# Correlation of Albian European and Tethyan ammonite zonations and the boundaries of the Albian Stage and substages: some comments

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Owen, H.G. Correlation of Albian European and Tethyan ammonite zonations and the boundaries of the Albian Stage and substages: some comments. — Scripta Geol., Spec. Issue 3: 129-149, 5 figs., Leiden, December 1999.
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Key words: Early Cretaceous, Albian Stage, ammonite zonation, European and Tethyan faunal provinces
Although the so-called 'standard' ammonite zonation of the Albian contains index species which occur in the Tethyan province, the scheme largely reflects the faunal succession in the European faunal province with its endemic sonneratiinid and hoplitinid faunal elements. Workers in the Tethyan province, stretching from South America in the west to Australia in the east, including southern Africa, Madagascar and India, face problems in the correlation of their successions with this so-called 'standard' scheme. There are other problems in that the succession of hoplitinid ammonites used in the biostratigraphy of European Albian sediments allows a far more detailed zonation to be made than in the case of some of the longer time-ranging Tethyan forms. This paper comments on proposals made recently for the delimiting of the base of the Albian Stage, and the Middle and Upper Substages, based on ammonite faunas. New information which affects the Albian ammonite zonation in the European faunal province and its correlation with the Tethyan province is discussed. The current hierarchical framework of zones and subzones used in the European faunal province may prove to be unsatisfactory in interprovincial correlation and particularly if the lower boundary of the Albian Stage was placed within the current *Leymeriella tardefurcata* ammonite Zone, instead of at its base.

## Contents



## Introduction

The placement of the lower boundaries of the Albian Stage and its substages has, hitherto, been linked to the ammonite succession. Because of the rapid morphological evolution of ammonites, a precise zonation and relative dating of sediments in which they occur is possible. Other zonations (mainly microfossil) have been linked to the ammonite zonation where possible. However, there are serious problems in the relative dating of Albian sediments where ammonites have not been preserved and where the standard microfossil dating is not linked to the macrofaunal zonations — such as those occurring extensively in the deeper oceanic regions. This problem is compounded by the provincial nature of ammonite faunal distributions in which inter-provincial links are few or non-existent. Moreover, there is a perceived need to determine unique boundary stratotype sections which are relatively permanent of access and in which the greatest degree of faunal and floral correlation can be made. These problems were recognised and addressed during the Second International Symposium on Cretaceous Stage Boundaries held in Brussels (e.g. Hart et al., 1996). In the present contribution, the author has set out some of the problems which exist in the selection of lower boundaries to the stage and substages based on ammonites and the suitability of certain horizons in the various stratotype candidates suggested.

The writer has reviewed the 'standard' ammonite zonation of the Albian and its known links between the Arctic, European and Tethyan faunal provinces on several occasions (e.g. Owen, 1971, 1973, 1984a,b, 1988a,b, 1996a). The current paper is confined mainly, therefore, to recent work only. The so-called 'standard' ammonite zonation of the Albian used today springs essentially from the work of Spath on the English Gault Ammonoidea (e.g. Spath, 1923-43). His scheme evolved essentially from 1923, when he recognised a series of 'zones' grouped in hemerae, until it reached its final form in 1941-42 when he treated these 'zones' as subzones, grouping them into zones (Spath, 1923-43). Subsequently, changes and improvements have been made to the Early Albian (Casey, 1961; Owen, 1988b), Mid Albian (Owen, 1971) and Late Albian (Owen, 1976; Gale et al., 1996) zonations, but the scheme in use today (Figs. 1-4) is still basically Spath's. The scheme largely reflects in the Early and Mid Albian and to a lesser extent in the Late Albian, the European province successions. Although it includes species-indices of genera which occur in more than one faunal province, such as *Leymeriella* and *Douvilleiceras* in the Early Albian, *Lyelliceras* and *Dipoloceroides* in the Mid Albian and *Dipoloceras, Hysteroceras, Prohysteroceras, Mortoniceras* and *Stoliczkaia* in the Late Albian, it has been recognised for a long time that the scheme is applicable in detail essentially to the European province only. This poses dating problems for workers in the Tethyan province, where the short-ranging (in time) hoplitinid ammonites used in the European Province scheme are absent and the longer ranging lyelliceratid, brancoceratid, mortoniceratid, and stoliczkiinid ammonites are characteristic.

In the Albian, the Tethyan Province extended eastward from the Pacific borders of Peru and California, to include Colombia, Venezuela, Mexico, and Texas in the Americas, the proto-Atlantic, Spain and the Mediterranean region of Europe, southern Asia (including Georgia, Pakistan and northern India) and the epicontinental seas of Africa, Madagascar and Australia. To what extent this faunal province was characteristic of the Albian Pacific region is unknown.

## Lower Albian Substage

### The *Leymeriella tardefurcata* Zone and the base of the Albian Stage

Breistroffer (1947) proposed drawing the base of the Albian at the base of the *Leymeriella tardefurcata* Zone, and this view has been accepted widely (see Owen, 1984a, b). This section reviews the subdivision and some important faunas of this zone and then considers current proposals for defining the base of the Albian.

| Superzone | Zone | Subzone |
|---|---|---|
| *Douvilleiceras mammillatum* | *Otohoplites auritiformis* | *Pseudosonneratia (Isohoplites) steinmanni*<br>*Otohoplites bulliensis*<br>*Protohoplites (Hemisonneratia) puzosianus*<br>*Otohoplites raulinianus* |
| | *Sonneratia chalensis* | *Cleoniceras floridum*<br>*Sonneratia kitchini*<br>*Sonneratia (Globosonneratia) perinflata* |
| | *Leymeriella tardefurcata* | *Leymeriella regularis*<br>*Leymeriella acuticostata*<br>*Leymeriella schrammeni* |

Fig. 1. Ammonite zonal and subzonal scheme for the Lower Albian in the European faunal province.

Subdivision of the *tardefurcata* Zone (Fig. 1)

In England, Spath (e.g. 1923-1943, p. 4) divided his Leymeriellan hemera into three zones, of *L. schrammeni, Parahoplites milletianus* and *L. regularis*. Brinkmann (1937), working on the *Leymeriella* succession in the Hannover-Braunschweig area of northern Germany, modified this scheme into three zones of *Leymeriella schrammeni, Leymeriella tardefurcata* and *Leymeriella regularis*. These were regrouped by Spath (1923-43, p. 668) as subzones within the *Leymeriella tardefurcata* Zone (Fig. 1). The use of *L. tardefurcata* in both a zonal and subzonal sense required Spath to substitute a Subzone of *Leymeriella acuticostata* for Brinkmann's *tardefurcata* Zone; as it happens, this was an unsatisfactory selection in the light of subsequent work.

