

BELEMNITES IN BIOSTRATIGRAPHY

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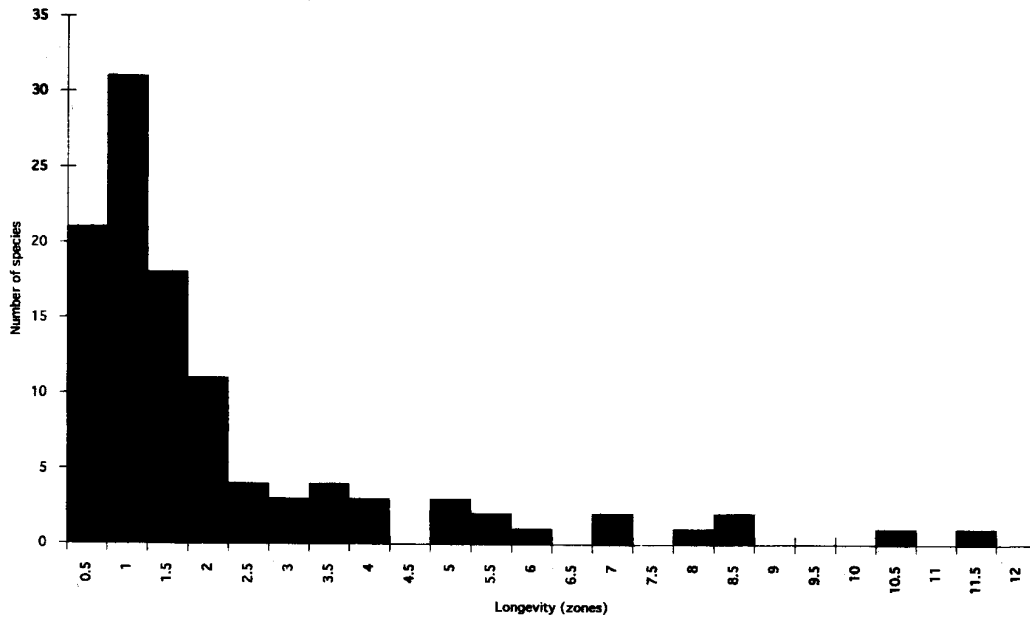
ABSTRACT. Belemnites are common fossils in Mesozoic sequences. They have been used as biostratigraphical tools since the nineteenth century, but the only belemnite biozonation in general use is that of the Upper Cretaceous of northern Europe. The potential for broader application of belemnites in biostratigraphy is discussed with reference to first principles. In essence, belemnites are widespread, were relatively fast evolving and largely facies independent, in addition to being relatively simple to identify, abundant and robust. Current belemnite biozonal schemes are discussed in relation to belemnite palaeobiogeographical distribution. It is clear that the greatest potential for intercontinental correlation exists at times of global expansion (e.g. the Toarcian). The scope for development of local or regional belemnite biozonations of stratigraphical value is considerable in uppermost Lower Jurassic through to Upper Cretaceous successions. These are worthy of development, if only for comparison with those based on the undoubtedly excellent, but sometimes uncommon, ammonites.

BELEMNITES have long been regarded as valuable biostratigraphical indicators. For example, William Smith (1816–1819) included at least one characteristic belemnite, *Cylindroteuthis*, from the Clunch (Oxford) Clay in *Strata Identified by Organised Fossils*. In one of the earliest comprehensive reviews of belemnites, Blainville (1827) was well aware of the potential that they had in the correlation of Jurassic and Cretaceous successions. Oppel (1856–1858) described several species which were components of his zonal scheme for the Jurassic as a whole in his monumental *Die Juraformation*. Despite these credentials, and with some notable exceptions (e.g. Lang 1928), the greatest biostratigraphical utility for belemnites has lain with Cretaceous, rather than Jurassic successions. Over the last 150 years or so, a comprehensive scheme for the Upper Cretaceous Boreal Realm (North Temperate of authors) has been developed, with some important early papers (e.g. Strombeck 1855; Schlüter 1870, 1876; Moberg 1885). Continuing research, fully reviewed in Christensen (1988, 1990), illustrates that belemnites are very powerful tools in correlating Upper Cretaceous sequences. Work on other parts of the stratigraphical column has lagged behind, but the development of a similar scheme for the Boreal Lower Cretaceous can also be traced back to the late nineteenth century (Lamplugh 1889, 1896; Pavlow and Lamplugh 1892; Stolley 1911) and research is continuing in this area (Mutterlose 1990). However, overall, relatively few belemnite biozonation schemes exist.

The aim of this paper is to review the current rôle of belemnites in biostratigraphy in order to promote their more widespread use. In order to achieve this aim, it is necessary, first, to examine the fundamental basis of the biostratigraphical utility of belemnites, and second, to review briefly the status of Jurassic and Cretaceous biozonations. This paper is intended to complement two important recent reviews (Christensen 1990; Mutterlose 1990) which have discussed in some detail the belemnite biostratigraphy of the European Cretaceous. As a consequence, the focus of the present paper is towards non-European and Jurassic sequences.

