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A proposal for the Global Boundary Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage (Lower Jurassic)

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Key words: Stratotype, Lower Jurassic, Pliensbachian, Wine Haven, Robin Hood's Bay (North Yorkshire), UK, biostratigraphy, isotope stratigraphy, sequence stratigraphy, GSSP

ABSTRACT

Wine Haven, a coastal exposure at Robin Hood's Bay (North Yorkshire, UK), fulfils the criteria indicated in the Guidelines of the International Commission on Stratigraphy (ICS) (Remane et al. 1996) for definition as the Global Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage (Early Jurassic): 1) The succession of about 30m comprises pale grey and buff-coloured sandy mudstones which very gradually pass upward into silty dark grey shales. This marine sequence was deposited during an overall transgression and is relatively expanded stratigraphically. 2) There is absence of unconformities in the Sinemurian-Pliensbachian interval and the exposure is continuous. 3) Ammonites are abundant and well preserved, enabling detailed correlations to be made (see Dommergues & Meister 1992). The ammonite fauna below the boundary interval allows recognition of the *Leptechioceras* gr. *meigeini, Paltechioceras aureolum* and *Paltechioceras tardecrescens* horizons of latest Sinemurian age and, above the boundary, the *Bifericeras donovani* and *Apoderoceras* gr. *aculeatum* horizons of earliest Pliensbachian age. A suitable level for the boundary is defined with the association of the *Bifericeras donovani* DOMMERGUES & MEISTER and *Apoderoceras* sp. at the base of bed 73b. Other fossils (palynomorphs, foraminiferas, ostracods, etc) give no precise biostratigraphic information or have not been studied. 4) Complementary results are: a) Strontium-isotope stratigraphy, based on analysis of belemnites which yield a calcite $^{87}Sr/^{86}Sr$ ratio for the suggested boundary level of 0.707425 and supports an interpretation of continuous sedimentation. b) Belemnite oxygen-isotope data indicate a significant temperature drop (~5 °C) across the boundary at this locality. c) A Transgressive Systems Tract (TST) initiated in the Aplanatum Subzone (uppermost Sinemurian) continues into the Lowermost Pliensbachian (Taylori Subzone); it forms part of a transgressive facies cycle *sensu* Graciansky et al. 5) The section is well exposed in the cliff and on the foreshore and access is straight forward. 6) Structural complexity and metamorphism are negligible. 7) The locality is the part of a Site of Special Scientific Interest (SSSI), and thereby under statutory protection.

RESUME

La coupe de Wine Haven exposée à Robin Hood's Bay (North Yorkshire, UK), correspond pleinement aux directives de la Commission Internationale de Stratigraphie (Remane et al. 1996) pour définir un "Global Stratotype Section and Point (GSSP)" à la base du Pliensbachien (Jurassique inférieur): 1) La coupe comprend environ 30m d'argiles sableux de couleur gris-clair à jaune-clair qui passent graduellement à des schistes argileux et silteux de couleur gris-foncé. Cette séquence, relativement étendue stratigraphiquement, s'est déposée durant une vaste trangression marine. 2) Il y a absence de discordance pour cet intervalle sinémurien-pliensbachien et l'affleurement est continu. 3) Les ammonites sont abondantes et bien préservées, permettant ainsi des corrélations précises (voir Dommergues & Meister 1992). La faune d'ammonites située de part et d'autre de la limite du Sinémurien-Pliensbachien permet de mettre en évidence les horizons à *Leptechioceras* gr. *meigeini, Paltechioceras aureolum* et *Paltechioceras tardecrescens* d'âge sinémurien terminal et les horizons à *Bifericeras donovani* et *Apoderoceras* gr. *aculeatum* d'âge pliensbachien basal. Un niveau pertinent pour la définition de cette limite est situé à la base du banc 73b et caractérisé par l'association *Bifericeras donovani* DOMMERGUES & MEISTER et *Apoderoceras* sp. Les autres groupes fossiles (palynomorphes, foraminifères, ostracodes, etc.) n'apportent pas d'informations biostratigraphiques précises ou n'ont pas été étudiés. 4) Les résultats complémentaires sont: a) La stratigraphie des isotopes du Strontium, basée sur l'analyse des bélemnites, fournit, pour le rapport $^{87}Sr/^{86}Sr$ de la calcite, un résultat de 0.707425 à la limite Sinémurien-Pliensbachien et renforce l'interprétation d'une sédimentation continue à cette limite. b) Les données pour l'isotope de l'oxygène ($\delta^{18}O$) basé sur les bélemnites indiquent une chute de la température (~5 °C) dans cette localité pour la limite du Sinémurien-Pliensbachien. c) Un "Transgressive Systems Tract (TST)" amorcé dans la sous-zone à Aplanatum (Sinémurien terminal) se poursuit dans le Pliensbachien basal (sous-zone à Taylori); il constitue une partie d'un "transgressive facies cycle" *sensu* Graciansky et al. (1998) 5) La coupe affleure bien tant dans la falaise que sur la plage et l'accès est très aisé. 6) Pas de complexités structurales et un métamorphisme négligeable. 7) Cette localité fait partie d'un "Site of Special Scientific Interest (SSSI)" et est ainsi sous protection statutaire.

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Foreword

The authors are part of an international team, the Pliensbachian Working Group (C. Meister, convenor) set up by the International Subcommission on Jurassic Stratigraphy (ISJS) of the International Union of Geological Sciences (IUGS). The text, apart from some minor amendments which do not affect the scientific content, was the proposal document submitted for voting to all members of the Pliensbachian Working Group and Voting Members of the Jurassic Subcommission. The results of the votes (January 2003) were: Pliensbachian Working Group - 28 YES 3 ABSTAINS 0 NO; Jurassic Subcommission - 18 YES 0 ABSTAIN 0 NO. The proposal has therefore been accepted by the Jurassic Subcommission (ISJS). Agreement on the choice of Wine Haven and on the definition of the Sinemurian-Pliensbachian boundary being achieved, the proposal will now be submitted to the International Commission on Stratigraphy (ICS) and, if accepted, to IUGS for ratification.

1. Introduction

There exist only very few well studied sections spanning the Sinemurian-Pliensbachian boundary that have any potential as boundary stratotype. Of those known only one profile shows apparently continuous sedimentation, abundant fossil content, and fulfilled the other basic criteria of the International Commission on Stratigraphy (ICS) (Remane et al. 1996).

Multidisciplinary research on the boundary stratotype, developed over years by the Pliensbachian Working Group of the International Subcommission on Jurassic Stratigraphy is now brought to a conclusion with the proposition of the Wine Haven section at Robin Hood's Bay (Yorkshire, UK) as the best outcrop for defining the Global boundary Stratotype Section and Point (GSSP) of the Stage.

2. History of Research (K. Page, C. Meister, J.L. Dommergues, S. P. Hesselbo)

The classic foreshore and cliff exposures of the Lower Lias in Robin Hood's Bay are undoubtedly one of the most important and complete "mid"-Sinemurian to Pliensbachian sequences in Europe (Fig. 1). The earliest scientific references to the site are probably those within Young & Bird's famous 1822 volume describing the Yorkshire coast as a whole, followed by Williamson in 1840. But surprisingly the only detailed published description of the lower part of the section (Sinemurian to Lower Pliensbachian) is within Tate & Blake's classic work "The Yorkshire Lias" (1876), more than 125 years old (and reproduced many times by later authors such as Fox-Strangeways & Barrow (1882) and Buckman (1915). This is not because the sequence has received no subsequent attention, indeed Bairstow spent many years, from at least the 1930s, carefully mapping and measuring the shore, but never published anything more than a brief summary (e.g. in Sylvester-Bradley 1953 and in Hemingway et al. 1968). The copious notes and specimens he left are now in the Natural History Museum in London, and are now revised and published (Howarth 2002).

Partial sections, supported by bed-by-bed description, are available in Howarth (1955), Getty (1972, 1973), Gad (1966), Phelps (1985) and Dommergues & Meister (1992). Hesselbo & Jenkyns (1995) provide a complete graphic log from the Sinemurian to the Toarcian. Further notes and observations are incorporated into field excursion guides to the area, such as Wright in Rawson & Wright (1992) and Senior (1996). A number of the formal lithostratigraphic units of the Cleveland basin Lower Jurassic sequence have type localities and reference sections in Robin Hood's Bay, including the Siliceous Shales, Pyritous Shales and Ironstone Shales "members" of the Redcar Mudstone Formation (Powell 1984, Cox 1990).

Sedimentological aspects of the sections have also been studied, especially within the Pliensbachian, and these include Hallam (1967), Sellwood (1971), Greensmith et al. (1980) and Howard (1985), but the most frequent references to Robin Hood's Bay are in the taxonomic and stratigraphic descriptions of ammonite faunas (Young & Bird 1828, Simpson 1843, 1855, 1865-68, Buckman 1909-1930, Tate & Blake 1876, Spath 1925, Howarth 1955, 1958, 1992, Getty 1972, 1973, Dommergues & Meister 1992). Significantly, the sections in Robin Hood's Bay figure prominently in a number of stratigraphic reviews, most importantly as stratotypes, both historical and actual, for zonal units at the level of chronozone, subchronozone and horizon (e.g., Buckman 1915, Dean et al. 1961, Phelps 1985, Page 1992, Howarth 1992, Dommergues et al. 1994, Blau & Meister 2000) and figure prominantly in reviews of the stratigraphy and correlations of the Cleveland Basin (e.g. Cope et al. 1980, Howard 1985, Hesselbo & Jenkyns 1995 and Rawson & Wright 1995). A key development in this field is the identification of the exposures in the southern part of the bay. The boundary between Sinemurian and Pliensbachian strata occurs within the Redcar Mudstone Formation (Powell 1984) and is particularly well exposed on wave-washed rock platforms and at the foot of the cliff on the south side of the bay, at Wine Haven, a former harbour that served the adjacent Peak Alum Works. Following the description of the stratigraphy and sedimentology by Hesselbo & Jenkyns (1995) for the Robin Hood's Bay area of Yorkshire "The Hettangian to mid-Pliensbachian strata are predominantly mudstone with subordinate sandy and Fe-rich intervals". The Redcar Mudstone (Powell 1984), is subdivided into a number of informal units correlatable within the basin. Sandstone beds are developed in the Upper Sinemurian Siliceous Shales, whereas mudstone dominates both below, in the Lower Sinemurian Calcareous Shales, and above, in the lower Pliensbachian Pyritous and Ironstone Shales. Organic-rich shales are developed in the lowermost Pliensbachian (Jamesoni Zone) "Pyritous Shales".