This subdivision reflects the morphological evolution of the various species of *Leymeriella* from its puzosiinid ancestor *Callizoniceras (Wollemanniceras) keilhacki* (Wollemann) of the latest Aptian to the disappearance of the genus *Leymeriella* at the end of the *regularis* Subzone. The picture of a continuously morphologically evolving population has been complicated, unnecessarily in the author's opinion, by the grouping of the *schrammeni* Subzone forms in a Subgenus *Proleymeriella* by Breistroffer (1947) and the more tuberculate late forms of the *regularis* Subzone in a Subgenus *Neoleymeriella* by Saveliev (1973). Although *Leymeriella tardefurcata* (d'Orbigny) does not appear in the earliest *schrammeni* Subzone, an early form occurs in the later part of the subzone and the species extends to the end of the *regularis* Subzone. The *tardefurcata* Zone is, therefore, almost a total range zone as Spath in effect recognised.

For the purpose of this paper, the writer follows Spath's scheme of a *Leymeriella tardefurcata* Zone with three subzones (Brinkmann's zones), as shown in Table 1, although this approach might need to be changed especially if the base of the Albian Stage is drawn at a level *within* this zone. However, several workers continue to use the subdivisions as distinct zones, as indicated below.

Critical *tardefurcata* Zone faunas (Fig. 2)

**North Germany** — Brinkmann's (1937) work in north Germany was extended by Kemper (e.g. 1975, 1982a-c; Kemper et al., 1975; Kemper & Zimmerle, 1978), who followed Brinkmann in using the *tardefurcata* Zone subzones as zones. Kemper illustrat-

| A: Arctic faunal province | | |
|---|---|---|
| Korjak-Kamchatka | Alaska-Canadian Arctic | Greenland-Spitzbergen |
| not proven | not proven | not proven |
| ? | ? | |
| *Arcthoplites (Subarcthoplites) talkeetnanus* | *Arcthoplites* sp. | *Leymeriella acuticostata* |
| *Freboldiceras praesingulare* | *Freboldiceras praesingulare* | *Leymeriella schrammeni* |

| B: European faunal province | | |
|---|---|---|
| England | NW Germany | Col de Pré-Guitard |
| *Leymeriella regularis* | *Leymeriella regularis* | *Leymeriella regularis* |
| *? Hypacanthoplites milletioides* *Farnhammia farnhamensis* | *Leymeriella acuticostata* *(Leymeriella tardefurcata)* | Paquier horizon ? |
| not proven | *Leymeriella schrammeni* | ? |

| B: European faunal province (continued) | | |
|---|---|---|
| Austria | Bulgaria | Mangyshlak |
| *Leymeriella regularis* | *Leymeriella regularis* | *Leymeriella regularis* |
| Tannheim Fm. ? | *Leymeriella acuticostata* *(Leymeriella tenuicostata)* | *Leymeriella acuticostata* *(Leymeriella tardefurcata)* |
| not proven | not proven | not proven |

| C: Tethyan faunal province | | |
|---|---|---|
| Southern Caucasus | Iran | Madagascar |
| *Leymeriella regularis* | *Leymeriella regularis* | not proven |
| ? | *Leymeriella acuticostata* | *'Pseudosonneratia' sakalava* |
| not proven | not proven | not proven |

Fig. 2. Degree of representation and probable correlation of the three subzones of the *Leymeriella tardefurcata* Zone; in ascending order, *Leymeriella schrammeni, Leymeriella acuticostata* and *Leymeriella regularis,* at selected areas in the Arctic, European and Tethyan faunal provinces (for sources see text).

ed ammonites from the *Leymeriella ('Proleymeriella') schrammeni* and *Leymeriella tardefurcata* (= *acuticostata*) Subzones. The latest Subzone, that of *Leymeriella ('Neoleymeriella') regularis,* was imperfectly known until recently in this area of northern Germany. It is well represented in the Kirchrode 1/94 boring drilled in the southeastern outskirts of Hannover (Fenner et al., 1996, Owen, in prep.).

**England** — In the Folkestone Formation, Casey (1961) recognised an earlier Subzone of *Farnhamia farnhamensis* which he correlated with the north German *schrammeni* Subzone and a later Subzone of *Hypacanthoplites milletioides,* correlated with the *acuticostata* Subzone. This scheme is based on a few isolated sections in which the superposition of these subzones cannot be determined (Owen, 1996a, c; Casey, 1996). The ammonites of the *farnhamensis* Subzone, known essentially from the Farnham area, Surrey, include *Farnhamia* with forms close to *Bellidiscus* Savaliev (1973) (regarded as a synonym of *Arcthoplites*), species of *Hypacanthoplites* which occur in the *acuticostata* Subzone in Germany, and also *Anadesmoceras,* a genus unknown in the *schrammeni* Subzone but present in the *acuticostata* and *regularis* Subzones. At the base of the overlying Gault - Lower Greensand Junction Member at Wrecclesham, *Leymeriella* *tenuicostata* Saveliev occurs (Casey, 1978) This ammonite is characteristic of the highest *acuticostata* Subzone sediments in Mangyschlak (Saveliev, 1973) and elsewhere. The ammonites of the *farnhamensis* Subzone are consistent with an early *acuticostata* Subzone age.

The *milletioides* Subzone contains species of *Hypacanthoplites* which indicates that it cannot be later than the *acuticostata* Subzone. It could be earlier, not later, than the *Farnhamia*-bearing sediments. At Sandling Junction, East Kent, Bed 1 of the Gault-Lower Greensand Junction Member (Owen, 1992), which rests unconformably on *milletioides* Subzone sediments, contains species of *Hypacanthoplites* characteristic of the *schrammeni* or *acuticostata* Subzones.

Ammonites of the *regularis* Subzone have been described and illustrated by Casey (1957, 1978) from sections in southern England and East Anglia.

