by G. Pavia and R. Enay

Definition of the Aalenian–Bajocian Stage boundary

The Global boundary Stratotype Section and Point (GSSP) for the Bajocian Stage, formally defined at the base of bed AB11 of the Murtinheira section at Cabo Mondego (Portugal), has been ratified by the IUGS. Multidisciplinary biostratigraphical data, mainly based on ammonite and calcareous nannofossil assemblages, assure worldwide correlations; magnetostratigraphic data increase the correlation power. The position of the boundary coincides with the first occurrence of the ammonite assemblage characterized by Hyperlioceras mundum *and related species (*H. furcatum, Braunsina aspera, B. elegantula*). The boundary lies just below the nanno-horizon of the entry of* Watznaueria communis *and* W. fossacincta, *and closely corresponds with an inversion to normal polarity correlated with the up-to-date Jurassic magnetic polarity time scale. An Auxiliary Stratotype Point (ASP) is also selected at the base of bed U10 of the Bearreraig Bay section on the Isle of Skye, Scotland, as the complementary reference for the palaeobiological key of the Bajocian lower boundary, i.e. the evolutionary transition* Graphoceras–Hyperlioceras.

Introduction

Multidisciplinary research on the boundary stratotype, developed over many years by the Bajocian Working Group (BWG), was brought to a conclusion in 1994 with the nomination of the Murtinheira section at Cabo Mondego, Portugal, as the best outcrop for defining the Global boundary Stratotype Section and Point (GSSP) of the Stage. After a positive ballot within the BWG, the resolution was submitted to the Congress of the International Subcommission on Jurassic Stratigraphy (ISJS) in Mendoza, Argentina, in October, 1994. In addition to the GSSP, the selection of the Bearreraig Bay section on the Isle of Skye, Scotland, as the Auxiliary Stratotype Point (ASP) was also suggested as a complementary outcrop where the palaeobiological key (evolutionary transition within the ammonite group *Graphoceras–Hyperlioceras*) for recognizing the Bajocian lower boundary is finely represented. The consensus at the Mendoza meeting encouraged submission of the proposal of both the Bajocian GSSP and the ASP (Pavia and others, 1995) to the ISJS which unanimously accepted the resolution.

This paper gives details on the definition of the Bajocian GSSP recommended by the ICS at the end 1995. The proposal was formally ratified by the IUGS at the meeting of the Executive Committee in January 1996.

The lower boundary of the Bajocian Stage

The original definition of the Bajocian Stage dates back to 1850 (d'Orbigny, 1842–51, p. 606, and 1849–52, pp. 477, 483; see Rioult, 1980 for references) with geographic references to Bayeux and the area around Caen, NW France. In the Jurassic Colloquium held in Luxembourg, Rioult (1964) proposed the section at Sainte-Honorine-des-Pertes, near Bayeux, as the stratotype of the Bajocian Stage. However, Pavia (in Cresta and Pavia, 1994, p. 93) observed that stratigraphic condensation and fossil reworking dictate exclusion of any section in the area of Bayeux as the stratotype of the Stage.

On the basis of ammonite fossil assemblages, the European Bajocian presently comprises seven 'Standard Zones' (Figure 1),

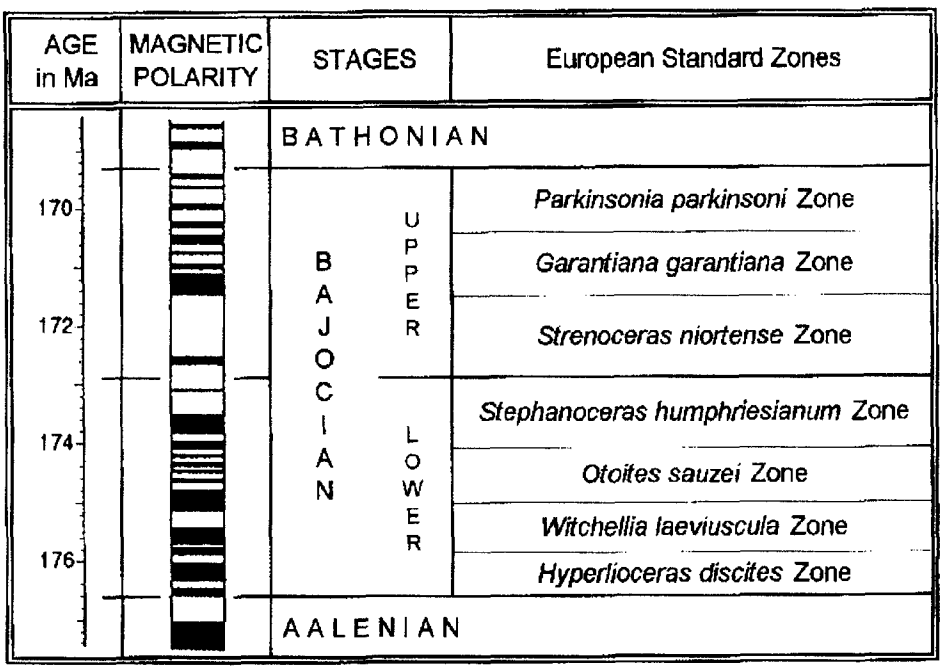

Figure 1 Bajocian ammonite Standard Zones in Europe correlated with magnetic polarity time scale (modified from Gradstein and others, 1994; Ogg, 1995).