A review of the Wine Haven section at the Sinemurian-Pliensbachian boundary together with comparisons with European ammonite faunas (Dommergues & Meister 1992) has indicated that this section exhibits the most complete ammonite faunal succession known from the European region, thus spotlighting its potential as a Global Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage (Meister, ISJS Newsletter 1997, 1999a, 1999b, 2001).

Below we detail the lithostratigraphy, ammonite stratigraphy, foraminiferal stratigraphy and isotope stratigraphy across

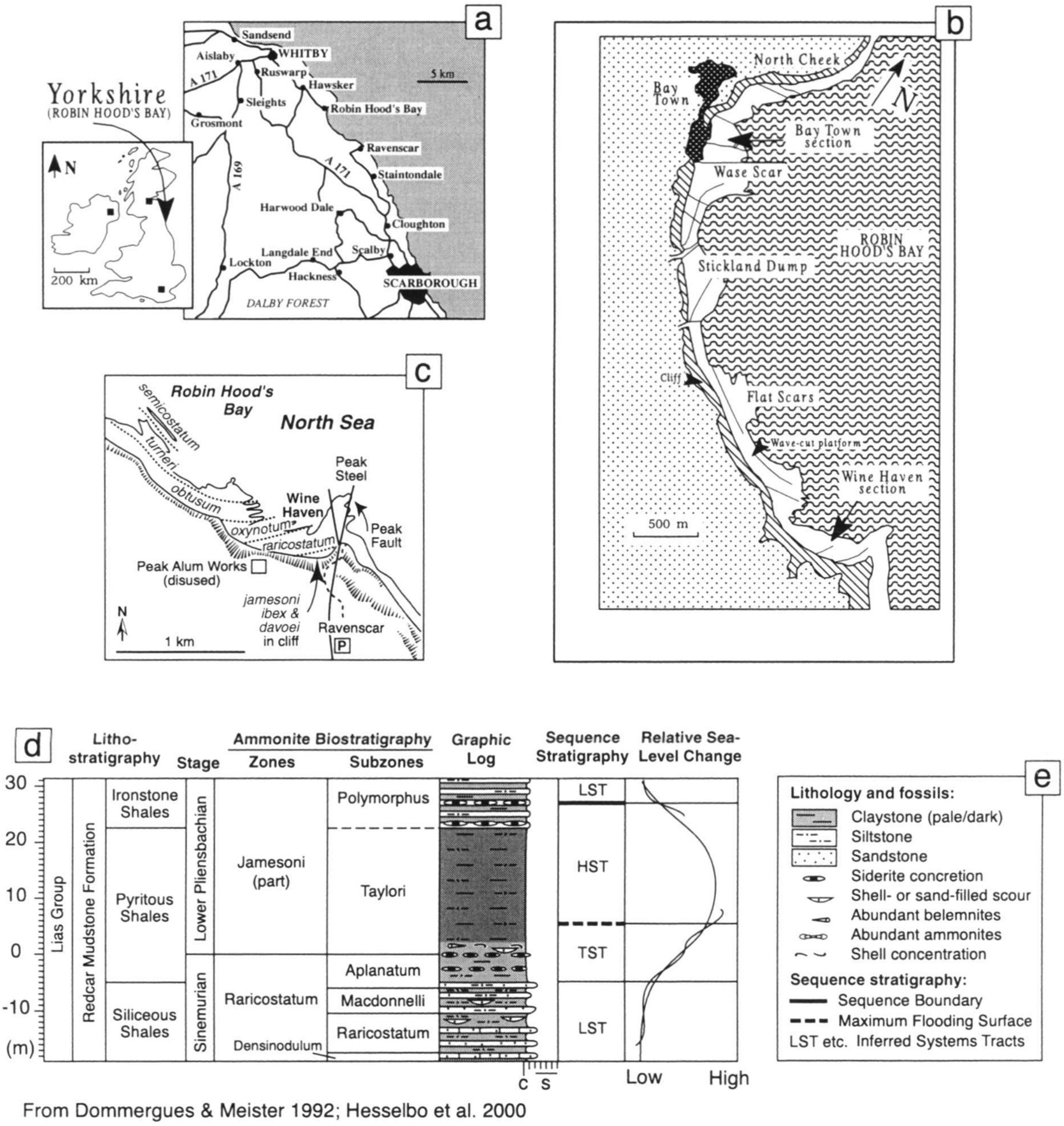

Fig. 1. Wine Haven section. (a, b) Location of Robin Hood's Bay, Yorkshire, UK (from Dommergues & Meister 1992). (c) Detailed sketch geological map of the Wine Haven area (adapted from Rawson & Wright, 1992). (d) Summary stratigraphic log for the Late Sinemurian to Early Pliensbachian succession of Robin Hood's Bay, Yorkshire, based on data in Hesselbo & Jenkyns (1995, 1998) and Cope et al. (1980). The sea-level curves are of 3[rd] and 4[th] order *sensu* Graciansky et al. (1998). (e) Key to panel (d) and Figure 4 (from Hesselbo et al. 2000 partim).

the boundary to determine the criteria which fulfill the recommendations of the ICS (Remane et al. 1996) and to appraise the potential for correlation to the boundary section from other sequences of unknown age.

3. The lower boundary of the Pliensbachian Stage (C. Meister)

The original definition of the Pliensbachian Stage dates back to 1858 (Oppel, p. 248–249, 256), formerly d'Orbigny's Liasien. When d'Orbigny and Oppel described the Sinemurian and Pliensbachian in the middle of the nineteenth century, they located the boundary between these two stages at a level of important faunal changes corresponding roughly to the disappearance of the Echioceratidae (Psiloceratoidea) and the subsequent full development of the Eoderoceratoidea which split up with a significant increase of disparity (morphology) (Dommergues et al. 1996) and diversity (taxonomy) (Meister & Stampfli 2000). The Psiloceratoidea dominated the first

STAGES	ZONES	SUBZONES	HORIZONS based on NW European faunas
TOARCIAN			
PLIENSBACHIAN	SPINATUM	Hawskerense	*Pleuroceras hawskerense* *Pl. elaboratum / Emaciaticeras lotti*
		Apyrenum	*Pleuroceras solare* *Pleuroceras transiens* *Amaltheus salebrosum*
	MARGARITATUS	Gibbosus	*Arieticeras ruthenense* *Arieticeras algovianum* *Arieticeras bertrandi* *Paltarpites kurrianus* *Leptaleoceras ugdulenai* *Arieticeras macrum* *Reynesoceras ragazzoni*
		Subnodosus	*Fuciniceras boscense* *Protogrammoceras normanianum / Proto. depressum*
		Stokesi	*Protogrammoceras celebratum* *P. (Matteiceras) nitescens* *P. (Matteiceras) monestieri* *P. (Matteiceras) occidentale*
	DAVOEI	Figulinum	*Oistoceras figulinum* *Oistoceras angulatum*
		Capricornus	*Aegoceras crescens* *Aegoceras capricornus* *Aegoceras lataecosta*
		Maculatum	*Aegoceras maculatum* *Aegoceras sparsicosta*
	IBEX	Luridum	*Beaniceras luridum* *Beaniceras crassum* *Beaniceras rotundum*
		Valdani	*Acanthopleuroceras alisiense* *Acanthopleuroceras actaeon* *Acanthopleuroceras valdani* *Acanthopleuroceras maugenesti* *Acanthopleuroceras arietiforme*
		Masseanum	*Tropidoceras masseanum*
	JAMESONI	Jamesoni	*Uptonia bronni*
		Brevispina	*Platypleuroceras submuticum / Platy. tenuilobus* *Platypleuroceras brevispina / Platy. brevispinoides*
		Polymorphus	*? Polymorphites polymorphus / E. (Coelod.) biruga*
		Taylori	*Phricodoceras taylori* *A. nodogigas / T. quadrarmatum / A.* gr. *aculeatum* *Bifericeras donovani*
Uppermost SINEMURIAN	RARICOSTATUM	Aplanatum	*Paltechioceras tardecrescens / Palt. romanicum* *Palt. tardecrescens / Palt. oosteri / Palt. recticostatum* *Paltechioceras aureolum*
		Macdonnelli	*Leptechioceras meigeni / Leptechioceras macdonnelli* *Leptechioceras meigeni* *Leptechioceras meigeni / Paltechioceras charpentieri*
		Raricostatum	*Paltechioceras liciense / Paltechioceras rothpletzi* *Paltechioceras favrei* *Paltechioceras boehmi / "Palt."* cf. *intermedium* *Echioceras raricostatum / Echioceras crassicostatum* *Echioceras raricostatum / Echioceras raricostatoides* *Echioceras quenstedti / E. rhodanicum / E. aeneum*
		Densinodulum	*Echioceras* (?) sp. 3 *"Orthechioceras" radiatum* *Eoderoceras* gr. *armatum* *Eoderoceras bispinigerum* *"Oxynoticeras" lymense / Crucilobiceras densinodulum* *"Echioceras" edmundi / Bifericeras subplanicosta* *Plesechioceras delicatum / Plesechioceras* cf. *typus*

from Dean et al., 1961; Meister, 1995; Corna et al., 1997; Dommergues et al., 1997; Blau & Meister, 2000

Fig. 2. Uppermost Sinemurian – Pliensbachian biochronologic subdivisions and horizons.

two Jurassic stages, Hettangian and Sinemurian during about 12 my. The second superfamily (Eoderoceratoidea) which dominated the NW European ammonite fauna of the Pliensbachian (about 7 my) and, with the Dactylioceratidae, persisted through to the middle Toarcian. The Sinemurian-Pliensbachian ammonoid event is a good example of faunal renewal at a global scale. Nevertheless, this period of transition is usually poorly documented where the late Sinemurian and early Pliensbachian strata are exposed. Two cases are evident: (a) sediments are present but beds (condensed or not) are hardly fossiliferous, (b) sediments are obviously missing (very often).

The Pliensbachian name is a geographic reference to Pliensbach, a small village in SW Germany not far from Holzmaden. The Jurassic outcrop, situated SE of the village, was regarded until now as the the type locality (see Geyer 1962, p. 164, Morton 1971, p. 85, Schlatter 1980). In SW Germany (Swabian Alb: Pliensbach and Wutach areas), the only well exposed section for this boundary is Aselfingen (Wutach area) which was worked by Schlatter (1991), but it shows a strong relative condensation (Meister *in* ISJS Newsletter 1999a). This dictates the exclusion of all these regions, specially the Pliensbach area [absence of the two uppermost subzones of the Sinemurian, Schlatter (1980 textfig. 5)], as the stratotype of the Stage.

The Pliensbachian is divided in two substages. The Carixian (see Lang 1913, p. 401) is an alternative to Lower Pliensbachian and the Domerian was proposed by Bonarelli (1894) for the Margaritatus and Spinatum Zones of Oppel's (1856) Upper Pliensbachian.

