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Review paper

A review of *Macoma balthica* (L) as a stratigraphic marker in the Pleistocene sediments of the southern North Sea Basin

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ABSTRACT

The first occurrence and presence of the bivalve *Macoma balthica* in the Pleistocene shallow marine sediments (Crags) of East Anglia has long been used to characterise the youngest "Weybourne" or "Wroxham" Crag Formation of Early to early Middle Pleistocene age. A review of recent work on the morphological variation and genetic lineages of living populations of the species and of work on fossil discoveries in East Greenland suggests that the current palaeontological species definition is too narrow, that the species arrived in the Atlantic about 2.4 Ma and much earlier than is envisaged from the studies of the North Sea Basin, and that there were several trans-Arctic migrations of the species during the Pleistocene. This paper reviews these findings and concludes that: (i) detailed morphometric analyses of fossil *Macoma* species from the Crag need to be undertaken and the species definitions comprehensively reviewed to take account of the morphological and genetic variation seen in modern populations; (ii) detailed morphometric analysis of modern *M. balthica* should be undertaken and tied to the different genetic lineages, and (iii) the current palaeontological definition of *Macoma balthica* should not be relied on as the basis for a First Appearance Datum (FAD) in the Southern North Sea basin.

Contents

1. Introduction

The Late Pliocene and Early to Early Middle Pleistocene sediments of East Anglia, eastern England have had a major role in the development of the Quaternary stratigraphy of Europe and our understanding of aspects of environmental change for this period (West, 1961; Gibbard et al., 1991; Funnell, 1995, 1998; Gibbard et al., 1998; Rose et al., 2001; Rose, 2009). These sediments are mainly shallow marine deposits and are known as 'Crag' (Taylor, 1827; Charlesworth, 1835). The use of fossils to correlate the East Anglian Crag is constrained by the lack of widespread and rapidly evolving forms. Fossil mollusca have been used to indicate a relative age for the sediments but molluscan records are possibly influenced by facies as much as by age. The most well known of the molluscan stratigraphic indicators is *Macoma balthica* which has been used to characterise the "Weybourne Crag" of Harmer (e.g. 1877, 1897, 1902, 1906) and used as a First Appearance Datum (FAD) by Harmer (1902) to define the "Weybourne stage" and by Rose et al. (2001), using the work of Cambridge (1978), to define the "Wroxham Crag". The

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proposal that the sands containing *M. balthica* (''Tellina solidula'') form the youngest unit of the Crag was first proposed by Wood and Harmer (1868) and has been accepted by all subsequent workers. Although occurrences of *M. balthica* are widely reported in the Crag literature (Wood, 1851–1861; Wood, 1866; Wood and Harmer, 1868, 1872–1874; Harmer, 1877, 1896, 1897, 1902, 1906; Woodward, 1881; Reid, 1882; Norton, 1967; Cambridge, 1956, 1978; Meijer and Preece, 1995), detailed work by Spaink and Norton (1967) has refuted many of these identifications on the basis of their conchological diagnosis of fossil forms. Spaink & Norton believe that much of the earlier mis-identification was due to confusion with other *Macoma* species, notably *M. praetenuis* and they noted that this problem was particularly the case in juvenile forms. However, this view, especially with regard to *M. praetenuis* was not shared by everyone (Janssen et al., 1984, referenced in Meijer, 1993). Unfortunately no detailed diagnoses, comparable to that for *M. balthica* by Spaink and Norton have been published for the two species with which *M. balthica* has been confused: *M. praetenuis* and *M. obliqua*.

Since Spaink and Norton's 1967 work, there have been a number of papers published on phenotypic and genetic variation in modern populations of *M. balthica.* These have considered the extent and causes of morphological variation (e.g. Beukema and Meehan, 1985; Kamermans et al., 1999; Azouzi et al., 2002; Luttikhuizen et al., 2003b; Gantsevich et al., 2005), the genetic variation (e.g. Meehan, 1985; Meehan et al., 1989; Hummel et al., 2000; Luttikhuizen et al., 2003a,b; Väinölä, 2003; Sokolowski et al., 2002, 2004) and mitochondrial lineages and species migration (Luttikhuizen et al., 2003a; Nikula et al., 2007; Nikula, 2008). This work has revealed a complex genetic and migration history and provides some data on the wide variation in shell morphology found in the modern species.

Currently, it appears that early Crag molluscan experts (e.g. Harmer and S.V. Wood, Jnr) mis-identified *M. balthica* based on the later species diagnosis of Spaink and Norton (1967). However, Spaink and Norton's work was predominantly on fossil forms and work on living *M. balthica* populations, which indicates a significant variation in shell morphology, has been published subsequently. Therefore this paper seeks to examine the robustness of Spaink and Norton's (1967) fossil species definition of *M. balthica* in order to evaluate its use as a stratigraphic marker (FAD) in sediments of Late Pliocene to early Middle Pleistocene age in the southern North Sea Basin. Locations referred to in the text are shown in Fig. 1. This review was undertaken as part of research into the palaeoenvironmental history of Lower to early Middle Pleistocene sediments of East Anglia in order to understand the robustness of the correlation frameworks available for building temporal-spatial interpretations.

