

The ammonite faunas of the Callovian-Oxfordian boundary interval in Europe and their relevance to the establishment of an Oxfordian GSSP

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ABSTRACT: The latest Callovian and Early Oxfordian are characterised by one of the highest levels of mixing of Boreal, Submediterranean and even Mediterranean faunas. In particular the massive expansion of Boreal Cardioceratidae from their original “home” in Arctic areas as far south as south-east France, brings them into contact with Mediterranean-style faunas rich in Phylloceratidae. This so-called “Boreal Spread” provides the framework within which high-resolution inter-bioprovincial correlations are possible and hence the context for a successful GSSP designation for the base of the Oxfordian Stage within Europe (and hence the beginning of the Upper Jurassic). Associated with the Cardioceratidae, especially in more Tethyan areas is a great variety of Perisphinctoidea, including Aspidoceratidae, Perisphinctinae, Grossouvrinae and rarer Pachyceratidae as well as frequent Hecticoceratinae and rarer Phylloceratidae. As several of these persist beyond Europe they therefore provide tantalising indications that a truly global correlation of any GSSP established in Europe will ultimately be possible. The stratigraphical, taxonomic and palaeobiogeographical context and significance of the trans Callovian-Oxfordian boundary faunas within Europe is here reviewed and the faunas of the candidate GSSP at Redcliff Point, Weymouth, SW England are described, including the basal Oxfordian species *Cardioceras (Pavloviceras) redcliffense* sp. nov.

INTRODUCTION

The latest Callovian and Early Oxfordian represent one of the most dynamic intervals in the history of Jurassic Ammonoidea and is characterised by one of the highest levels of mixing of Boreal, Submediterranean and even Mediterranean faunas. The key event is a massive expansion of the range of Boreal Cardioceratidae from their original home in Arctic Province areas (Panboreal Realm or Superrealm *sensu* Westermann 2000), across Europe to as far south as SE France, bringing them

into contact with diverse Mediterranean-style faunas rich in Phylloceratidae (Pantethyan Realm or Superrealm). Not surprisingly, this intermixing means that exceptionally detailed high-resolution correlations are possible across the area, this providing one of the best contexts for establishing the Global Stratotype Section and Point for the base of any Jurassic Stage.

Associated with the Cardioceratidae in the south is a great variety of Perisphinctoidea, including Aspidoceratidae, Perisphinctinae, Grossouvrinae and rarer Pachyceratidae as well as frequent

Hecticeratidae, Phylloceratidae and Lytoceratidae. Most of these groups are commonest in Submediterranean and Mediterranean Province areas, but the Aspidoceratidae do persist well into the Pan-Boreal Realm and are locally common amongst the latest Callovian Subboreal faunas of England and Scotland. Crucially, several groups of Perisphinctoidea, including Peltoceratidae, do range beyond Europe and are known in East Pacific and Indo-Pacific areas (Westermann 1992), therefore providing tantalising indications that a truly global correlation of any GSSP established in Europe will ultimately be possible.

The current paper will review the stratigraphical, taxonomic and palaeobiogeographical contexts and significances of the trans-Callovian-Oxfordian boundary faunas within Europe, building on recent results from the candidate Oxfordian GSSP near Redcliff Point, Weymouth, Dorset.

BIOPROVINCIAL CONTEXT

The marked north to south zonation of ammonite faunas during the latest Callovian and Early Oxfordian in Europe reflects a transition from the relatively environmentally restricted and cooler waters of the circum-polar Arctic Sea to the warm margins of the Tethys Ocean. As would be expected, diversity increases steadily southwards and as a result a series of essentially east-west trending bioprovinces are recognisable, as reviewed by Page (1996, 2008). Although overlapping geographical ranges facilitate some correlations between adjacent provinces, it is the sudden spread of the Cardioceratidae southwards from their Arctic home in the latest Callovian, that provides the context for correlation of the interval across Europe. The character of each successive bioprovincial belt is reviewed below.

Arctic or Boreal-Atlantic Realm: Arctic Province (including Greenland, Spitzbergen, Alaska, western Canada, far eastern Russia, Scotland)

A distinct Arctic Province for ammonoids was already established in the Triassic and its use in the Jurassic is reviewed by Page (1996). It is equivalent to the “inner Boreal” Province of Callomon (1985), although often referred to as simply a “Boreal Province” by many authors. Callovian and Oxfordian Arctic Province faunas are virtually exclusively composed of Cardio-

ceratidae, with cadoceratids in the Lower and Middle Callovian which evolve into *Longaeviceras* in the early Upper Callovian and eventually give rise to *Cardioceras* at the end of the terminal Callovian, Lamberti Chronozone. The expansion of *Quenstedtoceras* into Subboreal and Submediterranean province areas – the Boreal Spread of Callomon (1985) – provides an excellent correlative event, now established as the base of the Lamberti Chronozone. Detailed records of trans-boundary ammonite faunas from the Arctic Province are few although there is no reason to suspect that the basic succession of *Quenstedtoceras* to *Cardioceras* faunas differs in any significant way from that in adjacent Subboreal areas, as described below. The local persistence of *Longaeviceras* into the Lower Oxfordian, however, is noteworthy.