On the basis of ammonite assemblages the European Pliensbachian presently comprises 5 "Standard Zones", further subdivided into 15 subzones (Dean et al. 1961) (Fig. 2) and very often detailed in horizons sensu Callomon (1995) (Fig. 2). The standard zonation (zone, subzone, horizon) is tentatively correlated with different zonations proposed for the Tethyan or Pacific regions (e.g. Dommergues et al. 1983, Meister 1995, Dommergues et al. 1997, Palfy et al., 2000, Blau & Meister 2000) and shows quite good potential for the biochronological correlations between the different paleogeographical areas.

Other biostratigraphic zonal schemes for the Pliensbachian are in progress (e.g., for belemnites, brachiopods, ostracods, foraminifera, echinoids, dinoflagellates, calcareous nannofossils) and are synthetized by Dommergues (1997, p. 350-351).

The base of the Jamesoni Zone (respectively the base of the Taylori Subzone) is traditionally used to determine the base of the Pliensbachian.

In the present case, the base of the first Pliensbachian subzone (Taylori subzone) was defined by Spath (1923) in the Dorset coast section and later discussed by Dean et al. (1961) and other authors. In the Dorset coast section, Spath (1923) and then Lang (1928) indicated the association of *Phricodoceras taylori* (SOWERBY) with *Apoderoceras* in bed 105 which is considered to be the first bed of the Taylori subzone (see also discussion in Hesselbo & Jenkyns 1995, p. 115 and 119). This definition allowed authors to recognize the Taylori subzone in the major part of the NW European areas even if the base, often depending on the presence of *Phricodoceras* gr. *taylori* (SOWERBY) only, could not be determined with sufficient precision. Since *Phricodoceras* gr. *taylori* (SOWERBY) was already known by rare specimens from the Upper Sinemurian (Dommergues & Meister 1990, Schlatter 1990), it became apparent that its record was inadequate to define the base of the Taylori subzone (see Dommergues & Meister 1992) and the definition of the boundary had to be reconsidered and improved. Consequently, the position of the boundary is now based in NW Europe on particular taxa of the Eoderoceratoidea or on their associations. It is now the presence of species of the genus *Apoderoceras* [*Apoderoceras nodogigas* (QUENSTEDT)-*leckenbyi* (WRIGHT), *Apoderoceras* ssp.) or *Tetraspidoceras quadrarmatum* (DUMORTIER)] which indicate the base of the Pliensbachian. At the present time, only this pattern can be accepted as being the biochronological event which enables recognition of the base of Pliensbachian Stage. The Taylori Subzone can be recognized widely across northwestern Europe (Dommergues & Meister 1992), although beyond Robin Hood's Bay its base can be identified only tentatively with Eoderoceratid taxa that require further study.

One section has been demonstrated to be the best for such a biostratigraphic datum: Wine Haven section at Robin Hood's Bay, England (Dommergues & Meister 1992, Hesselbo et al. 2000).

4. Improving the proposal for the GSSP

Since 1997, several sections have been visited by the members of the Working Group: Aselfingen (SW Germany) in 1997 with the German Subcommission on Jurassic Stratigraphy, Bünde (NW Germany) in 1998, Robin Hood's Bay (England) and Bosso River (Italy) in 1999.

The aim was to find a continuous and expanded section through the Sinemurian-Pliensbachian, to discuss the biostratigraphical indicators for the recognition of the Pliensbachian basal boundary, and to develop a common proposal for defining the Pliensbachian GSSP in accordance with the guidelines of the ICS (Remane et al. 1996).

Apart from Robin Hood's Bay (Wine Haven section), all sections were disqualified because they do not agree with the recommandation of the ICS, mainly by reason of reduced sedimentation (Aselfingen), important vertical facies changes (Pabay, Hebrides), slumps and fault (Bosso River) and biostratigraphic gaps (Bünde). For more details see Meister ISJS Newsletter (1999a). In fact the choice of a GSSP for the Sinemurian-Pliensbachian was very restricted and the work concentrated on the Robin Hood's Bay succession as no further proposals have been presented.

On the basis of Dommergues & Meister's data (1992) and the meeting in Robin Hood's Bay in 1999 where the section was remeasured and recollected for paleontology and geo-

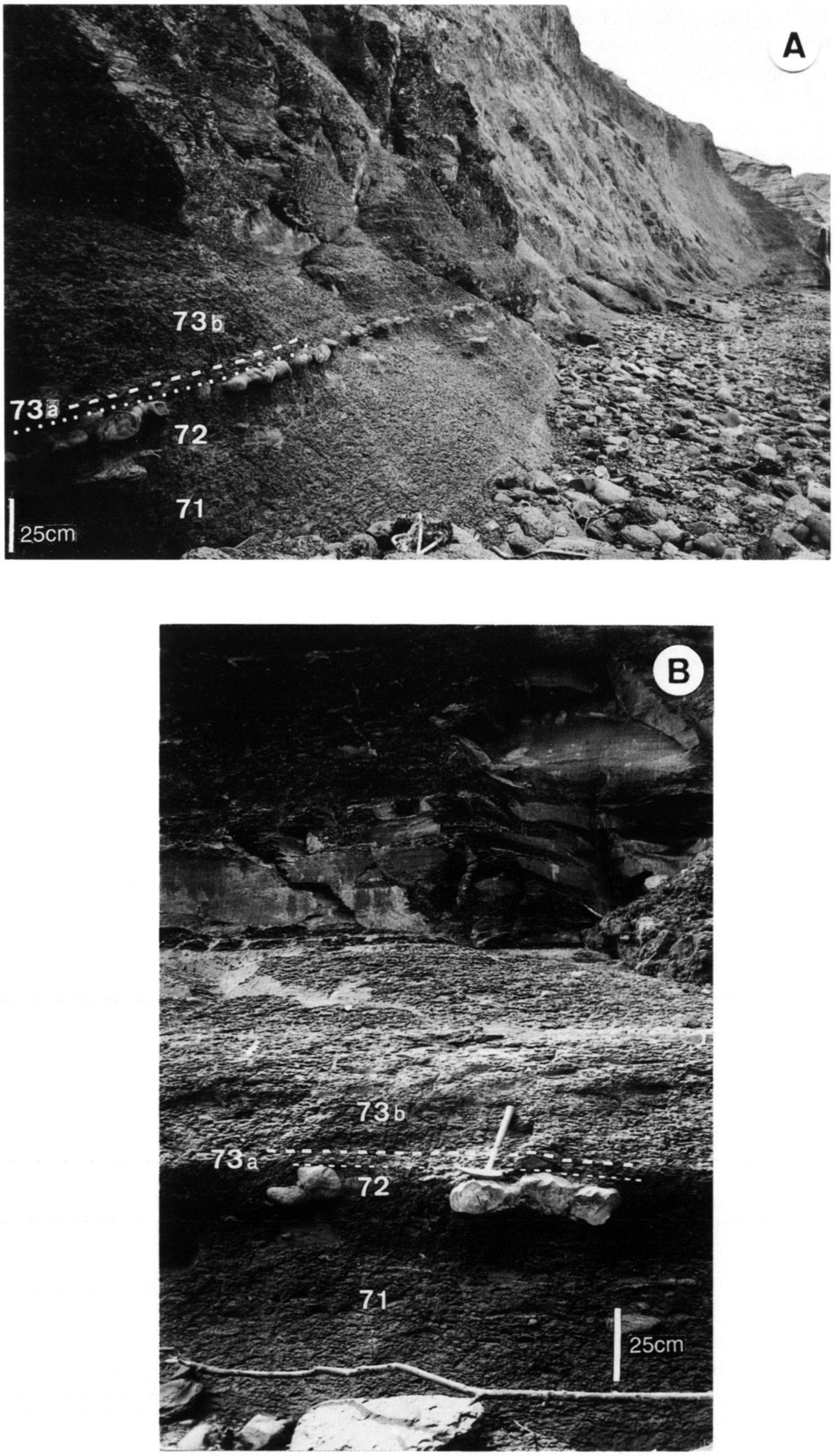

Fig. 3. Wine Haven outcrop, (A-B) Lithological sequence at the Sinemurian-Pliensbachian boundary, bed 73b indicates (broken line) the base of the Pliensbachian.

chemistry (Hesselbo et al. 2000), it has been proposed to define the Pliensbachian GSSP at the base of bed 73b (*Bifericeras donovani* Horizon) of Robin Hood's Bay section.

5. The Wine Haven section (Yorkshire, UK): recommended Stratotype

The Sinemurian-Pliensbachian is well developed in Robin Hood's Bay and contains a complete succession of quite well-preserved ammonite assemblages. The relevance of the section of Wine Haven for the Sinemurian-Pliensbachian was first pointed out by Dommergues & Meister (1992), whose section was measured in the intertidal zone. The Sinemurian–Pliensbachian boundary succession lies within the Pyritous Shales Member and comprises pale grey and buff-coloured sandy mudstones which pass upwards into silty dark grey shales (Sellwood 1970, Hesselbo & Jenkyns 1995) (Fig. 3).

The lithologies of the Raricostatum and Jamesoni Zones are fairly uniform with ammonites in almost every bed and the upward transition from pale grey to dark grey shale is gradational. In the field, two of the most noticeable features of this interval are the 10-cm-thick beds of concretionary siderite (Figs. 3A, B: bed 72). Above the upper concretionary level, macrofossils are abundant, and are concentrated into several discrete shell-beds. The whole succession was deposited in a shallow-marine environment, but the facies sequence from the upper part of the Sinemurian (Aplanatum Subzone) to the lower part of the Pliensbachian (Taylori Subzone) represents a long-term relative sea-level rise of at least regional extent, possibly global (Hallam 1961, 1981, Sellwood 1971; Hesselbo & Jenkyns 1995, 1998, Van Buchem & Knox 1998, Hesselbo et al. 2000) (Fig. 1d).

6. Sequence Stratigraphy and cyclostratigraphy (S. P. Hesselbo)

The Yorkshire coast successions of the Cleveland Basin have been remeasured and interpreted in the context of sequence stratigraphy by Hesselbo & Jenkyns (1998). The Sinemurian – Pliensbachian boundary at Wine Haven lies within a sequence that generally progresses upwards from relatively pale and thoroughly bioturbated sandy mudstone into dark shales, a change that takes place over some 20 m, but is particularly well marked at the boundary itself. Superimposed on this overall facies change are smaller-scale (0.5-5m) alternations of coarser and finer sediment. In terms of sequence stratigraphy, the succession can be interpreted with some confidence as a transgressive systems tract and the sediments record an overall deepening of at least regional extent (Sellwood 1971, Hesselbo & Jenkyns 1995, 1998).