**France** — In the Col de Pré-Guittard (a candidate section for the base of the Albian) and adjacent sections in the Vocontien Trough, Horizon A5, the black shale horizon called the Paquier level, contains an indigenous crushed fauna described and illustrated by Delamette (in Bréheret et al., 1986). According to the material seen by the writer, the non-heteromorph ammonites from A5, including some of those figured by Delamette, are as follows: *Hypacanthoplites* cf. *clavatus* (Fritel) (Musée d'Histoire Naturelle Genève: MHNG N1482; pl. 6, fig. 7, figd as *H. trivialis*; *Hypacanthoplites* cf. *trivialis* Breistroffer (pl. 6, fig. 6; not seen); *Hypacanthoplites* cf. *bifrons* Saveliev (MHNG N1483; pl. 6 fig. 8; the slab also contains a small crushed *Leymeriella (Leymeriella)*); *Leymeriella (Leymeriella) tardefurcata* (d'Orbigny) (MHNG N1509; pl. 6, fig. 9) with nuclei of *Leymeriella* (*L.*), *Hypacanthoplites*, *Silesitoides*, etc.; *Leymeriella* (*L.*) *tardefurcata* (d'Orbigny) *acuticostata* Subzone variant (pl. 7, fig. 1); *Leymeriella* (*L.*) *tardefurcata* (d'Orbigny) (not seen; pl. 7, fig. 2); *Leymeriella* (*L.*) aff. *tenuicostata* Saveliev (MHNG N1488; not figd); *Leymeriella* (*L.*) cf. *tera* Saveliev (MHNG N1481; pl. 8, fig. 3; figd as *Leymeriella* (*Neoleymeriella*) *pseudoregularis* Seitz); *L.* (*L.*) cf. *tera* Saveliev (MHNG N1490; not figd). *Douvilleiceras* cf. *pustulosum* Casey with non-figured small *Leymeriella* (*L.*) spp. (MHNG 1474; pl. 7 fig. 4; figd as *Douvilleiceras* gr. *mammillatum*); *Parabrancoceras* sp. (MHNG N1485; pl. 8, fig. 4 figd as *Brancoceras* sp. nov.) with *Leymeriella* (*L.*) sp. juv.; *Silesitoides* sp. (MHNG N1486; pl. 8, fig. 5 figd as cf. *Brancoceras* sp. nov.) with a fragment of *Leymeriella* and *Hypacanthoplites* sp. juv.; *Oxytropidoceras* sp. (MHNG N1487; pl. 8, fig. 8; figd as *Oxytropidoceras* aff. *douglasi* Knetchel).

In summary, the assemblage contains *Hypacanthoplites* together with species of *Leymeriella* (*Leymeriella*) consistent with a latest *acuticostata* Subzone age, a fauna closely comparable to the equivalent one in the Hannover-Braunschweig area and particularly in the Kirchrode I/94 boring (Owen, in prep.). Associated with these in the French section is the earliest *Douvilleiceras* yet known from a European section, together with *Parabrancoceras* and *Silesitoides* among other ammonites typical of the Tethyan Province. Unfortunately, the specimen of *Oxytropidoceras* is not associated with examples of *Leymeriella* in the same slab. If it is definitely from the same horizon as the other specimens, it is, together with the specimens figured by Kennedy & Kollmann (1979) from the Tannheim Formation of Upper Austria, the earliest known *Oxytropidoceras* in Europe. This suggests that *Oxytropidoceras* has an origin in an earlier Albian group and not from Mojsisovicsiinae. In the Natural History Museum, London, there is a specimen from Peru containing *Leymeriella* and an early *Oxytropidoceras* (J.V. Harrison coll., no.1208).

In the Col de Pré-Guittard section, below the Paquier level, there are sediments of earlier *acuticostata* Subzone age and possibly of the *schrammeni* Subzone also. Hopefully, current research on this section will improve the ammonite zonal representation in this part of the section. Above the Paquier level, the sediments are of *regularis* Subzone age. Hence the Paquier level represents only the latest *acuticostata* Subzone. No species of *Hypacanthoplites* have yet been found in sediments of *regularis* Subzone age where the fauna is free of earlier Albian pebble-fauna admixture.

**Austria** — Kennedy & Kollmann (1979) described an Early Albian fauna from black shales with ammonites in the Tannheim Formation, near Losenstein in Upper Austria. They reported that the lower part of the Tannheim Formation contains a Late Aptian microfauna and is overlain by the black shales containing an indigenous *Leymeriella* fauna which they placed in the *L. regularis* Subzone. The illustrations show that this fauna is consistent with a late *acuticostata* Subzone age, comparable to that obtained from the Paquier level discussed above. The figured specimens of *Leymeriella* (as re-identified here) include, apart from *L. tardefurcata*, *Leymeriella* cf. *germanica* Casey (pl. 2, figs 2, 8: central group), *L.* cf. *acuticostata* Brinkmann (pl. 5, fig. 11), *L.* cf. *astrica* Glazunova (pl. 6, figs 1, 5, 6, 8, 9), *L.* cf. *tenuicostata* Saveliev (pl. 7, figs. 3-4), *L.* cf. *recticostata* Saveliev (pl. 5, fig. 5) and *L.* cf. *tera* Saveliev (pl. 5, fig. 3, 7). These are accompanied by *Douvilleiceras* and *Oxytropidoceras*, as in the Paquier interval.

**NW Bulgaria** — Ivanov (1991) has described a thick succession of sediments of *tardefurcata* Zone age in the Sumer Formation. Sediments representing the *schrammeni* Subzone and the basal part of the *acuticostata* Subzone (with *Arcthoplites*) are apparently absent. There is, however, a very thick succession representing the rest of the *acuticostata* Subzone (his *Leymeriella (L.) tenuicostata* Subzone), surmounted by an equally thick *regularis* Subzone succession. The importance of these sections is that they have yielded a European fauna of *Leymeriella* associated with *Hypacanthoplites*, together with distinct Tethyan elements. These sections have yielded earlier *acuticostata* Subzone faunas than those yet known from the Col de Pré-Guittard succession below the Paquier interval.

**Mangyshlak** — Saveliev (1973), like Kemper and Brinkmann, used Spath's subzones as zones and this practice is followed in the comprehensive review of Albian zonation in the former Soviet Union by Mikhailova & Saveliev (in Bogdanova et al., 1989). In his description of the stratigraphy and ammonite faunas of the *Leymeriella*-bearing sediments of the Lower Albian succession in the Mangyschlak Peninsula, Kazakhstan, Saveliev (1973) showed that the *schrammeni* Subzone is not present. He recognised a *Leymeriella tardefurcata* Zone for beds equivalent to the German *Leymeriella acuticostata* Subzone only. This is confirmed by the occurrence of various species characteristic of Saveliev's *tardefurcata* Zone in the *acuticostata* Subzone clays in the Hannover-Braunschweig area (Owen, 1984b, in prep.). Saveliev also demonstrated that the *regularis* Subzone is well represented in the Mangyshlak succession.

