GOLDEN SPIKED! — THE UK'S FIRST GLOBAL STRATOTYPE SECTION AND POINT FOR A JURASSIC STAGE BOUNDARY, IN SOMERSET

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Page, K.N. 2001. Golden spiked! – The UK's first Global Stratotype Section and Point for a Jurassic stage boundary, in Somerset. *Geoscience in south-west England*, **10**, 000-000.

The Sinemurian Stage, the second in a contemporary Jurassic System, was first proposed by Alcide d'Orbigny in 1842 and named after Semur-en-Auxois in eastern France. As exposures in the historical type area are stratigraphically incomplete, the search for a suitable stratotype, at which to formally define the stage, commenced elsewhere. Attention turned to SW England, and ultimately the West Somerset coast, where a considerably expanded Hettangian-Lower Sinemurian sequence has been proved. Subsequent work on the ammonite faunas has also revealed a much more complete sequence of ammonite faunas than had been recorded anywhere else in Europe at this level – ultimately leading to exposures near East Quantoxhead being highlighted as a potential Global Stratotype Section and Point (GSSP) for the base of the Sinemurian Stage. International multidisciplinary study then led to intensive sampling of the Quantoxhead sections documenting macro- and microfossil, gamma-ray and magnetostratigraphical changes across the stage boundary. The proposal was subsequently ratified by the International Commission on Stratigraphy at the IUGS Rio de Janeiro (Brazil) symposium in August 2000. The first UK Jurassic "*Golden Spike*" can now be driven, globally defining for the first time, the base of the Sinemurian division of geological time.

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INTRODUCTION

The Sinemurian Stage is the second in the Jurassic System and was first used by Alcide d'Orbigny in 1842, deriving its title from the original Latin name of Semur-en-Auxois in northern Burgundy, France. D'Orbigny was inspired by the rich ammonite faunas and other fossils recovered during canal construction and from other excavations around the town – as still spectacularly displayed in the local museum (Figure 1). Current usage, however, differs slightly from d'Orbigny's, as his original stage included lower levels now assigned to the Hettangian Stage, as proposed by Renevier in 1864.

***Figure 1**. Spectacular collections of Sinemurian ammonites in Semur-en-Auxois museum, France – the inspiration for d'Orbigny's original "Sinémurien" stage of 1842.*

Recent study of sections around Semur (e.g. by Corna and Mouterde, 1988), has revealed that exposures in this historical type area are stratigraphically incomplete and consequently unsuitable for a modern definition of a stage boundary as a Global Stratotype Section and Point (GSSP), as regulated through the International Commision on Stratigraphy (ICS, a UNESCO project; Remane *et al.,* 1996). GSSPs provide unambiguously and objectively defined boundaries between successive divisions of a chronostratigraphic scale at a chosen stratotype locality and are therefore of fundamental importance for the effective communication of the relationships in time and space between different rock bodies and events and processes during the evolution of the Earth (Salvador, 1994).

The basic framework of ammonite-correlated chronozones for the Sinemurian Stage was originally established by Oppel (1856) and subsequent refinement led to the standard scheme of Donovan *in* Dean *et al*. (1961). The base of the stage is drawn at the base of the lowest subchronozone of the lowest zone, namely the Conybeari Subchronozone of the Bucklandi Chronozone, the type area of which is south-west England, including Somerset (Tutcher, 1918). Donovan *in* Morton (1971) consequently proposed that sections near Lyme Regis, on the Devon-Dorset coast, as described by Lang (1924) should be established as a stratotype for the Sinemurian Stage.