Higher in the succession - in the Ironstone Shales, above the Taylori Subzone – the succession is again charaterized by lithological cyclicity which has been interpreted as a response to Milankovitch climate forcing (Van Buchem et al. 1992, 1994, Weedon & Jenkyns 1999). It is possible that the Pyritous Shales (Taylori Subzone) contains a cryptic lithological cyclicity that would allow a Milankovitch-based cyclostratigraphy to be extended across the stage boundary at Wine Haven.

7. Paleontological records.

The diversity of the fossil assemblages is low with a prevalence of the ammonites. If present at this boundary, bivalves, belemnites and brachiopods are very rare and have not been studied. In this section the Foraminera, Ostracoda and the palynology provide essentially no information for the definition of the boundary by microfossils. At the present time, we have no information about the calcareous nannofossils of this period. Paul R. Bown (University College London) looked at the Upper Pliensbachian and Toarcian from the Yorkshire coast and all samples were barren.

Ammonites (C. Meister, J. Blau, J.-L. Dommergues)

The ammonite assemblage in the Wine Haven section is charactized by material that is quite abundant, easy to sample, and contemporaneous with the sediment deposition. Ammonites are preserved as internal moulds in limestone beds, pyritic phragmocones and crushed body chambers in marly levels.

The detailed ammonite succession has been determined across the Sinemurian-Pliensbachian boundary interval at Wine Haven (Dommergues & Meister 1992) and recently completed by us in 1999 (Working Group). The succession of these assemblages allows the recognition and characterisation of the subzones and horizons within the Raricostatum Zone in the Upper Sinemurian and the Jamesoni Zone in the lower Pliensbachian. The different associations, grouped into horizons (cf. Callomon 1995, Blau & Meister 2000) are compatible with the standard biozonation of Dean et al. (1961) and the standard succession of horizons proposed by Dommergues et al. (1994, 1997) and Meister (1995) (Fig. 4 and 5).

UPPER SINEMURIAN

Upper Raricostatum Zone

Aplanatum Subzone (4,60 m, levels 69-73a) is characterized by the *Paltechioceras* gr. *aplanatum* (HYATT)-*tardecrescens* (HAUER) and allied species. Two horizons are recognized in the subzone.

P. aureolum horizon (level 69 partim = 1002-1003b): *Paltechioceras aureolum* (SIMPSON), *Eoderoceras* gr. *armatum* (SOWERBY)-*miles* (SIMPSON).

P. tardecrescens horizon (level 69 partim - 71 partim = 1004a-1009): *Paltechioceras tardecrescens* (HAUER), *Paltechioceras* aff. *romanicum* (UHLIG), *Eoderoceras* gr. *armatum* (SOWERBY)-*miles* (SIMPSON), *Leptonotoceras* sp. *sensu* BLAU et al., *Gleviceras* sp.

The last *Gleviceras* sp. and *Eoderoceras* gr. *armatum* (SOWERBY)-*miles* (SIMPSON) are recorded from the upper part of bed 71 = respectively bed 1008 and bed 1009 in Dommergues & Meister 1992 (Howarth 2002).

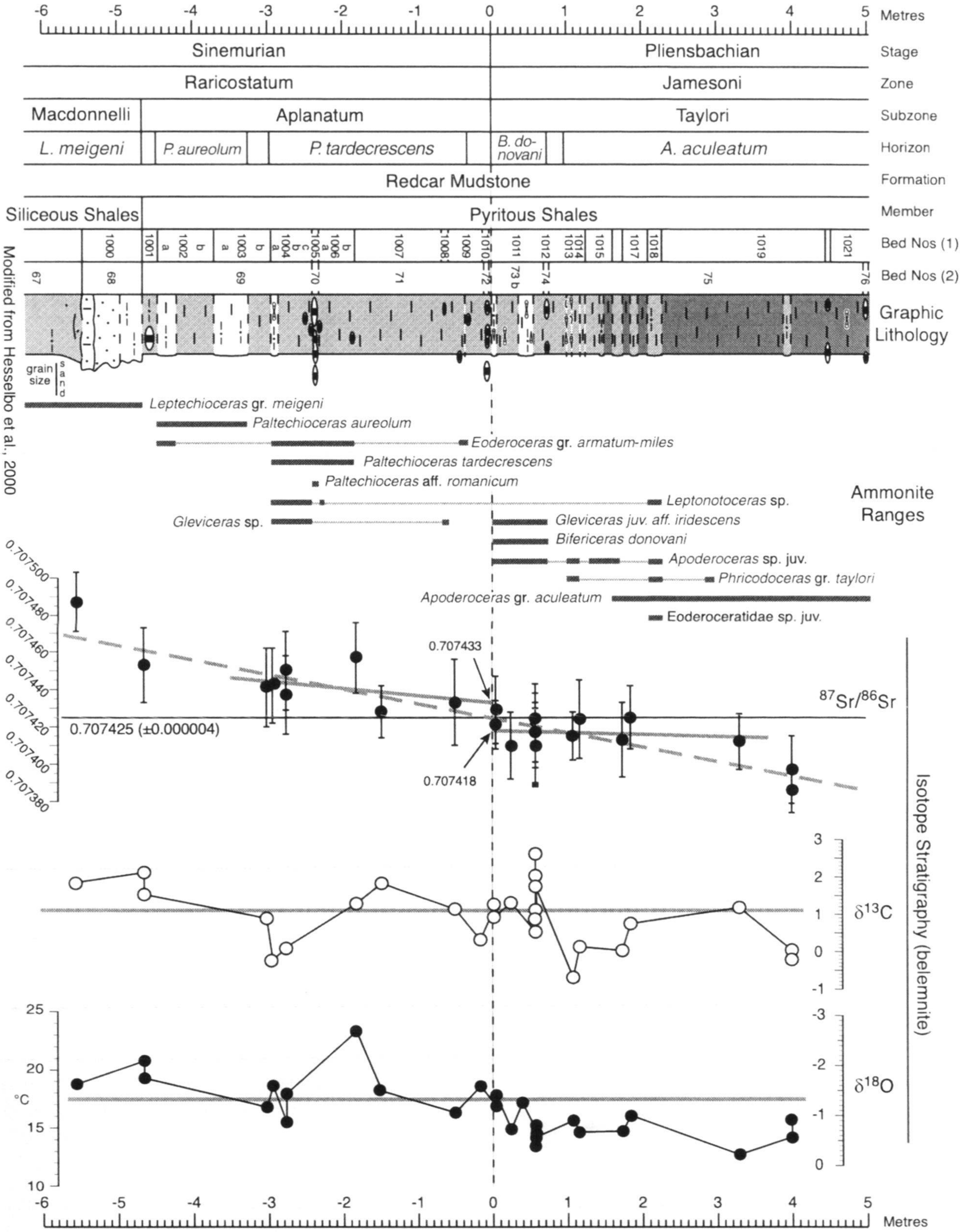

Fig. 4. Detailed log of the Sinemurian-Pliensbachian boundary section at Wine Haven, Robin Hood's Bay. Bed numbers are from Dommergues & Meister (1992)[1] (beds 1000–1021) and Hesselbo & Jenkyns (1995)[2] (beds 67–76). Key as for Fig. 1. Isotopic values are from diagenetically unaltered samples only. No ammonites have been recorded from between – 0,36 to 0 m in the section (from Hesselbo et al. 2000 and partim from Howarth 2002 fig. 23, p. 147).

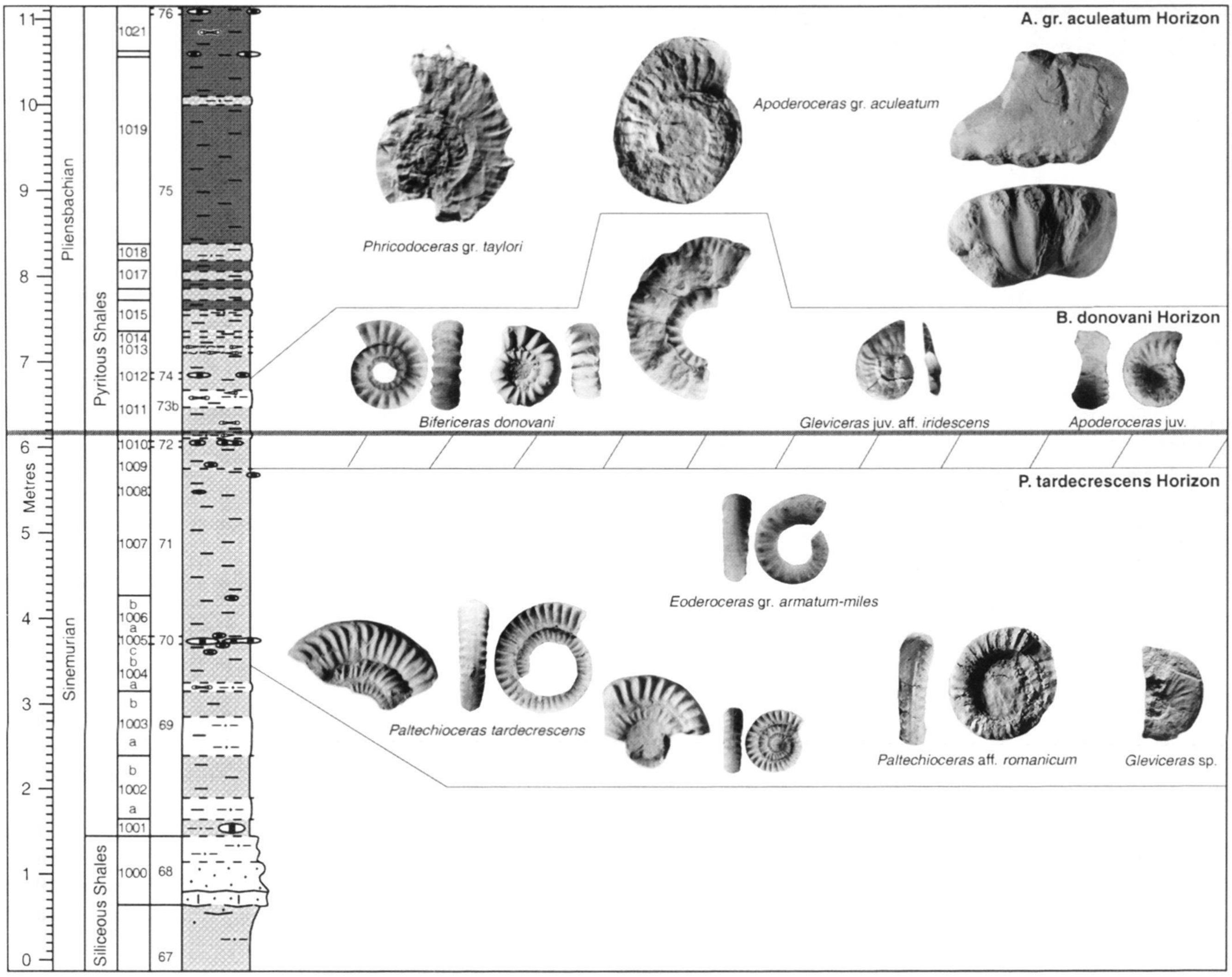

Fig. 5. Ammonite faunas and horizons at the Sinemurian-Pliensbachian boundary.

