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The Global Boundary Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage (Lower Jurassic), Wine Haven, Yorkshire, UK

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Following votes by the Pliensbachian Working Group, the Jurassic Subcommission and the International Commission on Stratigraphy, IUGS ratified the proposed Global Boundary Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage (Lower Jurassic) at the base of bed 73b in the Wine Haven section, Robin Hood's Bay, Yorkshire Coast, UK. This level contains the characteristic ammonite association Bifericeras donovani *Dommergues and Meister and* Apoderoceras *sp. Complementary data include: a) Strontium-isotope stratigraphy, based on analysis of belemnites which yield a calcite* $^{87}Sr/^{86}Sr$ *ratio for the boundary level of 0.707425 and data supporting interpretation of continuous sedimentation; b) Belemnite oxygen-isotope data indicate a significant temperature drop (~5 ºC) 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. (1998); d) The Upper Sinemurian to lowermost Pliensbachian at Wine Haven section has a predominantly normal magnetic polarity, but two discrete reversed polarity magnetozones are present. The first spans much of the latest Sinemurian* Aplanatum *Subzone. It terminates <0.5m below the Sinemurian-Pliensbachian boundary and may prove a valuable chronostratigraphic marker. The second extends from the latest* Oxynotum *Subzone probably through to the lower part of the* Raricostatum *Subzone.*

Foreword

The Pliensbachian is the third Stage of the Jurassic System, and the fourth Jurassic Stage to be defined by a GSSP. Jurassic Stages were first named by A. d'Orbigny in the 1840's and seven of the eleven Global Standard Stages currently recognised were named by him. This is despite numerous additions and revisions by subsequent authors and is due to the influence of W.J. Arkell in the 1950s and the Jurassic Subcommission from the 1960s in limiting the number of Stages recognised officially as the Global Standard. As it happens, the name Pliensbachian was introduced by A. Oppel in 1858 to replace d'Orbigny's name 'Liasien' and was adopted internationally.

From d'Orbigny until the 1960s, Jurassic Stages have been traditionally defined by the Standard (ammonite) Zones they contain. For example, the Pliensbachian was defined, following Oppel, as having the 'Zone des *Amm. Jamesoni*' at the base and the 'Zone des *Amm. Spinatus*' at the top. The Jurassic Subcommission accepted the internationally agreed requirement for more precise definitions of the bases of Stages at a point in a stratotype section. Working Groups were established for each Stage, to recommend basal boundary stratotypes. The task of the Pliensbachian WG, as with several others, was made more difficult by the presence of a widespread hiatus, limiting the number of sections available with a continuous record of sedimentation across the basal (Sinemurian-Pliensbachian) boundary interval. The availability in this interval, as in many parts of the Jurassic, of extremely precise relative dating and correlation based on ammonite biochronology, has been crucial to the successful overcoming of this problem by the Pliensbachian Working Group.

The original proposal by the Group was accepted by the Jurassic Subcommission and published (in *Eclogae Geologicae Helvetiae*) in 2003. Before submission to the International Commission on Stratigraphy in 2004 it became possible to incorporate the results from a preliminary palaeomagnetic survey (partly sponsored by the Jurassic Subcommission) and various other suggested modifications. The proposal was accepted unanimously by ICS in 2004 and ratified by IUGS in March 2005. For this Episodes paper some additional data on international correlations have been included.

Introduction

The present paper, defining the Global Boundary Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage, is the result of intensive work by the Pliensbachian Working Group (C. Meister, convenor). The proposal document submitted for voting to all members of the Pliensbachian Working Group and Voting Members of the Jurassic Subcommission was published in 2003 (Meister et al.). The results of the votes were: Pliensbachian Working Group — 28 YES, 3 ABSTAIN, 0 NO; Jurassic Subcommission — 18 YES, 0 ABSTAIN, 0 NO. The present paper that summarizes previous works and reports from members of the Pliensbachian Working Group (Dommergues and Meister, 1992; Hesselbo et al., 2000; Meister, ISJS Newsletter 1997, 1999a, 1999b, 2001, 2002, 2003, 2004, 2005; Howarth, 2002; Meister et al., 2003) is completed by integrated zonation and correlation tables for ammonites, belemnites, brachiopods, ostracods, foraminifera, dinoflagellate cysts, calcareous nannofossils, bivalves and by the results of the paleomagnetostratigraphy. It is the official presentation of the GSSP for the base of the Pliensbachian Stage.

Historical Background

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 (Figure 1). The earliest scientific references to the site are probably those within Young and Bird's famous 1822 volume describing the Yorkshire coast as a whole, followed by Williamson in 1840. Surprisingly the only detailed published description of the lower part of the section (Sinemurian to Lower Pliensbachian) is within Tate and Blake's classic work "The Yorkshire Lias" (1876), more than 125 years old (and reproduced many times by later authors such as Fox-Strangeways and 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, 1969). The copious notes and specimens he left are now in the Natural History Museum in London, and have been 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 and Meister (1992). Hesselbo and 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 and 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 and Bird, 1828; Simpson, 1843, 1855, 1865-68; Buckman, 1909-1930; Tate and Blake, 1876; Spath, 1925; Howarth, 1955, 1958, 1992; Getty, 1972, 1973; Dommergues and 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 and 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 and Jenkyns, 1995; Rawson and Wright, 1995). A key development in

