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Larger benthic foraminifera from the Middle Eocene to Oligocene of Tanzania

Laura J. COTTON*) & Paul N. PEARSON

School of Earth and Ocean Sciences, Cardiff University, Main Building, Park Place, Cardiff. CF10 3AT, UK;

*) Corresponding author, cottonlj@cardiff.ac.uk

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Abstract

Larger benthic foraminifera (LBF) are common and diverse throughout the Paleogene sediments of southern Tanzania, but have previously been little studied. A recent programme of onshore drilling known as the Tanzania Drilling Project has recovered large proportion of this succession for palaeoclimatic and palaeontological study. The sediment is largely a hemipelagic clay with secondary gravity sediment flow limestones and calcarenites. LBF occur concentrated in the secondary beds and are present in some clay horizons. Planktonic foraminiferal, nannofossil and, in some cases, stable isotope studies of the clays allow the larger benthic foraminiferal ranges to be tied to global stratigraphy. Here we use nine of these drill sites to examine the LBF from the Middle Eocene to Oligocene. Within this interval several global turnover events of long-ranging and widespread LBF genera are known to occur. However, problems with biostratigraphy mean the exact timing and therefore mechanisms remain uncertain. Our study shows that ranges of Tanzanian LBF genera are within known global ranges. Additionally, there is a change in the LBF assemblage with a number of local first and last occurrences of genera during the Bartonian, which may have potential links to the onset of the Mid Eocene Climatic Optimum.

1. Introduction

The coastal basins of southern Tanzania contain a thick succession of Paleogene marine sediments that have been the focus of much recent research on the palaeontological and palaeoclimatic history of the area (Pearson et al., 2004, 2006; Nicholas et al., 2006, 2007; Pearson et al., 2008; Wade and Pearson, 2008; Lear et al., 2008; Dunkley-Jones et al., 2008, 2009; Pearson et al., 2009). Rich assemblages of larger benthic foraminifera (LBF) occur throughout but have received relatively little attention. Blow and Banner (1962) gave a brief overview of LBF species found in much of the succession, but largely concentrated on the planktonic foraminifera. Here we focus on the Middle Eocene to Oligocene distribution of LBF taxa as recorded in drill cores and compare the record to other areas. This work builds on the study of Cotton and Pearson (2011) which focused on the Tanzanian LBF at the Eocene Oligocene transition (EOT), extending the record at lower resolution to a much longer time period.

The Kilwa and Lindi Districts of Tanzania contain a thick succession of clay sediment from Santonian to Oligocene age (Figure 1; Nicholas et al 2006; 2007). These sediments are formally defined as the Kilwa group and are split into four formations: the Nangurukuru (Santonian to Paleocene), Kivinje (Paleocene to lower Lutetian), Masoko (lower Lutetian to mid Bartonian) and Pande formations (mid Bartonian to the Rupelian; Nicholas et al., 2006). A large proportion of this succession has been recovered in a series of shallow drill cores by the Tanzania Drilling Project (TDP; see Nicholas et al., 2006 for review). The sediments of the Kilwa group are broadly homogeneous and consist of a succession of dark greenish grey clays and claystones to marls with limestones and calcarenites deposited as sediment gravity flows. LBF are abundant in the limestone beds and they also occur in clay horizons in the succession. Specimens from the clays are generally better preserved than those from the limestone, but are smaller and more dispersed. Calcareous micro- and nannofossils are often exceptionally well-preserved (e.g. Pearson et al., 2008; Bown et al., 2008) and planktonic foraminiferal and nannofossil studies have been used to determine the stratigraphy of the succession (Pearson et al., 2004, 2006; Nicholas et al., 2006; Wade and Pearson, 2008, Dunkley Jones et al., 2008a,b, 2009). Stable isotope analysis has been carried out on three sites which span the Eocene - Oligocene transition enabling these sites to be correlated with the global isotope stratigraphy (Pearson et al., 2008).