There is some evidence, however, of endemic cardioceratid species in Boreal-Pacific areas (*sensu* Westermann 2000) of North America as suggested by reviews in Westerman (1992, for instance pp. 29-92, 225-272). The East Pacific context of these faunas, however, may suggest that assignment to a different biogeographic province might be more appropriate, perhaps even a Northwest Pacific Province as is recognised at the end of the Jurassic and into the Lower Cretaceous (*cf.* Page 1996).

Boreal-Atlantic Realm: Subboreal Province (including England, Normandy, southern Germany, northern Poland, Russian platform)

Subboreal Province Late Callovian to Early Oxfordian faunas are also dominated by Cardioceratidae, but in addition include levels with frequent Perisphinctoidea, especially *Euaspidoceras* and *Peltoceras* (both Aspidoceratidae) and locally also Opeleidae, including Hecticeratidae. The Upper Callovian, Lamberti Subchronozone, in particular the *lamberti* Biohorizon is particularly diverse with a wide variety of Tethyan forms and also frequent *Kosmoceras* (*K.*) which is characteristic of the province, for instance in North Yorkshire (Wright 1968). In the Lower Oxfordian, although no clearly endemic Subboreal taxa are currently recognised (comparable for instance with Lower Callovian Proplanulitinae or Upper Oxfordian to Kimmeridgian Aulacostephanidae), the Province maintains a clear Boreal character due to the dominance of Cardioceratidae. The presence of frequent Tethyan forms, however, demon-

strates a classic “Subboreal” character within an Arctic to Mediterranean province spectrum of increasing Tethyan influence as has been described by many authors (*e.g.* Enay 1980; Page 1996, *etc.*). A synthesis of typical Subboreal ammonite faunas in the UK is provided by Page (2004) and the candidate GSSP near Redcliff Point in Dorset, SW England, as described in more detail below, is characteristic.

In Scotland (as reviewed by Page 2004) the fauna is much less diverse and more Arctic in style. Latest Callovian faunas include typical Boreal *Quenstedtoceras* spp. with occasional *Kosmoceras* (*K.*). With the exception of *Euaspidoceras* at one level, no other genera seem to have been recorded. Early Oxfordian faunas of the Mariae Subchronozone are virtually exclusively of *Cardioceras* (*Pavloviceras*) and only very rare late *Longaeviceras* (*L. staffinense* Sykes) appears to be present – other Perisphinctoidea (*e.g.* *Peltoceras* and very rare *Mirosphinctes*) not being recorded until the Costicardia Subchronozone of the Cordatum Chronozone.

Mediterran-Caucasian Realm: Submediterranean or Mediterranean Province – east (SE France, etc.)

Eastern Submediterranean Province faunas have a strong Mediterranean Province flavour and are characterised by a remarkable mixing of Boreal and Tethyan faunas with frequent Cardioceratidae, varied Perisphinctoidea (*Peltoceras*, *Poculisphinctes*, *Alligaticeras*, *etc.*) and common Hecticoceratinae in association with common Mediterranean Province Phylloceratidae, including *Sowerbyceras*. Subboreal *Kosmoceras* is rare as is Tethyan *Pachyceras*. The faunas of the alternative candidate Oxfordian GSSP at Savournon and Thoux in SE France exemplify such assemblages and have been described by Fortwengler and Marchand (1994, 1997) and Bonnot *et al.* (1995) (see also Cariou *et al.* 1997, and Thierry *et al.* 1997). Similar faunas are also known as far east as Iran (Seyed-Emami *et al.* 1995).