which have been tentatively correlated with the standard ones proposed for the Pacific Realm (Hillebrandt and others in Westermann, 1992, p. 254). The biochronological correlation power of the European Standard Zones thus would spread out the palaeobiogeographical sectors where they are usually recognized and applied. Other biostratigraphic zonal schemes are in progress, e.g. for calcareous nannofossils, palynomorphs, inoceramid bivalves and others (Cresta and Pavia, 1994).

The Bajocian is divided in two substages (Pavia *in* Michelsen and Zeiss, 1984, p. 65). The European Lower Bajocian encompasses the *Hyperlioceras discites* to the *Stephanoceras humphriesianum* Zones. The base of the *H. discites* Zone is traditionally used to determine the base of the substage. For its recognition, in many Jurassic Colloquia (Erlangen 1984, Lisboa 1987, Poitiers 1991, Mendoza 1994) and related BWG meetings (Cresta and Pavia, 1990; Morton, 1991; Cresta and Pavia, 1994), the evolution of the ammonite family Graphoceratidae has been stated as providing the highest biostratigraphical resolution. In particular the first occurrence of species of the genus *Hyperlioceras*, evolved from *Graphoceras*, has been largely accepted as being the biochronological event which best enables recognition of the basal boundary of the Bajocian Stage, particularly in the Sub-Mediterranean and Sub-Boreal Provinces.

The recent usage means that the *H. discites* Zone is an Assemblage Zone in the sense of the International Stratigraphic Guide (Salvador, 1994). It is mainly characterized by species of the genus *Hyperlioceras*. On the basis of the more recent literature, the lower boundary of the *H. discites* Zone can be assumed to be marked by the first occurrence of the ammonite assemblage with *Hyperlioceras mundum* and related species (*H. furcatum, Braunsina aspera, B. elegantula*). Early forms of the evolutionary transition *Graphoceras–Hyperlioceras* (Callomon and Chandler in Cresta and Pavia, 1990, p. 96; Morton in Cresta and Pavia, 1994, p. 79) are referable to the topmost Aalenian.

Two sections have been demonstrated to be the best for recording such a biostratigraphic datum: Murtinheira at Cabo Mondego in Portugal and Bearreraig Bay on the Isle of Skye in Scotland. Both furnish supplementary biostratigraphic and magnetostratigraphic data. The Scottish section, as far as the ammonite biostratigraphy is concerned, is limited to Graphoceratidae and can be regarded as the reference section for the evolution within this family and for the onset of the genus *Hyperlioceras*. On the contrary, the Murtinheira section contains more diversified ammonite assemblages useful for worldwide correlation.

In conclusion, the lower boundary of the *H. discites* Zone in the Murtinheira section can be used to define the GSSP for the base of the Bajocian Stage. In the same time the section of Bearreraig Bay is formally proposed as the ASP of the Bajocian Stage.

Improving the proposal for the GSSP

Since 1988, BWG members have met in Italy (Cresta and Pavia, 1990), Scotland (Morton, 1991) and Morocco (Cresta and Pavia, 1994) both to discuss the biostratigraphical key for the recognition of the Bajocian basal boundary and to develop a common proposal for defining the Bajocian GSSP according to the Guidelines of the ICS (Cowie and others, 1986).

In 1988 at Piobbico, central Italy, several sections were documented: Digne, south-eastern France, by G. Pavia; Barranco de Agua Larga, southern Spain, by A. Linares and J. Sandoval; Wutach, southern Germany, by G. Dietl; Dorset, southern England, by J. Callomon and R. Chandler; Bearreraig Bay, Isle of Skye, Scotland, by N. Morton; Murtinheira, Cabo Mondego, Portugal, by R. Rocha and collaborators. Discussion for defining the Bajocian lower boundary stratotype centred on the sections of Isle of Skye and Cabo Mondego. The conclusions were brought together in a document supported by most of the participants:

1 The basal boundary of the *H. discites* Zone is marked by an ammonite assemblage which contains the *H. mundum* group, late representatives of *Graphoceras* and *Haplopleuroceras*; other taxa, like *Euhoploceras* and Hammatoceratidae, did not seem so useful for stratotype definition because of wide biostratigraphic range and low frequency in the Sub-Mediterranean sequences.
2 The Murtinheira section was provisionally regarded as the more suitable candidate for GSSP with the Bearreraig Bay section being considered as the auxiliary stratotype.
3 For these two sections, nevertheless, more information on biostratigraphy and magnetostratigraphy was to be done.