LOWER PLIENSBACHIAN

Lower Jamesoni Zone

Taylori Subzone: (partim, more than 5 m, levels 73b-76)

Two horizons are recognized:

B. donovani horizon (level 73b = 1011 partim): *Bifericeras donovani* DOMMERGUES & MEISTER, *Apoderoceras* sp. juv., *Gleviceras* juv. aff. *iridescens* (TUTCHER & TRUEMAN).

A. gr. *aculeatum* horizon (level 74 – 76 = 1012–1021): *Apoderoceras* gr. *aculeatum* (SIMPSON), *Apoderoceras* sp. juv., *Phricodoceras* gr. *taylori* (SOWERBY) *Leptonotoceras* sp. *sensu* BLAU et al., Eoderoceratidae sp. juv.

Amongst this fossil assemblage, the presence of the genus *Apoderoceras* provides a useful indication for the first level of the Lower Pliensbachian (see discussion in part 3). Consequently, the boundary between the Pliensbachian and Sinemurian stages is placed very close to the base of bed 73 (1011), exactly at the base of bed 73b in the Wine Haven section (it means 6 cm above the mid-line of nodules forming bed 72) (Fig. 6) and is charaterized by the association of *Apoderoceras* sp. and *Bifericeras donovani* DOMMERGUES & MEISTER. The ammonite *Gleviceras* juv. aff. *iridescens* (TUTCHER & TRUEMAN) belongs to this association, too. This fossil assemblage overlies the last Upper Sinemurian Echioceratidae and precedes the first classic Lower Pliensbachian *Apoderoceras* and *Phricodoceras taylori* (SOWERBY). We note, however, that ammonites have not been recorded from the 36 cm of strata below the proposed boundary level.

Foraminifera (M. Hylton, M. Hart, G. Price)

A total of 34 samples were collected (on two separate visits) in order to investigate the fossil changes across the Sinemurian-Pliensbachian boundary in Robin Hood's Bay. The

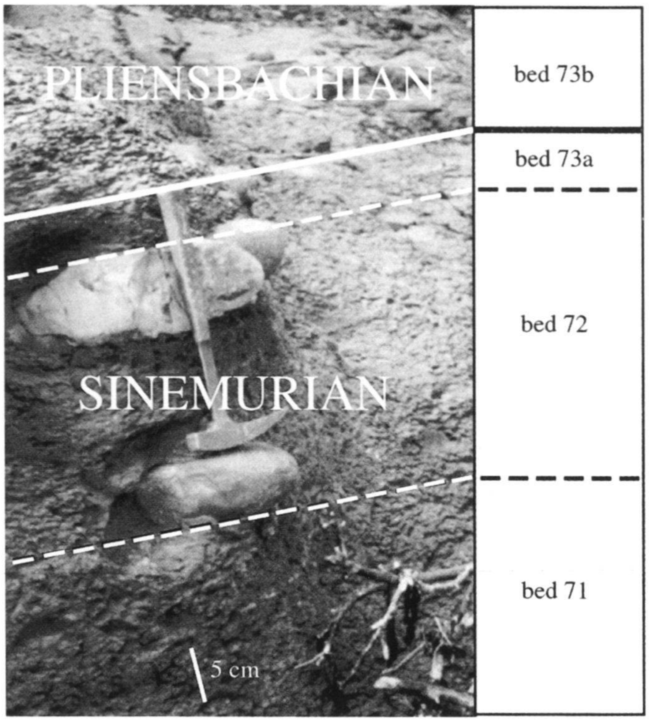

Fig. 6. Detail of the Sinemurian-Pliensbachian boundary in Wine Haven.

majority of the samples collected from this locality either proved to be resistant to any of the disaggregation techniques employed or did not yield any microfauna. As indicated in Figure 7, a number of standard preparation techniques were attempted. Where a method failed to yield a viable residue for analysis another technique was employed, moving progressively from left to right across the figure. In all cases 150 grams of sediment were processed with the remainder of the field sample being retained as a reserve. Only four samples yielded any fauna and these are indicated in Figure 8. The four samples are all located in the uppermost Sinemurian strata and, in descending order from the boundary, record 182, 166, 153 and 265 individuals counted on the >75 mm size fraction. All the other samples were barren.

The presence of *Dentalina matutina* (D'ORBIGNY) is diagnostic of the Sinemurian - Pliensbachian boundary (Copestake & Johnson 1989) while the first occurrence of *Frondicularia terquemi muelensis* is seen at the base of the *raricostatum* Zone in the British Jurassic. The long-ranging, characteristic members of Early Jurassic foraminiferal assemblages are also present at this locality: *Lingulina tenera tenera, Lingulina tenera tenuistriata, Lenticulina muensteri muensteri* and *Marginulina prima prima* indicating normal marine conditions and connections with the other basins during this period. In their review of Lower Jurassic foraminifera, Copestake & Johnson (1989) indicate that the boundary is marked by the first occurrence of *Vaginulinopsis denticulatacarinata* (FRANKE). As no samples above the boundary yielded any fauna we did not record this taxon. Copestake & Johnson (1989) record this species in the Northern North Sea Basin, the Moray Firth Basin, the Southern North Sea Basin, the Cleveland Basin (which includes Robin Hood's Bay) and the East Midlands Shelf. In the same range charts (Copestake & Johnson 1989, figs 6.2.8, 6.2.9, 6.2.10) it is also indicated that the boundary is marked by the extinction of *Nodosaria issleri* FRANKE, although this taxon has not been found in our investigation.

Aside from the published charts (Copestake & Johnson 1989, figs 6.2.6 – 6.2.10) in the *Stratigraphical Atlas of Fossil Foraminifera* there are very little published data available on coeval successions in the UK. The most comprehensive account of foraminifera from the Lower and Middle Lias is that by Copestake (1978) on the Mochras Borehole. Summary charts of some of these data are available in Copestake (1985) and Copestake & Johnson (1984) – much of which is repeated in their 1989 compilation.

The Dorset Coast does provide a potential succession for investigation but the only published information is provided by Copestake (1987). In this 'Field Guide' Copestake lists the foraminifera from a few 'spot' samples in the Upper Sinemurian (top of Black Ven Marls) and the Lower Pliensbachian

Technique/ → Lithology ↓	**Basic Solvent Method**	**Solvent with hot Na_2CO_3**	**Boiling in Na_2CO_3**	**Hydrogen Peroxide**	**NaOH**	**NaTBP**
High % Clay	✓	✓	$\neq$	$\neq$	$\neq$	$\neq$
High % mud	✓	✓	✓	$\neq$	$\neq$	$\neq$
Shale	$\approx$	$\approx$	✓	$\neq$	$\neq$	$\neq$
Bituminous Shale	$\equiv$	$\equiv$	$\equiv$	$\approx$	$\approx$	✓
Indurated (Siliceous) shale	$\equiv$	$\equiv$	$\neq$	$\neq$	$\neq$	$\neq$

✓ - very successful $\approx$ - moderate success $\equiv$ - no effect $\neq$ - not tried

Fig. 7. Summary of the effectiveness of disaggregation techniques on the range of lithologies encountered in the investigation of the micropalaeontological samples.

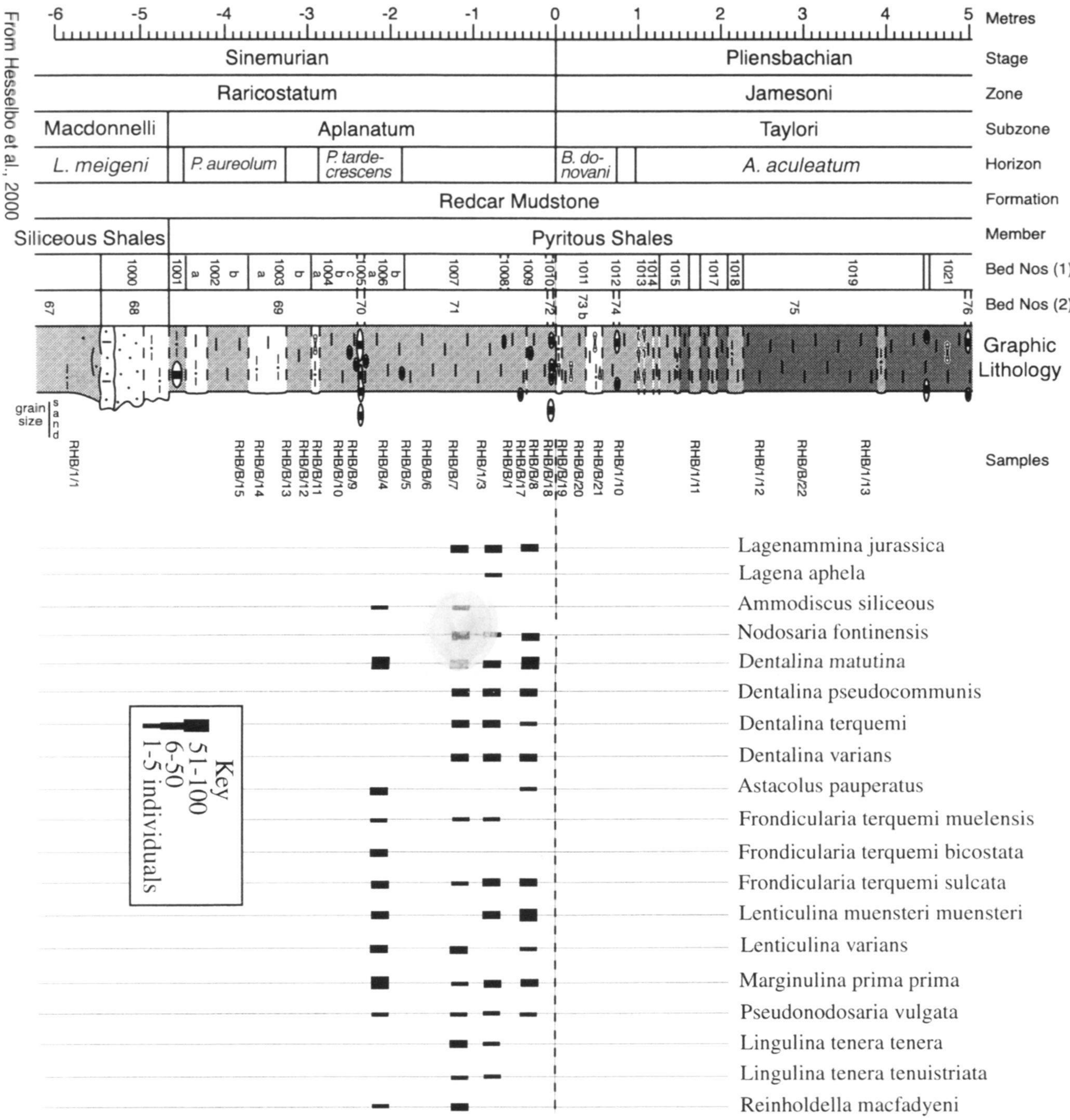

Fig. 8. Distribution of Foraminifera in the Wine Haven succession. Unfortunately none of the samples from the Lower Pliensbachian yielded any identifiable fauna.