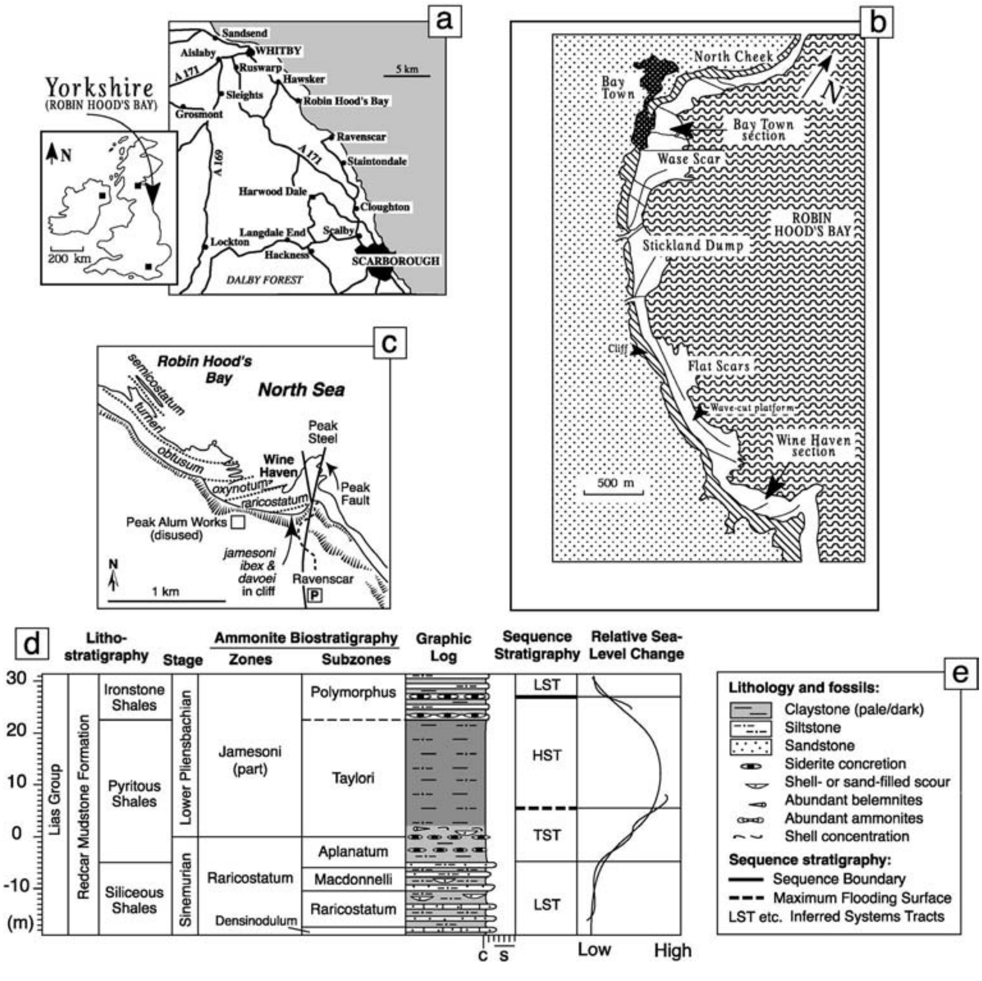

Figure 1 Wine Haven section. (a, b) Location of Robin Hood's Bay, Yorkshire, UK (from Dommergues and Meister 1992). (c) Detailed sketch geological map of the Wine Haven area (adapted from Rawson and Wright, 1992). (d) Summary stratigraphic log for the Late Sinemurian to Early Pliensbachian succession of Robin Hood's Bay, Yorkshire, based on data in Hesselbo and Jenkyns (1995, 1998) and Cope et al. (1980). The sea-level curves are of 3rd and 4th order sensu Graciansky et al. (1998). (e) Key to panel (d) and Figure 4 (from Hesselbo et al., 2000 partim and Meister et al., 2003).

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 and 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 and 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.

The Global Boundary Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage

Location

The GSSP (Wine Haven) is located about 3 km S-SE of the small town of Robin Hood's Bay, Yorkshire, UK (Figures 1a-c, 2A, B).

Coordonates
UK grid reference NZ 9762 0230
Longitude 0º 29' 51" W (nearly on the Greenwich meridian)
Latitude 54º 24' 25"N

Very easily accessible from Whitby or Scarborough, the GSSP can be reached by foot from Bay Town along the coast or more directly from the Ravenscar parking.

Protection of the site

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, 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.

Description of the GSSP

The Sinemurian-Pliensbachian sequence is well developed in Robin Hood's Bay and contains a complete succession of quite well-preserved ammonite assemblages. 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 and Jenkyns, 1995).

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 (Figures 2A, B and 3: 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 and Jenkyns, 1995, 1998; Van Buchem and Knox, 1998; Hesselbo et al., 2000) (Figure 1d).

The Yorkshire coast successions of the Cleveland Basin have been remeasured and interpreted in the context of sequence stratigraphy by Hesselbo and 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 and Jenkyns, 1995, 1998).

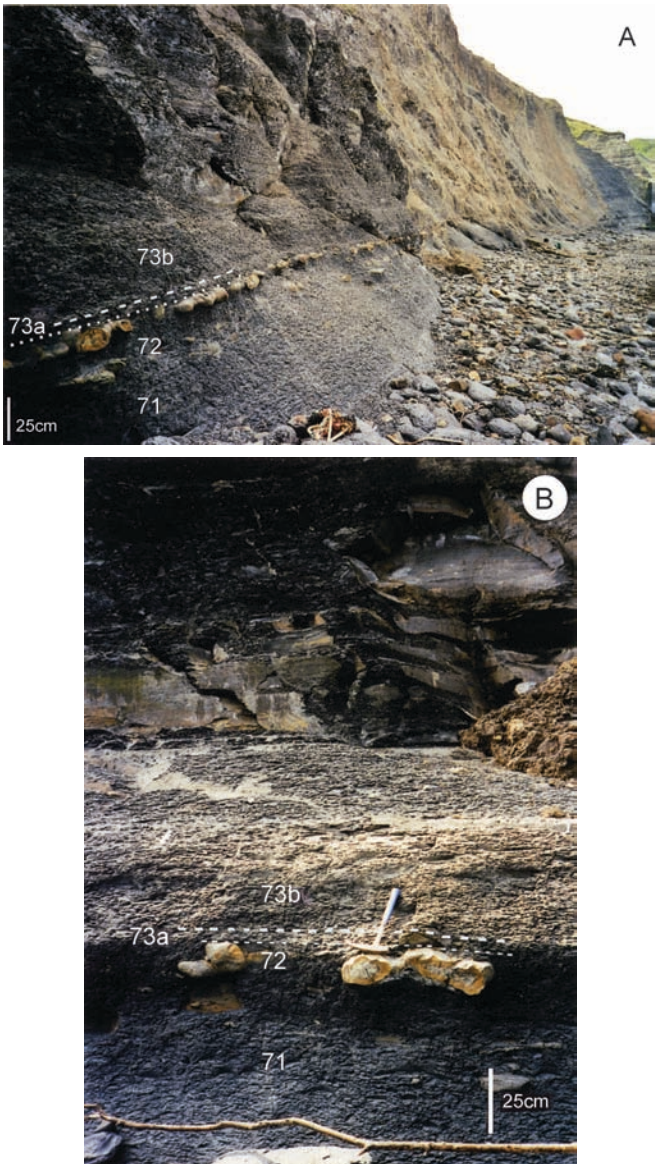

Figure 2 Wine Haven outcrop, (A-B) Lithological sequence at the Sinemurian-Pliensbachian boundary, bed 73b indicates (broken line) the base of the Pliensbachian (from Meister et al., 2003).