Nine of the TDP sites are stratigraphically placed between the Upper Ypresian and Upper Rupelian (Pearson et al., 2004, 2006; Nicholas et al., 2006). During this interval LBF are known to have undergone several global turnover events (Hallock et al., 1991). Towards the late Middle Eocene there is a large turnover in nummulitids, followed by the extinction of *Assilina* and then the extinctions of *Alveolina* and large species of *Nummulites*. A further global extinction of LBF is then seen at the Eocene - Oligocene Transition, with the extinction of the orthophragmines, the pellatispirids and several species of *Nummulites* (Adams et al., 1986). All of these are long ranging and widespread groups of LBF.

However, biostratigraphy of LBF is often problematic. The mutually exclusive environments of planktonic microfossils and LBF mean that cross-correlation is often difficult. This, coupled with species endemism, has resulted in the use of regional zonations, such as the Shallow Benthic Zones in the Tethyan region (Cahuzac and Poignant, 1997; Serra Kiel et al., 1998) and the East Indian Letter Classification in the Indo-Pacific region (Adams, 1970; Renema, 2007). Accurate correlations between LBF events and planktonic foraminiferal, nannofossil and climatic events are therefore often difficult to determine and mechanisms remain uncertain.

Here we use samples from the Middle Eocene to Oligocene TDP sites to give an overview of LBF genera present in southern Tanzania. The well-dated stratigraphy allows correlation of LBF ranges with global biostratigraphy and allows potential links between LBF extinctions and global climatic events to be explored.

2. Materials and methods

This study utilises nine TDP sites from the top of the Kivinje Formation to the top of the Pande Formation to examine LBF occurrences across the Middle Eocene to Oligocene interval. The locations (Figure 1), assigned planktonic foraminiferal Zones and ages of these cores are summarised in Table 1.

Clay samples were washed through a 63 μm sieve and residues dried. Oriented sections of loose individual LBF from clays were made for identification. The secondary beds were studied in randomly oriented thin section and acetate peels (prepared according to Dickson, 1965, 1966).

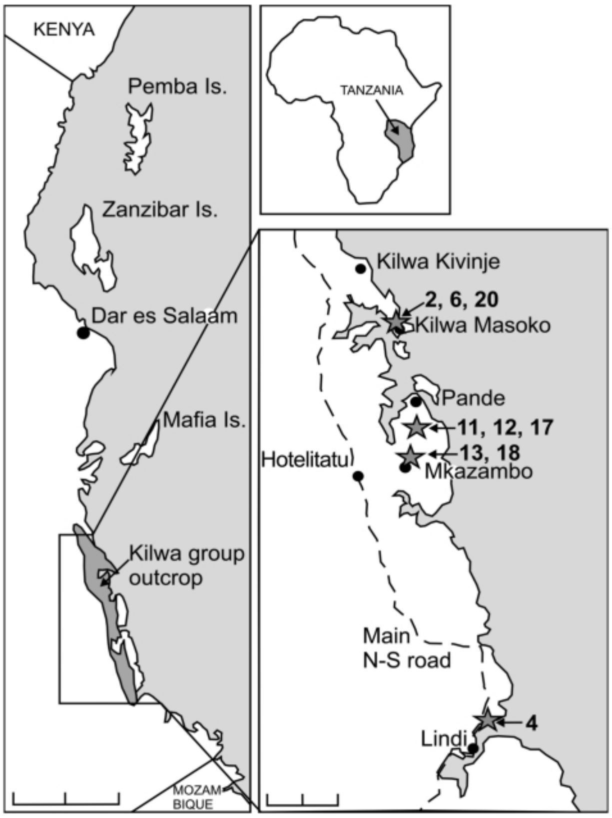

Figure 1: Location map showing Middle Eocene to Oligocene Tanzanian Drilling Project sites.

