 to 2.456). In sample 5, $\delta^{13}C$ *increases in a single step by over 2‰ to* 4.389, and values remain constantly high between 4.0‰ and 4.5‰ for the remainder of the succession. This plateau corresponds to the lower part of the $\delta^{13}C$ spike observed in many Late Cenomanian sections (Schlanger et al. 1987) as represented in the extremely expanded succession of les Lattes. However, the curve from les Lattes lacks the intricate detail, which is found elsewhere in this excursion (Gale et al. 1993). The increase in $\delta^{13}C$ in the lower part of Unit 3 at les Lattes can be correlated with the rise seen in Bed 1 of the Plenus Marls in the Anglo-Paris Basin (Jarvis et al. 1988, Gale et al. 1993).

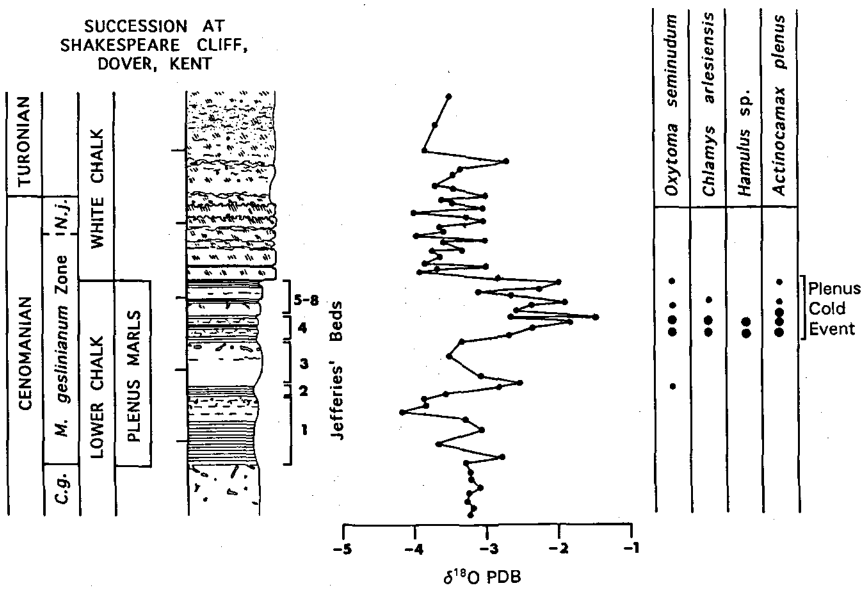


Fig. 4. The succession in the Late Cenomanian at Shakespeare Cliff, Dover, Kent (southeast England), to show the relationship between occurrence of the North Boreal species of Jefferies, and oxygen-isotope ($\delta^{18}O$) values (data from Lamolda et al. 1994, Fig. 7). The Plenus Cold Event is characterized by heavy $\delta^{18}O$ values and occurrences of the four taxa shown. The records of fossils are taken from Jefferies' collection in the Sedgwick Museum, Cambridge. The single specimen of *A. plenus* known from Bed 8 was collected by Mr S. Friedrich (BMNH CL179). Scale on left of column in metres. Size of dots indicates relative frequency of fossil occurrence. *C. g.* = *Calycoceras guerangeri; N. j.* = *Neocardioceras juddii.*

Correlation of les Lattes with the Plenus Marls in the Anglo-Paris Basin

In the Plenus Marls of the Anglo-Paris Basin, Jefferies (1962, 1963) was able to trace eight beds, defined by lithological and faunal criteria, throughout the area of standard succession in the central part of the basin. Using a combination of faunal, carbon isotope, event- and sequence stratigraphical data, we are able to identify certain of these beds at les Lattes.

Units 2–4 at les Lattes yield the ammonites *M. geslinianum* and *S. gracile*, which indicate the *M. geslinianum* Zone. In southern England, *M. geslinianum* appears in Bed 1 of the Plenus Marls and persists above into the overlying Melbourn Rock. As described above, elements of the fauna of Unit 3 at les Lattes are diagnostic of Bed 4 of the Plenus Marls.