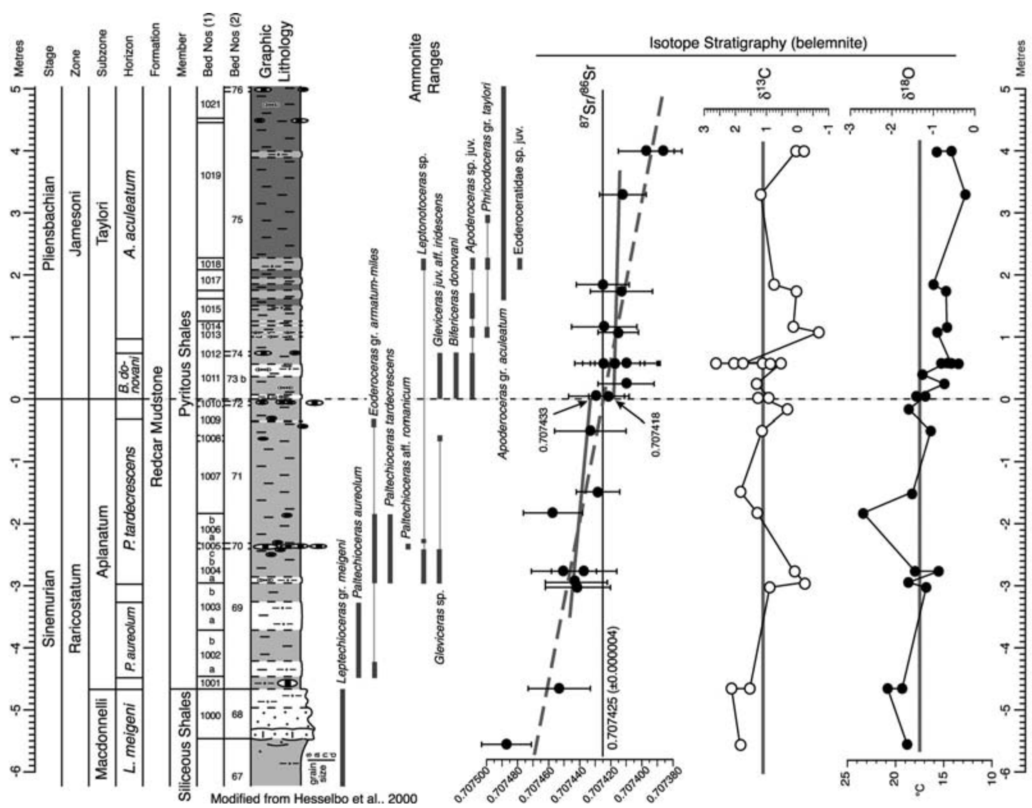

Figure 3 Detailed log of the Sinemurian-Pliensbachian boundary section at Wine Haven, Robin Hood's Bay. Bed numbers are from Dommergues and Meister (1992)[1] (beds 1000–1021) and Hesselbo and Jenkyns (1995)[2] (beds 67–76). Key as for Figure 1. Isotopic values are from diagenetically unaltered samples only. No ammonites have been recorded from between – 0.36 to 0 m in the section (from Hesselbo et al., 2000, partim from Howarth, 2002 figure 23, p. 147 and Meister et al., 2003).

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 and 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.

The boundary level and the fossil record

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 Foraminifera, 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.

Ammonites: the primary and unique marker

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 and Stampfli, 2000). The Psiloceratoidea dominated the first 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.

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 and 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 and Meister, 1990; Schlatter, 1990), it became apparent that its record was inadequate to define the base of the Taylori subzone (see Dommergues and 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 and Meister, 1992), although beyond Robin Hood's Bay its base can be identified only tentatively with Eoderoceratid taxa that require further study.

The ammonite assemblages in the Wine Haven section are characterized 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 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 and Meister, 2000) are compatible with the standard biozonation of Dean et al. (1961) and the succession of horizons proposed by Dommergues et al. (1994, 1997) and Meister (1995) (Figures 3 and 4).

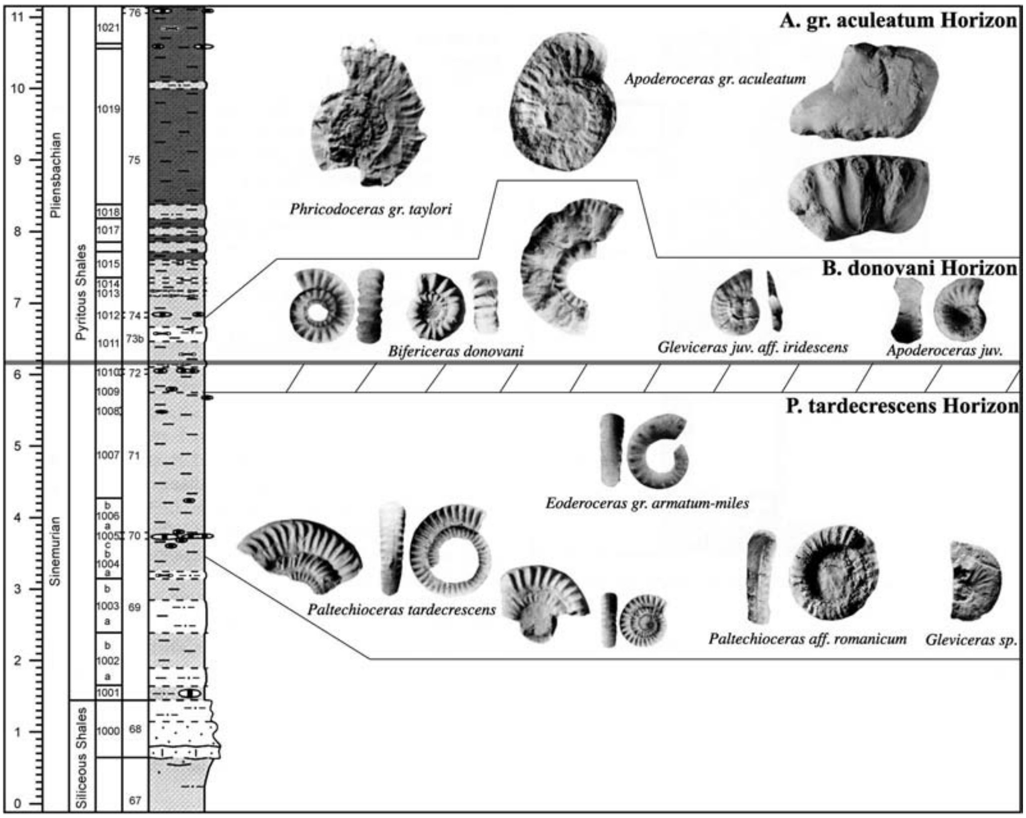

Figure 4 Ammonite faunas and horizons at the Sinemurian-Pliensbachian boundary (from Meister et al., 2003).