Mediterran-Caucasian Realm: Submediterranean Province – west (including Spain)

In contrast to eastern Submediterranean areas, faunas in the west are characterised by a virtually absence of Boreal forms – Cardioceratidae in particular appear to be unrecorded – and only

rare Phyllo- and Lytoceratidae. Representative boundary sections are few, however, and most of the recorded fauna has been recovered from stratigraphically condensed levels associated with a major regional non-sequence which typical omits most of the Middle and Upper Callovian and the Lower and basal Middle Oxfordian. Where typical faunas have been recorded, the Upper Callovian, including equivalents of the Lamberti Chronozone is characterised by common Hecticoceratinae with varied Perisphinctoidea including *Peltoceras*, *Alligaticeras* and *Poculisphinctes* (Meléndez *et al.* 1982; Page *et al.* 2004). Remarkably, a few very rare *Kosmoceras* (*K.*) are also known. Lower Oxfordian faunas are also dominated by Perisphinctoidea, although equivalents of the Mariae Chronozone are difficult to recognise. *Peltoceras*, *Properisphinctes*, *Mirosphinctes* and OPELLIIDAE are typical. Phylloceratidae, including *Sowerbyceras*, are only locally recorded, and never common. As in the Mediterranean Province (see below), in the absence of Cardioceratidae, reliable correlation of the terminal Callovian, Lamberti Chronozone and the basal Oxfordian Mariae Chronozone is currently problematic.

Mediterran-Caucasian Realm: Mediterranean Province [including Italy, Sicily, S Spain (Betics)]

In addition to abundant Phylloceratidae, Mediterranean faunas of the latest Callovian and earliest Oxfordian include a wide range of Perisphinctoidea which are broadly similar to those of Submediterranean areas (*e.g.* as recorded by Checa and Sequiros 1990). In the absence of characteristic Cardioceratidae, however, the Callovian-Oxfordian boundary becomes difficult to recognise with precision.

THE AMMONITE FAUNAS OF THE CANDIDATE OXFORDIAN GSSP AT REDCLIFF POINT, WEYMOUTH, DORSET, SW ENGLAND AND THEIR CORRELATION

As discussed by Page (1994, 2004), one of the stratigraphically most complete trans Callovian-Oxfordian boundary sequences in the UK is exposed near Redcliff Point, west of Weymouth, on the Dorset coast (SW England; National map grid reference SY716818). The section is developed in the mudrock facies of the Oxford Clay Formation

ZONATION (Submediterranean/Subboreal /Arctic)		SUBBOREAL PROVINCE BIOHORIZONS (UK)	SUBMEDITERRANEAN PROVINCE (EAST) HORIZONS	
OXFORDIAN	Mariae Chronozone, Scarburgense Subchronozone		Woodhamense (sensu Fortwengler and Marchand)	
		Ox4: aff. <i>scarburgense</i>		
		Ox3: <i>scarburgense</i>	Scarburgense	
		Ox2: <i>woodhamense</i>		
Ox1: <i>redcliffense</i>				
CALLOVIAN	Lamberti Chronozone, Lamberti Subchronozone			
		LL3d: <i>pauci.</i> γ , <i>Peltomorphites</i>	Thouxensis (?)	
		LL3c: <i>paucicostatum</i> γ		
		LL3b: <i>paucicostatum</i> β	Paucicostatum	
		LL3a: <i>paucicostatum</i> α		
		LL2b: <i>Quenstedtoceras</i> sp. 1	Lamberti	
LL2a: <i>lamberti</i>				
LL1: <i>praelamberti</i>	Praelamberti			

Fig. 1. Correlation of ammonite biohorizons and horizons across the Callovian-Oxfordian boundary between the UK and SE France.

and includes the boundary between its component Stewartby and Weymouth members (see also Arkell 1947; Callomon *in* Callomon and Cope 1995; Chapman 1999; Page *et al.* 2003; Page 2004). As well as a remarkably complete sequence of ammonite faunas, which includes assemblages not clearly recorded elsewhere, the site has also now yielded rich microfossil assemblages and high resolution geochemical data which confirms its suitability as a GSSP (see Page, Meléndez, Hart *et al.*, 2009, this volume).

The sequence of ammonite faunas now recorded can become a standard for correlation throughout Subboreal areas and is described below as a sequence of biohorizons (*sensu* Page 1995). Biohorizonal labelling for the Callovian follows Page (2004) with new units accommodated in a conventional way, for instance biohorizon LL2 is now separated into biohorizons LL2a and LL2b (*n.b.* each unit is of full biohorizonal status as subunits are not permitted by the methodology; see Page 1995, *etc.*). Oxfordian biohorizons are renumbered

consecutively, however, in a style analogous to that used for the Aalenian and Bajocian by Callomon and Chandler (1990), using the prefix "Ox". As formal stratigraphical units biohorizons are conventionally quoted as, for instance, either a *lamberti* Biohorizon or a Lamberti Biohorizon (Fig. 1).

Upper Callovian, Lamberti Chronozone, Lamberti Subchronozone

LL1: *praelamberti* Biohorizon.