Robaszynski et al. (in press) have provided a sequence stratigraphical interpretation of the Plenus Marls in which the basal sub-plenus erosion surface of Jefferies is taken as a sequence boundary, and the bed 3–4 boundary as a transgressive surface. Both boundaries are omission surfaces, which pass into hardgrounds on the condensed basin margin sections in Dover, Normandy, and Sarthe. These two surfaces are represented by burrowed omission surfaces overlain by glauconitic sediments (Units 2 and 4) at les Lattes.

Correlation between les Lattes and the Anglo-Paris Basin is shown in Figure 3. In summary, the omission surface underlying the glauconitic Unit 1 at les Lattes probably correlates with the sub-plenus erosion surface in the Anglo-Paris Basin. Units 2–3 correlate with (undifferentiated) Beds 1-3 of the Plenus Marls, supported by the rise in $\delta^{13}C$ values low in Unit 2. The omission surface at the base of Unit 4 correlates with the bed 3–4 erosion surface of the Plenus Marls succession, and Unit 4 correlates faunally (*A. plenus*, etc.) with the lower part of Bed 4. The higher parts of the succession have not yielded any diagnostic fossils and a detailed correlation is impossible at present.

Palaeoenvironmental significance

The section at les Lattes is of particular interest because a single bed yields part of Jefferies' North Boreal fauna, notably the belemnite *A. plenus*, 540 km south of the most southerly known occurrence in the Anglo-Paris Basin. Indeed, this is the first record of *A. plenus* in the entire Tethyan Realm.

The glauconitic marl (Unit 4, Fig. 2) at les Lattes, which yields *A. plenus*, is correlated with Bed 4 of the Plenus Marls in the Anglo-Paris Basin on both faunal and sequence stratigraphical criteria. For Jefferies (1962, 1963) Beds 4–6 of the Plenus Marls represented a cold event, marked by a southerly and westerly extension of his North Boreal fauna. This argument, based on faunal grounds, is supported by detailed oxygen isotope data from Dover, Kent (Lamolda et al. 1994, Fig. 7), who show a positive shift of nearly 2‰ $\delta^{18}O$ between Jefferies' Beds 3 and 4 (Fig. 4 herein). If this was entirely a temperature effect in a ice-free globe, it would indicate a temperature fall of about 6°C; in practise, there is probably a diagenetic component to the signal. The incursion, albeit brief, of North Boreal species into Tethys at the time Bed 4 was deposited thus ties in with other evidence for a significant temperature fall during this interval. This cold period is called the Plenus Cold Event.

Although Late Cenomanian sediments occur extensively and are well exposed in southeastern France, they are mostly developed in facies which are very unlikely to yield belemnites and the associated boreal benthic group. Shallow water Tethyan platform carbonates containing rudists, *Chondrophora*, and larger benthic foraminiferans are developed in the area east of Marseilles (Crumière-Airaud et al. 1990). Much of the Vocontian Basin itself is occupied by deep water marl facies with a depauperate benthic fauna, which includes organic-rich laminated horizons of latest Cenomanian age called the Niveau Thomel (Crumière 1990). It is probable that the relatively shallow, oxygenated water and marly facies found at les Lattes provided an environment closely similar to that extensively developed in northern Europe and allowed colonization during a brief cool episode.

Systematic palaeontology of the belemnites

Family Belemnitellidae Pavlow, 1914
Genus *Actinocamax* Miller, 1823
Type species. – Actinocamax verus Miller, 1823 by original designation.

Discussion. – Naidin (1964) recognized three subgenera of *Actinocamax:* the nominotypical subgenus; *A. (Praeactinocamax)* Naidin, 1964, type species *Belemnites plenus* Blainville, 1825; and *A. (Paractinocamax)* Naidin, 1964, type species *A. grossouvrei* Janet, 1891. Christensen (1986) discussed *A. (Paractinocamax)* and placed it in synonymy with *Belemnellocamax* Naidin, 1964, type species *Belemnites mammillatus* Nilsson, 1826. Christensen & Schulz (in press) recently discussed and accepted subgenera *A. (Actinocamax)* and *A. (Praeactinocamax)*. The former includes small species, usually with a long cone-shaped alveolar fracture, and isometric growth. The latter comprises medium-sized to large species, usually with a short cone-shaped alveolar fracture, and allometric growth. They provided an emended diagnosis for the nominotypical subgenus. An emended diagnosis for *A. (Praeactinocamax)* is given below.