## The base of the Albian Stage — discussion and recommendation

### Discussion

The writer (Owen, 1979) described a claypit section at Vöhrum in which he recognised a lithostratigraphical base of the *schrammeni* Subzone and of the Albian Stage in the classic north German succession. Subsequently, detailed studies of the stratigraphy, macro and micro faunas and floras across the Aptian and Albian boundary succession were made (Kemper, 1982a). This work formed the basis of the recommendation for the drawing of the boundary of the Albian as recognised by Breistroffer (1947) at the base of the *schrammeni* Subzone in the Hannover area, made during the First International Symposium on Cretaceous Stage Boundaries, held in Copenhagen in 1983 (Birkelund et al., 1984; Owen, 1984a,b).

However, at the Second International Symposium on Cretaceous Stage Boundaries held in Brussels in September 1995, where the placing of the lower boundary of the Albian was discussed (Hart et al., 1996), it was recognised that a boundary based on the first appearance of *Leymeriella schrammeni* is of limited geographical application (Table 2). At the inter-provincial level, links are known only within the Arctic regions (Nagy, 1970; Birkelund & Hakansson, 1983; Owen, 1984a,b, 1988a,b). Moreover, it was recognised that there is no permanent section in North Germany; a requirement for defining a stage boundary stratotype. These problems led to the suggestion that a more permanent section at the Col de Pré-Guittard in southern France, described by Bréheret et al. (1986), be examined as a possible candidate for a type section of the Aptian/Albian boundary. Although the *schrammeni* Subzone may be present in this section, it has not been confirmed (see above) and in effect, the suggestion made in Brussels implies that the boundary of the Albian could be placed at a higher horizon, *within* Spath's *tardefurcata* Zone, and indeed, as will be shown below, within the *acuticostata* Subzone.

In his reviews of ammonite faunal geographical distributions, the writer (Owen, 1984a,b, 1988a,b 1996a) demonstrated that the *Leymeriella acuticostata* Subzone was widely represented by sediments ranging from the Arctic Province, across northern and eastern Europe to the Near East (Iran: Seyed-Emami, 1980), and into Madagascar (Table 2). The species of *Leymeriella* characteristic of the *acuticostata* Subzone itself are restricted to the area from Peary Land (North Greenland) through to Iran. However, the genus *Arcthoplites* is characteristic of the basal part of the *acuticostata* Subzone and is geographically much more widespread, ranging from northeast Russia (Alabushev, 1995a, b), through the Canadian Arctic (e.g. Jeletzky, 1964, 1971, 1977, 1980), Peary Land (Birkelund & Hakansson, 1983), Spitzbergen (Nagy, 1970), Germany (*'Protohoplites* (*Hemisonneratia* ?)*' hapkei* Kemper, 1975), Moscow Basin (Baraboshkin, 1991), Kazakhstan (Saveliev, 1973), to Madagascar (Owen, 1988a); thus spanning all three Arctic, European and Tethyan provinces. *Arcthoplites* evolved from the Arctic province genus *Freboldiceras* (Owen, 1988b) in *schrammeni* Subzone times and itself evolved rapidly into *Anadesmoceras* and *Cleoniceras*, present in the later part of the *acuticostata* Subzone. The Late Aptian parahoplitid genus *Hypacanthoplites* was also present in *acuticostata* Subzone times and does not appear to have survived them.

Thus ammonite faunal links permit a correlation of the lower boundary of the *L. acuticostata* Subzone from the Arctic faunal province across Europe to the Tethyan

Province. However, it is apparent that the early part of the *acuticostata* Subzone is also not well represented outside of Kazakhstan (Saveliev, 1973), the Moscow Basin region (Baraboshkin, 1991), northern Germany, north Greenland and Spitzbergen (Birkelund & Hakansson, 1983). Although the *acuticostata* Subzone is more geographically widespread than the *schrammeni* Subzone, there is still a serious problem in selecting the base of the *acuticostata* Subzone as the base of the Albian. On the other hand, the base of the *acuticostata* Subzone provides one of the few points of interprovincial correlation in the Early Albian, including the *Douvilleiceras mammillatum* Superzone (Owen, 1988a,b). Moreover, outside of Madagascar where the *'Sonneratia' sakalava* Zone of Collignon (e.g. 1963, 1978a) can be correlated with the base of the *acuticostata* Subzone, there is, as yet, no other described section in the Tethyan province which can be equated with the lower and middle Subzones of the *Leymeriella tardefurcata* Zone. In Colombia, Etayo-Serna (1979) has described a succession in which he recognises a *Douvilleiceras solitae - Neodeshayesites columbianus* Assemblage Zone. Apart from *Douvilleiceras*, he records *Eodouvilleiceras*. If the latter is correct, this assemblage zone is latest Aptian to earliest Albian in age. At present, *Eodouvilleiceras* is known from the *Nolaniceras nolani* and *Hypacanthoplites jacobi* Subzones. Neither have been found in sediments of the earliest Albian *schrammeni* Subzone and the earliest *Douvilleiceras* yet known is of *acuticostata* Subzone age. The overlying *Platyknemiceras colombiana - Rinconiceras rincoi - Lyelliceras pseudolyelliforme* Assemblage Zone in Colombia is of latest Early Albian and early Mid Albian (*Lyelliceras lyelli* Subzone) age.