(Belemnite Marls and Green Ammonite Beds). The lowermost sample from the Lower Pliensbachian (Copestake 1987, fig. 5; Sample D12) contains only *Bathysiphon* sp., *Lenticulina muensteri* s.s. and *Marginulina prima rugosa.* The latter taxon is a long-ranging Sinemurian-Pliensbachian form and provides no detailed stratigraphic information. Sample D13 was taken from the upper part of the Belemnite Marls and while there are some new taxa present; this mid-Pliensbachian fossil change (Copestake & Johnson 1989, fig. 6.2.9) is well above the level of the proposed GSSP.

The species listed in Figure 8 are all well known Lower Jurassic taxa and belong to long-ranging morphogroups. The taxonomic details of these species and subspecies are as follows:

Ammodiscus siliceous (TERQUEM); *Involutina silicea* TERQUEM 1862, p. 456, pl. 6, fig. 11a,b.
Astacolus pauperatus (JONES & PARKER); *Planularia pauperata* JONES & PARKER 1860, p. 454, pl. 20, fig. 39.
Dentalina matutina D'ORBIGNY 1849, p. 243, no 259.
Dentalina pseudocommunis FRANKE 1936, p. 30, pl. 2, fig. 20a,b.
Dentalina terquemi D'ORBIGNY 1849, pl. 2, figs 5-7, pl. 6, fig. 10.
Dentalina varians TERQUEM 1866, p. 485, pl. 19, figs 26, 27.
Frondicularia terquemic bicostata D'ORBIGNY; *Frondicularia bicostata* D'ORBIGNY 1849, p. 242, no 256.
Frondicularia terquemi muelensis RUGET & SIGAL; *Frondicularia muelensis* RUGET & SIGAL 1970, p. 92, pl. 3, figs 19-32, pl. 4, figs 1-6.
Frondicularia terquemi sulcata BORNEMANN; *Frondicularia sulcata* BORNEMANN 1854, p. 37, pl. 3, fig. 22a,c.
Lagena aphela TAPPAN 1955, p. 82, pl. 28, figs 13, 14.
Lagenammina jurassica (BARNARD); *Proteonina jurassica* BARNARD 1959, p. 134, pl. 11, figs 6-8.
Lenticulina muensteri muensteri (ROEMER); *Robulina muensteri* ROEMER 1839, p. 48, pl. 20, fig. 29.
Lenticulina varians (BORNEMANN); *Cristellaria varians* BORNEMANN p. 41, pl. 4, figs 32-34.
Lingulina tenera tenera (BORNEMANN); *Lingulina tenera* BORNEMANN 1854, p. 38, pl. 3, fig. 24a-c.
Lingulina tenera tenuistriata (NORVANG); *Geinitzina tenera* (BORNEMANN) subsp. *tenuistriata* NORVANG 1957, p. 56, figs 13, 16, 17, 24.
Marginulina prima prima D'ORBIGNY 1849, p. 242, no 262.
Nodosaria fontinensis TERQUEM; *Nodosaria fontinensis* TERQUEM 1870, p. 251, pl. 26, figs 1, 5.
Pseudonodosaria vulgata (BORNEMANN); *Glandulina vulgata* BORNEMANN 1854, p. 31, pl. 2, fig. 1a,b.
Reinholdella macfadyeni (TEN DAM); *Astigerina macfadyeni* TEN DAM 1947, p. 396, text-fig. 1a-c.

The taxonomy of all of these species and subspecies is available in a number of Ph.D. theses (Copestake 1978, Muller 1990, Hylton 2000) in the United Kingdom, but the only published summary is that in Copestake & Johnson (1989).

Palynology (S. Feist-Burkhardt)

A subset of 12 samples, out of the 34 samples collected for micropalaeontological investigations (see section above, Foraminifera record), has been selected for a palynological study. These samples cover the whole interval of interest across the Sinemurian – Pliensbachian boundary from the Macdonelli Subzone [bed 53 (503a in Dommergues & Meister 1992)] to the Taylori Subzone [lower part of bed 75 (1018/1019 ibidem 1992)]. Preparation followed standard palynological processing techniques, including HCl and HF treatment, heavy liquid separation, oxidation with HNO_3, and staining with Fuchsine.

All samples yielded a rich palynological residue with palynomorphs being moderately well-preserved. Composition of the organic residues (= palynofacies) is quite similar in all samples. The palynofacies is generally composed of high amounts of opaque phytoclasts, some brown translucent phytoclasts, translucent degraded phytoclasts, and few to no amorphous organic matter (AOM), high amounts of pollen grains, some spores, very few acritarchs, prasinophytes and foraminiferal test linings. Amorphous organic matter is abundant only in the two samples (RBH/B/10 and RBH/B/14) from bed 69 (respectively beds 1004 and 1002 in Dommergues & Meister 1992). Dinoflagellate cysts have not been found in any of the samples investigated.

In all the palynological samples studied, the pollen and spore assemblages are very similar and correspond to assemblages known from Lower Jurassic sediments elsewhere in Europe (e.g. Weiss 1989, Rauscher & Schmitt 1990). No characteristic change in the assemblages has been encountered. This was to be expected since pollen and spores have relatively little potential in Jurassic stratigraphy and enable only a gross biostratigraphical breakdown of the period in an early, middle and late Jurassic unit (e.g. Weiss 1989).

The palynomorph group with the best palynostratigraphical potential in marine Jurassic sediments are dinoflagellate cysts. Especially from the Toarcian/Aalenian onward dinoflagellate cyst biostratigraphy can reach a resolving power in the order of ammonite Zones. However, only very few dinoflagellate cysts are known from the Sinemurian and the Pliensbachian. The uppermost Sinemurian and lowermost Pliensbachian interval is considered by some authors to be barren of dinoflagellate cysts (e.g. Stover et al. 1996), whereas others report on the scarce occurrences of small dinoflagellate cysts with inconspicuous morphologies (*Mancodinium/Maturodinium* spp., *Valvaeodinium* spp., *Dapcodinium* spp.,? *Beaumontella* sp.) (e.g. Feist-Burkhardt & Wille 1992, Feist-Burkhardt 1998). However, the number of palynological studies with precise ammonite control is low and therefore the stratigraphical ranges of these species are not exactly known so far.

In the present palynological study no dinoflagellate cysts at all have been found. This is in agreement with a previous study on the organic microplankton from the Sinemurian – Pliensbachian of Yorkshire by Bucefalo Palliani & Riding (2000), who analysed spot samples from Robin Hood's Bay and came to the same results. Their two samples from the siliceous shale (Raricostatum Zone) at Robin Hood's Bay were barren of dinoflagellate cysts, as well as the one sample from the Lower Pliensbachian (Davoei Zone) from the neighbouring Cowbar Nab section. The same authors describe monospecific samples from underlying sediments of the Oxynotum Zone with *Liasidium variabile* DRUGG 1978 as the only dinoflagellate cyst present. Abundant occurrence of that species in the Oxynotum Zone from Robin Hood's Bay was already known from the first description of *L. variabile* by Drugg (1978). A critical review of the pertinent literature seems to confirm the range top of *L. variabile* in the Late Sinemurian Oxynotum Zone to be a reliable stratigraphical marker datum (Feist-Burkhardt, ongoing study). Similar results, with productive samples from Oxynotum Zone and barren samples from Raricostatum and earliest Jamesoni Zones, were also reported from the Brown Moor borehole, some 50 km away from Robin Hood's Bay (Bucefalo Palliani & Riding 2000).

The palynofacies of the studied samples is characterised by high amounts of terrigenous phytoclasts, pollen and spores. Marine components are rare, but present in all samples and composed of acritarchs, prasinophytes and foraminiferal test linings. The high amounts of terrigenous components together

The requirements for a GSSP (ICS)	Wine Haven, Yorshire
GEOLOGICAL REQUIREMENTS	
exposure over an adequate thickness	Yes
continuous sedimentation	Yes
rate of sedimentation	**about 30 m** for the Aplanatum and Taylori Subzones
absence of synsedimentary and tectonic disturbances	Yes
absence of metamorphism and strong diagenetic alteration	Yes for macrofauna (ammonites)
BIOSTRATIGRAPHIC REQUIREMENTS	
abundance and diversity of well-preserved fossils	Very abundant ammonite faunas and well preserved
absence of vertical facies changes at or near the boundary	Yes
favourable facies for long-range biostratigraphic correlations	Yes
OTHER METHODS	
radioisotopic dating	no information
magnetostratigraphy	no significant result
chronostratigraphy	no information
sequence stratigraphy	Hesselbo & Jenkyns 1988, 1998
OTHER REQUIREMENTS	
the GSSP should be indicated by a permanent fixed marker	Yes, if accepted
accessibility	Depending on the tide only
free access for research	Yes
protection of the site	Part of a Site of Special Scientific Interest

Fig. 9. Summary of the requirements of the International Commission on Stratigraphy for Wine Haven section.

with minor amounts of amorphous organic matter is typical for a nearshore oxygenated environments with strong terrigenous input. The abundance of amorphous organic matter in both samples (RBH/B/10 and RBH/B/14) from bed 69 (respectively beds 1004 and 1002 in Dommergues & Meister 1992) is interpreted as the result of less oxygenated conditions.

In conclusion, the palynological study provides little information in support of the selection of Wine Haven as GSSP because of the absence of dinoflagellate cysts. Thanks to its consistent occurrence, the range top of *L. variabile* in the Late Sinemurian Oxynotum Zone is considered to be a reliable stratigraphical marker datum.