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): *Paltechioceras aureolum* (Simpson), *Eoderoceras* gr. *armatum* (Sowerby)-*miles* (Simpson).

P. tardecrescens horizon (level 69 partim – 71 partim): *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 (Howarth 2002).

LOWER PLIENSBACHIAN

Lower Jamesoni Zone

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

Two horizons are recognized:

B. donovani horizon (level 73b): *Bifericeras donovani* Dommergues and Meister (Figure 5), *Apoderoceras* sp. juv., *Gleviceras* juv. aff. *iridescens* (Tutcher and Trueman).

A. gr. *aculeatum* horizon (level 74–76): *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). Consequently, the boundary between the Pliensbachian and Sinemurian stages is placed very close to the base of bed 73, exactly at the base of bed 73b in the Wine Haven section (this means 6 cm above the mid-line of nodules forming bed 72) (Figure 6) and is charaterized by the association of *Apoderoceras* sp. and *Bifericeras donovani* Dommergues and Meister. The ammonite *Gleviceras* juv. aff. *iridescens* (Tutcher and 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 (Figure 6).

Bivalvia

In general, Jurassic bivalves are long-ranging, with a mean species longevity of European representatives of 15 Million years (Hallam, 1976). For this reason bivalves rarely contribute significantly to Early Jurassic correlation and zonation. Tentatively, a zonation of Early Jurassic strata in western Europe may be based on the *Gryphaea* lineage. Early Jurassic members of *Gryphaea* are abundant and have been studied intensively (e.g. Hallam, 1968, 1982; Johnson, 1993, 1994). Within western Europe, three species have been recognized: *Gryphaea arcuata* Lamarck from the Angulata Zone to the lower Semicostatum Zone, *Gryphaea mccullochi* J. de C. Sowerby from the upper Semicostatum Zone to the Jamesoni Zone, and *Gryphaea gigantea* J. de C. Sowerby from the Ibex Zone to the basal Bajocian. This informal zonation does not permit the identification of the Sinemurian-Pliensbachian stage boundary. A few bivalves are reported, however, whose stratigraphic ranges appar-

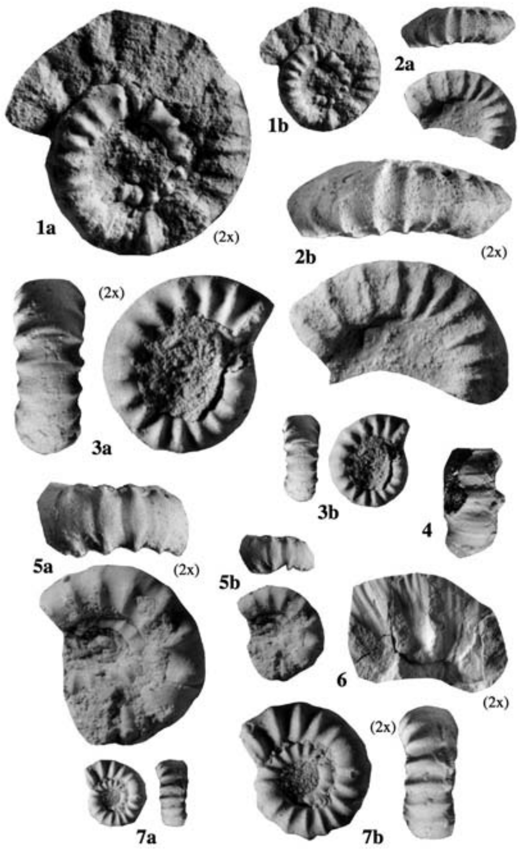

Figure 5 Bifericeras donovani Dommergues and Meister bed 73b, Donovani Horizon, Taylori Subzone, Lower Pliensbachian.

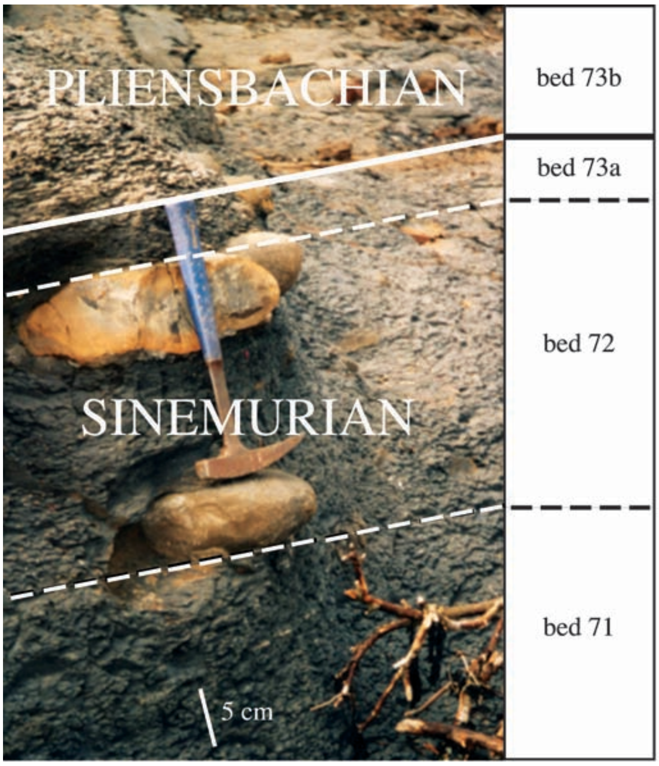

Figure 6 Detail of the Sinemurian-Pliensbachian boundary in Wine Haven (from Meister et al., 2003).

ently terminate in the Raricostatum Zone, while others seem to have originated in the Jamesoni Zone. In western Europe, these include *Protocardia truncata* (J. de C. Sowerby) which ranges from the Lower Pliensbachian Jamesoni Zone to the Toarcian Tenuicostatum Zone, whilst *Protocardia philippiana* (Dunker) occurs in Hettangian and Sinemurian strata (e.g. Hallam, 1987). First occurrences of bivalve species in the Jamesoni Zone are also recorded for the limids *Pseudolimea acuticostata* (Münster) and *Pseudolimea cristata* (Dumortier) (see Cox, 1944), and for the anomalodesmatan bivalve *Goniomya hybrida* (Münster).

A correlation chart for several circum-Pacific regions based on bivalves has been compiled by Damborenea et al. (1992). For South America, the *Otapiria neuquensis* Assemblage Zone has been recognized, which is approximately coeval to the Jamesoni, Ibex and Davoei zones (Riccardi et al., 1990).