FUNDAMENTALS OF BELEMNITE BIOSTRATIGRAPHY

In this paper, the term 'belemnite' refers to members of the order Belemnitida, and excludes the Aulacocerida (Devonian–Jurassic). The first true belemnites are considered to have evolved in the Early Jurassic (pending investigation of Triassic records from China), and are taken to have been



TEXT-FIG. 1. Histogram of belemnite species longevity for the Jurassic (Hettangian–Tithonian). Longevity is measured in ammonite biozones. Primary data taken from range charts of Riegraf (1980, 1981).

extinguished with the ammonites at the Cretaceous–Palaeogene boundary. The Bayanoteuthididae, of Palaeogene age, are considered to be dubious belemnoids in need of much further study. Most Palaeozoic records belong to the Aulacocerida.

At its simplest, a good guide or zonal fossil should, ideally, satisfy at least six basic criteria (e.g. Doyle *et al.* 1994). In general, the best guide fossils are those which are: widespread in geographical range, limited in stratigraphical range (i.e. display rapid evolution), independent of facies, abundant, readily preservable, and readily identifiable. The utility of belemnites in biostratigraphy is assessed relative to these criteria below.

Geographical range

Belemnites were widespread from the latter part of the Early Jurassic (Toarcian) until the end of the Cretaceous. Prior to the Toarcian, true belemnites were restricted to Europe (Stevens 1973a; Doyle 1994) and are unknown from the Americas, the Southern Hemisphere, and Russia. Lower Jurassic 'belemnites' recorded from these areas are actually aulacocerids of the family Xiphoteuthididae (e.g. Hillebrandt and Schmidt-Effing 1981; Doyle 1988; Challinor and Grant-Mackie 1989) and are therefore excluded from this discussion, although they may also prove to be of some stratigraphical value.

Belemnites exhibit provincialism from Toarcian times onwards (Stevens 1973a; Doyle 1987a), with characteristic Boreal and Tethyan realm faunas developing early and becoming well established in the Mid to Late Jurassic (Doyle 1987a). This pattern continued into the Cretaceous, with periodic intermixing of faunas (Doyle 1987a; Mutterlose 1988), and changed to a bipolar Boreal and Austral realm pattern in the latter part of the Early Cretaceous (Doyle 1992). These patterns mean that for the pre-Toarcian record, correlation using true belemnites is limited to

Europe. Global correlation is feasible for the Toarcian onwards, but is hampered by the developing provincialism. Intra-realm correlation is possible utilizing near pandemic taxa (e.g. *Neohibolites*, *Hibolites*; Stevens 1973b), and at realm boundaries (e.g. European–Tethyan transition; Christensen *et al.* 1990, 1993).

Stratigraphical range

Belemnites appeared in the Early Jurassic (Hettangian) and became extinct in the Maastrichtian. Few studies have compiled origination rates for belemnite species, and in general there is insufficient data to estimate an average. Ernst (1964) and Schulz (1979) erected detailed belemnite biostratigraphical schemes for the Upper Cretaceous of Germany, with eight *Goniotentis* biozones for the Santonian–Lower Campanian (Ernst 1964; Ernst and Schulz 1974) and six *Belemnella* biozones for the Maastrichtian (Schulz 1979). Using these as a basis, Christensen (1995) has estimated that the Upper Cretaceous belemnite biozones may have had durations of c. 0.6–0.7 million years. Data for the Jurassic and Lower Cretaceous are more sparse. In one of the few studies dealing with the belemnites from the Jurassic as a whole, Riegraf (1980, 1981) charted the development of the belemnite fauna of the Jurassic of southern Germany. An analysis of his data shows a strongly skewed distribution towards a species longevity of 0.5–1.5 ammonite biozones (Text-fig. 1). These data are crude, but illustrate that for the Jurassic at least, there is a comparable longevity of some ammonite and belemnite species.

Independence of facies

The life habits of belemnites have been the subject of speculation. Few studies have adequately set out to determine the full range of facies that contain belemnites. Recently, authors have considered that belemnites were nekto-benthic in habitat (e.g. Martill *et al.* 1994). It is clear, however, that their rostra are found commonly in a wide range of facies: in Britain alone, belemnites are abundant in nearshore coarse clastics (e.g. Bearreraig Sandstone Formation, Bajocian), condensed limestone sequences (e.g. Marlstone Rock Formation, Pliensbachian) and shelf mudrocks (e.g. Oxford Clay Formation, Callovian, and Whitby Mudstone Formation, Toarcian), and therefore belemnites may have inhabited a greater range of environments than has previously been documented.

According to Christensen (1976) and Surlyk and Birkelund (1977), Late Cretaceous belemnites of the family Belemnitellidae are common only in nearshore facies. In various nearshore carbonate facies, belemnite populations typically include all growth stages, while in offshore chalks, rostra are rarer and mainly adult. Belemnites are, however, recorded from deeper water facies; for example, Butterworth *et al.* (1988) recorded abundant belemnite rostra in offshore and turbiditic facies of the Late Jurassic–Early Cretaceous Fossil Bluff Group of Antarctica. Belemnites occur in deep water facies within a similar setting within the Austral Basin of southern Argentina (Doyle, unpublished data). It is therefore possible to postulate both neritic and pelagic lifestyles for belemnites (cf. Doyle and Howlett 1989, p. 178). This may be supported on simple morphological grounds, as it is likely that belemnites were closer in life-habit to neritic/neritic–pelagic squid than the more specialized and benthic-adapted cuttlefish (Bandel and Spaeth 1988).

