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# Discussion on the Eocene–Oligocene boundary in the UK

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**Jerry Hooker, Margaret Collinson, Stephen Grimes, Nick Sille & David Mattey** write: Recognition of the Eocene–Oligocene boundary in the Hampshire Basin, UK, has been debated since naming of the Oligocene Epoch in 1854. Previously, this was because the boundary itself had not been stabilized and because the strata concerned are largely non-marine. A Global Boundary Stratotype and Stratigraphic Point (GSSP) was established at Massignano, Italy, in 1993 in marine strata. Recognition of the boundary on extinction of the planktonic foraminiferan family Hantkeninidae made boundary identification difficult in the continental realm. Correlation to marginal marine and non-marine strata is nevertheless possible via magnetostratigraphic and sequence stratigraphic studies and, importantly, biostratigraphically via dinocyst zones at Massignano (Brinkhuis & Biffi 1993; Brinkhuis & Visscher 1995). Therefore, recent publication of the magnetostratigraphy, sequence stratigraphy and orbital cyclicity of much of the Hampshire Basin Solent Group (Gale *et al*. 2006) is welcomed and substantially increases the number of correlation tools available in this area. Such cyclical phenomena, however, rely on absolute dating or biostratigraphy for calibration. No radiometric dates exist for the Solent Group, so biostratigraphy remains the best means of dating the succession.

There are, however, problems with the way Gale *et al*. (2006) have interpreted biostratigraphic markers and therefore with their placement of the Eocene–Oligocene boundary and associated events. The organisms concerned are calcareous nannoplankton (NP zones) and mammals (MP reference levels). Thus, the record by Aubry (1985) of NP22 in the Argiles Vertes de Romainville, Paris Basin, was subsequently qualified by her (Aubry 1986, p. 307) as 'zone NP22 (not younger; possibly older: NP21?)'. This dating was based solely on the presence of rare *Isthmolithus recurvus*, which ranges from NP19/20 to NP22 (Aubry 1992), this being the real level of dating for the Argiles Vertes de Romainville on nannoplankton evidence. Moreover, NP22 is latitudinally diachronous (Aubry 1992). Thus, the NP22 record in the Ruisbroek Sand in Belgium, according to the dinocyst zonation (Stover & Hardenbol 1994; Vandenberghe *et al*. 2003), largely predates its standard low-latitude range (Hooker *et al*. 2004, fig. 3).

The Belgian sequence is critical because it allows the MP21 Hoogbutsel Mammal Bed, overlying the Neerrepen Sand with the Adi dinocyst zone, to be calibrated to the northwesterly, more marine succession with contiguous dinocyst zones (Steurbaut 1992). These can then be calibrated to the sequence stratigraphically and magnetostratigraphically controlled succession in Italy (Brinkhuis & Visscher 1995). Therefore, the Grande Coupure, the turnover separating MP20 from MP21, must correlate with a point early in Chron C13n, thus approximating the onset of the Oi-1 glaciation (Zachos *et al*. 1992). This calibration of the Grande Coupure to C13n is directly demonstrated in the Ebro Basin, Spain, where an early post Grande Coupure MP21 fauna occurs at Santpedor (Barberà *et al*. 2001). Therefore, the Bembridge normal polarity zone (Gale *et al*. 2006, pp. 403–404, fig. 3), which calibrates to mammal reference level MP19 (Hooker 1992) cannot be C13n. Consequently, neither the Eocene–Oligocene boundary nor the Oi-1 event should be as low as the base of the Bembridge Limestone Formation (Gale *et al*. 2006, p. 413, fig. 12).

This raises the question of the true identity of the Bembridge normal polarity zone. At Massignano, Priabona and Bressana, Italy, the next sequence boundary (SB) below that marking Oi-1 has been calibrated by Brinkhuis & Biffi (1993) and Brinkhuis & Visscher (1995) to TA4.2/4.3 of Haq *et al*. (1987) (= Pr2/3 of Hardenbol *et al*. 1998). At Priabona this SB is at the base of dinocyst zone Aal, which at Massignano is close to a normal subchron named 'C13n2' (Brinkhuis & Visscher 1995) or 'short polarity excursion I' (Premoli Silva *et al*. 1988). This subchron occurs late in Chron C13r (Premoli Silva *et al*. 1988). It has been recognized as far away as the South Atlantic and is an important marker, as the Eocene–Oligocene boundary hantkeninid extinction occurs just after (Premoli-Silva *et al*. 1988). It may also be represented in the continental Sarral section, Spain (Barberà *et al*. 2001). In the Hampshire Basin, the next clearly marked SB below that which coincides with the Grande Coupure and thus Oi-1 is that at the base of the Bembridge Limestone, the base of sequence 5 of Gale *et al*. (2006) (their intervening sequences 6 and 7 within the Bembridge Marls and lower Hamstead members being poorly defined). Subchron I in Chron C13r therefore provides the best fit for the Bembridge normal polarity zone.