3. Results

The Eocene secondary beds are bioclastic pack-grainstones. LBF are the dominant bioclastic component, but also present are echinoid fragments, red algae, smaller foraminifera and serpulid worm tubes. The LBF occur in a matrix of finer carbonate fragments including smaller-sized foraminifera and quartz grains. Most LBF have suffered at least some abrasion to the outer test whorls, comparable with category 2 to 3 on the scale of Beavington-Penney (2004). Intraclasts are present in some samples, but are rare. Several large-sized LBF show evidence of boring and/or overgrowth by red algae. The Oligocene secondary beds are calcarenites with a high fine grained quartz content. Bioclasts including LBF are present but less abundant than in the Eocene beds. The samples from TDP Site 6 are distinctly different from the rest of the succession. These contain a large number of reworked carbonate clasts including LBF in a finer quartz-rich matrix.

The stratigraphic occurrences of the LBF genera are shown in Figure 2 with the levels of the TDP sites. The assemblage throughout the Lutetian (TDP Sites 2, 20 and 13) remains fairly constant and is generally dominated by *Nummulites* and *Alveolina* with orthophragmines and *Linderina*. Also present but less frequent are *Lockhartia*, *Assilina*, *Glomalveolina* and *Orbitolites*, although the latter two genera only occur in the lower half of the Lutetian. *Assilina* are rare in the core samples, but

Site	Location	UTM	Planktonic foraminiferal Zone	Age
TDP 2	SW Kilwa prison (80m from TDP 20)	37L 555371 9013813	E7-E9	L. Ypresian to Mid Lutetian
TDP 20	SW Kilwa prison	37L 555457 9013846	E7-E9	L. Ypresian to Mid Lutetian
TDP 30	Roadside N of Mkazambo	37L; 558673 8975981	E9-E11	Middle to Upper Lutetian
TDP 18	Roadside N of Mkazambo	37L; 558640 8975370	E12 (lower part)	Bartonian
TDP 4	Ras Tipuli	37L; 578530 8900033	E12-E13	mid Bartonian
TDP 11	Close to the village of Stakishari	37L; 560250 8983211	E16-O1	Upper Priabonian to Lower Rupelian
TDP 12	Close to the village of Stakishari	37L; 560222 8981309	E16-O1	Upper Priabonian to Lower Rupelian
TDP 17	Close to the village of Stakishari	37L; 560539 8984483	E15-O1	Upper Priabonian to Lower Rupelian
TDP 6	W of Kilwa Masoko airstrip	37L; 555752 9014922	O2-O4	Lowe Oligocene

Table 1: Location and age data for the TDP sites used in this study.