Ostracoda (M. Hylton, M. Hart)

Very few ostracod valves were found in the samples. As a result, it has not been possible to produce a definitive statement on the fossil changes at this level. The only taxon identified is *Ogmoconcha* sp. Lord (1978) records that the base of the Pliensbachian is marked by the appearance of *Ogmoconcha contractula* TRIEBEL and *Gammacythere ubiquita* MALZ & LORD in N.W. Germany, although in the UK the appearance of both taxa is slightly above the Sinemurian-Pliensbachian boundary. Lord (1978, fig.4) also indicates that *Liasina lanceolata* (APOSTOLESCU) appears either just below, at, or just above the boundary in various parts of Europe (although the stratigraphical range in the Robin Hood's Bay succession is not given). Aside from the published work of Lord, the only other information on Liassic ostracoda remains unpublished (see Clarke, 1969; Field, 1968).

8. Isotope stratigraphy (S. P. Hesselbo)

Strontium isotope data derived from belemnites collected across the Sinemurian – Pliensbachian boundary have been reported previously by Hesselbo et al. (2000). Their results are reproduced in Figure 4. The data confirm the results of Jones et al. (1994) and provide a high-resolution record. A $^{87}Sr/^{86}Sr$ ratio of of 0.707425 ± 0.000021 is recorded for the boundary. The data also suggest continuous sedimentation across the boundary section because there is no abrupt change in values at this level.

Stable-isotope data were also obtained by Hesselbo et al. (2000) from the same belemnites. Oxygen isotope data ($\partial^{18}O$) show a marked rise of about 1 per mil over the 10 m interval sampled in detail (Fig. 4), equivalent to a water temperature drop of about 5 °C if interpreted only in those terms (as opposed to changes in background water mass oxygen isotope values or habitat preferences of the organisms, for example). Carbon-isotope data from belemnites around the boundary interval show considerable scatter, but notably they conform to general pattern of relatively low values evident from other localities in Europe (Jenkyns et al. 2002). High-resolution carbon-isotope stratigraphy based on analysis of other materials may yet lead to identification of recognizable and correlatable pattern at the Sinemurian – Pliensbachian boundary.

Remark: For paleomagnetostratigraphy, no data are currently available.

9. Protection of the site (K. Page)

The Wine Haven section (Robin Hood's Bay) already forms part of a Site of Special Scientific Interest, protected by law through the Countryside and Rights of Way Act 2001 (and previously through the Wildlife and Countryside Act 1981). This statutory protection will not change if the GSSP is approved, but it is a good system of national conservation law. This protection does not stop responsible collection of material for geological research but this "freedom" is, of course open to abuse by fossil collectors.

10. Conclusion

The GSSP for the base of the Pliensbachian is formally proposed at the base of bed 73b of the Wine Haven Section. The section fulfills most of the requirements indicated in the Guidelines of the ICS (Fig. 9):

- Succession of about 30 m of pale grey and buff-coloured sandy mudstones which pass upward very gradually into silty dark grey shales.
- Absence of unconformities in the Sinemurian-Pliensbachian interval and continuous exposure.
- Correlation by means of ammonites (see Dommergues & Meister 1992) which are abundant and quite well preserved and supplemented by Strontium isotope stratigraphy.
- Easy accessibility of the section well exposed on the cliff and the foreshore.
- No structural complexity or metamorphism
- Part of a Site of Special Scientific Interest and, therefore, protected under U.K. legislation.

Acknowledgements

The present report is the result of hard work by many members of the Pliensbachian Working Group in Wine Haven and in other regions, namely our colleagues in Germany (Ebel) for the section of Herford-Diebrock (NW Germany, see Blau et al. 2000), Schlatter in Pliensbach (SW Germany, see Schlatter 1980, 1991) and our Italian Colleagues (Faraoni, Macchioni, Marini, Pallini, Parisi & Venturi) for the section Bosso River (Central Apenine, Italy, see Faraoni et al. 1996). We would like to thank G. Bloos, N. Morton, J. Remane and H. Rieber for constructive comments which improved this paper.

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Plate 1

Fig. 1–6, 10, 14. *Paltechioceras tardecrescens* (HAUER)
Tardecrescens Horizon, Aplanatum Subzone, Upper Sinemurian
1*, 2–3, 4*, 14: bed 69 (1004)
5, 6: same specimen, ex situ
10: bed 70 (1005)

Fig. 7–9. *Paltechioceras* aff. *romanicum* (UHLIG)
Tardecrescens Horizon, Aplanatum Subzone, Upper Sinemurian
7, 8: Same specimen, ex situ
9: bed 70 (1005)

Fig. 12–13. *Gleviceras* sp.
Tardecrescens Horizon, Aplanatum Subzone, Upper Sinemurian
12, 13: same specimen, bed 69 (1004)

Fig. 11, 15–17. *Eoderoceras* gr. *armatum* (SOWERBY) – *miles* (SIMPSON)
Tardecrescens Horizon, Aplanatum Subzone, Upper Sinemurian
11: bed 71 (1006)
15*: bed 69 (1004)
16, 17: same specimen, bed 69 (1002c)

Remark: In plates 1 and 2 are illustrated some important specimens (*) published in Dommergues & Meister 1992. The collections are stored in Dijon University and in the Natural History Museum of Geneva.

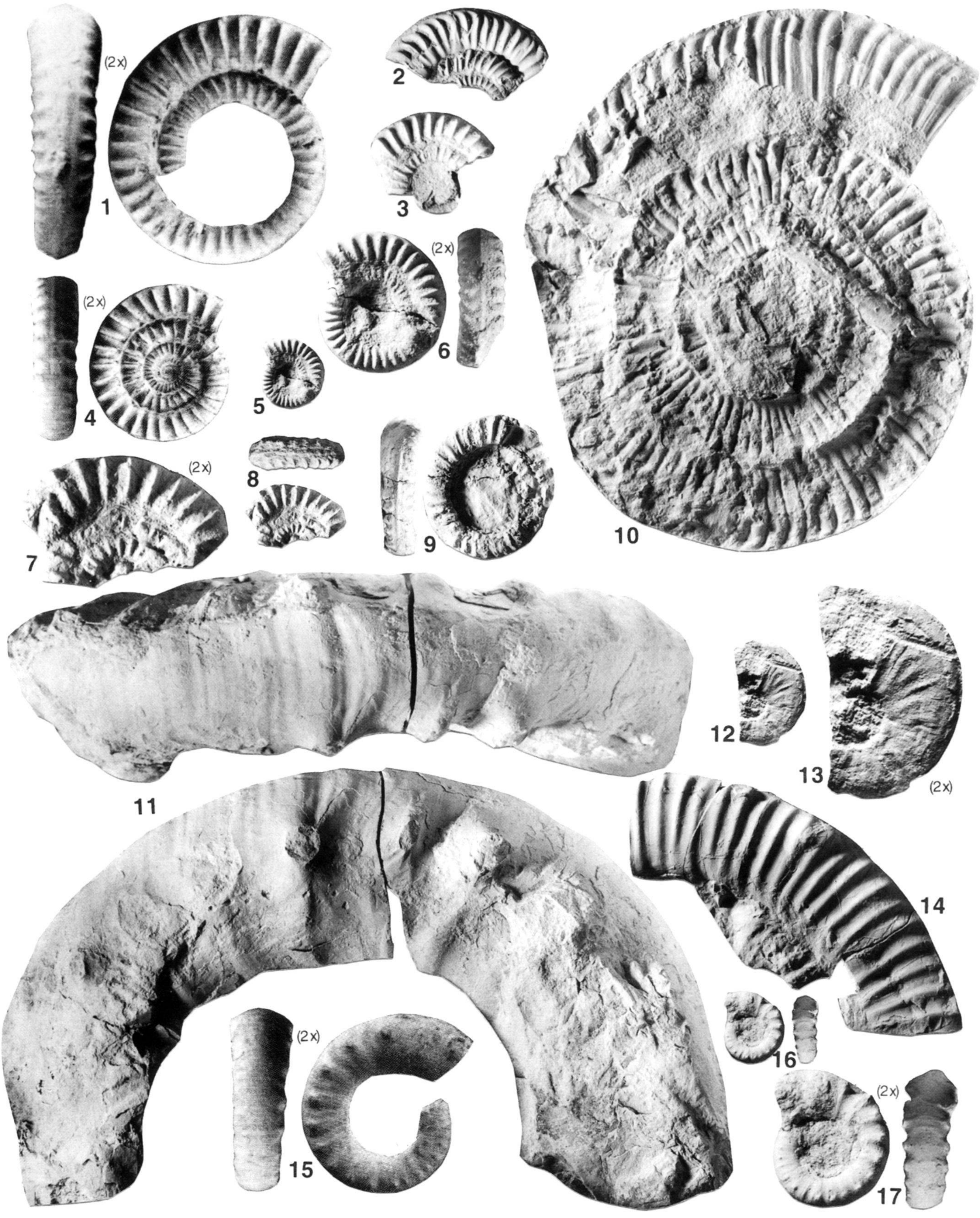
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Plate 2

Fig. 1. *Eoderoceras* gr. *armatum* (SOWERBY) – *miles* (SIMPSON)
Tardecrescens Horizon, Aplanatum Subzone, Upper Sinemurian
1: bed 71 (1006a)

Fig. 2–15. *Bifericeras donovani* DOMMERGUES & MEISTER
Donovani Horizon, Taylori Subzone, Lower Pliensbachian
2–8, 9*, 10–14, 15*: bed 73b (1011)

Fig. 16–19. *Leptonotoceras* sp.
Aculeatum Horizon, Taylori Subzone, Lower Pliensbachian
16, 17: same specimen, bed 75 (1018)
Tardecrescens Horizon, Aplanatum Subzone, Upper Sinemurian
18, 19: same specimen, bed 69 (1004)

Fig. 20. *Phricodoceras taylori* (SOWERBY)
Aculeatum Horizon, Taylori Subzone, Lower Pliensbachian
20: bed 75 (1014)

Fig. 21–22. *Gleviceras* juv. aff. *iridescens* (TUTCHER & TRUEMAN)
Donovani Horizon, Taylori Subzone, Lower Pliensbachian
21, 22: same specimen, bed 73b (1011)

Fig. 23–25, 27. *Apoderoceras* gr. *aculeatum* (SIMPSON)
Aculeatum Horizon, Taylori Subzone, Lower Pliensbachian
23: bed 75 (1020)
24, 25: same specimen, bed 75 (1017c)
27: bed 75 (1014)

Fig. 26. *Apoderoceras* sp. juv.
Donovani Horizon, Taylori Subzone, Lower Pliensbachian
26*: bed 73b (1011)

Fig. 28–29. (?) *Apoderoceras* sp.
28, 29: same and crushed specimen, bed 75 (1018)