Abundance

Belemnites were abundant in the Mesozoic shelf seas. This is illustrated by the density of their occurrence in many successions, and their presence in a wide range of facies. Indications of this abundance are that mass accumulations of belemnite rostra are relatively common in the fossil record (Doyle and Macdonald 1993), and that belemnites and coleoids in general may well have been the staple food stocks of a range of marine vertebrates (Pollard 1968).

Preservation potential

Belemnite rostra are constructed of low-magnesium calcite (Saelen 1990). They are, for the most part, robust, having served as a counterbalance to the buoyant phragmocone or as a solid support for apical fins, and they are therefore readily preservable. Dissolution of belemnite rostra would take some considerable time to achieve, and in consequence they are often associated with omission surfaces (e.g. Urlichs 1971; Jarvis 1980). Belemnites are often present where ammonites are absent, possibly as a result of the relatively fragile nature and aragonitic composition of the ammonite phragmocone. With care, belemnites may be identified at least to generic level from rostral fragments. This greatly assists in their biostratigraphical utility.

Recognition

Although seemingly difficult to differentiate on morphological grounds, belemnite taxa have a relative simplicity of design which offers the potential for programmed identification of at least generic taxa. Computer programs have been designed with this in mind (R. Moore, pers. comm. 1990). Homeomorphy is subdued in belemnite genera and families, which are readily distinguished by a combination of shape characteristics and such surface features as grooves. Species are distinguished largely by shape, size, ontogenetic development and surface features (e.g. Christensen 1975, 1986). Despite conservatism in overall morphology, belemnite species are no more difficult to determine in practice than many ammonite species (Upper Jurassic perisphinctids, for example).

Summary

Belemnites were widespread neritic or pelagic organisms which had a global distribution from the later Early Jurassic (Toarcian) onwards. Although relatively few studies are available, it seems clear that belemnite species on average had a longevity of 0.5–1.5 ammonite biozones. Belemnites probably inhabited shelf and deeper water environments, and occur in a wide range of marine facies. In general, belemnites are common, readily preserved, and relatively easy to recognize, or at least, no more difficult than some other guide fossils.

Belemnites are ideal guide fossils and have great potential in the development of new biostratigraphies for the Mesozoic. In view of this, the current status and areas of development for belemnite biostratigraphy are reviewed below for the Jurassic and Cretaceous. In each case, a review of the geographical distribution of the belemnites is given to illustrate problems of provincialism and, therefore, wider correlation.

JURASSIC BELEMNITE BIOSTRATIGRAPHY

Palaeobiogeography

The biogeography of Jurassic belemnites has been reviewed by Stevens (1965, 1973*a*), Saks and Nal'nyaeva (1966, 1975*a*), Stoyanova-Vergilova (1982), Doyle (1987*a*, 1994), Combémorrel (1988), Mutterlose (1988), Doyle and Howlett (1989) and Challinor (1991).

Excluding anomalous Chinese Triassic records which require further study (Zhu and Bian 1984), it is apparent that the belemnites first appeared in Europe, and spread during the Late Pliensbachian to Toarcian interval, becoming widespread at this time (Stevens 1973*a*; Doyle 1987*a*, 1994). Although many taxa were pandemic (e.g. *Passaloteuthis*), others were endemic, particularly in the high Arctic (Saks and Nal'nyaeva 1975*a*; Doyle 1987*a*).

After the extinction of the Passaloteuthididae in the early Mid Jurassic, the development of Boreal and Tethyan faunas became well-advanced. Saks and Nal'nyaeva (1975*a*) distinguished Arctic and Boreal–Atlantic provinces within the Boreal Realm, dominated by the *Cylindroteuthididae*. In contrast, the Tethyan Realm, extending from the Tethyan Ocean southwards circum-Gondwana, was dominated by the *Belemnopseidae* (Stevens 1973*a*; Combémorrel 1988;

Mutterlose 1988; Doyle and Howlett 1989; Challinor 1991). This pattern continued throughout the Mid and Late Jurassic.

Biozonation schemes

Lower Jurassic. So far, only two formal belemnite biozonation schemes have been erected for the Lower Jurassic; by Stoyanova-Vergilova (1977) for eastern Europe; and Doyle (1990b) for northwest Europe. This is presumably because of the availability of ammonite schemes for this interval (Dean *et al.* 1961). Other papers discussing the biostratigraphical utility of Lower Jurassic belemnites, or giving detailed stratigraphical ranges include Lang (1928), Schumann (1974), Saks and Nal'nyaeva (1970, 1975a, 1975b), Palmer (1972), Riegraf (1980, 1981), Nal'nyaeva (1983, 1984, 1986), Riegraf *et al.* (1984), Doyle (1991) and Doyle and Mariotti (1991).