Recommendation

From the above, there is an argument for placing the base of the Albian Stage at the base of the geographically widespread *Leymeriella acuticostata* Subzone and equivalents, if this will also assist correlation with the more globally widespread microfaunal and microfloral zonations. However, the boundary would be placed within the *Leymeriella tardefurcata* Zone, immediately above the essentially transitional early forms of *Leymeriella* from *Callizoniceras* (*Wollemanniceras*) to typical *Leymeriella* of the *tardefurcata* group. This is seen and well-documented in the continuous sedimentary succession of the Hannover-Braunschweig area of north Germany, the originally selected stratotype area for the Aptian/Albian boundary. On the other hand, if this correlation cannot be achieved, there seems little point in changing the existing boundary at the base of the *Leymeriella schrammeni* Subzone, which is well documented both stratigraphically and faunistically (Kemper, 1982a). The selection of a black-shale event — the Paquier level — is inappropriate as its date is latest *acuticostata* Subzone only. If the boundary is shifted to a point later in time, there is an additional problem of zonation nomenclature, which relates more to Spath's hierarchical concept of zones and subzones rather than of faunal occurrences. It would appear best to adopt the zone concept of Brinkmann, Kemper, Saveliev and others (e.g. Bogdanova et al., 1989) which promotes subzones in Spath's scheme to the rank of zones and thus a return to a Zone of *Leymeriella tardefurcata* in Brinkmann's sense for Spath's *Leymeriella acuticostata* Subzone.

| Zone | Subzone |
|---|---|
| *Euhoplites lautus* | *Anahoplites daviesi* (including *A. rossicus*)<br>*Euhoplites nitidus* |
| *Euhoplites loricatus* | *Euhoplites meandrinus*<br>*Dipoloceroides subdelaruei*<br>*Dimorphoplites niobe*<br>*Anahoplites intermedius* |
| *Hoplites dentatus* | *Hoplites spathi*<br>*Lyelliceras lyelli* |

Fig. 3. Ammonite zonal and subzonal scheme for the Middle Albian in the European faunal province.

## Middle Albian Substage

### The *Hoplites dentatus* Zone and the base of the Middle Albian Substage (Figs. 3, 5)

Owen (1984a,b) presented reasons for placing the base of the Middle Albian Substage at the base of the *Lyelliceras lyelli* Subzone, the earliest subzone of the *Hoplites dentatus* Zone of the European province (Fig. 3). The river cliff section on the Meuse at Les Côtes Noires, près de Moeslain, is suitable as a boundary stratotype on ammonite data (e.g. Hart et al., 1996). In the author's original interpretation of the *lyelli* Subzone (Owen, 1971), the thin development of sediments in the Paris Basin, which contained the transitions from the *Douvilleiceras mammillatum* Superzone genus *Tegoceras* to *Lyelliceras* of the *lyelli* group, such as *Lyelliceras pseudolyelli*, was included in that Subzone. It was indicated that *Lyelliceras* is not present throughout the European province and was essentially confined to the western and southern regions. Elsewhere in the province, the earliest species of *Hoplites* of the *dentatus* Zone such as *H. pseudodeluci* Spath, *H. baylei* Spath, and including *Hoplites dentatus* (J. Sowerby) itself, are already present and characterise sediments of this transitional interval. During the 1995 Brussels meeting, Amedro suggested that the Subzone of *Lyelliceras lyelli* should commence at the first appearance of the typical *L. lyelli*, thus excluding the interval containing forms transitional from *Tegoceras* (Hart et al., 1996). This suggestion has merit, as these transitional faunas are geographically widespread within the Tethyan province as well as in European Province, occurring just below the appearance of typical *Lyelliceras*. Thus, a boundary sedimentary succession between the latest Early Albian and the earliest Mid Albian can be recognised in a number of sections in both the Tethyan and European provinces. It is important to note, however, that early, true *Hoplites* occur associated with *Lyelliceras pseudolyelli* and this will produce a problem in eastern Europe where *Lyelliceras* is absent. Here, the placing of the Lower/Middle Albian boundary depends on the morphological transition from *Pseudosonneratia (Isohoplites)* of the *steinmanni* group to *Hoplites*. This disparity was recognised by the author (Owen, 1971) when including the interval with *L. pseudolyelli* in the *lyelli* Subzone.

Apart from the occurrences noted in Owen (1971), this Early/Mid Albian boundary succession, as modified by Amedro, can also be recognised in Colombia (e.g.

Etayo-Serna, 1979), Venezuela (Renz, 1982), South Africa (e.g. Kennedy & Klinger, 1975), while Young (1993) has illustrated a fauna of latest Early Albian age from west-central Chihuahua, Mexico.

There is a tendency for authors to assign an Early Albian, *Douvilleiceras mammillatum* Superzone, age to sediments which contain *Douvilleiceras*. It is important to recognise that the earliest known *Douvilleiceras* occurs in the late *acuticostata* Subzone (mid-*tardefurcata* Zone) in the European province. The genus ranges through the remainder of the Early Albian to die out abruptly at the end of the *Lyelliceras lyelli* Subzone (early Mid Albian) in western Europe. *Douvilleiceras* is apparently the direct morphological descendant of *Eodouvilleiceras* which is widespread in the Tethyan province from South America to Madagascar in sediments of latest Late Aptian age (the equivalents of the *Nolaniceras nolani* and *Hypacanthoplites jacobi* Subzones).

## Higher Middle Albian European and Tethyan faunal province correlations (Fig. 5)

The genus *Hoplites* and its direct successor *Euhoplites* are unknown outside the European Province. However, above the *lyelli* Subzone in the western marginal regions of the European province (e.g. Owen, 1971; Destombes, 1979) and to a certain extent in Poland (Marcinowski & Wiedmann, 1985, 1990), several Tethyan genera are present and provide some data for broad post-*lyelli* Subzone correlation (Fig. 3). In the *spathi* Subzone, *Dipoloceroides* of the *delaruei* group, *Mojsisovicsia* (including *Falloticeras*, see Gebhard, 1983), *Oxytropidoceras*, *Brancoceras* and *Eubrancoceras* are relatively rare, but characteristic forms. Their occurrence permits correlation with contemporaneous geographically widely separated successions in Peru (e.g. Knetchel et al., 1947; Benavides-Caceras, 1956), South Africa (Kennedy & Klinger, 1975; Kennedy & Cooper, 1977) and perhaps Pakistan (Spath, 1930). Rare occurrences of *Brancoceras* are known from sediments of *Anahoplites intermedius* and *Dimorphoplites niobe* Subzones age in western Europe, together with *Puzosia* and *Desmoceras*. In the *Dipoloceroides subdelaruei* Subzone there is a more general but short lived incursion of *Dipoloceroides*, *Brancoceras* and *Oxytropidoceras* (*Venezoliceras*) into the western marginal area of Europe. Within the *Euhoplites nitidus* and *Anahoplites daviesi* Subzones, there are similar rare occurrences of early *Dipoloceras* of the *cornutum* group (transitional from *Dipoloceroides*) within this marginal area. Unfortunately, even as rarities, there is no succession of *Oxytropidoceras* spp. in these higher Middle Albian sediments which would permit exact correlation with a broad *Oxytropidoceras* Zone widely recognised in the Tethyan province which occupied part or all of Mid Albian time.