Index: *Quenstedtoceras praelamberti* (R. Douvillé).

Author: Marchand (1986).

Reference: 3.0-2.75 m below the top of Bed 1 (=Datum), Stewartby Member, Oxford Clay Formation, Redcliff Point/Ham Cliff, Weymouth, Dorset, UK.

Fauna: Relatively evolute but closely ribbed *Quenstedtoceras praelamberti* (R. Douvillé) is typical (*cf.* Douvillé 1912, pl. 4: 34-36), associated with occasional *Euaspidoceras* sp.

Comments: For consistency with Thierry *et al.* (1997), the *praelamberti* Biohorizon is taken as the lowest within the Lamberti Subchronozone.

LL2a: *lamberti* Biohorizon.

Index: *Quenstedtoceras lamberti* (J. Sowerby).

Author: Callomon (1964). Reference (provisional): c. 2 m + below top of Bed 1, Stewartby Member, Oxford Clay Formation, Redcliff Point/Ham Cliff, Weymouth, Dorset, UK.

Fauna: *Quenstedtoceras lamberti* (J. Sowerby) *sensu stricto* abundant with characteristic evolute microconchs with arcuate, forward curving ribbing, well developed ventral chevrons and well space primary ribbing with up to 4 secondary ribs developing between each.

Comments: The characteristic fauna was recorded low in the Ham Cliff section during initial sampling in 2002, but appears to have been covered by beach material by 2003. The exact level has not been established relative to the Datum used for sampling from 2003 onwards and therefore requires confirmation when beach levels lower once more. By comparison with other localities in the UK, the associated fauna is likely to be relatively diverse, with *Hecticoceras* (*Putealicerias*) *puteale* (Leckenby), *Peltoceras* (*Peltomorphites*) sp. cf. *subtense* (Bean), *Grossouvria* (*Poculisphinctes*) *poculum* (Leckenby), *Euaspidoceras hirsutum* (Bayle), *Kosmoceras* (*K.*) ex gr. *spinosum* (J. de C. Sowerby), *Alliga-*

ticeras (A.) alligatum (Leckenby), etc. Representative figures of these and other typical Lambertii Subchronozone taxa are listed by Page (2004).

LL2b: *Quenstedtoceras* sp. 1 Biohorizon nov.

Index: *Quenstedtoceras* sp. with common coarsely ribbed and relatively involute microconchs (= "*Vertumnicer* spp." *sensu* Buckman 1909-1930).

Reference: 1.65 to 0.2 m below top of Bed 1, Stewartby Member, Oxford Clay Formation, Redcliff Point/Ham Cliff, Weymouth, Dorset.

Fauna: Characterised by relatively coarsely ribbed and involute microconchs of *Quenstedtoceras* sp.; associated fauna includes *Euaspidoceras hirsutum*, *Hecticoceras (Putealicer)* sp., *Alligaticeras (A.) alligatum*, *Grossouvría (Poculisphinctes) poculum* and *Kosmoceras (K.) ex gr. spinosum*.

LL3a. *paucicostatum* transient α Biohorizon nov.

Index: *Quenstedtoceras* ex gr. *paucicostatum* Lange transient α nov.

Reference: Bed 2, 0.1-0.8 m above base, Weymouth Member, Oxford Clay Formation, Redcliff Point/Ham Cliff, Weymouth, Dorset, UK.

Fauna: *Quenstedtoceras* transitional between *Q. ex gr. lamberti* and *Q. paucicostatum sensu stricto*. Although dominated by the latter morphology (see below) frequent forms retain a *lamberti*-style with relatively widely primary spacing. Overall, however, the fauna is noticeably more involute than typical *lamberti* group. Rare *Hecticoceras* sp. and ?*Poculisphinctes* sp. also present.

LL3b: *paucicostatum* transient β Biohorizon.

Index: *Q. ex gr. paucicostatum* transient β (= *Q. paucicostatum* Lange *sensu stricto*).

Author: Marchand (1979).

Reference: Beds 2-4, 0.85-1.45 m above the base of Bed 2, Weymouth Member, Oxford Clay Formation, Redcliff Point/Ham Cliff, Weymouth, Dorset, UK.

Fauna: Dominated by typical *Q. paucicostatum* morphs, with ribbing bending forward from relatively straight primary ribs at around 45° towards the venter on the outer part of the whorl sides and with a tendency to swell towards the venter. Ventral rib chevrons persist. *Euaspidoceras hirsutum* frequent.

Comments: Following Callomon (1990) and Fortwengler and Marchand (1994, etc.), the *pauci-*

costatum fauna is included within the Callovian.