More recent study, however, by Palmer (1972) and Whittaker and Green (1983, including Ivimey-Cook and Donovan, 1983 –

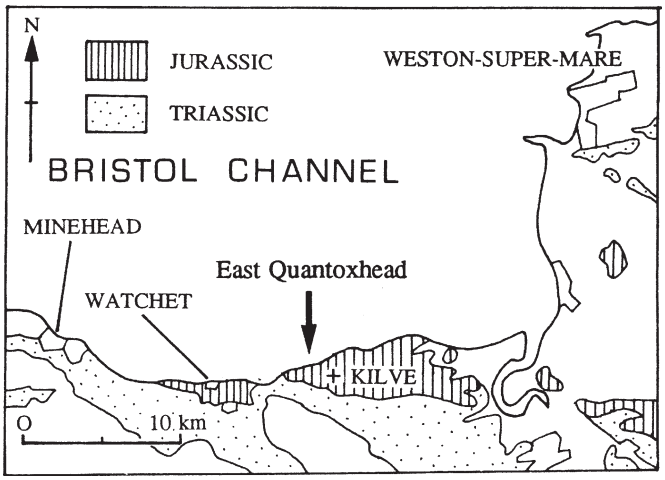

***Figure 2**. Location map for East Quantoxhead (based on Warrington and Ivimey-Cook, 1995).*

see also Warrington and Ivimey-Cook, 1995) has revealed a considerably expanded Hettangian/Sinemurian boundary sequence nearly five times thicker than at Lyme Regis, on the West Somerset coast between Watchet and Stolford (Figure 2). Detailed study of the ammonite fauna by Page (1992, 1994) and Bloos and Page (1999) revealed a Conybeari Subchronozone an exceptional 13 m thick, yielding a remarkably complete sequence of ammonite faunas, facilitating the establishment of *nine* intrasubzonal correlative units at the level of biohorizon (*sensu* Callomon, 1985; Page, 1995). In addition it was possible to demonstrate that the earliest recorded Sinemurian-type faunas in West Somerset *predated* those at Lyme Regis - the Devon-Dorset sections were clearly not suitable for designating a GSSP for the stage boundary, whereas the West Somerset succession had great potential. One site in particular in the latter region, north of East Quantoxhead (National Grid Reference ST137 443), had an optimum quality exposure, with both cliff and foreshore exposures across the boundary (Figures 3, 4) and the added bonus of a convenient beach access point – the "Limekiln Steps" of Palmer (1972).

Collaboration was subsequently developed with the Universities of Plymouth and Oxford to document other key aspects of the boundary interval, to consolidate any GSSP proposal and fulfil the requirements of ICS. This sampling included aspects of microfossil, gamma-ray and magnetostratigraphical changes across the boundary (Figure 5). The results of these studies are described by Page *et al*. (1999), and key points are reviewed below:

Figure 3*. The cliffs and upper foreshore adjacent to "Limekiln Steps", East Quantoxhead (the steps lie between the two small headlands, just out of sight). The prominent thick, dark mudrock unit in the cliff is Bed 145-146, and includes the Hettangian-Sinemurian boundary, with Depressa Subchronozone below and Conybeari Subchronozone above.*

THE NATURE OF THE BOUNDARY INTERVAL

Ammonites

The sequence of ammonite faunas across the Hettangian-Sinemurian boundary in West Somerset is the most complete known in the North West European Province. The change from typically "Hettangian" to typically "Sinemurian" faunas is conventionally indicated by the virtual replacement of faunas dominated by *Schlotheimia* spp. (Schlotheimiidae) of the Angulata Chronozone (Upper Hettangian), by faunas dominated by Arietitinae (including *Vermiceras, V. (Epammonites)* and *Metophioceras*) of the early Bucklandi Chronozone (Lower Sinemurian) (Bloos, 1988).

The Quantoxhead section includes the first confirmation of the terminal Hettangian, Depressa Subchronozone in Britain and a basal Sinemurian fauna characterised by the new species *Vermiceras quantoxense* Bloos and Page, 1999 and *V. palmeri* Bloos and Page, 1999, in association with *Metophioceras* sp. indet. A (Figures 6 and 7) in Bed 146/145. This fauna correlates the base of the Sinemurian Stage, the proverbial "Golden Spike", defining the base of the Stage, being drawn immediately below its first appearance at East Quantoxhead.