During the BWG meetings of Portee in Scotland (1991) and Marrakech in Morocco (1994) no agreement on a single proposal was reached. The dilemma was that:

1 the Bearreraig Bay section is better for documenting the evolutionary lineage within the ammonite family Graphoceratidae and the early development of *Hyperlioceras*;
2 the Murtinheira section is more suitable for direct correlation based on ammonite assemblages;
3 no alternative candidates had been submitted.

In a postal vote within the BWG, a majority of 65.7% favoured Murtinheira. The resolution to define the GSSP of the Bajocian Stage in the Murtinheira section was presented during the meeting of the ISJS (Argentina, 1994); it was also suggested that a joint proposal be made for the Bearreraig Bay section to become the Bajocian ASP.

In order to refine the proposal as much as possible, a group of workers met in Coimbra (Pavia and others, 1995) with the aim of revising the taxonomy of graphoceratid ammonite specimens on which the Bajocian lower boundary had been formerly recognized at Cabo Mondego by Rocha and others (*in* Cresta and Pavia, 1990, p. 49, pls. 1-4) and by Henriques and others (*in* Cresta and Pavia, 1994, p. 79). By availability of Buckman's types and comparative material specially brought by R. Chandler and N. Morton from Great Britain (Dorset and Skye), it was possible to improve and sometimes modify previous determinations of Graphoceratidae listed from Cabo Mondego. Even though rare specimens referable to *Hyperlioceras* had been reported from beds AB9 and AB10 of the Murtinheira section, the most significant biostratigraphical change occurs between beds AB10 and AB11. It records the first occurrence of the ammonite assemblage with *H. mundum* and related species. This assemblage is precisely correlatable with other ammonite successions from Sub-Mediterranean (e.g. Morocco) and Sub-Boreal (e.g. Dorset, Skye) localities. As a result of the revision, it has been proposed to define the Bajocian GSSP at the base of bed AB11 of the Murtinheira section.

The Murtinheira section (west Portugal)

The relevance of the sections of Cabo Mondego was firstly pointed out by Mouterde and others (1972) and all the subsequent works strongly emphasized its importance for correlation with other provinces (e.g. Rocha and others *in* Cresta and Pavia, 1990, p. 49; Henriques, 1992; Henriques and others *in* Cresta and Pavia, 1994, p. 63; Henriques and others, 1996), based on the richness in ammonites which show both north-European and Mediterranean affinities. The main stratigraphic data, useful to define the Bajocian GSSP, are here summarized from Pavia and others (1995).

Recommended stratotype

Cabo Mondego is located on the Portuguese Atlantic coast, 40 km west of Coimbra and 7 km north of Figueira da Foz. The Murtinheira section is at the foot of Cabo Mondego cliff, south-west of the village of Murtinheira (Figure 2). There is exceptional exposure along the cliffs and inland for about 5 km (the northern flank of Serras da Boa Viagem and Alhadas) without significant facies variation or

structural complication. The beds are monoclinal and dip at about 30° S. The precise geographical location of the GSSP is shown on the 1:25 000-scale topographic map of Vais (sheet 238A) by coordinates M = 134.4, P = 359.2.

The succession consists of marine sediments ranging from Upper Toarcian to Middle Callovian with a thickness exceeding 400 m. The Aalenian–Bajocian section corresponds to a more-or-less rythmic alternation of gray limestones and marls (*Calcários e margas do Cabo Mondego* formation), sometimes very fossiliferous (ammonites, brachiopods), with bioturbation marks, coal fragments, disseminated pyrite and rare celestite nodules. Strata are normally thin (0.15 to 0.25 m) and the stratification surfaces are more-or-less regular. At the Lusitanian Basin organization scale, the Aalenian–Bajocian boundary is placed within the Megasequence F (Soares and others, 1993) between discontinuity 6, which marks a generalized absence of the base of mid-Aalenian *L. murchisonae* Zone, and discontinuity 7 placed towards the top of the *H. discites* Zone.

The Aalenian–Bajocian boundary is defined at 77.8 m from the base of the section measured along the coast (Henriques, 1992), at the base of bed AB11 of former works (e.g. Henriques and others *in* Rocha and Soares, 1988, p. 243) or bed M337 of recent works (e.g. Henriques and others *in* Cresta and Pavia, 1994, p. 63) (Figures 3 and 4).