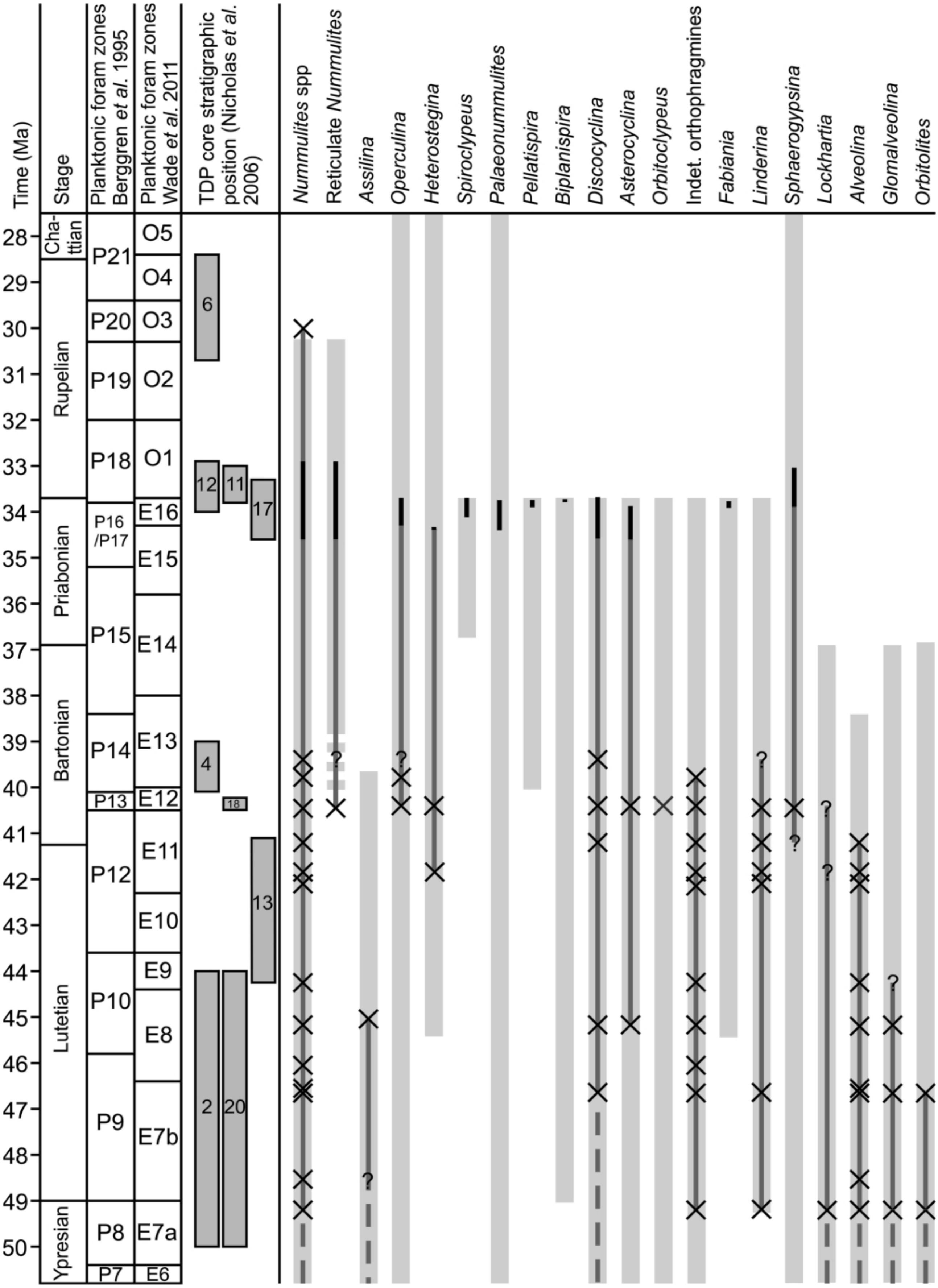

Figure 2: Range chart showing the stratigraphic occurrence of LBF genera in the TDP succession. Stratigraphic levels of the TDP sites are shown in the left hand column. Crosses indicate the occurrence of a genus; black lines are used to indicate the occurrences of genera in TDP 11, 12 and 17 as a high resolution study has been carried out. Pale grey bars in the background show known global ranges of genera (Hallock et al., 1991; Renema, 2002; BouDagher-Fadel, 2008).

abundant in outcrops on the edge of Kilwa Creek, close to the drill sites of TDP 2 and TDP 20 and thought to be of similar age. Towards the top of TDP Site 13 the last *Alveolina* specimen is found, which has had an almost continuous pre-sence in the TDP samples to this point. In the Bartonian (TDP Site 18) there is a high diversity of LBF genera and there appears to have been a change in the LBF assemblage between the uppermost samples of TDP Site 13 and the lowermost samples of TDP Site 18. In TDP Site 18 there are the first occurrences of reticulate *Nummulites*, *Operculina* and *Sphaerogypsina*. *Heterostegina* also becomes more common, thus far represented by a single specimen towards the top of TDP 13. There is also the last occurrence of *Lockhartia*, and the last definite occurrence of *Linderina*. TDP Site 4 is still within the Bartonian but stratigraphically slightly higher than TDP Site 18. In these samples *Nummulites* are most common and occur with *Discocyclina*, *Operculina* and possible *Linderina*. There is then a gap in the TDP record and the next sites are Upper Priabonian to Lower Rupelian (TDP Sites 11, 12 and 17) and continuously span the EOT (Pearson et al., 2008). These samples also show a relatively high diversity of LBF. At these sites the majority of the genera present go extinct at the Eocene/Oligocene boundary, coincident with the extinction of the Hantkeninidae (see the more detailed study by Cotton and Pearson, 2011). Only *Sphaerogypsina* and some species of *Nummulites* pass through the boundary apparently unaffected. Several of the genera which do go extinct at the boundary, including *Fabiania*, *Pellatispira* and *Palaeonummulites*, are only present in these samples. In the Upper Rupelian (TDP Site 6) secondary beds there are a large number of intraclasts and the only LBF in them that do not appear to have been reworked are small *Nummulites*.