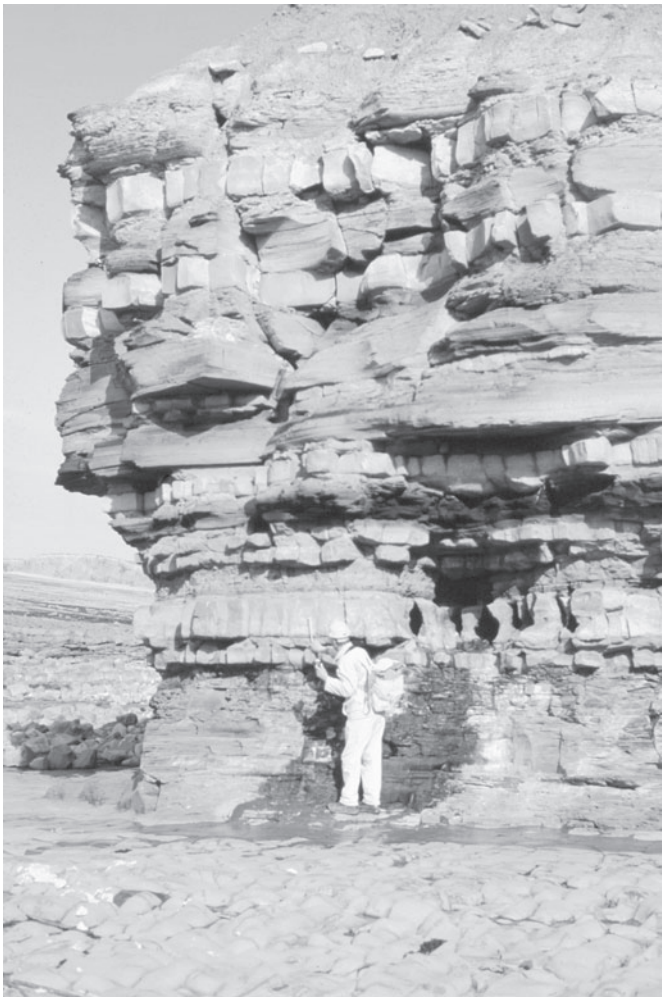

Figure 4*. The boundary mudrock unit (beds 145/146) with the Conybeari Subchronozone above, in the cliff adjacent to and on the east side of "Limekiln Steps". Bed 144 forms the rock platform at the base of the cliff, and the top of the cliff is at the level of beds 158-160.*

It is not until Bed 149, however, that the first geographically widespread Sinemurian fauna is found, with *M. brevidorsale* (Quenstedt), *V. spiratissimum* (Quenstedt), *V. rougemonti* (Reynès), *V. conybearoides* (Reynès), and schlotheimiids of the *charmassei* group. This fauna is often the lowermost recorded elsewhere in Britain (e.g. from around Bristol) and in Germany and France (Page, 1995; Bloos and Page, 1999, *in* Page *et al*., 1999). Near the top of the Conybeari Subchronozone, the index *Metophioceras conybeari* (J. Sowerby) itself is common (Figures 5 and 6).

Foraminifera

Calcareous benthic foraminifera, especially the *Lingulina tenera* plexus group are predominant, and typical of Lower Jurassic sequences in Northern Europe and the United Kingdom. The restriction of *Lingulina tenera* plex. *substriata* to the top of the Hettangian (Angulata Chronozone) and the consistent appearance of *Planularia inaequistriata* and the *Frondicularia terquemi* plexus group above the Sinemurian boundary at East Quantoxhead is characteristic at East Quantoxhead (Figure 5). As these taxa are already recognised to be of correlative value elsewhere (Copestake and Johnson, 1984, 1989), they indicate that foraminifera also have great potential for international correlation of the base of the Sinemurian Stage (Hylton, 1998, 1999; Hart and Hylton *in* Page *et al.,* 1999).