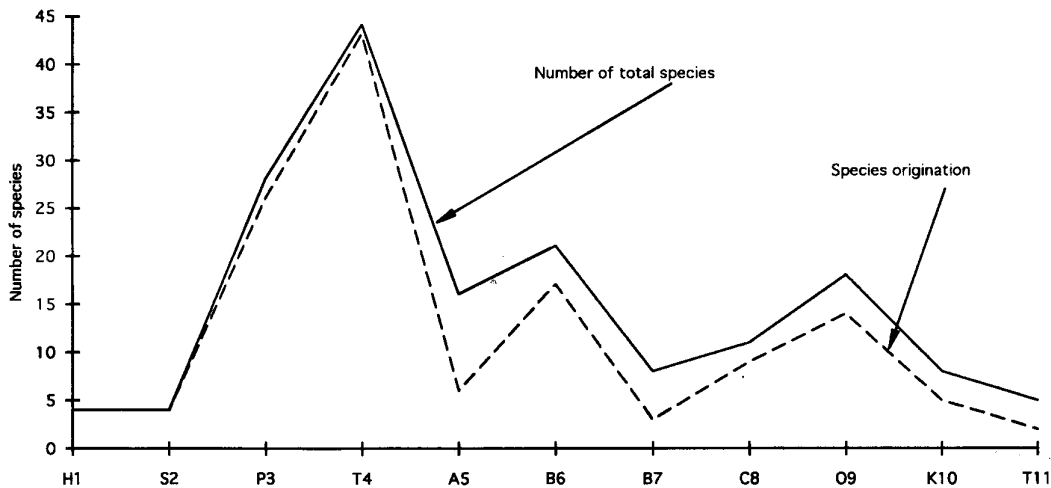
Belemnites are rare in the Hettangian, and so far the only certain record is of the simple genus *Schwegleria* in southern Germany (Text-fig. 2, Schwegler 1962; Riegraf 1980). The Sinemurian

	N.W.EUROPE	E.EUROPE	ARCTIC			GONDWANA
TOARCIAN	B BREVIFORMS	A. SUBTRICISSUS	ACROCOELITES spp.	LENOBELUS spp.	ARCOBELUS spp.	BELEMNITINA
	DACTYLOTEUTHIS spp.					
	A.VULGARIS-S.DORSALIS	ACROCOELITES spp.				
	A.TRISULCULOSUS					
PLIENSACHIAN	P.BISULCATA	P.BRUGUIERIANA				
	Ps.APICICURVATA	Ps.APICICURVATA				
SINEMURIAN	NANNOBELUS spp.	NANNOBELUS spp.				
HETTANGIAN	SCHWEGLERIA spp.					

TEXT-FIG. 2. Belemnite biostratigraphy of the Lower Jurassic. Boxes imply formally erected biozones, range bars indicate useful taxa. Compiled from numerous sources. A, *Acrocoelites*; B, *Brevibelus*; P, *Passaloteuthis*; Ps, *Pseudohastites*; S, *Simpsonibelus*.

holds more promise, with abundant faunas recorded from Europe (e.g. Schumann 1974). Across Europe, this interval is dominated by the distinctive genus *Nannobelus*, and this has prompted Stoyanova-Vergilova (1977) to erect a *Nannobelus* spp. Biozone for Bulgaria, which in practice can be extended to the rest of Europe (Text-fig. 2).

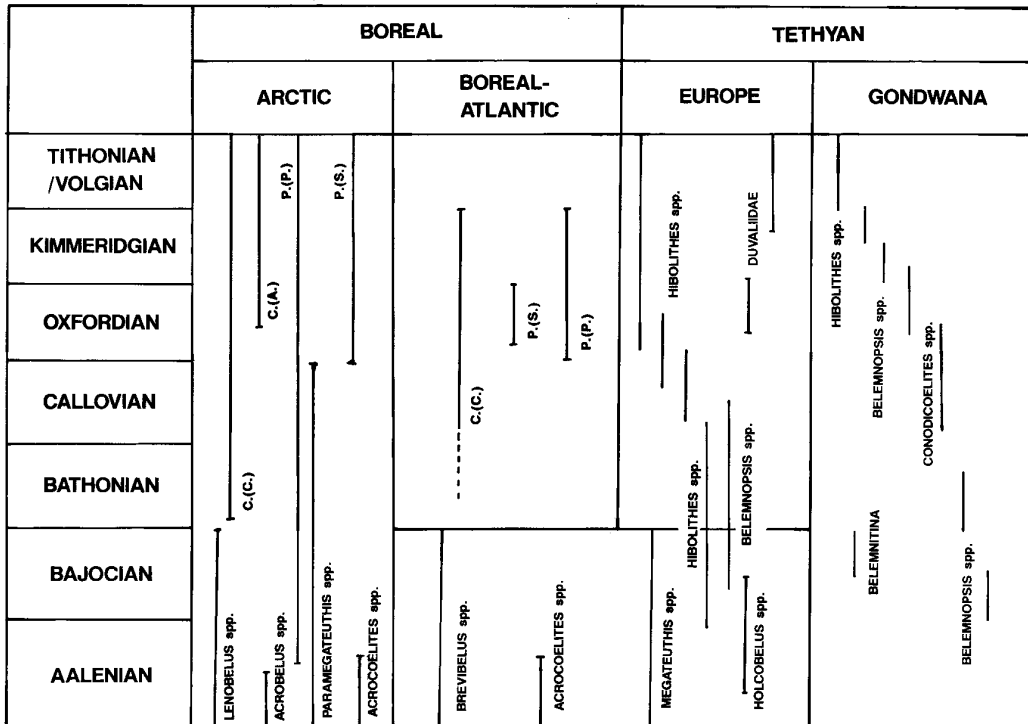
The genera *Passaloteuthis* and *Pseudohastites* (*sensu stricto*) characterize the Pliensbachian Stage (Text-fig. 2). In particular, *Pseudohastites* is an important guide fossil for the Lower Pliensbachian,