Gale *et al*. (2006, p. 407) claimed a maximum SB incision value of 15 m at the base of their sequence 5, suggesting to them that this represented a best fit for the major sea-level fall coincident with Oi-1. However, this ignores a more important sea-level fall at the base of the Nematura Bed, Hamstead Member, evidenced by reworking of rooted soil clasts and absence of lowstand and early transgressive systems tracts (Hooker *et al*. 2004), which calibrates well with the biostratigraphy.

The 2‰ positive shift in freshwater $\delta^{18}O$ values, recorded in rodent tooth enamel by Grimes *et al*. (2005) between the Osborne Member and the Bembridge Limestone, has been misinterpreted by Gale *et al*. (2006, p. 413) as representing a cooling event coincident with their position of the onset of the Oi-1 glaciation. Grimes *et al*. (2005) clearly demonstrated that this shift represents a warming in summer season temperatures. This is because temperature shifts are dependent upon changes in both the local water $\delta^{18}O$ values and the carbonate proxy $\delta^{18}O$ values. Between the Osborne Member and the Bembridge Limestone the isotopic shift in the local water value is greater than that in the three carbonate proxies, indicating a rise in temperature. Moreover, cooling between the Osborne Member and the Bembridge Limestone (Gale *et al*. 2006, p. 413) was only one of the interpretations by Sille *et al*. (2004) of increased charophyte gyrogonite volume, another being warming, through increased photosynthesis and calcium carbonate secretion, consistent with the isotope results.

By equating the Bembridge normal polarity zone with Chron C13r subchron I, the Eocene–Oligocene boundary in the Hampshire Basin, UK, should lie above this normal interval, more than 4.5 m above the base of the Bembridge Marls. This means that the Insect Limestone, an important source of late Palaeogene insects and plants and usually regarded as earliest Oligocene, which lies within the Bembridge normal polarity zone, should instead be dated as latest Eocene. Therefore, the Eocene–Oligocene boundary in the Hampshire Basin is best placed around the middle of the Bembridge Marls Member, whereas the Grande Coupure and contemporaneous Oi-1 glaciation are situated immediately beneath the Nematura Bed of the overlying Hamstead Member.

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**Andy Gale, Jenny Huggett & Ewan Laurie** write: We thank Hooker *et al*. for their interesting and useful review of the arguments pertaining to the position of the Eocene–Oligocene boundary in the Isle of Wight succession and elsewhere. However, some points they make and issues they raise, particularly those referring to the paper by Hooker *et al*. (2004), need further discussion.

The stratigraphical arguments of Hooker *et al*. (2004, fig. 6) supporting the placement of the Eocene–Oligocene boundary around the Nematura Bed in the Upper Hamstead Member in the NE Isle of Wight are based on two lines of evidence. The first and better supported of these concerns the mammal biostratigraphy, which Hooker (1987, 1989, 1992) and Hooker *et al*. (2004) have documented in detail. Precisely horizoned collecting has allowed the identification of mammal zones MP19, 20 and 21 in the Hampshire Basin succession; MP19 is recorded from the Bembridge Limestone, MP20 from the Bembridge Marl, and MP21 from the Upper Hamstead Member, immediately above the Nematura Bed and overlying brackish shell beds. The Grande Coupure, a major turnover in mammal faunas long associated with terrestrial concepts of the Eocene–Oligocene boundary, can now be located to a 4 m gap in the mammal record over an interval including the Nematura Bed and overlying shell beds (Hooker *et al*. 2004). However, the GSSP defining the base of the Oligocene is placed in deep marine strata at Messignano in Italy, and is defined by the extinction of the planktic foraminiferan *Hantkenina* (Premoli Silva *et al*. 1988). This in turn can be related to the base of magnetochron C13n, and a major heavy oxygen isotope event called Oi-1a within the nannoplankton zone NP21 (Zachos *et al*. 1996). To establish a first-order correlation between the land mammal record and these marine events, Barberà *et al*. (2001) investigated the magnetostratigraphy of the Ebro Basin in Spain, where the Grande Coupure and the MP zones had been identified.