Collignon (e.g. 1949, 1963, 1978a) has recognised in Madagascar, a zone characterised by *Oxytropidoceras acutocarinatum* and *Manuaniceras jacobi*, intervening between the *lyelli* Subzone and his *Dipoloceras cristatum* Zone sediments. This interval may be present in the Middle Albian sediments of Pakistan (Spath, 1934; Owen 1971) and Ladakh (Thieuloy et al., 1990). Kotetishvili (1977, 1979, 1986), working on sections in the Georgian Republic, has added weight to the evidence of the presence of this broad zone of *Oxytropidoceras* occupying much of the post-*lyelli* Subzone Middle Albian in the Tethyan province. Kennedy & Klinger (1975) recognised the same interval in their Albian IV division in the Mzinene Formation in Zululand. Young (1966, and see commentary by Owen, 1971) has described a Middle Albian succession characterised by *Oxytropidoceras* from Texas which demonstrates the geographically widespread occurrence of this broad zone which occupies his *O. salasi* and much of his *O. carbonarium* Zones. The position of the Zone of *Oxytropidoceras buarquianum* recognised by Bengtson (1983) in Brazil and the equivalent succession in Angola which has been equated with the *lyelli* Subzone (Cooper, 1974, 1982) is strictly uncertain. It is strange when considering the very widespread occurrence of *Lyelliceras lyelli*, that it has not been found associated with the *buarquianum* fauna and this might indicate a later Mid Albian date for this assemblage. On the other hand, *O. buarquianum* (White) has a very similar pattern of simple ribbing to that seen in the late *Leymeriella acuticostata* and *Douvilleiceras mammillatum* Superzone species of *Oxytropidoceras* (compare the specimens figured by Cooper (1982) with those of Delamette (in BrJheret et al., 1986) and Kennedy & Kollmann (1979)). Collignon (1978b) described and figured a specimen of *Dipoloceroides* from Angola under the name of *Dipoloceras remotum* Spath (pl. VIII, figs 2a,b) which, while indicating a Mid Albian age, appears to be earlier than the *Dipoloceroides subdelaruei* Subzone of the European province. In Texas, towards the top of this broad zone of *Oxytropidoceras* (within the *carbonarium* Zone of Young, 1966), early species of *Dipoloceras* of the *cornutum* group are present, similar to those occurring in the *Euhoplites nitidus* and *Anahoplites daviesi* Subzones of the European faunal province.

## The bivalve lineage *Actinoceramus concentricus-sulcatus-concentricus* and zonation

The precise Mid and early Late Albian range of the inoceramid bivalve lineage *'Birostrina' concentrica-subsulcata-sulcata-subsulcata-concentrica* in relation to the ammonite subzonal succession in the European faunal province has been accurately documented in the Gault of SE England, France and northern Germany. This lineage is found elsewhere in the world and is useful for interprovincial correlation. Recently, Crampton (1996) has monographed the Albian-Cenomanian inoceramids grouped by Cox (1969) in *Birostrina*, treating this generic name as invalid under the articles of the International Code of Zoological Nomenclature; he recognised instead the generic name *Actinoceramus* Meek 1864. Both genera have *Inoceramus sulcatus* Parkinson as type-species. It is not entirely clear that Crampton's argument is correct, but Meek's generic name will be used here.

As the *concentricus-subsulcatus-sulcatus-subsulcatus-concentricus* lineage is important in biostratigraphical zonation, it is necessary to make the following observations based on direct experience of their stratigraphical occurrence. In the Anglo-Paris Basin, wherever sediments of late Mid Albian (*Anahoplites daviesi* Subzone) age are known, especially at Folkestone, Kent (e.g. Owen, 1971, 1976), *Actinoceramus concentricus* (Parkinson) is present alone. At Folkestone, the development of the top sediments of Bed VII of the Lower Gault are affected by the erosion event in the early *Dipoloceras cristatum* Subzone marked by Bed VIII (i). Occasionally, just below Bed VIII, sediments are preserved which yield the ammonites of Saveliev's *Anahoplites rossicus* Zone in Kazakhstan, which also contains *A. concentricus*. In the earliest sediments of *Dipoloceras cristatum* Subzone age (earliest Late Albian) seen well at Wissant, France, morphological transitions occur (the *subsulcatus* stage) from the typical concentric folds of the *concentricus* morphotype to the radial folds of the *sulcatus* morphotype. These are associated with *Dipoloceras bouchardianum* (d'Orbigny). The development of these radial folds in this stock is relatively rapid at the base of the *cristatum* Subzone sediments and the *sulcatus* morphotype is characteristic of both the *cristatum* and *Hysteroceras orbignyi* Subzones. At the end of the *orbignyi* Subzone a relatively rapid reversion from the *sulcatus* to the *concentricus* morphotype of the *Hysteroceras varicosum* Subzone occurs through a similar *subsulcatus* stage. During the *varicosum* Subzone, the late form of *Actinoceramus concentricus* (including *A. concentricus gryphaeoides* Sowerby) is present and this species is not present in the *Callihoplites auritus* Subzone. The writer has given precision to these observations in a detailed analysis of the Late Albian sediments in Kent and Surrey in England (Owen, 1996b). Within these ornament patterns, there is variation in marginal outline and some of these variations are seen to be facies controlled when specimens from contemporaneous arenaceous deposits of relatively marginal areas and the clays and mudstones of the deeper basins are compared.