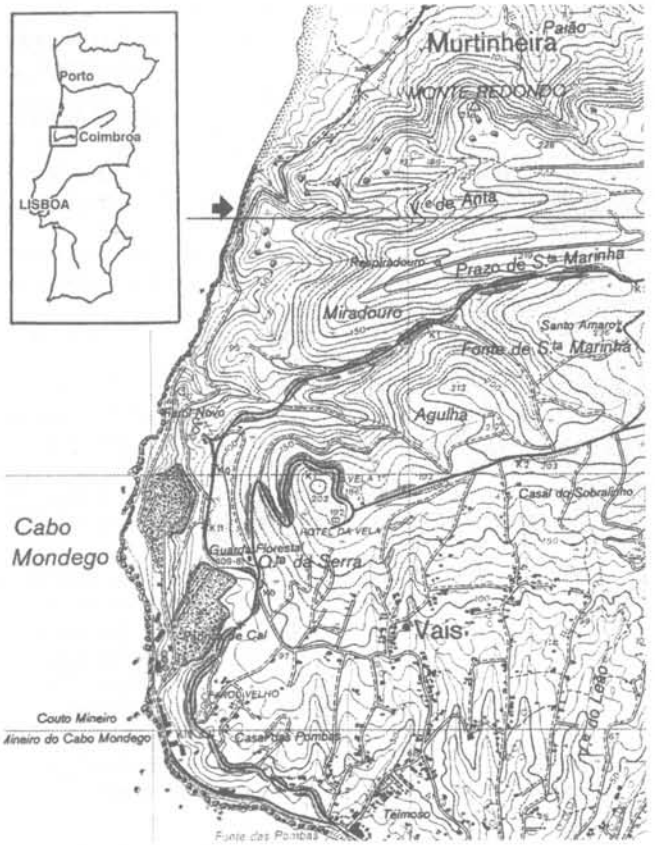

Figure 2 Location of the Murtinheira section in the northern part of the Cabo Mondego cliff (arrow), 7 km north of Figuera da Foz, west Portugal. 1:25000 topographic map of Vais, sheet 238 A, coordinates M=134.4, P=359.2.

Ammonite record

The ammonite assemblages in the Cabo Mondego sections (Rocha and others in Cresta and Pavia, 1990, p. 49, pls. 1-4) have several biostratigraphic advantages:

1 the material is quite abundant and easy to sample;
2 it is well preserved as internal moulds providing easy identification;
3 in general, it includes individuals representing different ontogenetic stages; this fact is particularly evident for microconchs which are more frequent due to paleoecological and taphonomic reasons;
4 ammonites can be sampled in widespread micritic limestone beds and are contemporaneous with the sediment, as they correspond to resedimented elements in the taphonomic sense of Fernandez Lopez (1991).

The definition of the Aalenian—Bajocian boundary at bed AB11 is based on ammonite biostratigraphy (Figure 5). In particular, it marks the first occurrence of the assemblage with *Hyperlioceras mundum* and related species (*H. furcatum, Braunsina aspera, B. elegantula*), even though the genus *Hyperlioceras* makes early appearance in the underlying beds AB9 and AB10, according to Fernandez Lopez and others (*in* Rocha and Soares, 1988, p. 301). The *H. mundum* assemblage also contains other *Hyperlioceras* taxa and late representatives of *Graphoceras* and *Haplopleuroceras*, as well as species of *Zurcheria*, *Parazurcheria* and *Fontannesia*. Less frequent ammonites of the basal Bajocian refer to genera *Euhoploceras*, *Son-*

Figure 3 The GSSP of the Bajocian Stage (arrow indicates bed A11) in the alternating limestones and marls of the Murtinheira section, foot of the Cabo Mondogo cliff.

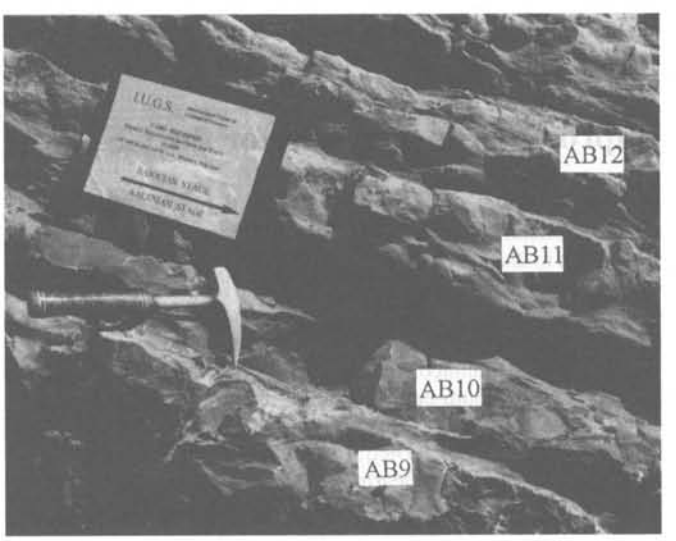

Figure 4 The position of the GSSP of the Bajocian Stage at the base of bed A11 (arrow) in the Murtinheira section.