Barbera *et al*. (2001) obtained consistent palaeomagnetic data from multiple sections in the southeastern Ebro Basin, and were able to identify chrons 6n.3n to c15n (Late Eocene–Oligocene) and relate these to mammal zones MP19/20 to MP30 (Fig. 1). The succession of mammal zones MP19–MP21, and the position of the Grande Coupure at the MP20–21 boundary can be correlated between the Sarral section in the Ebro Basin and the Whitecliff–Hamstead sections in the Isle of Wight (Fig. 1). If this correlation is used to interpret the magnetic zones on the Isle of Wight (Gale *et al*. 2006), then the Bembridge normal polarity zone could be reinterpreted as C15n, and the Headon normal polarity zone as C16n (Fig. 1). Alternatively, Hooker *et al*. suggest that the Bembridge normal polarity zone could be a short normal subchron within C13r, identified in the South Atlantic

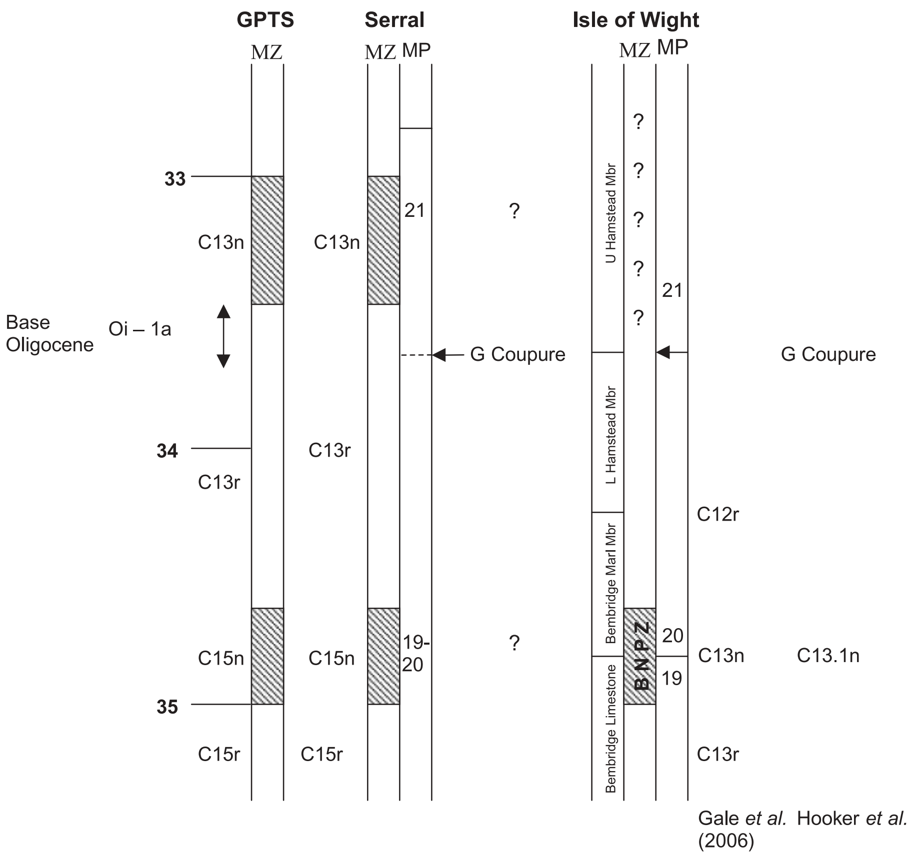


**Fig. 1.** Possible correlations to the Geomagnetic Polarity Time Scale (GPTS, calibrated in millions of years) of successions at Serral in the Ebro Basin, Spain (Barbera *et al*. 2001) and the Isle of Wight, Hampshire Basin, UK. The first-order correlation of Barbera *et al*. (2001) of the MP mammal zones based on the section at Serral to the GPTS is shown. Correlation to the Isle of Wight is more problematic. Gale *et al*. (2006) correlated the Bembridge normal polarity zone (BNPZ) with C13n, but Hooker *et al*. suggest a correlation with a short normal subchron within C13r (C13.1n). Mammal evidence from Serral (presence of MP19/20 in C15n) might suggest that the Bembridge normal polarity zone is actually C15n, but supporting evidence is required of a normal magnetozone equivalent to C13n, which would be predicted to fall within the Upper Hamstead Member on the Isle of Wight. However, this solution creates numerous other problems including chron durations that differ greatly from those of the GPTS. It should be noted that the position of the Isle of Wight succession in relation to C13n given by Hooker *et al*. (2004, fig. 3) is entirely hypothetical, as no investigation of the magnetostratigraphy was available at the time of publication.

and called C13.1n by Channell *et al*. (2003). In this regard, it is important to note that the position of the Isle of Wight succession in relation to C13n given by Hooker *et al*. (2004, fig. 3) is entirely hypothetical, as no investigation of the magnetostratigraphy was available at the time of publication.