LL3c: *paucicostatum* transient γ Biohorizon nov.

Index: *Q. ex gr. paucicostatum* transient γ nov.

Reference: Bed 2, +?1.55-2.1 m above the base of Bed 2, Weymouth Member, Oxford Clay Formation, Redcliff Point/Ham Cliff, Weymouth, Dorset, UK.

Fauna: *Q. ex gr. paucicostatum* including forms showing features transitional to *C. (Pavloviceras) scarburgense* (Young and Bird) as occasional microconch specimens show body chambers with a fine, *scarburgense*-style forwards swept ribbing and reduced ventral ribchevrons and a consequently an incipient keel. Rare *Alligaticeras* sp. also present.

LL3d: *paucicostatum* – *Peltomorphites* sp. Biohorizon nov.

Indices: *Q. paucicostatum* transient γ , *Peltoceras (Peltomorphites)* sp.

Reference: Bed 2, 2.2-2.3 m above the base of Bed 2, Weymouth Member, Oxford Clay Formation, Redcliff Point/Ham Cliff, Weymouth, Dorset, UK.

Fauna: *Q. paucicostatum* transient γ abundant (Pl. 1 H) with common nuclei of *Peltoceras (Peltomorphites)* sp.

Comments: The stratigraphical position of this relatively *Peltoceras*-rich fauna, immediately below the first *Cardioceras ex gr. scarburgense* is highly suggestive of a correlation with the lower part of the Elisabethae Horizon in SE France of Fortwengler and Marchand (1994), a level also with common *Peltoceras eugenii* (Raspail) (Bonnot *et al.* 1995; Fortwengler and Marchand 1997).

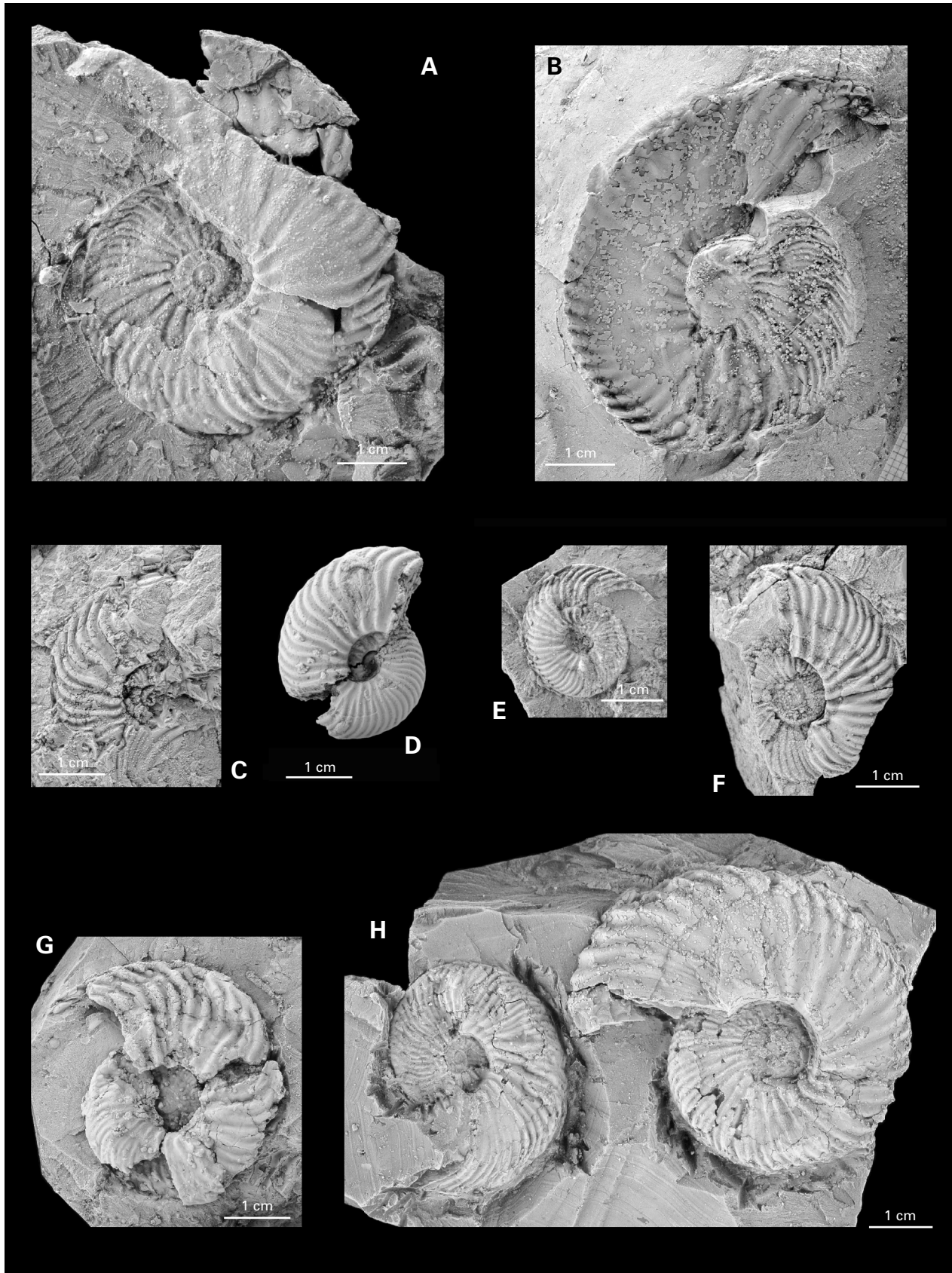
Lower Oxfordian, Mariae Zone, Scarburgense Subzone