TEXT-FIG. 3. Chart of total species (solid line) and species origination (dashed line) for the Jurassic (Hettangian–Tithonian). Species origination is calculated on the number of new species appearing within a stage. Primary data taken from the range charts of Riegraf (1980, 1981). H1, Hettangian; S2, Sinemurian; P3, Pliensbachian; T4, Toarcian; A5, Aalenian; B6, Bajocian; B7, Bathonian; C8, Callovian; O9, Oxfordian; K10, Kimmeridgian; T11, Tithonian.

the distinctive and widespread species *Ps. apicicurvata* (Blainville) being particularly common and a useful guide fossil. The assemblage of taxa first described by Lang (1928) from the Belemnite Marls of Dorset has particular biostratigraphical utility (Palmer 1972). Thus apart from occurring in Europe (Dumortier 1869; Troedsson 1951; Schwegler 1962; Stoyanova-Vergilova 1977; Riegraf 1980), this distinctive fauna is recognizable in East Greenland (Doyle 1991) and Turkey (Doyle and Mariotti 1991). In Europe, the Upper Pliensbachian is distinguished by the ubiquitous species *Passaloteuthis bisulcata* (Blainville) (= *P. paxillosa* and *P. bruguieriana* of authors). Stoyanova-Vergilova (1977) defined a biozone based on this taxon which extends into the Lower Toarcian; this biozone can also be recognized in western Europe (Doyle 1990b). The biozonal index species, and the genus *Passaloteuthis* in general, migrated into Russia (Saks and Nal'nyaeva 1970) and the Southern Hemisphere at this time (Stevens 1973a), indicating a possibility for intercontinental correlation with further work.

Analysis of data taken from Riegraf's (1980, 1981) study of southern German belemnites shows that species diversity and origination reached a strong maximum in the Toarcian, with falls in the Middle Jurassic (Text-fig. 3). The Toarcian belemnites have, historically, been well studied in Europe, and therefore the observed diversity may be a 'monographic' artefact of this. However, this is unlikely to be totally the case as it is clear that the Toarcian marks the first widespread geographical dispersal of belemnites outside Europe and its periphery. Thus, for the first time, there is potential for correlation outside Europe. In particular, the migrant genus *Acrocoelites* is widespread, and North European species have been recorded from North America (Doyle 1987a, Challinor *et al.* 1992) and Russia (Siberia: Saks and Nal'nyaeva 1975a), although no clear identification of this taxon has been made from Gondwana. *Acrocoelites* forms the basis for the Toarcian zonal schemes of Stoyanova-Vergilova (1977) and Doyle (1990b), which are broadly comparable (Text-fig. 2). In addition, the genera *Dactyloteuthis* and *Brevibelus* (= *Brachybelus* of authors) are distinct Upper Toarcian taxa, although neither are recorded from Siberia. Siberia established itself as a major endemic centre after it was colonized by belemnites in the Toarcian. Endemic genera include members of the Pseudodicoelitidae (e.g. *Lenobelus*) and Passaloteuthididae



TEXT-FIG. 4. Belemnite biostratigraphy of the Middle and Upper Jurassic. Range bars indicate most useful taxa. Compiled from numerous sources. C. (C.), *Cylindroteuthis*; C. (A.), *Cylindroteuthis (Arctoteuthis)*; P. (P.), *Pachyteuthis*; P. (S.), *Pachyteuthis (Simobelus)*.

(*Arcobelus* = *Nannobelus* and *Brachybelus sensu* Saks and Nal'nyaeva 1975a). These taxa are valuable for correlation within the Arctic basin, however (Jeletzky 1980; Doyle and Kelly 1988).

Middle and Upper Jurassic. Few belemnite biozonation schemes have been erected for the Middle and Upper Jurassic. The only true biozonations that have been developed are from the Southern Hemisphere, erected by Howlett (1989) for Antarctica, and Challinor (1990) for Papua New Guinea. Papers dealing with the stratigraphical utility of, or giving detailed stratigraphical range data for, Middle and Upper Jurassic belemnites include Saks and Nal'nyaeva (1964, 1966), Combémoré and Mariotti (1986), and Doyle and Kelly (1988).