However, neither of the above alternative interpretations are congruent with either the limited nannofossil data or the known durations of magnetic chrons, and we are reluctant to change the original interpretation of Gale *et al*. (2006) without first finding evidence of a normal polarity magnetozone representing C13n in the Upper Hamstead Member. One problem (of many) with the interpretation of the Bembridge normal polarity zone as C15n relates to the duration of the reversed magnetozone that then becomes C15r. Our orbitally tuned time scale (Gale *et al*. 2006) gives a duration for this reversed zone of nearly 1 Ma, whereas the Geomagnetic Polarity Time Scale (GPTS) indicates a duration for this interval of less than 0.5 Ma. A further concern is that support for the relationship between the mammal zones and magnetostratigraphy is based on a single study at a single locality (Barbera *et al*. 2001).

The second part of the stratigraphical argument presented by Hooker *et al*. (2004, fig. 3) is based on their identification and correlation of two inferred major hiatuses in the Isle of Wight succession, the lower at the base of the Bembridge Marls, and the higher immediately underlying the Nematura Bed in the Upper Hamstead Member. The durations of these gaps were given as 0.15 and 0.35 Ma, respectively, and Hooker *et al*. (2004) correlated them with sequence boundaries identified in the marine Late Eocene of Belgium and central Italy. Both the supposed magnitudes of these hiatuses and evidence for their correlation are inferential and unsupported by any data. The perceived need to find a break in this part of the succession led Pomerol (1989) and subsequently Vandenberghe *et al*. (2003) to interpret a minor, pedogenically modified, surface at the base of the Black Band as the major break at the base of the Oligocene. This correlation was rejected on biostratigraphical grounds by Hooker *et al*. (2004), who instead selected a similar minor surface higher in the succession (base of the Nematura Bed, 10 m above the Black Band) as the hiatus supposedly created by the ice-driven regression associated with Oi-1a.

The erosional surface at the base of the Nematura Bed is decidedly unimpressive, as there is no significant incision (less than 1 m), and mottled, pedogenically altered silty clays are overlain by grey estuarine clays containing a brackish water mollusc fauna (*Polymesoda*, etc.). It is similar to numerous other brackish transgressions identified in the Solent Group, which were related by Gale *et al*. (2006) to the 400 ka eccentricity cycle. Moreover, the orbitally tuned clay signal does not suggest any significant break in the continuity of the 400 ka cycles at the level of the Nematura Bed. It is important to remember that the Oi-1a sea-level fall is inferred to be at least 60–90 m in magnitude, and would be expected to create deep incision, major facies shifts, and the retreat of the shoreline far towards the shelf margin, a similar pattern to changes caused by major sea-level fall in the late Quaternary (e.g. Woodcock 2001). There is no evidence of any such events at the base of the Nematura Bed.

The lower hiatus of Hooker *et al*. (2004), at the boundary between the Bembridge Limestone and Bembridge Marl Formations, has been identified as a sedimentological break since Daley & Edwards (1971) recorded evidence of local erosion of the summit of the Bembridge Limestone. In the most complete Hampshire Basin succession, in Whitecliff Bay, the lithological transition from the Bembridge Limestone to the overlying Bembridge Oyster Bed is abrupt, but the continuity of the 400 ka cyclic clay signal (Gale *et al*. 2006, fig. 9) does not support the existence of a large hiatus.

Hooker *et al*. (2004) correlated the sub-Bembridge Oyster Bed and sub-Nematura Bed hiatuses to two sequence boundaries identified in the marine succession in central Italy by Brinkhuis & Visscher (1995). We fail to see how it is possible to correlate sequences from a marine Tethyan succession to a continental Boreal one in the absence of any fossil species common to both or other supporting data (magnetostratigraphy, chemostratigraphy). Much of the correlation proposed by Hooker *et al*. (2004, fig. 3) therefore appears to be inferential, conveniently used to support their stratigraphical argument.

In conclusion, the correlation of the continental and estuarine succession of the Solent Group on the Isle of Wight to the marine standard record remains problematic, and accurate positioning of the Eocene–Oligocene boundary requires further magnetostratigraphic investigation, to identify at least one higher normal polarity zone in the upper part of the Solent Group and thus strengthen correlation with the Geomagnetic Polarity Time Scale.

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