Ox1: *Cardioceras (Pavloviceras) redcliffense* Biohorizon nov.

Index: *Cardioceras (Pavloviceras) redcliffense* sp. nov. (Pl. 1A-G; see Appendix for description).

Reference: Bed 2, 2.4-2.5 m above the base of Bed 2, Weymouth Member, Oxford Clay Formation, Redcliff Point/Ham Cliff, Weymouth, Dorset, UK.

Fauna: Cardioceratid fauna transitional between *Quenstedtoceras ex gr. paucicostatum* and *C. (Pavloviceras) ex gr. scarburgense*; *scarburgense*-morphs with a keel developed through most of their ontogeny represent around 20% of



the assemblage but are still associated with *paucicostatum* morphs.

Comments: The incoming of *scarburgense* morphs alongside *paucicostatum* morphs in SE France corresponds to a level near the middle of the Elisabethae “Horizon” of Fortwengler and Marchand (1994), thereby, providing a very accurate correlation between the two regions. The biohorizon is, therefore, potentially recognisable across Europe from the UK to SE France based on this association of morphs. *C. redcliffense* is also present in Russia in the key Callovian-Oxfordian boundary section of Kislev *et al.* (2006) (JKW observation 2007).

Ox2: *woodhamense* Biohorizon.

Index: *Cardioceras (Pavlovceras) woodhamense* Arkell (non Fortwengler and Marchand 1994, 1997).

Author: Page *et al.* (2003).

Reference: Bed 2, 3.1-3.2 m above the base of Bed 2, Weymouth Member, Oxford Clay Formation, Redcliff Point/Ham Cliff.

Fauna: *Cardioceras (Pavlovceras) woodhamense* Arkell (non Marchand) is typical and characterised by common relatively strongly ribbed morphs. Occasional *Euaspidoceras* sp. also present.

Comments: The use of a *woodhamense* Biohorizon follows Callomon’s (1993) interpretation of Arkell’s (1939) species as basal Oxfordian. “*C. woodhamense*” of Fortwengler and Marchand (1994, *etc.*) is a later form, from the upper part of the Scarburgense Subchronozone (Page 2004).

Ox3: *scarburgense* Biohorizon.

Index: *C. (Pavlovceras) scarburgense* (Young and Bird).

Author: Buckman (1913).

Reference: Bed 3 (4.5 to at least +6.2 m above the base of Bed 2), Weymouth Member, Oxford Clay Formation.

Fauna: *C. (P.) scarburgense* sensu stricto is common with typical compressed variants with

slightly flexuous primary ribs on inner whorls and secondaries which curve on the outer half of the whorl side towards a carinate venter. Rare *Peltoceras (Peltomorphites)* also present and probably also hecticoceratids.

Comments: Relatively inflated and more strongly ribbed morphs resembling “*Q.*” *mariae* Douvillé common.

Ox4: aff. *scarburgense* Biohorizon.

Index: *Cardioceras (Pavlovceras)* aff. *scarburgense* (Young and Bird).

Author: Page *et al.* (2003), broadly equivalent to the Woodhamense “Horizon” of Fortwengler and Marchand (1994, 1997).

Reference: Bed 3, Weymouth Member, Oxford Clay Formation, Warboys Clay Pit, Cambridgeshire (Spath 1939; Callomon 1968).

Fauna: *Cardioceras (Pavlovceras)* aff. *scarburgense* is typical, a species including morphologies transitional to *C. praecordatum* Douvillé (with a more accentuated forward sweep of the secondary ribbing towards a more prominent keel).