Following the species diversity and origination maximum in the Toarcian, there were distinct falls in the Aalenian, Bathonian and Tithonian (Text-fig. 3). Text-figure 3 also indicates the relative paucity of belemnite species towards the latter part of the Jurassic, which illustrates the reduced potential for biozonation in this part of the stratigraphical column. In addition, Boreal and Tethyan realms were well developed for most marine organisms in the Mid Jurassic (Hallam 1973), with a corresponding decrease in correlation potential between realms.

For the early Mid Jurassic (Aalenian–Bajocian) interval, correlation is possible between the Boreal–Atlantic (northern European) province and the European borders of the Tethyan Ocean (Text-fig. 4). Here, the last representatives of the Passaloteuthididae: *Brevibelus*, *Acrocoelites*, *Megateuthis* and *Holcobelus*, are common and relatively widespread (Text-fig. 4; Stevens 1973a; Doyle 1987a). In the Arctic Province, the endemic genera *Arcobelus* and *Lenobelus*, together with *Acrocoelites* spp., continued (Text-fig. 4). In the Bajocian, the first of the truly Tethyan

Belemnopsidae appeared, and similar taxa spread south into Gondwana at this time (Stevens 1965, 1973a; Challinor 1991). Little published work documents the utility of belemnites in Gondwana and Tethys at this time, and faunal links between these regions are apparent only in as much that the earliest Gondwanan *Belemnopsis* closely resemble examples from Europe (Stevens 1965), but much further study is necessary. *Belemnopsis* from the Bajocian–Callovian interval is distinct in morphology from the later Gondwanan representatives, and therefore holds potential for correlation between the Boreal and Tethyan borders and Gondwana, but much more work is needed to establish true ranges for species.

The Bathonian interval is relatively species-poor (Text-figs 3–4) in both hemispheres. The *Cylindroteuthidae* and *Belemnopsidae* dominated the Boreal and Tethyan realms respectively. In the Southern Hemisphere, endemic *Belemnopsis*-dominated assemblages began to appear (Stevens 1965). In the Boreal Realm, maximum diversity was achieved in the Arctic regions (Saks and Nal'nyaeva 1964, 1975a; Doyle 1987a; Doyle and Kelly 1988) with many species of *Cylindroteuthis* and *Pachyteuthis* (Text-fig. 4). Most were endemic, however, with few having penetrated into the Boreal–Atlantic province (northern Europe). Despite this, widespread taxa such as *Cylindroteuthis puzosiana* (Orbigny), and periodic influxes of taxa such as *Lagonibelus (Holcobeloides) beaumontiana* (Orbigny) are useful indicators in the Callovian and Oxfordian intervals. By the Kimmeridgian and Tithonian/Volgian, belemnites are only common in the Arctic province.

Little recent work has been carried out on the later Jurassic belemnites of southern Europe. Some belemnites have been recognized as having stratigraphical utility (Riegraf 1981; Combémoré and Mariotti 1986), but few comprehensive studies have been completed. Most attention has concentrated upon Gondwana with recent advances in our understanding by Combémoré (1988), Howlett (1989), Challinor (1989, 1990, 1991), and Challinor and Grant-Mackie (1989). These studies build upon the earlier synthesis by Stevens (1965) which developed the concept of a successive development of largely undifferentiated *Belemnopsis* faunas, punctuated by periodic domination by other genera, particularly *Hibolithes* (Text-fig. 4). The concept of the *Belemnopsis uhligi*-complex developed by Stevens allowed for the recognition of a widespread belemnite fauna with much potential for correlation. Recent scrutiny has demonstrated that this 'complex' may in fact be subdivided to give even greater resolution (Challinor 1989).

These works illustrate the possibility of a greater degree of correlation across the Gondwanan continents than was previously known, at least for the Upper Jurassic. For example, Challinor (1990) has recognized the importance of the southwest Pacific belemnite faunas, in Indonesia, New Caledonia and New Zealand. His finely tuned work has enabled a much greater degree of stratigraphical subdivision, and therefore correlation potential, in the south-west Pacific region than has been possible before. Howlett (1989) has identified the value of belemnites in the Antarctic Peninsula region, especially in the correlation of West Pacific faunas. This is the focus of continuing work, especially comparisons with the rich Jurassic faunas of the Antarctic Peninsula.

CRETACEOUS BELEMNITE BIOSTRATIGRAPHY

Palaeobiogeography

The biogeography of Cretaceous belemnites has been summarized by many authors (e.g. Stevens 1973b; Christensen 1976; Mutterlose *et al.* 1983; Mutterlose 1988; Combémoré 1988) and most recently by Doyle (1992), and therefore a detailed treatment is not necessary here. However, in brief, the pattern initiated in the Mid and Late Jurassic continued through to the Early Cretaceous (Hauterivian–Barremian) with the Boreal and Tethyan realms maintained. In the Aptian, a new, entirely endemic, austral belemnite fauna developed, centred on the *Dimitobelidae*, and by the end of the Cenomanian, the Tethyan Realm, as recognized on belemnite evidence alone, cannot be identified. For the rest of the Cretaceous, the pattern was one of an Austral Realm (the *Dimitobelidae*) with a corresponding Boreal Realm (the *Belemnitellidae*) in the north.