4. Discussion

As LBF are known to inhabit the shallow carbonate environment (Beavington-Penney and Racey, 2004) all specimens occurring in the hemipelagic clay succession of the Kilwa group have been transported. Despite this, they can still be used to give ranges of LBF as the majority appear to have been deposited penecontemporaneously with the clay sediments. Intraclasts are rare and the foraminifera appear to have been deposited as uncemented grains, evidenced by tests that have been abraded during transport. The high levels of abrasion suggest high energy transport and rapid deposition (Beavington-Penney, 2004). There are occasional examples of large-sized LBF which have been bored and so were dead tests when re-deposited, the borings are infilled by the surrounding matrix indicating they were still uncemented when re-deposited. The exception to this penecontemporaneous sedimentation are the secondary beds from site TDP Site 6 which contain a very large amount of intraclasts often with biostratigraphically older LBF. The only LBF in this site that do not appear to be reworked are small *Nummulites*.

The ranges of the LBF genera found in the TDP sites from Tanzania all fall within global ranges (Adams 1970; Adams et al., 1986; Hallock et al., 1991; Serra Kiel et al., 1998; Renema, 2002, Renema, 2007). One of the largest changes in the Tanzanian LBF assemblage takes place between the last sample of TDP Site 13 and the first sample of TDP Site 18. These two sites were drilled less than 1 km from each other, making it unlikely that the assemblage change is due to geographic location or varying sediment source. The succession in TDP Site 18 has been assigned to the lower part of planktonic foraminiferal Zone E12 (Nicholas et al., 2006) and is therefore close to a global climatic warming event known as the Mid Eocene Climatic Optimum (MECO). The MECO was a global interval of rapid warming from ~40 Ma to ~40.8 Ma which interrupted the overall cooling trend of the Eocene (Bohaty et al., 2009; Edgar et al., 2010). The MECO is relatively little studied with regards to both planktonic foraminifera and LBF response. Some overturning within the planktonic acarininids and morozovelloidids is associated with this period and there is the occurrence of a short ranging 'excursion taxon', *Orbulinoides beckmanni*, which spans the MECO (Edgar et al., 2010). In LBF, overturning within *Nummulites* and the first occurrences of reticulate *Nummulites* have been noted to occur around this level (Hallock et al., 1991) although have not been directly associated with the MECO event.

Studies of planktonic biostratigraphy from TDP Site 18 show that the *Orbulinoides beckmanni* present are apparently early forms (Nicholas et al., 2006), suggesting that the succession is from the very early stages of, or even slightly before, the MECO. Therefore the faunal change in Tanzania occurred before the peak of the MECO. Additionally TDP Site 18 samples contain reticulate *Nummulites* from the *N. fabianii* group and therefore their evolution pre-dates the main phase of the MECO. Preceding the MECO is an interval of cooling from ~40.6-41.6 Ma which has also been recognised in $\delta^{18}O$ records (Bohaty et al., 2009). A cooling trend followed by the onset of rapid warming may have been responsible for at least local changes in the faunal distribution.