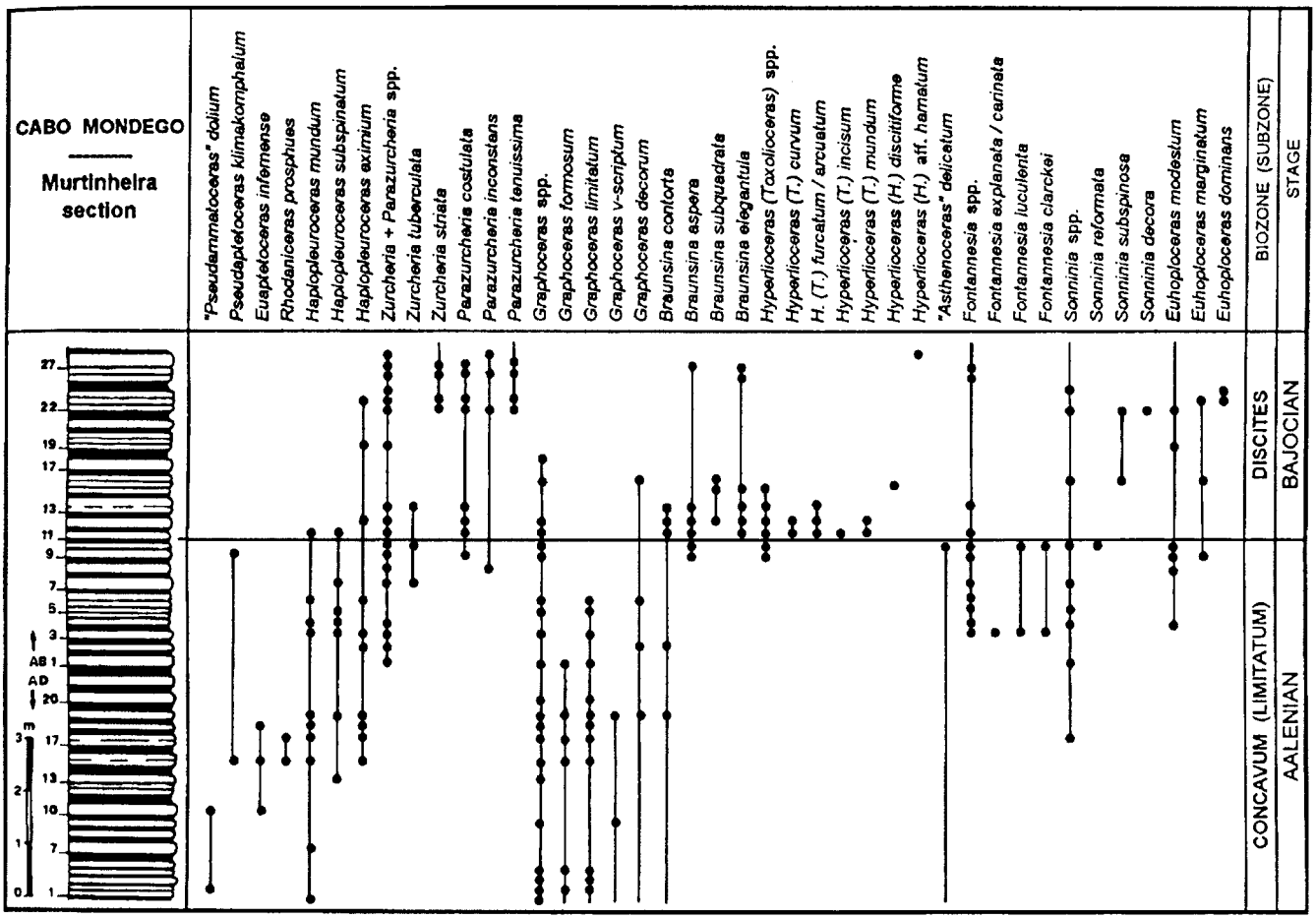

Figure 5 Distribution of the most significant ammonites through the Aalenian—Bajocian boundary in the Murtinheira section.

ninia, 'Docidoceras', Pelekodites, Nannoceras, Praestrigites, Bradfordia, 'Asthenoceras', Protoecotraustes and *Trilobiticeras.*