Biozonation Schemes

Lower Cretaceous. Biozonations for the Lower Cretaceous have been developed by Lamplugh (1889), Stolley (1911), Pinckney and Rawson (1974), Mutterlose (1983), Howlett (1989) and Challinor (1991). A belemnite biozonation for the whole of the European Lower Cretaceous has been compiled by Mutterlose (1990) (Text-fig. 5). A minor modification of this was suggested by

	BOREAL		TETHYAN		AUSTRAL
	BOREAL-ATLANTIC	ARCTIC	EUROPE		
ALBIAN	NEOHIBOLITES spp.				PARAHIBOLITES spp. D. (DIMITOBELUS) PERATOBELUS TETRABELUS
APTIAN					
BARREMIAN	O. BRUNSVICIENSIS	A. (A.)			GONDWANA
	AULACOTEUTHIS spp.	A. (B.)			
	P. PUGIO		C. (A.)		
HAUTERIVIAN	H. JACULOIDES				
	A. ACOMONOIDES	P. (P.)			
VALANGINIAN	A. ACREI				
	A. KEMPERI				
BERRIASIAN	A. EXPLANATOIDES				BELEMNOPSIS spp.
	A. LATERALIS				HIBOLITES spp.

TEXT-FIG. 5. Belemnite biostratigraphy of the Lower Cretaceous. Boxes imply formally erected biozones, range bars indicate useful taxa. Compiled from numerous sources. A. (A.), *Acroteuthis*; A. (B.), *Acroteuthis* (*Boreioteuthis*); C. (C.), *Cylindroteuthis*; C. (A.), *Cylindroteuthis* (*Arctoteuthis*); D., *Dimitobelus*; H., *Hibolites*; P. (P.), *Pachyteuthis*; P. (S.), *Pachyteuthis* (*Simobelus*).

Mitchell (1992). Papers dealing with the general biostratigraphical utility of belemnites in the Lower Cretaceous include Jeletzky (1964), Saks and Na'nyaeva (1964, 1966, 1975b), Rawson (1972); Combémoré (1973, 1979, 1988), Combémoré *et al.* (1981) and Mutterlose *et al.* (1987).

In Boreal regions, the Lower Cretaceous up to the Barremian is dominated by the *Cylindroteuthididae*. *Acroteuthis*-dominated assemblages have proved to be of the greatest utility in both Arctic and Boreal-Atlantic provinces, with several species in common (e.g. Jeletzky 1964; Saks and Na'nyaeva 1966, 1975b; Pinckney and Rawson 1974; Doyle and Kelly 1988; Mutterlose 1990) (Text-fig. 5). In the Barremian, the *Cylindroteuthididae* are common only in the Arctic. In Europe, a detailed biozonation is possible utilizing the *Oxyteuthididae* (Mutterlose 1983, 1990) (Text-fig. 5).

In the Tethys, *Duvalia* and other representatives of the *Duvaliidae* have proved valuable as guide fossils (e.g. Combémoré 1979) (Text-fig. 5). Recent records indicate a greater geographical

	BOREAL		TETHYAN	AUSTRAL	
	N.EUROPEAN	N.AMERICAN			
MAASTRICHTIAN	BELEMNELLA CASIMIROVENSIS	B. BULBOSA BELEMNITELLA			D.(DIMITOCAMAX)
	B. JUNIOR				
	BELEMNELLA spp. (6 ZONES)				
CAMPANIAN	B.LANGEI	B. AMERICANA BELEMNITELLA			D.(DIMITOBELIUS)
	B.MINOR				
	B.MUCRONATA				
SANTONIAN	GONIOTEUTHIS spp. (8 ZONES)	A. PRAECURSOR			
CONIACIAN		A. GROENLANDICUS			
TURONIAN		ACTINOCAMAX A. MANITOBENSIS			
CENOMANIAN	A.PLENUS		NEOHIBOLITES spp.	DUVALIIDAE	
	A.PRIMUS				

TEXT-FIG. 6. Belemnite biostratigraphy of the Upper Cretaceous. Boxes imply formally erected biozones, range bars indicate useful taxa. Compiled from numerous sources. A, *Actinocamax*; B, *Belemnitella*; D, *Dimitobelus*.

distribution in the Tethys and Gondwana than was previously recognized for this group (Combémoré 1988; Doyle and Mariotti 1991). Inter-realm correlation of Boreal and Tethyan sequences is hampered by provincialism, but notable migrations of Tethyan taxa northwards and arctic taxa southwards at times of sea level highstand (Rawson 1973; Mutterlose 1979; Doyle 1987a; Mutterlose *et al.* 1987) provide some potential for correlation.