The global extinctions of *Alveolina* and large species of *Nummulites* are known to occur in the late Middle Eocene, slightly preceded by the extinction of *Assilina* (Hallock et al., 1991). Although attempts have been made by the TDP to locate and drill this stratigraphy, thus far these have proved unsuccessful.

Assilina is rare in the TDP samples, and little light is shed on its extinction level. No examples of *Assilina* were seen above the Lutetian, however the abundance of them in outcrop suggests that this may be due to the small area sampled by the TDP cores and the fact that LBF assemblages vary across the shelf. Further outcrop samples may therefore be able to help with this issue. The disappearance of large sized species of *Nummulites* requires a more detailed species-level study. However, *Nummulites* specimens > 10 mm diameter are present in the clays of TDP Site 18 and *Nummulites* > 25 mm belonging to the *N. perforatus* group were found in outcrop close to the drill site. These large *Nummulites* are not found at TDP Sites 11, 12 and 17. This suggests that they became extinct within the un-sampled interval. *Alveolina* has a lower last occurrence at the top of TDP Site 13 and is found in almost all TDP samples until this point. This indicates that the mechanism causing the assemblage changes between the successions in TDP Sites 13 and 18 may have also caused a local “early” extinction of *Alveolina*.

The Eocene/Oligocene boundary shows a rapid extinction of a number of genera shown to have long ranges in the Tanzanian record. The Priabonian samples are the most diverse, but this could be in part due to the higher-resolution study carried out on them. The Tanzanian sites have allowed accurate correlation between the LBF extinctions and plankton extinctions in the Eocene-Oligocene transition (Cotton and Pearson, 2011). The extinction was found to be closely coincident with the extinction of the planktonic foraminiferal Family Hantkeninidae which defines the Eocene/Oligocene boundary. This precedes the global sea level drop known to occur in the transition by ~200,000 years, indicating this was not the cause of the LBF extinction as previously suggested.

5. Conclusion

This study gives an insight into the range of LBF genera present in a previously little-studied region. The penecontemporaneous redeposition of the LBF into the hemipelagic environment enables LBF ranges to be tied to global nannofossil and planktonic foraminiferal biostratigraphy. With further work, there is therefore a high potential for using the TDP data to help improve global LBF stratigraphy and provide links between LBF and climatic events. The Eocene-Oligocene transition cores have previously enabled the exact level of the LBF extinction to be determined relative to global isotope stratigraphy. Here we have shown faunal changes take place on the Tanzanian platform possibly linked to the MECO and preceding cooling interval.

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Laura J. COTTON*) & Paul N. PEARSON
School of Earth and Ocean Sciences, Cardiff University, Main Building, Park Place, Cardiff. CF10 3AT, UK;
*) Corresponding author, cottonlj@cardiff.ac.uk

Plate 1:

LBF in petrological thin sections from secondary limestones.

Figure A: *Nummulites sp.* (TDP 20)

Figure B: *Nummulites sp.* (TDP 18)

Figure C: *Nummulites sp.* (TDP 4)

Figure D: *Asterocyclina sp.* (TDP 20)

Figure E: *Discocyclina sp.* (TDP 13)

Figure F: *Heterostegina sp.* (TDP 18)

Figure G: *Linderina sp.* (TDP 18)

Figure H: *Lockhartia sp.* (TDP 20)