Subgenus *Actinocamax (Praeactinocamax)* Naidin, 1964
Type species. – *A. (P.) plenus* by original designation.

Emended diagnosis. – Medium-sized to large *Actinocamax* with allometric growth; adult specimens more slender and lanceolate in ventral view than juvenile specimens; commonly with a short cone-shaped alveolar fracture; no ventral fissure but occasionally with ventral furrow and ventral notch; generally without granulation; juvenile guard long and slender (needle-shaped).

Fig. 5. *Actinocamax (Praeactinocamax) plenus* from Unit 4 at les Lattes, Haute-Alpes de Provence, southeastern France. Four complete or nearly-complete specimens are figured in order to show different growth stages. All specimens are in the Palaeontological Collection of the Natural History Museum, London (BMNH). A, BMNH CL170, adult specimen with an average shape; B, BMNH CL171, adolescent, slender specimen; C, BMNH CL172, adolescent, stout specimen; D, BMNH CL173, juvenile specimen. All specimens are coated with ammonium chloride. A1, B1, C1 and D are natural size; A2, ×1.5, B2 and C2, ×2.

Distribution. – *A. (Praeactinocamax)* occurs in the North American and North European palaeobiogeographical Provinces (Christensen 1976, 1988, 1990b, 1993), in addition to the northern part of the Tethyan Realm (this paper). The subgenus occurs from the Early Cenomanian to the Early Santonian (Christensen unpublished).

Actinocamax (Praeactinocamax) plenus (Blainville, 1825)
Fig. 5

Table 1. Dimensions in mm and ratios of *Actinocamax (Praeactinocamax) plenus* from les Lattes, southeastern France. L = length of guard; DVDAF = dorso-ventral diameter at alveolar fracture; LDAF = lateral diameter at the same place; MLD = maximum lateral diameter; MDVD = dorso-ventral diameter at the same; * = estimated. The outermost posterior part of the guard is missing in BMNH CL171; the outermost posterior and anterior parts of the guard are missing in BMNH CL173.

Character	BMNH CL170	BMNH CL171	BMNH CL172	BMNH CL173
L	93.7	65*	66.0	55*
DVDAF	10.8	7.9	5.7	–
LDAF	10.0	6.8	5.4	–
MLD	13.7	9.9	7.3	5.2
MDVD	12.4	9.3	6.2	4.5
L/MLD	6.8	6.6	9.0	10.6
MLD/MDVD	1.1	1.1	1.2	1.2
MLD/LDAF	1.4	1.5	1.4	–

Synonymy. – See Christensen (1974).

Type. – Lectotype, here designated, the original of Blainville (1825-1827, Pl. 11bis, fig. 3).

Material. – Nine specimens: four complete or nearly-complete guards, two apical fragments, and three fragments of the middle part of the guard. They are housed in the Natural History Museum, London.

Dimensions. – See Table 1.

Short description. – Guard large, flattened over its entire length and compressed anteriorly; shape variable due to allometric growth; juvenile specimens subcylindrical to slightly lanceolate in ventral view and subcylindrical in lateral view, adult specimens lanceolate to markedly lanceolate in ventral view and subcylindrical to slightly lanceolate in lateral view; anterior end with a short cone-shaped alveolar fracture showing concentric growth lines and radial ridges; dorsolateral depressions fully developed.

Discussion. – *A. (P.) plenus* is closely allied to the Early and Middle Cenomanian *A. (P.) primus* Arkhangelsky, and the two species form an evolutionary lineage (Christensen 1990a). Christensen (1974) made a morphometric analysis of *A. (P.) plenus* from the Plenus Marls of the Betchworth Limeworks in Surrey, England. Christensen (1990a) analyzed biometrically *A. (P.) primus* from the so-called *primus* bed at Wunstorf west of Hannover, Germany. Christensen (1990a) discussed the affinity of the two species and concluded that *A. (P.) plenus* is distinguished by being larger and stouter than *A. (P.) primus*. The specimens from les Lattes differ in no significant respect from *A. (P.) plenus*.

The small sample of *A. (P.) plenus* from les Lattes includes all growth stages, indicating that the species bred in that area.