Foraminifera

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. Only four samples yielded any fauna and all are located in the uppermost Sinemurian. All species are all well known Lower Jurassic taxa and belong to long-ranging morphogroups. The taxonomic details of these species and subspecies are listed in Meister et al. (2003, p. 286). All the other samples were barren.

The presence of *Dentalina matutina* (d'Orbigny) is diagnostic of the Sinemurian – Pliensbachian boundary (Copestake and Johnson, 1989) while the first occurence 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 and Johnson (1989) indicate that the boundary is marked by the first occurence of *Vaginulinopsis denticulatacarinata* (Franke). As no samples above the boundary yielded any fauna we did not record this taxon. Copestake and 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 and Johnson, 1989, figures 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, but this taxon has not been found in our investigation.

Aside from the published charts (Copestake and Johnson, 1989, figures 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 and 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 (Belemnite Marls and Green Ammonite Beds). The lowermost sample from the Lower Pliensbachian (Copestake, 1987, figure 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 and Johnson, 1989, figure 6.2.9) is well above the level of the proposed GSSP.

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 and Johnson (1989). However, a synthesis of the 'larger' foraminifera ranges for Europe and North Africa is given by Bassoulet (1997).

Palynology

A subset of 12 samples, out of the 34 samples collected for micropalaeontological investigations, has been selected for a palynological study. These samples cover the whole interval of interest across the Sinemurian – Pliensbachian boundary from the Macdonelli Subzone to the Taylori Subzone [lower part of bed 75].

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 from bed 69. 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 and 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 is dinoflagellate cysts. Especially from the Toarcian/Aalenian onward dinoflagellate cyst biostratigraphy can achieve 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 the scarce occurrences of small dinoflagellate cysts with inconspicuous morphologies (*Mancodinium*/*Maturodinium* spp., *Valvaeodinium* spp., *Dapcodinium* spp., *?Beaumontella* sp.) (e.g. Feist-Burkhardt and 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 and 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 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 and 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 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 from bed 69 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

Very few ostracod valves were found. 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 and Lord in N.W. Germany, although in the UK the appearance of both taxa is slightly above the Sinemurian-Pliensbachian boundary. Lord (1978, figure 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). Two synthesis are proposed for European marine and limnic ostracods by respectively Bodergat (1997) and Colin (1997).

Correlation potential

On the basis of ammonite assemblages the European Pliensbachian presently comprises 5 'Standard Chronozones', further subdivided into 15 Chronosubzones (Dean et al., 1961) and very often into detailed horizons sensu Callomon (1995) (see Meister et al., 2003, figure 2). The standard zonation (zone, subzone, horizon) is tentatively correlated with different zonations/biohorizons proposed for the Tethyan or Pacific regions and shows quite good potential for biochronological correlations between the different paleogeographical areas even if some taxonomic problems occur. (see also Dommergues et al., 1983; Meister, 1995, Dommergues et al., 1997; Palfy et al., 2000; Blau and Meister, 2000; Meister et al., 2005). This proposed zonation and correlation is based on the most recent ammonite data available from the literature (Figures 7, 8, 9).

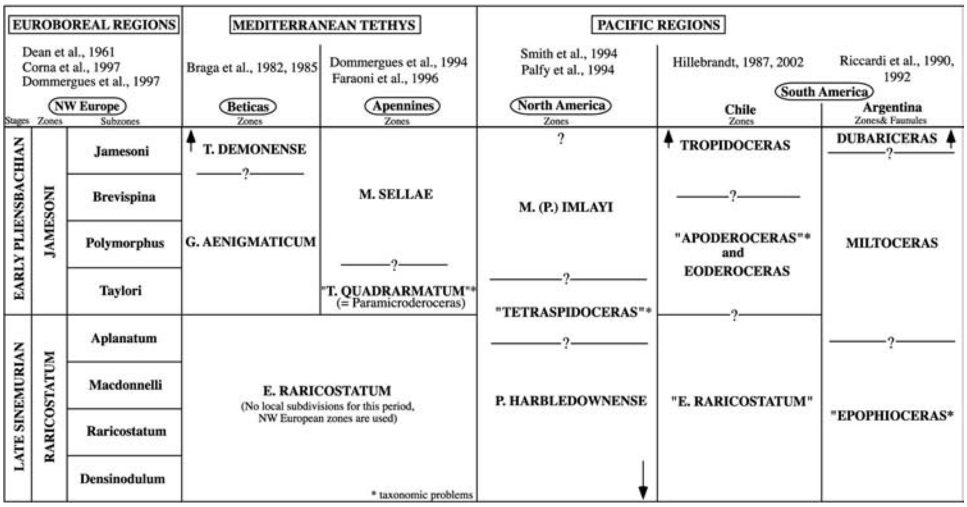

Figure 7 Tentative zonal correlations between Euroboreal regions, Mediterranean Tethys and Pacific regions (* indicates unresolved taxonomic problems).

STAGES	ZONES	SUBZONES	HORIZONS NW Europe and adjacent areas (Dean et al., 1961; Meister, 1995; Corna et al., 1997; Dommergues et al., 1997; Blau & Meister, 2000)	GSSP: WINE HAVEN,YORSHIRE (Dommergues & Meister, 1992; Howarth, 2002; Meister et al., 2003)
Lowermost PLIENSBACHIAN	JAMESONI	Jamesoni	*Uptonia jamesoni - bronni*	*U. jamesoni - bronni*
		Brevispina	*Platypleuroceras submuticum / Platy. tenuilobus*	?
			Platypleuroceras brevispina / Platy. brevispinoides	*P. brevispina*
		Polymorphus	*? Polymorphites polymorphus / E. (Coelod.) biruga*	*Platy. caprarium*
		Taylori	*Phricodoceras taylori / Apoderoceras ssp.*	*P. taylori / P. cornutum / Apoderoceras* ssp.
			**A. nodogigas / T. quadrarmatum / A. gr. aculeatum*	*A. gr. aculeatum/A subtriangulare/P. taylori*
			Bifericeras donovani	*B. donovani*
Uppermost SINEMURIAN	RARICOSTATUM (partim)	Aplanatum	*Paltechioceras tardecrescens / Palt. romanicum*	*P. tardecrescens / P.* aff. *romanicum / E. armatum-miles*
			Palt. tardecrescens / Palt. oosteri / Palt. recticostatum	*P. tardecrescens / E. armatum-miles*
			Paltechioceras aureolum	*P. aureolum / E. armatum-miles*
		Macdonnelli	*Leptechioceras meigeni / Leptechioceras macdonnelli*	*L. meigeni / L. macdonnelli*
			Leptechioceras meigeni	*L. meigeni*
			Leptechioceras meigeni / Paltechioceras charpentieri	*Paltechioceras planum*
		Raricostatum (partim)	*Paltechioceras liciense / Paltechioceras rothpletzi*	?