Calcareous nannofossil record

Detailed studies across the Aalenian–Bajocian boundary have been published recently by Henriques and others (*in* Cresta and Pavia, 1994, p. 63). The nannofossil assemblages are dominated by specimens of *Schizosphaerella punctulata, Lotharingius contractus, L. velatus, Triscutum tiziense, Biscutum depravatum* and *Discorhabdus criotus.* The genera *Crepidolithus* and *Carinolithus*, which dominate the early Jurassic assemblages, are rare. The results point to a gradual turnover across the Aalenian–Bajocian boundary with change in nannofossil dominance rather than abrupt appearences and/or disappearences of taxa. This change is initiated by the Watznaueriacea in the upper *G. concavum* Zone, from where the genus *Lotharingius* is more and more replaced by *Watznaueria* and *Cyclagelosphaera.*

Several nanno-horizons have been detected at the Aalenian–Bajocian transition, based on the onset of different species of *Watznaueria* (Figure 6). Two nanno-horizons are observed in the *G. concavum* Zone, defined by the appearence of *W. ovata* (AB1) and *W.* aff. *communis* (AB3). Six nanno-horizons characterize the *H. discites* Zone. Some data can be pointed out: *W. fossacincta* and *W.* aff. *manivitae* are observed from sample AB13; the entry of *W. communis* is recorded in sample AB14; the first occurrence of *W. britannica* is observed in sample AB17; *W. manivitae* appears in sample AB34.

The presence of forms such as *W.* aff. *communis* and *W.* aff. *manivitae*, precursory of the nominate species, and the gradual change in the nannofloral assemblages suggest continuous sedimentation across the boundary, as confirmed also by sedimentology.

Magnetostratigraphy

The succession of the Aalenian–Bajocian boundary has been sampled in a total thickness of 16 m. The intensity of rock magnetization in the Murtinheira section is generally weak (between 6.7×10^{-5} and 2.2×10^{-4} A/m), but it is measurable using a triaxial high-sensivity cryogenic magnetometer (CCL-GM400). The magnetic stability of the samples has been investigated by incremental thermal demagnetisation. The majority of samples carry two principal components of magnetisation. The lower stability component is progressivelly removed during demagnetisation in average up to 250°C and appears to represent a normal polarity overprint near the local present geomagnetic field. The high stability component direction results to be similar to the Dogger direction indicated for the Iberian Peninsula (Schott and others, 1981) after applying the bedding-tilt correction (average 40° towards 130°). Then it is clear that this component represents the record of the geomagnetic field polarity at the time of sedimentation. The values of the natural remanent magnetisation have positive inclinations; but during demagnetisation about 30% of the samples changes polarity and finally there are two groups of clear opposite polarity.

The final results of the palaeomagnetic field polarity record of the Aalenian–Bajocian boundary at Cabo Mondego are shown in Figure 7. The Bajocian lower boundary, at the base of bed AB11 of the Murtinheira section, coincides with an inversion from reversed to normal polarity, which can be correlated with the Jurassic magnetic

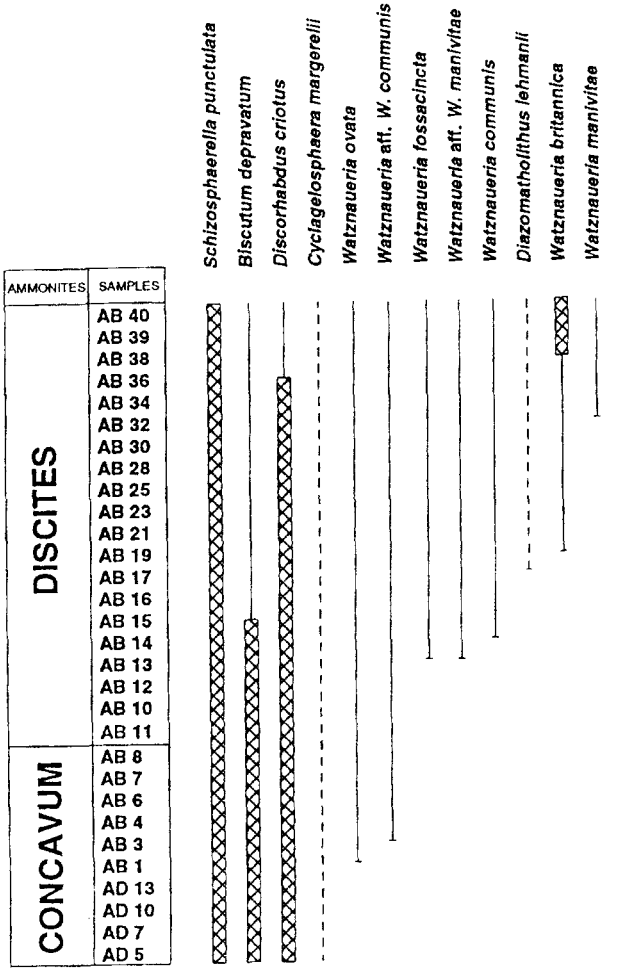

***Figure 6** Selected calcareous nannofossil FO at the Aalenian–Bajocian boundary in the Murtinheira section (modified from Henriques and others* in *Cresta and Pavia, 1994).*

polarity time scale (Ogg, 1995). Between beds AB11 and AB23, in the lower *H. discites* Zone, an interval of normal polarity is recorded, also in agreement with Steiner and others (1987).