Distribution. – *A. (P.) plenus* is widely distributed in the North European Province and is here recorded from the les Lattes, which is situated in the northern part of the Tethyan Realm. In the Anglo-Paris Basin it occurs mainly in Beds 4–6 of the Plenus Marls (Jefferies 1962, 1963). The Plenus Marls Formation is equivalent to the traditional *A. plenus* Zone and is placed in the middle Late Cenomanian *Metoicoceras geslinianum* Zone (Wright & Kennedy 1981). In northwest Germany it occurs in the same zone (Christensen 1990a). On the Russian Platform it is recorded from the Middle Cenomanian to the early Early Turonian (Naidin 1981).

Palaeobiogeography of European Late Cretaceous belemnitellids

The Late Cretaceous belemnitellids occur mainly in the North Temperate Realm (= Boreal Realm of authors), which includes the North American and North European Provinces. The latter extends from Ireland in the west to the Ural Mountains and beyond in the east, and comprises the Central European and Central Russian Subprovinces (Christensen 1976, 1988, 1990b) (Fig. 6). The belemnitellids were neritic animals occurring commonly in a variety of nearshore sediments, such as biocalcarenites, greensands, and marls, and less commonly in offshore sediments, such as chalk (Christensen 1976). Populations from nearshore sediments are characterized by containing all growth stages, whereas populations from offshore chalks mainly consists of adults (Christensen 1976).

The belemnitellids migrated intermittently into the northern part of the Tethyan Realm in Europe. Christensen et al. (1990) suggested that these southwards migrations may be due to short term influx of cold water, short lived lowering of sea water temperature, or fall in sea level.

The earliest belemmnitellid, *A. (P.) primus* appears

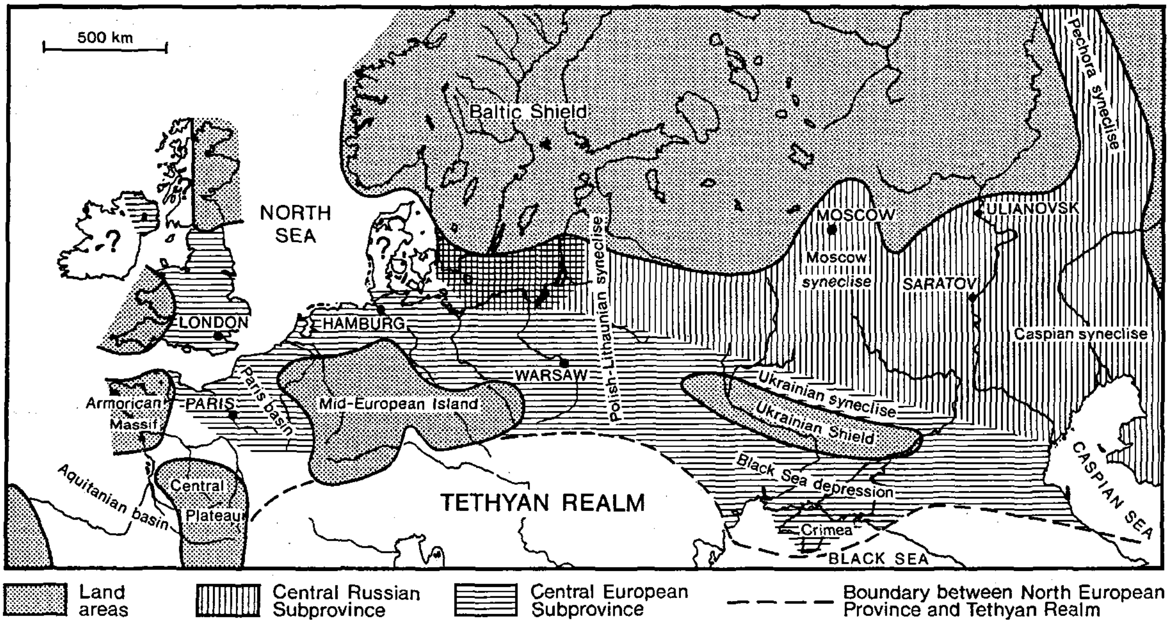


Fig. 6. Distribution of the Central European and Central Russian Subprovinces of the North European palaeobiogeographical Province as defined on belemnites. Upper Cretaceous land and sea areas represent maximum inundation for all stages. The boundaries of land areas are not reliable in detail, and the biogeographical units are typically gradational in character. After Christensen (1976).