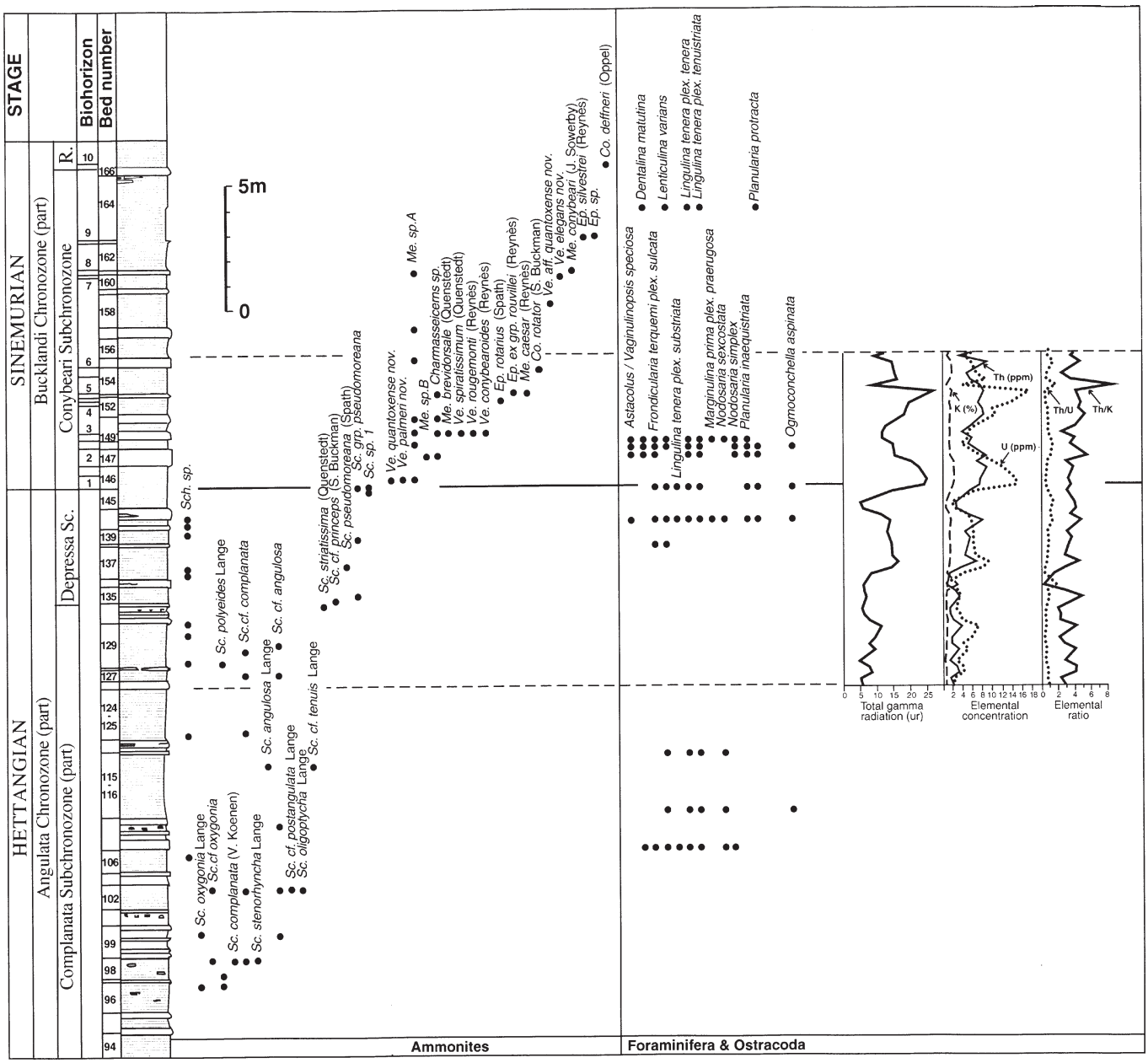

Figure 5. *The Hettangian/Sinemurian boundary sequence near Limekiln Steps, East Quantoxhead (alternating argillaceous limestones and mudrocks of the Blue Lias Formation): Stratigraphical synthesis (bed numbers are those of Whittaker and Green, 1983). Biohorizons numbered as follows (Bed numbers bracketed): 1- quantoxense (topmost 145-146), 2- Metophioceras sp. B (147), 3- conybearoides (149), 4- rotaries (152, upper part), 5- rouvillei (153), 6- rotator (154, upper part), 7- elegans (160, upper part), 8- conybeari (161), 9- silvestrei (163), 10- defneri (topmost 166-basal 167). (R. = Rotiforme Sunchronozone, Sc. = Schlotheimia, Ve. = Vermiceras, Me. = Metophioceras, Ep. = Epammonites, Co. = Coroniceras) (after Page et al., 1999).*