The Bajocian ASP in the Bearreraig Bay section (Scotland)

Name and geographical location of the ASP

Bearreraig Bay, west Scotland, eastern coast of the Isle of Skye some 10 km north of Portree. Topographic map 1:25000, sheet NG45/55 (Trotternish); National Grid reference: NG51705271.

Position of the ASP

The uppermost Aalenian (*G. concavum* Zone) and lowermost Bajocian (*H. discites* Zone) occur in a thick sequence of silty shales, the Udairn Shale Member of the Bearreraig Sandstone Formation. The outcrops and succession have been described in the proceedings of previous BWG meetings (Morton *in* Cresta and Pavia, 1990, p. 23, and 1994, p. 79). The Auxiliary stratotype Section and Point is located at the base of bed U10 in the lower Udairn Shale Member, 12.4 m above the base of the section recently revised by Morton (*in* Pavia and others, 1995). Fossils are preserved in scattered calcareous nodules.

Major character

The first occurrence of the ammonite assemblage with *Hyperlioceras mundum* and related species is well documented. This overlies an assemblage with *H. incisum* which marks the first step in the evolutionary lineage *Graphoceras* to *Hyperlioceras* at the topomost Aalenian. In particular, the following biostratigraphical markers are registered: (1) top bed U9 (1 m below the ASP): first occurrence of *H. incisum* (M)—*rotabilis* (m) and *H. micca*; (2) bed U10: first occurrence of *H. mundum, H. furcatum, B. aspera*; (3) middle bed U16 (9 m above the ASP): transition from *H. mundum* to *H. walkeri*; (4) middle bed U18 (11 m above the ASP): last representatives of *G. limitatum* (M)—*carbatinum* (m).

Correlation

In summary, the main biostratigraphical features of the ASP are:

1 **Ammonites**—Representatives of Hammatoceratidae and Sonninidae, although rare, improve correlations with the GSSP.
2 **Bivalves**—Fossil assemblages found in the lower part of the Udairn Shale Member show a significant change in the bivalve composition from the *G. concavum* Zone into the *H. discites* Zone. In particular, *Mytiloceramus polyplocus* first appears near the base of the Bajocian (top of bed U9). The species is also present at the base of the Bajocian in north Germany (Metz, 1994, pers. comm.), confirming its biostratigraphical potential in Europe. Inoceramids are widely used for Middle Jurassic biostratigraphy in eastern Russia and the circum-Pacific (Damborenea and others in Westermann, 1992), where *M. polyplocus* is recorded from the Upper Aalenian *P. tugurense* Zone.
3 **Microfossils**—Good results have been obtained with foraminifera, dinoflagellates, spores/pollen and calcareous nannofossils. For example, the base of the Bajocian is marked by radiation of gonyaulacacean cysts, and the boundary lies within the NJ8b nannofossil Subzone.
4 **Sequence stratigraphy**—The Aalenian–Bajocian boundary is placed within the genetic sequence D of the Hebrides Basin (Morton and others, 1987).

Conclusions

The GSSP of the Bajocian Stage, ratified by the Executive Committee of the IUGS in January 1996, has been defined at the base of bed AB11, at the point located 77.8 m from the base of the Murtinheira section at Cabo Mondego (western Portugal). The section fulfills most of the requirements indicated in the Guidelines of the ICS:

1 Succession of more than a hundred meters of rhythmic alternation of gray limestones and marls corresponding to an outer zone of sedimentation, beyond the platform, in the most subsiding part of northern Lusitanian Sub-basin. The Aalenian–Bajocian boundary is placed within the Megasequence F of the Lusitanian Basin.
2 Absence of unconformities in the interval from uppermost Aalenian to lowermost Bajocian with continuous exposure from Upper Toarcian (Lower Jurassic) to Callovian (Middle Jurassic).
3 Correlation by means of ammonite and calcareous nannofossil assemblages which show significant turnovers at the boundary, correlatable within Tethyan and Pacific Realms. In particular: bed AB11 is marked by the first occurrence of the ammonite assemblage with *Hyperlioceras mundum* and related species (*H. furcatum, Braunsina aspera, B. elegantula*); at about 0.30 m