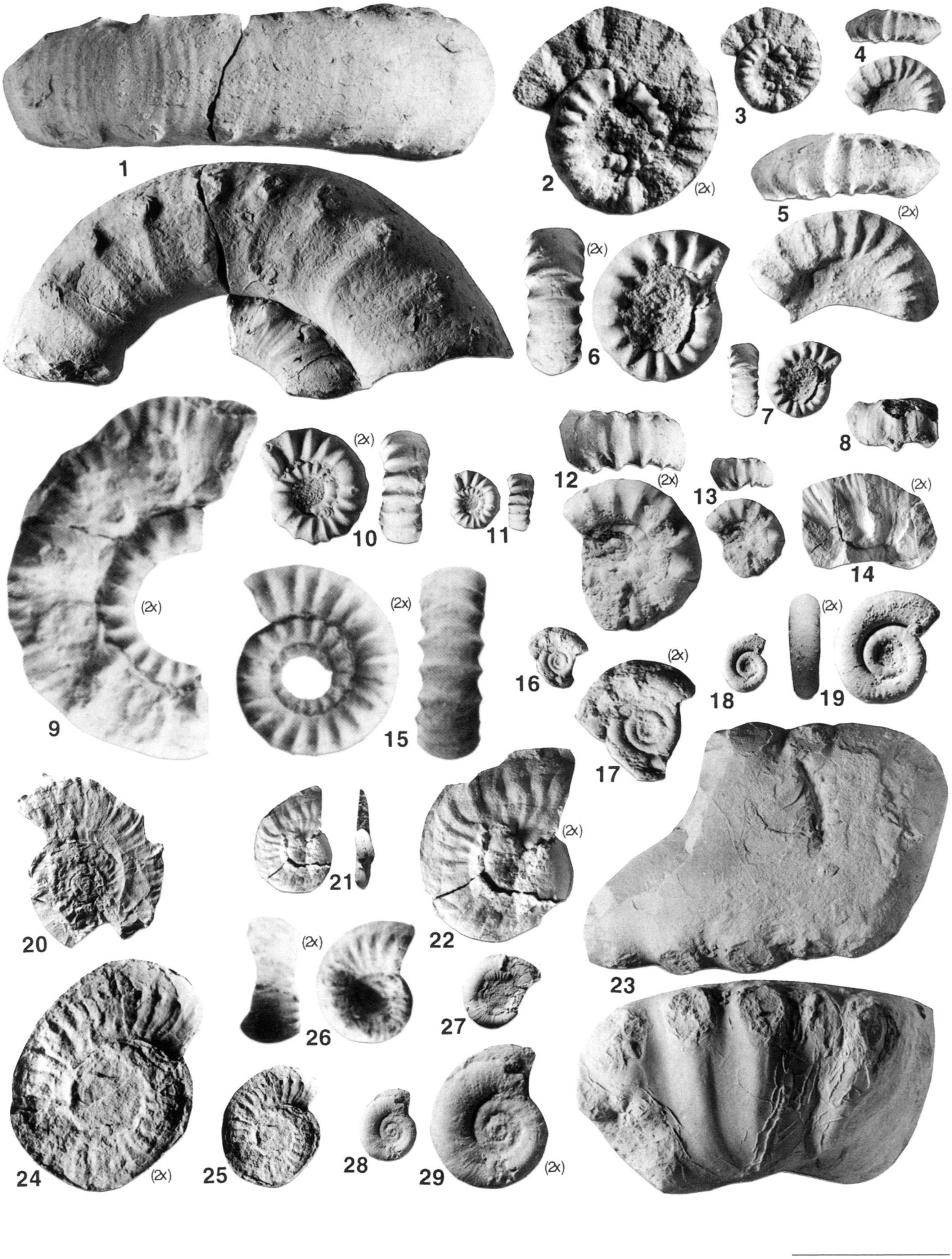
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Plate 3

Fig. 1. *Ammodiscus siliceous* (TERQUEM)
Scale bars 100mm. Main Alum Shales, south of Peak, Yorkshire, Fibulatum Subzone.

Fig. 2–3. *Lagenammina jurassica* (BARNARD)
Scale bars 100mm. 2: Main Alum Shales, south of Peak, Yorkshire, Fibulatum Subzone. 3: Down Cliff Clay, Eype, Levesquei Subzone.

Fig. 4–5. *Dentalina matutina* D'ORBIGNY
Scale bars 100mm. 4: East Quantoxhead, Conybeari Subzone. 5: Siliceous Shales, Robin Hood's Bay, Aplanatum Subzone.

Fig. 6. *Dentalina pseudocommunis* FRANKE
Scale bars 100mm. Main Alum Shales, south of Peak, Yorkshire, Fibulatum Subzone.

Fig. 7. *Dentalina varians* TERQUEM
Scale bar 100mm. Siliceous Shales, Robin Hood's Bay, Aplanatum Subzone.

Fig. 8–9. *Frondicularia terquemi bicostata* D'ORBIGNY
Scale bars 100mm. 8: Siliceous Shales, Robin Hood's Bay, Aplanatum Subzone. 9: Grey shale Member, Brackenberry Wyke, Paltum Subzone.

Fig. 10–11. *Frondicularia terquemi sulcata* BORNEMANN
Scale bars 100mm. 10: Barnard's form G. Siliceous Shales, Robin Hood's Bay, Aplanatum Zone. 11: Barnard's form E. Blue Band, Eype, Margaritatus Zone.

Fig. 12. *Lagena aphela* TAPPAN
Scale bar 100mm. Tilton, Margaritatus Zone.

Fig. 13. *Lenticulina muensteri muensteri* (ROEMER)
Scale bars 100mm. Uncoiled form, Barnard's form G. Blue Band, Eype, Margaritatus Zone.

Fig. 14–15. *Lingulina tenera tenera* (BORNEMANN)
Scale bars 100mm. 14: Kettleness Member, Brackenberry Wyke, Gibbosus Subzone. 15: Tilton, Margaritatus Zone.

Fig. 16. *Nodosaria fontinensis* TERQUEM
Scale bar 100mm. Tilton, Falciferum Subzone.

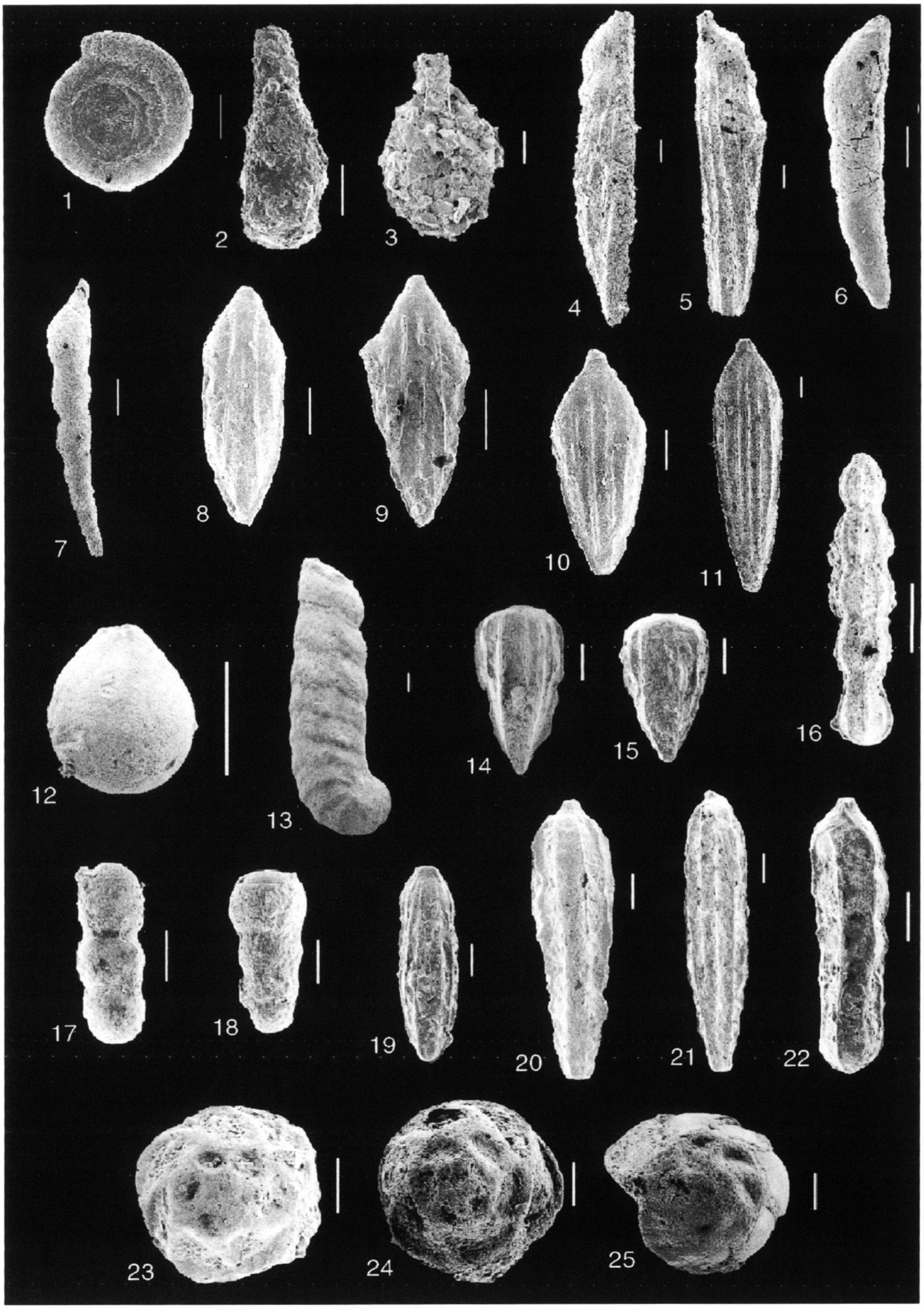
Fig. 17–18. *Pseudonodosaria vulgata* (BORNEMANN) gr.
Scale bars 100mm. 17, 18: Tilton, Falciferum Subzone.

Fig. 19. *Lingulina tenera tenuistriata* (NØRVANG)
Scale bar 100mm. Tilton, Margaritatus Zone.

Fig. 20–22. *Marginulina prima* plex. *prima* D'ORBIGNY
20, 21, 22: Grey Shales, Brackenberry Wyke, Paltum Subzone.

Fig. 23–25. *Reinholdella macfadyeni* (TEN DAM)
Scale bar 100µm. 23, 24: Port Mulgrave, Yorkshire, Semicelatum Subzone. 25: Brackenberry Wyke, Yorkshire Paltum Subzone.

Remark: The Foraminifera collection is stored in the University Plymouth.



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