2. Records of *Macoma balthica* prior to MIS 12 (pre-Anglian age)

Records of *M. balthica* from the Crag are quite widespread, particularly with reference to the northeast coastal and inland areas of Norfolk. The deposits of these areas are known respectively as Weybourne Crag and Bure Valley Beds (also known as ''Belaugh Crag'') (Wood, 1866; Wood and Harmer, 1872–1874; Harmer, 1877, 1896, 1897, 1902, 1906; Cambridge, 1978). *M. balthica* is also recorded in the ''Mammaliferous'' Crag (Wood, 1851–1861, p. 231) and the Norwich Crag (Woodward, 1881). Reid (1882, p. 17) stated that ''*Tellina Balthica* [*M. balthica*], which occurs, as Messrs Wood and Harmer have pointed out, in great abundance at nearly every locality in the Bure Valley''. Harmer (1902, p. 448) states that ''*Tellina balthica*'' is found no further south than Norwich. However, detailed work on fossil specimens by Norton and Spaink (Spaink and Norton, 1967; Norton and Spaink, 1973; Funnell et al., 1979; Riches et al., 2008) suggest that a

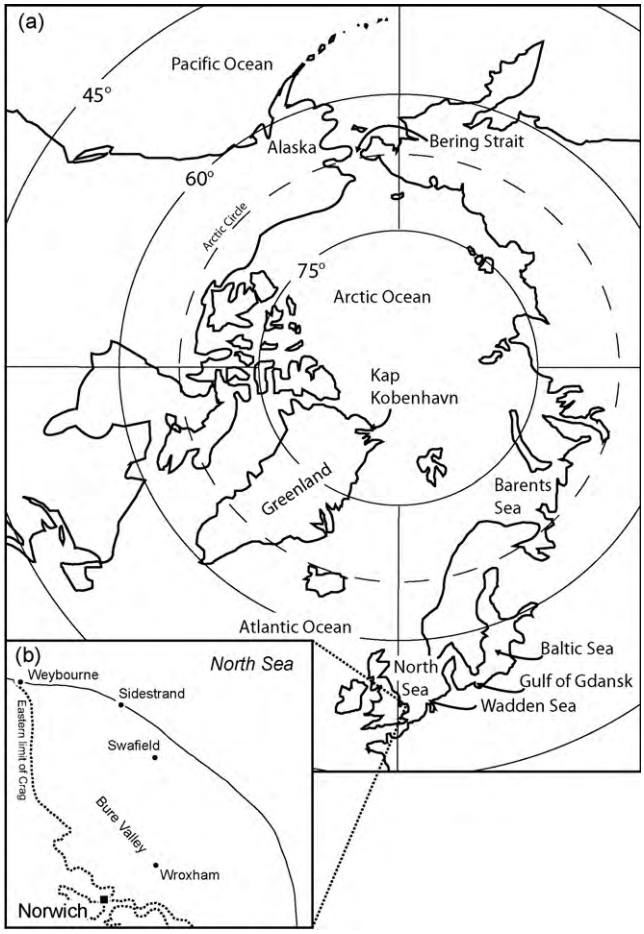

Fig. 1. Map showing locations referred to in the text with a detailed inset of locations in northeast Norfolk.

number of identifications of *M. balthica* from Pre-Anglian-age sediments are incorrect. Norton and Spaink (1973) conclude that *M. balthica* only occurs in the ''Baventian'' age sands (Weybourne Crag) of the northeast Norfolk coast. Funnell (1995) considers these deposits to have been deposited during the geomagnetic Olduvai Subchron (1.77–1.97 Ma). Spaink and Norton's figured specimen is shown in Fig. 2a. *M. balthica* usually occurs within a relatively impoverished fauna in the Weybourne Crag (Meijer and Preece, 1995) although as, at Sidestrand (Norton, 1967), it may be the most abundant species recorded. However, subsequent work by Norton (2000) has extended the presence of *M. balthica* to an inland locality with its identification in the sediments from the Swafield borehole.

An overview of the stratigraphical occurrences of *M. balthica* in the southern North Sea basin is provided by Meijer (1993). Records from boreholes in the Netherlands indicate *M. balthica* appears during the Late Tiglian Substage of the Netherlands (Meijer, 1988; Meijer, in Gibbard et al., 1991), but it is not common in the Netherlands until the Noordbergum interglacial (Zagwijn, 1996; Meijer and Preece, 1996). The records of *M. balthica* in Pliocene and early Pleistocene deposits of the Netherlands (Heering, 1950) have been refuted by Spaink and Norton (1967).

Further a field, *M. balthica* has been reported from sediments of Calabrian age (Early Pleistocene) of Italy (Moroni, 1967 referenced in Norton and Spaink, 1973) although the identification is questioned by Norton and Spaink (1973) on the basis of her figure which they judge to be *M. obliqua*. *M. balthica* has been recognised in the late Pliocene, Kap København Formation of North Greenland (Símonarson et al., 1998) (Fig. 2b) and in the late Pliocene