Perhaps the most significant belemnites for inter-regional, inter-continental and even inter-hemisphere correlation in the upper part of the Lower Cretaceous are the rather simple looking members of the genus *Neohibolites* and, to a lesser degree, *Parahibolites*. These genera have almost a worldwide distribution (e.g. Liddle 1946; Hanai 1953; Stevens 1965; Spaeth 1973, 1988; Combémoré 1988; Doyle 1987c), and are already used in the biozonation schemes of Christensen (1990) and Mutterlose (1990) (Text-fig. 5). These taxa are widespread and broadly indicative of the Aptian–Cenomanian interval in many countries (Combémoré *et al.* 1981).

In Gondwana, *Belemnopsis* and *Hibolites* dominate the Lower Cretaceous up to the Aptian, when members of the Dimitobelidae replace them (Text-fig. 5). As with the Upper Jurassic, belemnite biozonations have recently been developed by Howlett (1989) and Challinor (1990, 1991) which demonstrate the utility of belemnites in the correlation of Gondwanan successions. Challinor (1991) recognized that a succession of *Hibolites* species may have utility in the Berriasian–Hauterivian of the south west Pacific, while Crame and Howlett (1988) and Howlett (1989) have identified a late *Belemnopsis* fauna replacing *Hibolites* in the Antarctic Peninsula region in the Valanginian–Hauterivian; this may have implications for correlation with South American

successions (Text-fig. 5). From the Aptian onwards, the Dimitobelidae dominate the Cretaceous of the Southern Hemisphere (Doyle 1992). In these Gondwanan regions, distinct potential for correlation exists, with markers of both local and more widespread stratigraphical utility. Thus, *Tetrabelus willeyi* is a distinctive late Aptian marker for the Antarctic Peninsula (Crame and Howlett 1988), while *Dimitobelus diptychus* is widespread in the Albian, recorded from the Austral Basin of Argentina (Riccardi 1988), Australia (Ludbrook 1966) and Antarctica (Doyle 1987b).

Upper Cretaceous. A sophisticated scheme of belemnite biozones has been developed for the Upper Cretaceous, summarized most recently by Christensen (1988, 1990). These papers provide an excellent, comprehensive review and therefore the Upper Cretaceous is dealt with only briefly here. Particularly important are the refined schemes of Ernst and Schulz, erected on the basis of detailed morphological changes observed within lineages of *Goniotenthis* (e.g. Ernst 1964) and *Belemnella* (Schulz 1979). The detail of these and other biozones continues to be refined by Christensen and co-workers (papers in Christensen 1990), such that there is the possibility of widespread correlation across Europe (Text-fig. 6). Similar genera occur in North America, but species are punctuated in their stratigraphical range and are largely endemic, suggesting short-lived migrations from the North European Province (Christensen 1993). Intercontinental correlation is therefore barely possible at this time. However, recent discoveries of belemnitellids from southern France have increased the potential for correlation of Tethyan and Boreal regions (Christensen *et al.* 1990, 1993; Hancock *et al.* 1993) in the Upper Cretaceous.

In the Southern Hemisphere, records of Upper Cretaceous belemnites are relatively rare (Stevens 1965, 1973b; Doyle and Zinsmeister 1988; Doyle 1990a); dimitobelids dominate. The fullest Upper Cretaceous dimitobelid succession is in New Zealand (Stevens 1965), but most species are endemic, making correlations difficult. However, recent discoveries in the Antarctic Peninsula suggest that there may be considerable potential for cross-Gondwanan correlation, even into the Maastrichtian (Doyle and Zinsmeister 1988; Doyle 1990a). Recently collected material from the Santa Cruz Province in Argentina indicates that further inter-regional correlation could be possible in this interval, although much more work is necessary to be able to construct a meaningful biostratigraphy.

DISCUSSION

From the foregoing, it is clear that belemnites have, in theory at least, considerable potential in biostratigraphy. As neritic or even pelagic organisms, they have a wide distribution. Although many authors have commented on the perceived 'shallow water' habitat preference of belemnites, this is not substantiated by the range of facies and settings from which belemnites have been recorded. Paucity of study may have contributed to their underuse in biostratigraphical studies, but belemnites are common, and more importantly, robust fossils that are relatively easy to distinguish with care. Origination rates based on available data suggest that, in many cases, belemnites have a species longevity which compares well with other zonal indices. All facts considered, belemnites provide an important alternative to ammonites and microfauna/flora in Jurassic and Cretaceous sequences.

Belemnite provincialism represents the greatest problem in inter-regional correlation, and the development of faunal realms in particular hampers such comparisons. 'Event' horizons of rapid geographical expansion can be identified, particularly in the Lower Jurassic (Toarcian), and Lower Cretaceous (Aptian/Albian), but many minor faunal influxes can be recognized, often associated with sea level highstands. The greatest body of information and utility lies in the Upper Cretaceous of Europe, where a very detailed biozonation has been developed over a period of some 150 years. This scheme is in everyday geological use and, with refinement, similar examples, such as the recently developed European Lower Cretaceous biozonation, could increase in importance. This is of particular merit in regions where ammonites or other zonal indices are absent, and in complex tectonic terranes, where belemnites may survive in a better condition than the more fragile ammonites.

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