Comments: The characteristic fauna is present in the Redcliff Point area, but not in a continuous succession with the Callovian-Oxfordian boundary exposure.

CONCLUSIONS: GLOBAL CORRELATION POTENTIAL OF EUROPEAN CALLOVIAN-OXFORDIAN BOUNDARY FAUNAS

Detailed correlations are possible between the UK Subboreal sequence of ammonite faunas, as exemplified by the Redcliff Point/Ham Cliff section and the alternative candidate GSSP localities at Savournon and Thuoux in SE France, in an eastern Submediterranean or Mediterranean context (see Page, Meléndez, Hart *et al.* 2009, this volume). Faunas in the latter area facilitate correlations with both the cardioceratid-free western Submediterranean Province (Iberia) and Mediterranean areas

Plate 1

Quenstedtoceras and *Cardioceras* from the Callovian/Oxfordian boundary interval at Redcliff Point / Ham Cliff, Weymouth, Dorset, UK. A-G: *Cardioceras (Pavlovceras) redcliffense* sp. nov.; Bed 2, 2.4-2.45 m above base [*redcliffense* Biohorizon (Ox1)]. D: Holotype (inner whorls of macroconch?). A, B: Typical relatively involute macroconchs with ribbing fading on whorl sides. C, E-G: Microconchs with keel and tendency towards slightly flexuous ribbing and forward curving secondary ribs. H: *Quenstedtoceras paucicostatum* Lange transient γ nov.; Bed 2, 2.2-2.3 m above base [*paucicostatum*, *Peltomorphites* Biohorizon (LL3d)]. Large specimen is typical relatively involute macroconch with ventral rib chevrons; small specimen is finely ribbed microconch transitional to *Cardioceras* (Redcliff Ox.1). All specimens currently housed in SoGEES, University of Plymouth. Scale bar is 1 cm.

through various Perisphinctoidea. Beyond Europe, the Arctic Province provides links to Eastern Pacific areas through its cardioceratid faunas and the widespread distribution of Peltoceratinae into Pacific areas also has a potential to aid the global correlation of the Callovian-Oxfordian boundary.

The very wide correlation potential of the Callovian-Oxfordian boundary using ammonites – at the level of “Horizon” within central Europe, close to subchronozone level elsewhere in Europe and probably at around chronozonal level elsewhere – still provides the highest resolution method for correlating the stage boundary within marine sequences globally. Underpinning this correlation potential is a major bioevent, the “Boreal Spread” (*sensu* Callomon 1985, *etc.*) of the Cardioceratidae from their Arctic Province homeworld across Europe to the Mediterranean. Whatever oceanographic or palaeogeographic changes facilitated this colonisation is unclear, but it also enabled Tethyan Perisphinctoidea and Opelellidae to reach at least as far north as Britain in reasonable numbers at times. Crucially, it also facilitated a northwards movement of ocean-going Mediterranean Province Phylloceratidae, especially in the Early Oxfordian, most abundantly so in Sub-Mediterranean, SE France, but also in small numbers into Iberia and even as very rare occurrences in Subboreal Britain (Page 2004).

Whatever processes affected the distribution of ammonite faunas would be expected to have affected other groups. Changes in belemnite faunas across the boundary in the UK have been observed, with Tethyan forms becoming dominant in England in the Lower Oxfordian (see Page, Meléndez, Hart *et al.* 2009, this volume) but for other groups information is patchy. Probably the most significant, however, is the flood of early planktonic foraminifera in the earliest Early Oxfordian (Oxford *et al.* 2002), a bioevent recognisable elsewhere. Clearly whatever happened oceanographically or biogeographically during the Callovian-Oxfordian “transition” had a major effect across Europe – and not only on ammonite faunas...

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APPENDIX: DESCRIPTION OF NEW SPECIES
(INCLUDING NOTES ON CARDIOCERATID
GENERA AND SUBGENERA)

Cardioceras (Pavloviceras) redcliffense sp. nov.

TYPE: Original of Plate 1: A, (Specimen "Redcliff M1", SoGEES, University of Plymouth). Bed 2, 2.4-2.5 m above the base of Bed 2, Weymouth Member, Oxford Clay Formation, Redcliff Point/ Ham Cliff, Weymouth, Dorset, UK. Additional topotype material available.