Figure 8 Biohorizon successions for the NW European regions and for the GSSP (Wine Haven) and correlations.

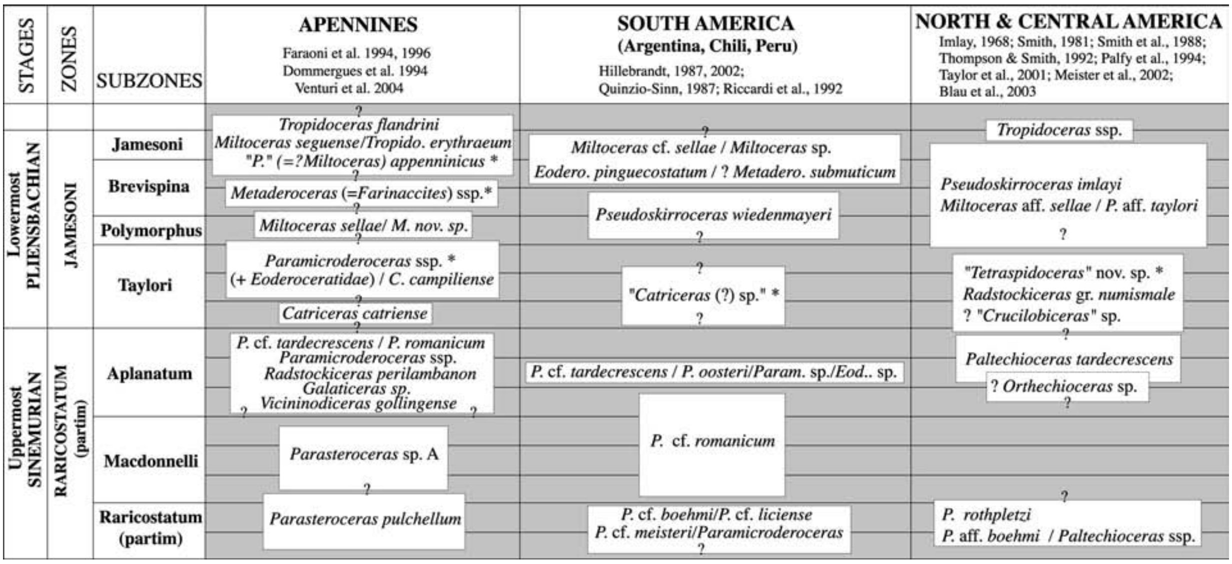

Figure 9 Proposed biohorizon succession for the Apennines (Mediterranean Tethys) and America (Pacific regions) and tentative correlations with the "standard" zones and subzones (* indicates unresolved taxonomic problems).

Studies on other biostratigraphic zonal schemes for the Pliensbachian are in progress (belemnites, bivalvia, brachiopods, ostracods, foraminifera, dinoflagellate cysts, calcareous nannofossils). They have been synthesized by Dommergues in 1997 and are completed here by S. Feist-Burkhardt and by M. Aberhan (Figures 10 and 11). Information about the ranges of echinoids and dasyclade algae are also provided respectively by Thierrry et al. (1997) and Bassoulet (1997).

Ammonite NW European Standard Zonation			Belemnites Combémorel, 1997		Brachiopods Alméras et al., 1997			Bivalves Hallam, 1968, 1982 Johnson, 1993, 1994
	Zones	Subzones	Zones	Subzones	NW Europe Zones	Tethys Zones	Tethys Subzones	Western Europe Zones
LOWER PLIENSBACHIAN (*partim*)	JAMESONI	Jamesoni	↑		↑	↑		
		Brevispina	Hastites clavatus (*partim*)	Coelotheuthis dens and Coelotheutis excavatus	Zeilleria (Cincta) numismalis (*partim*)	Gibbirhynchia curviceps (*partim*)	Cuersithyris davidsoni and Cuersithyris radstockiensis	
		Polymorphus						
		Taylori						Gryphaea mccullochi (*partim*)
UPPER SINEMURIAN (*partim*)	RARICOSTATUM	Aplanatum						
		Macdonnelli	Nannobelus acutus (*partim*)	Nannobelus oppeli (*partim*)	Piarorhyncia juvensis and Zeilleria (Cincta) cor (*partim*)	Spiriferina betacalcis, Piarorhynchia juvensis and Zeilleria (Cincta) cor (*partim*)		
		Raricostatum						
		Densinodulum	↓	↓	↓	↓		↓

Figure 10 Zonal and subzonal correlations for ammonites, belemnites, brachiopods and bivalves (from Dommergues, 1997 and completed by Aberhan).

Ammonite NW European Standard Zonation			Ostracoda Bodergat, 1997 Europe		Foraminifera Ruget & Nicollin, 1997	Foraminifera Copestake & Johnson 1989		Dinoflagellate cysts NW Europe Riding & Thomas, 1992		Dinoflagellate cysts Portugal Davies, 1985	Dinoflagellate cysts Offshore E Canada (Scotian Shelf) Davies in Williams et al.,1990		Calcareous Nannofossils Gardin, 1997	
	Zones	Subzones	Zones	Subz.	Faunal associations	Zones		Zones	Subz.	Zones	Zones	Subz.	Zones	Subz.
LOWER PLIENSBACHIAN (*partim*)	JAMESONI	Jamesoni	↑	?	↑	↑		↑	↑			↑	↑	↑
		Brevispina	AMALTHEI (*partim*)	Harpa	L. radiata mg M L. speciosa mg M M. prima (*partim*)	JF 9a	V. denticulatacarinata (*first appearance*)		b (*partim*)			B Liasidium variabile (*partim*)	Biscutum novum Nj 4 (*partim*)	Crepidolithus pliensbachiensis Nj 4 (*partim*)
		Polymorphus											— ? —	
		Taylori						Liasidium variabile (*partim*)		Dapcodinium priscum	Liasidium variabile (*partim*)			
UPPER SINEMURIAN (*partim*)	RARICOSTATUM	Aplanatum											Crepidolithus crassus Nj 3 (*partim*)	
		Macdonnelli	HAGENOWI (*partim*)	Plicata	L. radiata M. spinata I. muelensis	JF 8	N. issleri (*last occurrence*)		a (*partim*)			unnamed		
		Raricostatum												
		Densinodulum	↓					↓	↓			↓	↓	

Figure 11 Zonal and subzonal correlations for ammonites, ostracods, foraminifera, dinoflagellate cysts and calcareous nannofossils (from Dommergues, 1997 and completed by Feist-Burkhardt).