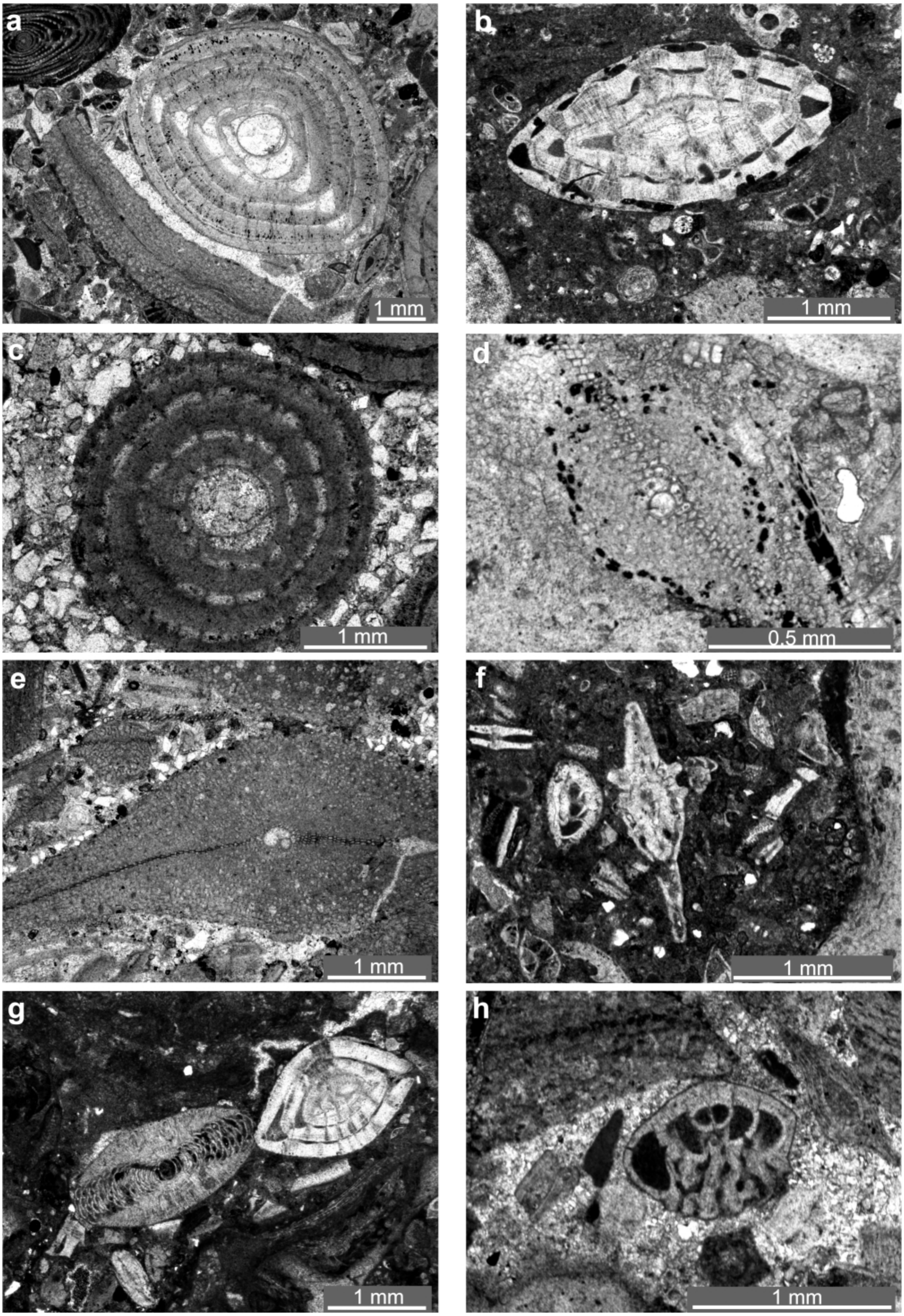
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Plate 2:

a-d) LBF in petrological thin sections from secondary limestones; e-h) Oriented individual LBF thin sections of specimens from clays.