DESCRIPTION: Cardioceratid species transitional between "Q." ex gr. *paucicostatum* Lange and *C. (Pavloviceras) ex gr. scarburgense* (Young and Bird) in which around 20% of the assemblage contains variants or morphologies ("morphs") resembling the typical *C. scarburgense* (e.g. as figured by Wright 1983). The latter have a keel developed through most if not all of their phragmone and consequently ribbing does not form ventral chevrons and the lateral profile is not therefore serrated or significantly undulose (i.e. where remnants of secondary ribbing crosses). The remainder of the assemblage, has a more *paucicostatum* style, however, as *Quenstedtoceras*-style rib-chevrons persist and ribbing is not as fine.

Microconchs of *C. redcliffense* show a similar involution to those of *Q. paucicostatum* but typically have slightly flexuous ribbing (biconvex) with forward curving secondaries, rather than the straight primary ribs and more angular inflexion of the latter. The keel is present on most although may be very slightly undulose on some, secondaries typically fading towards it and merging with it (in *Q. paucicostatum* ribs – the secondary ribs typical do not significantly weaken even when an incipient, gently undulose keel is present). Maximum, size observed is around 40 mm. Complete macroconchs are not yet available at the type locality, although

available material indicates a greater involution (*c.* 13-20%) than is observable in *paucicostatum* specimens (*c.* 30%). In addition ribbing appears to fade earlier on the whorl sides (*e.g.* by 40 mm) but with more pronounced secondaries on the outermost part of the whorl sides. In *paucicostatum*, however, blunt swollen ribbing often appears to persist to larger diameters. No specimens larger than around 60 mm have currently been observed, suggesting a relatively small species.

DISTRIBUTION: Characteristic of the *redcliffense* Biohorizon nov. (Ox1) (basal Oxfordian, Scarborough Subchronozone, Mariae Chronozone) at the type locality although probably absent at most other well known English localities due to the widespread non-sequence at this level (see Page 2004). Potentially recognisable across Europe where cardioceratid assemblages are reported to include a “mixing” of *C. paucicostatum* and *C. scarburgense* as in the upper part of the Elisabethae “Horizon” of Fortwengler and Marchand (1994) and the lowest part of the Scarborough Zonule (fauna 8A) of Fortwengler and Marchand (1997) in the Thoux-Savournon area of SE France. The species is now independently confirmed through new sampling at Savournon (April 2007; Meléndez *et al.* 2007). Now also noted at Dubki in Russia (JKW observation, 2007; section cited by Kiselev *et al.* 2006).

DISCUSSION: The transition between *Quenstedtoceras* and *Cardioceras* has become established as the “event” through which the the Callovian-Oxfordian boundary can be correlated (*cf.* Callomon 1964, 1990, *etc.*). The recognition of “*Cardioceras*” *paucicostatum* Lange as a form at the boundary level by Marchand (1979), however, precipitated a subjective discussion as to which genus the species should be assigned to. As a consequence, the *paucicostatum* “Horizon” has been juggled up and down between the Callovian and the Oxfordian depending on what genus its index was considered to be best assigned (Callomon 1990). In a conti-

nuously evolving lineage, however, such assignments are biological meaningless and as is admirably shown by the Redcliff Point sections, transitional assemblages are to be expected.

As already suggested by Callomon (1990), in a nomenclatural sense it is desirable to reduce this subjectivity by using a single genus to describe this lineage. As *Quenstedtoceras* Hyatt 1877 has priority over *Cardioceras* Neumayr and Uhlig 1881, however, its use for Oxfordian forms might meet resistance from some quarters. In addition, Meledina (1987) has reported some sutural differences between certain *Quenstedtoceras* and *Cardioceras* which lead to her proposal of a new subfamily, the Quenstedtoceratinae. Clearly, however, in the case of the *Q. paucicostatum* group, evolution directly into the *C. scarburgense* is demonstrable, so the significance of Meledina’s observations remains unclear, at least at this stratigraphical level. Pending a full revision of the Cardioceratinae, however, the conventional usage of the two genera is retained here, but noting that the disappearance of the genus *Quenstedtoceras* is a nomenclatural artefact – a true “pseudoextinction”. Later (*i.e.* post *paucicostatum*) records of “*Quenstedtoceras*” in the Lower Oxfordian, such as “*Q. mariae*” Douvillé are simply coarsely ribbed and inflated variants of *Cardioceras* such as are known throughout the history of the group well into the Middle Oxfordian (*cf.* Callomon 1985, for example “*Goliathiceras*” Buckman 1918).

Mariae Chronozone faunas are sufficient distinct from earlier and later assemblages to warrant subgeneric assignment as a distinguishable segment of the overall *Cardioceras* lineage. As already implemented by Page (1991), *Pavloviceras* Buckman 1920 – based on a macroconch morphospecies – has priority over *Scarburgiceras* Buckman 1924 – based on a microconch form – and the former is therefore used here to identify this group.