Ostracoda

Ostracod carapaces occur sporadically across the Hettangian-Sinemurian at East Quantoxhead, and assemblages are dominated by the healdiid genus *Ogmoconchella*, mainly as *O. aspinata* (Drexler) which is widespread in the European Hettangian (Lord, 1978). This form ranges from the Hettangian to Lower Sinemurian and is a useful index species for this part of the Lower Jurassic (Figure 5; Hart and Hylton *in* Page *et al.,* 1999; Hart and Hylton, 1999).

Palynology

Samples obtained to date have only yielded poorly preserved assemblages of limited stratigraphical use, probably largely due to surface weathering. However, further sampling is expected to yield better assemblages (Fitzpatrick and Hart *in* Page *et al.,* 1999).

Magnetostratigraphy

The data recovered indicate that the section has been remagnetised, possibly during recent weathering. Primary remanences were not recoverable, even with detailed progressive demagnetisation; the East Quantoxhead section is not therefore suitable for magnetostratigraphical correlation of the stage boundary, although future sampling of other cross-boundary sequences in the region may still yield useful results (Randall and Morris *in* Page *et al.,* 1999).

Gamma Ray

A spectral gamma-ray survey of the 'Blue Lias' sequence on the West Somerset coast and other Hettangian-Sinemurian sections in SW England, including the crucial Hettangian-Sinemurian boundary, demonstrates that pattern matching of gamma-ray characteristics can be used to correlate from outcrop to borehole, to a resolution that varies from about 0.5 to 3 m (Bessa and

***Figure 6**. Ammonites of the basal Sinemurian: 1.* Vermiceras quantoxense *Bloos and Page 1999 (holotype, Sedgwick Museum Cambridge X29332); 2.* Vermiceras palmeri *Bloos and Page 1999 (holotype, Sedgwick Museum Cambridge X29332). Bed 145/146, 0.75 m below the base of Bed 147, Blue Lias Formation, foreshore north of East Quantoxhead, West Somerset (*quantoxense *Biohorizon, Conybeari Subchronozone, Bucklandi Chronozone). Actual size.*

Hesselbo, 1997). A particular characteristic of the boundary section in West Somerset is the occurrence of two marked peaks in U concentration, linked to the presence of dark organic-rich shales, one just above the boundary and one some 4 m above it (Figure 5). Correlation with other basins has not yet been attempted but the observations in West Somerset indicate that gamma-ray logs have potential for correlation of the Hettangian-Sinemurian boundary, at least regionally (Bessa and Hesselbo *in* Page *et al.,* 1999).

***Figure 7**.* Metophioceras conybeari *(J. Sowerby), the index of the Conybeari Subchronozone, loose on the beach near East Quantoxhead, ex Bed 161 (diameter approximately 0.35 m).*

GSSP QUALIFICATION

The East Quantoxhead Hettangian-Sinemurian boundary sequence fulfils the GSSP requirements of Remane *et al.* (1996) in the following ways (after Page *et al.,* 1999):

"4.1 Geological requirements"

"(a) *Exposure over an adequate thickness*". The exposures at Quantoxhead are extensive, with the boundary interval accessible for over 200 m along the cliff and foreshore and forming part of a continuous sequence ranging from Norian (Upper Triassic) to the early Semicostatum Chronozone (middle Lower Sinemurian).

"(b) *Continuous sedimentation*" and "(c) *High rate of sedimentation"*. The relatively thick boundary sequence and the position of the boundary within a mudrock unit indicates a high rate of effectively continuous sedimentation. The presence of ammonite faunas not known from elsewhere also indicates that successive events can be adequately distinguished.