Isotope stratigraphy

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 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 ($\delta^{18}O$) show a marked rise of about 1 per mil over the 10 m interval sampled in detail (Figure 3), equivalent to a water temperature drop of about 5 ºC 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 the 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 a recognizable and correlatable pattern at the Sinemurian – Pliensbachian boundary.

Magnetostratigraphy: Winehaven to Boggle Hole Section, Robin Hood's Bay

A set of 22 oriented samples was collected for paleomagnetic study across the Pliensbachian–Sinemurian boundary in the Winehaven to Boggle Hole cliff/foreshore section. The samples were taken at a fairly wide spacing, to test the possibility of defining a magnetostratigraphy for the section. Various lithologies were sampled, including siderite concretions, siltstones, silty mudstones and silty limestones. The prepared specimens were measured on either a JR5A spinner magnetometer, or a GM400 CCL squid magnetometer. The NRM intensities range from 1.7 to 0.007 mA/m. Trials of the magnetisation behaviour during thermal demagnetisation suggest that heating-induced magnetomineralogical changes commonly occurred between 250 and 350 ºC. Consequently, most of the samples were treated to thermal demagnetisation up to 250 ºC (some to 325 ºC), followed by alternating field demagnetisation. This is similar to the best procedure identified by Yang et al. (1996) and Moreau et al (2002) in paleomagnetic studies of the Lower Jurassic of the Paris Basin (see also Hounslow et al. 2004). In the present study, one to three specimens were measured from most horizons, usually two per horizon. The analysis of these data is not yet complete, and a preliminary assessment is presented here. Most of the specimens show a N to NE downward-directed magnetisation (i.e. normal polarity), with a smaller number displaying either NW downward magnetisations, southerly upwards-directed magnetisations (i.e. reverse polarity), or demagnetisation paths showing progressive isolating of a southerly directed magnetisation. The later two types are interpreted as reverse polarity magnetisations. Hence, the interpretation suggests that specimens show either reverse or normal polarity Jurassic-like magnetisations, but some appear to be quite strongly contaminated by a 'present-day like' magnetisation.

These data define a reverse polarity interval within the Aplanatum Subzone (Figure 12), represented by samples from three horizons, extending from the lower part of bed 69 to the top part of bed 71 of Hesselbo and Jenkyns (1995). This magnetozone appears to provide a useful datum for correlation, since its top appears to be <0.5m below the base of the Pliensbachian. A further reverse polarity interval has been tentatively identified, possibly spanning parts of

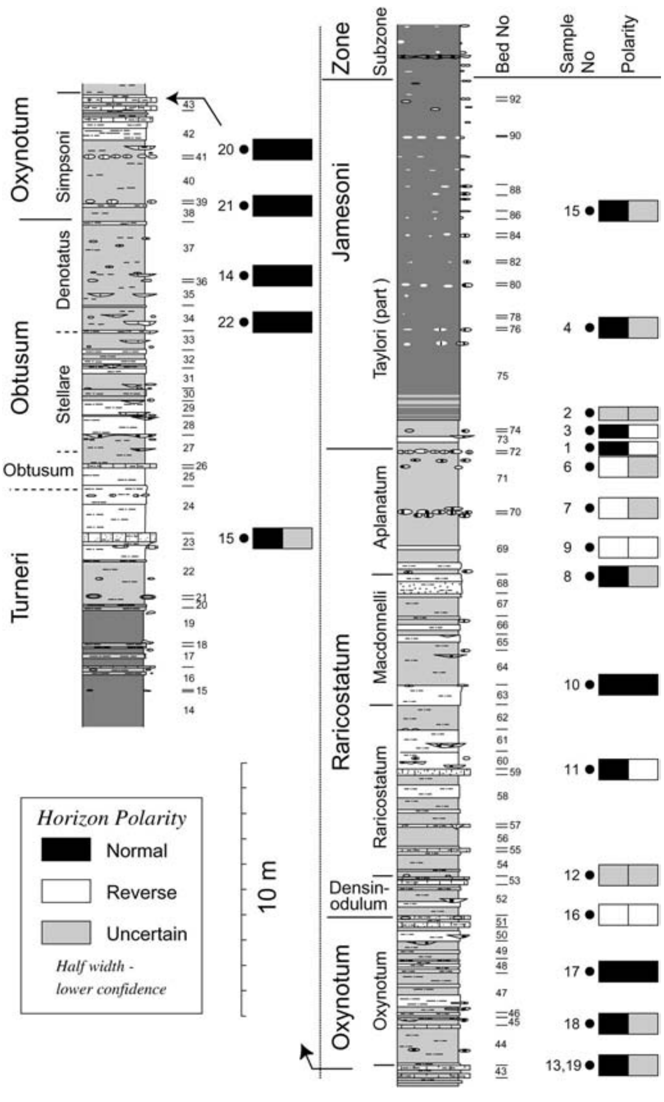

Figure 12 Summary magnetostratigraphy of the samples from the Winehaven to Boggle Hole section, Robin Hood's Bay. The lithological log and bed numbers are from Hesselbo and Jenkyns (1995). Magnetostratigraphic sample numbers are indicated, adjacent to the sampling position. 10m scale in 1m increments.