Figure A: *Alveolina sp.* (TDP 2)

Figure B: *Alveolina sp.* (TDP 2)

Figure C: *Glomalveolina sp.* (TDP 2)

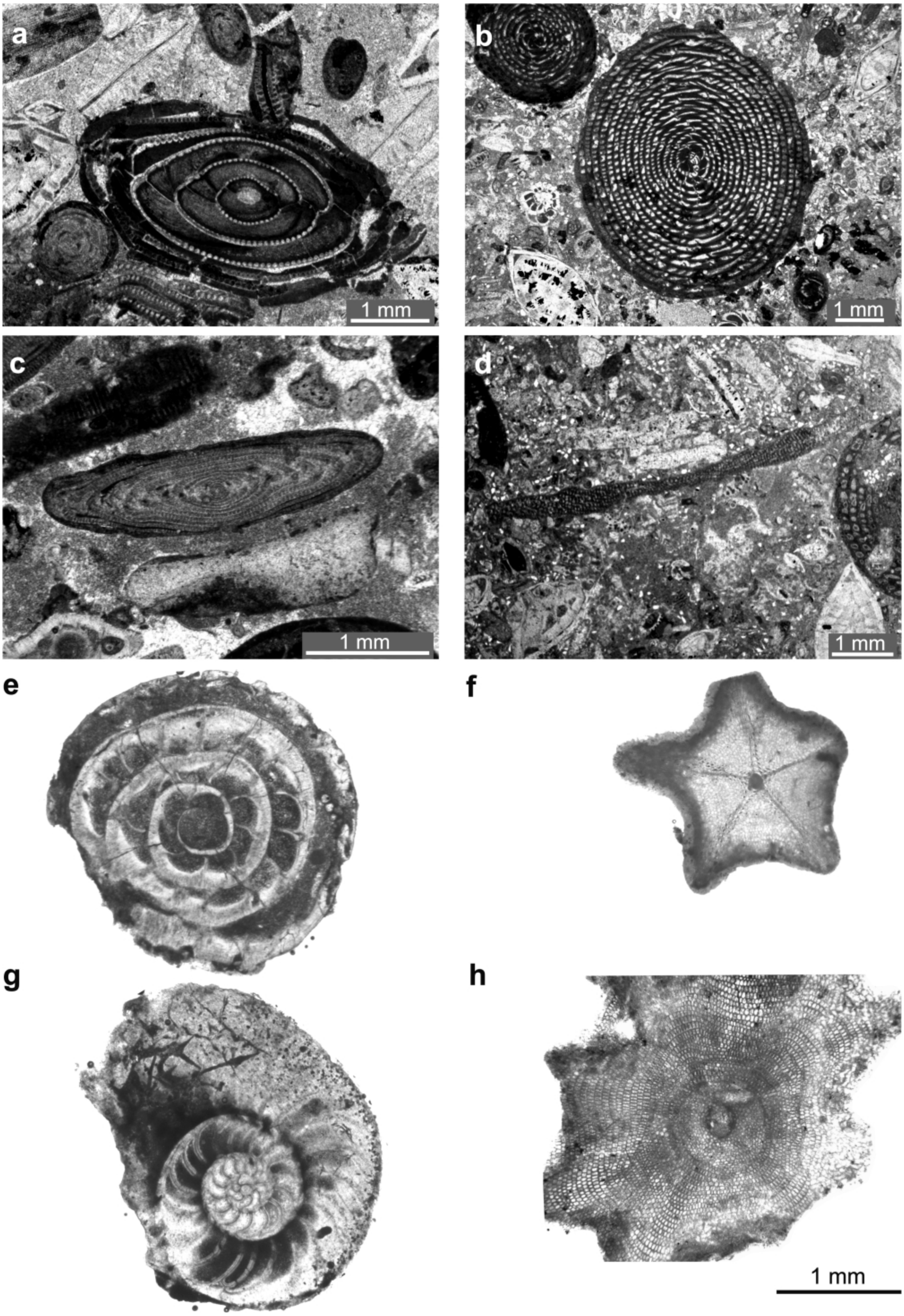
Figure D: *Orbitolites sp. (TDP 2)*

Figure E: Reticulate *Nummulites* of the *N. fabianii* group (TDP 18)

Figure F: *Asterocyclina sp.* (TDP 18)

Figure G: *Operculina gomezi* (TDP 18)

Figure H: *Orbitoclypeus* sp. (TDP 18)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