"(d) *Absence of synsedimentary and tectonic disturbances*" and "(e) *Absence of metamorphism and strong diagenetic alteration*". There are no significant Liassic synsedimentary disturbances in the area and the tectonic inversion which affects the basin (Dart *et al.*, 1995) has not lead to any significant alteration or disturbance of the boundary sequence. Some of the ammonite faunas within the section are well preserved, again suggesting a limited degree of diagenetic alteration.

"4.2 Biostratigraphic requirements"

"(f) *Abundance and diversity of well-preserved fossils*". Correlatively important ammonite and microfaunas are often abundant and generally well preserved at many levels across the boundary sequence. Palynological information is presently incomplete but has future potential.

"(g) *Absence of vertical facies changes*" and "(h) *Favourable facies for long-range biostratigraphic correlation*". The boundary interval lies within a thick, fully marine, sequence of alternating mudrocks and bedded or nodular limestone. The boundary itself is placed *within* a single bituminous mudrock unit. There is therefore no significant change of litho- or biofacies across the boundary. In addition, most of the taxa present are known to have a wide geographical range, throughout much of Europe and consequently a high correlation potential, especially as similar facies are also very widespread in this region.

"4.3 Other methods"

"(i) *Radioisotopic dating*" and "(k) *Chemostratigraphy*". The section offers good potential for at least the latter studies, including strontium isotope analysis, although no results are available to date.

"(j) *Magnetostratigraphy".* The section is not suitable for magnetostratigraphical correlation.

"(l) *Regional palaeogeographical context*" and "*facies relationships*". Free marine connections during the Hettangian and Sinemurian to the rest of Europe, and also Asia, and the very widespread occurrence of comparable facies (see (h) above also) throughout the region, suggests that the East Quantoxhead sections are suitable for the recovery of faunas, floras and chemostratigraphical data of widespread correlative value.

"4.4 Other requirements"

"(m) *Permanently fixed marker*". There is potential to place a marker adjacent to the exposure, perhaps attached directly to Limekiln Steps (any marking of the cliff itself is likely to be temporary due to coastal erosion).

"(n) *Accessibility*", "(o) *Free access*" and "(p) *Guarantees from the respective authority concerning free access for research and permanent protection of the site*". The conveniently placed "Limekiln Steps" descend over the boundary interval to the foreshore and connects, via public footpaths, to car parking near Kilve Beach and East Quantoxhead Church. Visiting on a falling tide is recommended.

The GSSP lies within the Blue Anchor to Lilstock Coast Site of Special Scientific Interest protected under the Countryside and Rights of Way Act 2001. For further information, including regarding sampling protocols, contact English Nature at Roughmoor, Bishops Hull, Taunton, Somerset, TA1 5AA, U.K.

RATIFICATION

The stratigraphical conclusions of the integrated study were formally presented to the Fifth International Symposium on the Jurassic System in Vancouver in August 1998 as a proposal for a candidate GSSP for the base of the Sinemurian Stage. Following subsequent approval by the International Subcommission on Jurassic Stratigraphy (ISJS), a submission was made to the International Commission on Stratigraphy (ICS), a project of the Union of Geological Sciences (UNESCO), proposing ratification of the proposed stratotype section. The proposal was reviewed at the global IUGS symposium Rio de Janeiro symposium in August 2000 and was successful. Consequently, the first UK Jurassic "*Golden Spike*" can now be driven, defining, for all time, the base of the Sinemurian division of geological time – definitely a global achievement for multidisciplinary stratigraphical work.

ACKNOWLEDGEMENTS

G. Bloos (Staatliches Museum fur Naturkunde, Stuttgart) and convenor of the Sinemurian Boundary Working Group first recognised the GSSP potential of the Quantoxhead sections and following intensive collaborative field and "laboratory" studies, skilfully guided the GSSP proposal through to full ratification with ICS. M. B. Hart (University of Plymouth) encouraged and co-ordinated the crucial micropalaeontological and magnetostratigraphical sampling of the boundary interval and S. Hesselbo made available the results of the gamma ray study. J. Abraham (University of Plymouth) produced the original figure of the boundary sequence. The East Quantoxhead Estate, kindly allowed the extensive sampling programmes to take place, without which all of these studies would have been incomplete.

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