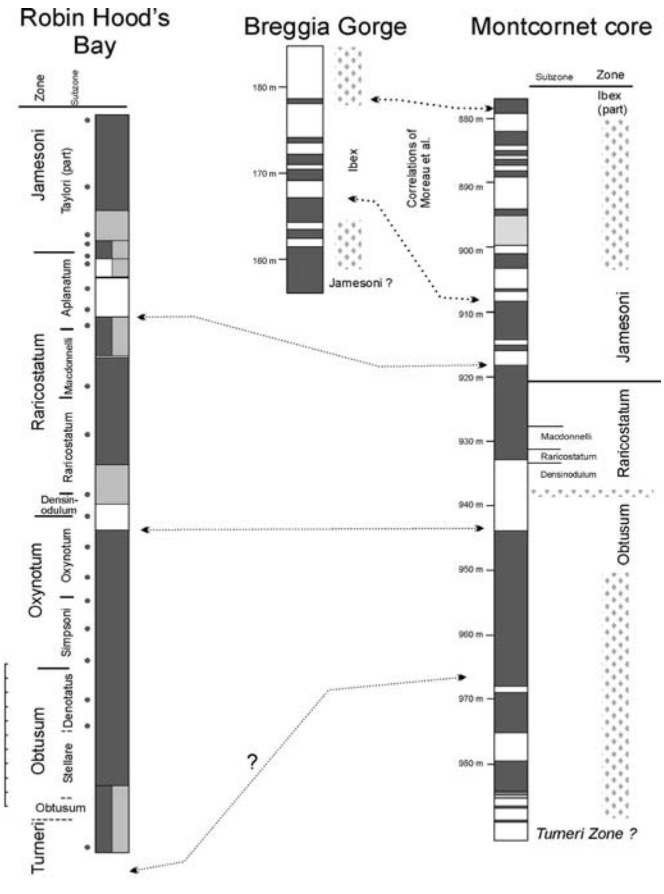

Figure 13 Comparison of the Robin Hood's Bay section to the base of the Pliensbachian section at Breggia Gorge, Switzerland (Horner and Heller, 1983) and the late Sinemurian succession in the Montcornet core (Yang et al., 1996; Moreau et al., 2002). Each is drawn in depth scale. Grey dotted interval represents uncertainty in placement of the biostratigraphic boundaries, and arrows probable correlations of magnetozones.

the Oxynotum and Densinodulum Subzones of the Sinemurian, although it is currently defined by results only from sample level 16 (Figure 12). These two reverse polarity intervals appear to be embedded within a predominantly normal polarity interval which spans the late Turneri Zone through to the middle part of the Jamesoni Zone.

This preliminary magnetostratigraphy compares well with the published studies from the Breggia Gorge in Switzerland (Horner and Heller, 1983), and the Montcornet borehole from the Paris Basin (Yang et al., 1996; Moreau et al., 2002). The reverse magnetozone at sample level 16 best equates with the reverse magnetozone from Montcornet, which there ranges from the mid uppermost part of the Obtusum Zone to the Raricostatum Subzone (Figure 13). However, Yang et al. (1996) found no diagnostic ammonites for the Oxynotum Zone, nor for the upper part of the Obtusum Zone. Consequently, the lower boundary of this reverse magnetozone cannot be placed with certainty relative to the biostratigraphy at Montcornet. However at Winehaven, this reverse magnetozone clearly starts in the Oxynotum Subzone.

From the data of Yang et al. (1996) a predominantly normal magnetozone extends downward into the lower part of the Obtusum Zone, where reverse polarity magnetozones occur, which we have not detected. This may be either because of our wide sample spacing in this part of the section, or alternatively the lack of good evidence for the position of the Turneri Zone in the Montcornet core. Hence, this normal magnetozone may extend into the Turneri Zone, as it appears to do in the Robin Hood's Bay sections (Figure 13).

The magnetostratigraphy suggests that the reverse magnetozone within the Aplanatum Subzone at Winehaven probably correlates to the reverse magnetozone between 918-915 m in the Montcornet core (Figure 13). However, Moreau et al. (2002) placed the position of the Jamesoni Zone in the Montcornet core at 920.65 m on the basis of the occurrence of the ammonite *Polymorphites* sp. at 920.7 m (indicative of Jamesoni Zone), above *Paltechioceras* gr. *tardecrescens* at 920.6 m (indicative of the Aplanatum Subzone). The magnetostratigraphic correlation and presence of *Paltechioceras tardecrescens* at both Winehaven and Montcornet are contradictory. Diagnostic ammonite fauna at other levels within the Raricostatum or Jamesoni Zones at Montcornet were lacking, and hence it may be that either the sparse ammonite fauna is misleading, or magnetisation acquisition at the Winehaven section was delayed in comparison to that at Montcornet. The sparse sampling in the Jamesoni Zone at Winehaven cannot discount the possibility that further reverse magnetozones might be present within this Zone.

Magnetostratigraphic studies from condensed pelagic limestones at Bakonycsernye (Márton et al., 1980), Fonte Avellana and Cingoli (Channell et al.,1984) show a dominance of reverse polarity across the Sinemurian- Pliensbachian boundary, in stark contrast to results presented here. This may be because the chronostratigraphy in these sections has both poor biostratigraphic control and hiatuses in the thin pelagic limestone successions may be frequent, as suggested by Opdyke and Channel (1996).

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 International Commission on Stratigraphy (ICS) (Remane et al., 1996):

- 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 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.
- The GSSP does not include potential chronometers for radiometric dating.
- A discreet reverse polarity magnetozones are present and spans much of the latest Sinemurian Aplanatum Subzone. It terminates <0.5m below the Sinemurian-Pliensbachian boundary and may prove a valuable chronostratigraphic marker.

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Appendix I

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Hutchison 'Young Scientist' Fund

William Watt Hutchison, "Hutch" to his many friends around the world, was a Scots-born Canadian geologist who served Canada and the IUGS in myriad dynamic and creative ways. Most notably, he served as the IUGS Secretary General (1976–1980) at a pivotal time in its history, and as IUGS President (1984–1987). The same boundless energy, enthusiasm, skill in communications, and ability to foster teamwork that characterized his work with the IUGS also carried him to preeminent scientific administrative positions in the Canadian Government, where he served as Director General of the Geological Survey of Canada and as Assistant Deputy Minister of Earth Sciences. His distinguished career was terminated in 1987 by his untimely death at the age of 52, following a painful struggle with cancer.

One of Hutch's last wishes was to establish under IUGS auspices a memorial foundation intended to promote the professional growth of deserving, meritorious young scientists from around the world by supporting their participation in important IUGS-sponsored conferences. The first 3 beneficiaries of the ***Hutchison "Young Scientist" Foundation*** attended the 28th International Geological Congress (IGC) in Washington, D.C., in 1989.

Initially, earned interest on the funds available to the Hutchison Foundation were insufficient to sustain comparable grants every four years without seriously eroding the principal. For that reason, the IUGS made no grants from the Foundation for the 30th IGC (1996), preferring instead to strengthen the fund by allowing it to earn interest for a longer period of time and by appealing for donations from the international geologic community. Grants from the Foundation again supported deserving young scientists beginning with the 31st IGC (2000), and should continue for future Congresses. The IUGS would like to expand the resources of the Foundation to make it possible also to offer support to deserving young scientists to attend other important IUGS-sponsored scientific meetings. The ***Hutchison "Young Scientist" Foundation*** is a worthy cause that honors a fine, caring man and a distinguished, public-spirited scientist and administrator. The foundation also celebrates and promotes those things that gave Hutch the most professional satisfaction: geology, international scientific collaboration, and stimulating young minds.

The IUGS welcomes contributions to the ***Hutchison "Young Scientist" Foundation***. Please send donations to:

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