some way above the base of the Early Cenomanian and has an acme in northwest Europe in the Middle Cenomanian *Turrilites costatus* Zone. It is mainly distributed in the Central Russian Subprovince and on Bornholm, Denmark. It occurs rarely in Northern Ireland, the Cleveland Basin (NE England), and Anglo-Paris Basin (southern England and northern France), in addition to the Münsterland and Lower Saxony Basins in northwest Germany (Christensen 1990a, Christensen *et al.* 1992, Gale 1995, Paul *et al.* 1994). Christensen (1990a) noted that a little less than 100 specimens have been collected at Wunstorf near Hannover, northwest Germany. This large number may falsely indicate that *A. (P.) primus* occurs commonly there. This is not the case, however, but relates to the fact that many private collectors have collected intensively in the pit for several years.

A. (P.) plenus is widely distributed in the North European Province, and this species was the first belemnitellid to migrate southwards into the Tethyan Realm, where it bred. As suggested above, the southward migration of *A. (P.) plenus* into the Tethyan Realm is most likely due to a significant fall of sea temperature working in concert with the development of suitable shallow water habitats.

After the Cenomanian, belemnitellids migrated into the Tethyan Realm from the late Santonian to the Maastrichtian. Christensen et al. (1990, 1993) recorded a small fauna, consisting of *Belemnitella praecursor* Stolley, *Belemnellocamax* ex gr. *grossouvrei* (Janet), and *Gonioteuthis* sp., from the Late Santonian-earliest Campanian of the Corbières in the French Pyrenees. *B. praecursor* is recorded also from the late Santonian-early Campanian of Azerbaijan in Caucasus (Ali-Zade 1972). At the same time *Belemnitella* migrated southwards, this genus spread also towards the north and west. Christensen (1993) recorded a small sample of *B.* ex gr. *alpha/praecursor* from central East Greenland, and Jeletzky (1955) described a single specimen of *B. praecursor* from the Niobrara Formation of Kansas.

Schmid & Schulz (1979) and Schulz & Schmid (1983) described late Early Maastrichtian species of *Belemnella* and *Belemnitella* from Bavaria in southern Germany, implying a southwards spread of these genera.

The Early Campanian *Gonioteuthis quadrata* (Blainville) has been recorded from the Aquitaine Basin, but the records need to be confirmed. The Late Campanian *Belemnitella mucronata* (Schlotheim) has been reported from many places in the northern part of the Tethyan Realm, e.g. the Aquitaine Basin, the Balkans, and Turkey. However, these records are open to question, because many authors in the last part of the 19th century and the beginning of the 20th century lumped *B. mucronata*-like specimens, that is species of *Belemnitella* as well as *Belemnella*, in *B. mucronata*.

Acknowledgements

ASG would like to thank Ani Stewart and Jenny Huggett for assistance in the field, and Steve Friedrich for donating a specimen of *A. plenus* from Bed 8 of the Plenus Marls to the Natural History Museum, London. Julie Cartlidge of the Department of Earth Sciences at Oxford University kindly provided the isotope analyses. WKC thanks Sten Jakobsen, who made the photographs.

Dansk sammendrag

Belemniten *Actinocamax plenus* fra Øvre Cenoman er vidt udbredt i den Nordeuropæiske palæobiogeografiske Provins, som strækker sig fra Nordirland i vest til Ural Bjergene i øst. Den beskrives her for første gang fra Tethys Regionen, hvor den er fundet ved les Lattes, som ligger i det Vocontiske Basin i sydøst Frankrig. Artens sydgrænse er hermed udvidet med ca. 600 km. På basis af denne art er det muligt at korrelere lagserien ved les Lattes med Plenus Merglen i Anglo-Paris Bassinet (= Wessex-Paris Bassinet). Forekomsten af *A. plenus* i sydøst Frankrig forklares ved et significant fald i havtemperaturen samt udviklingen af egnede lavtvands habitater.

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