## Upper Albian Substage

### *Dipoloceras cristatum* and the base of the Upper Albian Substage (Figs. 4-5)

Like *Lyelliceras* in the early Mid Albian, *Dipoloceras* is relatively common in the western, central and southern parts of the European faunal province, reflecting the substantial immigration into these areas of an essentially Tethyan stock via the extending North Atlantic and through the Polish Trough. Further east, in Russia and extending southward into Kazakhstan, *Dipoloceras* is absent and correlation of the Mid/Late Albian boundary with the remainder of the European province has been based on the occurrence of *Anahoplites* of the *daviesi* group with *Actinoceramus concentricus* Parkinson below and early *Semenovites* associated with *Actinoceramus sulcatus* above. The complex zonation across this boundary proposed by Saveliev (1981) was modified by Saveliev (in Bogdanova et al., 1989, which gives a detailed account of the development and variation of the zonation in various regions of the former USSR). Although the *Anahoplites rossicus* Zone of Saveliev is now correctly placed in the Mid Albian (Owen, 1984b; Bogdanova et al., 1989), there is some debate concerning the complexity of the ammonite zonation when compared with the sedimentary succession and its faunas (e.g. Marcinowski et al., 1996). However, the occurrence of *Actinoceramus concentricus* with *Anahoplites rossicus* (Sinzov) below, followed by *Actinoceramus sulcatus* and *subsulcatus* transitions with *Semenovites tamalakensis* Saveliev above, in the Koksyirtau Section of the Mangyschlak Mountains in Kazakhstan (confirmed by material collected by David Ward), places the boundary precisely in this region. It is important to repeat this observation in view of the occurrence of *Semenovites* in Iran (Amedro et al., 1977; Seyed-Emami & Immel, 1995). *Semenovites* is a direct descendant of *Anahoplites* of the *daviesi* group and there is much intergradation and variation in the ribbing pattern in the 'species' occurring in Saveliev's *litschkovi* Zone (cf. Marcinowski et al., 1996). The species identified as *Callihoplites* sp. from this time interval is incorrectly referred to that genus, being a coarsely ornamented end form of the contemporaneous *Semenovites* stock.

| Zone | Subzone |
|---|---|
| *Stoliczkaia (S.) dispar* | *Arrhaphoceras (Praeschloenbachia) briacensis*<br>*Mortoniceras (Durnovarites) perinflatum*<br>*Mortoniceras (M.) rostratum* |
| *Mortoniceras (M.) inflatum* | *Callihoplites auritus*<br>(early part + a later interval with<br>*Mortoniceras (Cantabrigites) minor*)<br>*Hysteroceras varicosum*<br>*Hysteroceras orbignyi*<br>*Dipoloceras cristatum* |

Fig. 4. Ammonite zonal and subzonal scheme for the Upper Albian in the European faunal province.

## *Hysteroceras orbignyi* and *H. varicosum* Subzones in the Tethyan Province

In the Tethyan province, the interval above the *cristatum* Subzone which is characterised by *Hysteroceras,* is not capable of subdivision at present into the equivalents of the European *Hysteroceras orbignyi* and *H. varicosum* Subzones when *Actinoceramus* is absent. Where genera such as *Prohysteroceras,* certain ubiquitous species of *Mortoniceras* sensu lato and *Hysteroceras choffati* are present in the fauna, as in southern Africa, classification and correlation with the mid and later parts of the *varicosum* Subzone can be made. The *Hysteroceras varicosum* Subzone is of widespread geographical occurrence outside of the European province. It is present in southern North America and northern South America. The ammonite fauna of *Oxytropidoceras, Mortoniceras, Hysteroceras,* engonoceratids, and *Neophlycticeras* from the La Puya Formation (Renz, 1982) and basal Aguada Member in Venezuela described by Renz (1968, 1970, 1971, 1982) are of *varicosum* Subzone age, not *orbignyi* Subzone as stated by him. This is further indicated by material in the J. V. Harrison Collection (no. 13204) from Peru which contains a specimen of *Oxytropidoceras (Venezoliceras) karsteni* Stieler, *Hysteroceras varicosum, H.* aff. *orbignyi,* and *Prohysteroceras* sp. associated with *Actinoceramus concentricus.* In Mexico, Young (1992) has described a small collection of *Hysteroceras* of *orbignyi* Subzone age relating them to similar occurrences in Texas (Young, 1984) and Angola (Haas, 1942; Collignon, 1978b). Van Hoepen (e.g. 1931, 1941, 1942, 1944, 1946, 1951) has described a fauna of similar age from South Africa and the stratigraphy has been described by Kennedy & Klinger (1975) (within their Albian V). Collignon (e.g. 1963, 1978a) has figured, and described the stratigraphical distribution of, ammonites of *varicosum* Subzone age which occur in his Zone B *Hysteroceras binum* at Mont Reynaud, Madagascar. Kotetishvili (1979, 1986) records *Actinoceramus sulcatus* and the transitions back to *Actinoceramus concentricus* along with ammonites marking the *orbignyi-varicosum* Subzone boundary in Georgia. Along the northern margin of the Tethyan province in Sardinia, Wiedmann & Dieni (1968) have described ammonites of late *varicosum* Subzone age in the condensed Late Albian pebble faunas from Orosei. The ammonites from the Tambo Series in eastern Australia described by Whitehouse (1926) contain a definite *Prohysteroceras (Goodhallites), P.(G.) richardsi* Whitehouse indicating a *varicosum* Subzone age for part of this Formation.

## The *Callihoplites auritus* Subzone of the European Province

Gallois & Morter (1982) and Woods et al. (1995), working in East Anglia (England) and the writer working on the ammonite fauna of the Late Albian of the Kirchrode borings, N Germany (Fenner et al., 1996; Wiedmann & Owen, in press), have concluded that the *auritus* Subzone can be divided roughly into early and late parts (Table 4). Whether these two divisions merit formal zonal recognition requires more research, but the ammonite fauna of the upper division contains elements which are more cosmopolitan than in the lower division. Moreover, there is a distinction in the bivalve fauna between the occurrence of *Inoceramus lissa* Seeley in the lower division and its abrupt replacement by *Aucellina gryphaeoides* at the boundary with the upper division. The latter species continued into the Cenomanian.

## The *Stoliczkaia dispar* Zone

Strong ammonite faunal links between the European province and the Tethyan province reflect the more cosmopolitan nature of the *Stoliczkaia dispar* Zone, with the exception of the hoplitinid ammonites which are still confined to the European province. Gale et al. (1996) have described the ammonite, inoceramid, planktonic foraminifera and nannofossil biostratigraphy of a thick succession at Mont Risou, Hautes Alpes, France, which spans the Albian/Cenomanian boundary.

This work provides a much more precise stratigraphical framework for the mid (*Mortoniceras (Durnovarites) perinflatum*) and late (*Arrhaphoceras (Praeschloenbachia) briacensis*) Subzones of the *dispar* Zone. The *briacensis* Subzone of Scholz (1973) represents the latest *dispar* Zone fauna known. It is the same interval that Owen (1984a,b, 1989) recognised in southern England and elsewhere in Europe, but which was not sufficiently delimited or its fauna well enough known, for it to be formally named. The index species *Arraphoceras* (*P.*) *briacensis* is used here (Fig. 4) but with reservation, because this ammonite is of limited range within this assemblage Subzone (Gale et al., 1996). These authors refer the ammonite faunule described from Misburg, Hannover (Owen, 1989) (which is not in a Flammenmergel facies as they state) to the *briacensis* Subzone. The absence of *Hyphoplites* spp. in this faunule and their presence both at Mont Risou and at Uplyme, Dorset, suggests an early *briacensis* Subzone age. Subsequent excavation of the Mittelandkanal in this area has detected a higher horizon within these marls of the Harz foredeep, which contains the subzonal index *A. (P.) briacensis*. The specimen figured by Owen (1989, pp. 375, 378; pl. 1, fig. 12a-b) from Misburg as cf. *Worthoceras* is identical to *Worthoceras pygmaeum* Bujtor (1991) of late *dispar* Zone age in Hungary and at Mont Risou (Gale et al., 1996, fig. 30d-n).