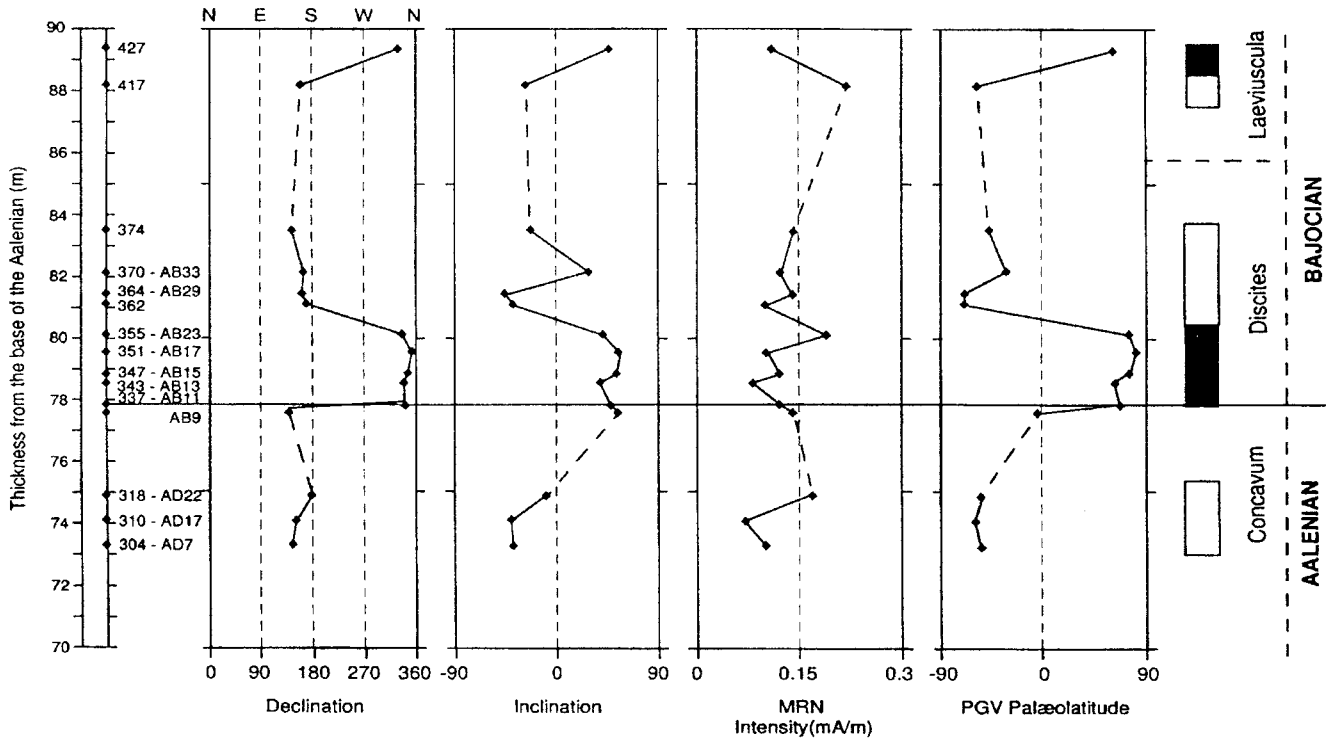

***Figure 7** Magnetostratigraphic sequence across the Aalenian–Bajocian boundary in the Murtinheira section (modified from Henriques and others in Cresta and Pavia, 1994).*

above the boundary, bed AB13 registers the first occurrence of nannofossils *Watznaueria fossacincta* and *W.* aff. *manivitae*.

4 Well correlatable palaeomagnetic results with an inversion from reversed to normal polarity exactly at the lower boundary of the Bajocian Stage.

5 Easy accessibility of the section well exposed on the cliff at Cabo Mondego, which is subject to marine erosion.

6 Classification of the Cabo Mondego area as a Natural Monument is in progress. A formal petition was submitted to the President of the Portuguese Republic in 1994.

The Bearreraig Bay section (Isle of Skye, west Scotland) has been accepted as the Bajocian ASP within the same GSSP proposal. It provides fine documentation of the ammonite lineage *Graphoceras-Hyperlioceras*, and complementary biostratigraphical data mainly related to the onset of the bivalve *Mytiloceramus polyplocus* near the boundary.

Acknowledgements

The present report is the result of hard work by many members of the Bajocian Working Group including R. Chandler, S. Fernandez Lopez, M.H. Henriques, N. Morton, R. Mouterde and R. Rocha, who together wrote the GSSP proposal submitted for ratification by the ICS. This proposal will be published in extended form in the very near future.

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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 Hutchinson "Young Scientist Foundation" attended the 28th International Geological Congress (IGC) in Washington, D.C., in 1989.

Currently, income earned as interest on the Hutchison fund is insufficient to sustain comparable grants every four years without seriously eroding the principal. For that reason, the IUGS made no grants from the fund for the 30th IGC, 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. It is expected that grants from the fund will again support deserving young scientists to attend the 31st IGC in the year 2000. 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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