The *dispar* Zone fauna is known in the Tethyan belt as far east as the Northern Territory of Australia. Henderson (1990) has described two ammonite faunas from the Darwin area; an older fauna found loose on a modern beach containing forms consistent with a late *varicosum* and *auritus* Subzone date and a younger fauna, collected in situ, of mid to late *dispar* Zone age. As yet, there is no evidence of the intervening *rostratum* Subzone. Henderson reiterates the view of Kennedy & Cooper (1979) that *Mortoniceras (M.) rostratum* (J. Sowerby) is a species of uncertain status. This is not so; it is a distinct species characteristic of sediments later than those of the *auritus* Subzone and earlier than those containing *Mortoniceras* (*Durnovarites*).

## Conclusions (Fig. 5)

In this review of the links which exist between the ammonite zonal scheme of the Albian in the European province and those recognised in the Tethyan province, emphasis has been placed on the lower boundaries of the stage and substages. The problems of fixing the Aptian/Albian boundary have been discussed more fully and the conclusion reached that even if the base of the *schrammeni* Subzone of the *tardefurcata* Zone was abandoned, there are still serious problems in faunal correlations if the base of the succeeding *acuticostata* Subzone is selected. Lithologically, the Paquier black-shale event might be capable of widespread recognition in sediments of Early Albian age, but faunistically in terms of ammonites, it is meaningless, merely representing an event towards the end of the *acuticostata* Subzone. Even with the predominantly sonneratiinid ammonite fauna of the later Early Albian *mammillatum* Superzone, and the hoplitinid faunas of the Middle Albian in the European province, it is apparent that much more can be achieved in inter-provincial correlation than is apparent from earlier international efforts (e.g. Hoedemaker et al., 1993). In the case of the Late Albian, there are many more points of correlation possible reflecting the much more cosmopolitan nature of the ammonite fauna. The need here is to illustrate the comparable material from both faunal provinces.

In terms of zonal nomenclature and hierarchical groupings, there is considerable variation in the treatment of the ranking of 'zones' and 'subzones' among Albian workers. Examples are given in this paper, but there are other schemes published based on ammonites (e.g. Amedro, 1992), which make it difficult for colleagues working in the Tethyan Province to decide which of the published European 'Standard'

| | Western Europe (Hoplitinid Province) | boundary (sub)zones | Mediterranean (Tethyan Province) |
|---|---|---|---|
| Late Albian | *Stoliczkaia (S.) dispar*<br><br><br><br>*Euhoplites lautus* | <br><br><br>*Diploceras cristatum* | *Stoliczkaia (S.) dispar*<br>*Mortoniceras (M.) inflatum*<br>*Hysteroceras* spp.<br>*Diploceras cristatum* |
| Middle Albian | *Euhoplites loricatus*<br>*Hoplites dentatus*<br>*Douvilleiceras mammillatum* Sz | <br>*Lyelliceras lyelli* | *Oxytropidoceras (O.)* spp.<br>*Lyelliceras lyelli*<br>*Douvilleiceras mammillatum* |
| Early Albian | *Leymeriella tardefurcata* | subject of discussion*) | *Leymeriella tardefurcata*<br>(sensu Spath, 1941) |

Fig. 5. Correlation of zones of the Hoplitinid and Tethyan faunal provinces with proposed subzonal/zonal markers for substage boundaries (Kotetishvili & Owen, in Rawson et al., this volume). Sz = Superzone.
*) Base of *Leymeriella schrammeni* Subzone, accepted at Copenhagen (Birkelund et al., 1984), is of limited known distribution in the northern part of the European Province and the boundary area with the Arctic Province. Base of the *Leymeriella acuticostata* Subzone (the *Leymeriella tardefurcata* Zone of Brinkmann et al.), proposed at Brussels (Hart et al., 1995), ranges from the geographical boundary with the Arctic Province across Europe to Iran. The early part of the subzone is characterised by *Arcthoplites* with transitions from *L. schrammeni* Subzone *Freboldiceras*

zonal schemes to use. The relative dearth of links in the Early and Mid Albian between the essentially European ammonite faunas represented by the total range subzones used in the scheme and adjoining provinces, require that provincial schemes be erected. However, much more can be done in the earlier part of the Late Albian to provide a more accurate and meaningful scheme applicable to both the European and Tethyan provinces. The >standard= European province scheme used here for the earlier part of the Late Albian is misleading. The zonal index, *Mortoniceras inflatum,* while having an early form in the *varicosum* Subzone, is typically of *auritus* Subzone age in the European hoplitinid province. It does not occur earlier, nor later. Indeed true *Mortoniceras* is not found in the *cristatum* Subzone if one excludes the *rigidum* group from that genus (Cooper, 1982). In South Africa, England and elsewhere, a *Dipoloceras cristatum* Zone instead of a 'Subzone' makes much greater sense. The existing *Hysteroceras orbignyi* and *H. varicosum* Subzones while recognisable in the European province are unsatisfactory in a wider context and need re-evaluation based not only on bivalve (*Actinoceramus*) criteria, but on the occurrence of geographically more widespread species of *Mortoniceras* and *Prohysteroceras.* The *Callihoplites auritus* Subzone is applicable only to the European hoplitinid province. Yet it contains genera and species which are more cosmoplitan in their distribution and if the 'subzone' was reorganised, would make the zonation of this interval of time of more widespread application. Only in the early and mid *Stoliczkaia dispar* Zone is there a truly cosmopolitan scheme of total range subzones.

## Acknowledgements

My thanks are due to David Ward and Andy Gale for allowing me to examine material collected by them in Kazakhstan and for useful discussions. Also to my research colleagues in the BCCP Group working on the Kirchrode borings, Hannover, and particularly Juliane Fenner of the Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover. I am most grateful to Peter Rawson for his review of the original manuscript.

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