A review of the foraminiferal biostratigraphy of the Melinau Limestone, Sarawak

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ABSTRACT

A study of the Melinau limestone, especially in the continuous Melinau Gorge section, reviews taxonomic concepts of Adams (1965) in the Heterostegina- Tansinhokella- Spiroclypeus lineage, proves the presence of Middle Eocene 'Letter Stage' Ta, at the base of the Melinau Limestone, examines the nature of the Eocene- Oligocene boundary and the absence of Wilfordia sarawakensis Adams from other Tb Eocene limestones in the region. Strontium dating and biostratigraphy calibrated to GTS04 shows there to be a significant change in sedimentary rates or preserved thickness during mid-Oligocene (latest Tc or intra-Td times), but the disconformity noted by Adams (1970) was not found, probably due to poor exposure. Observations on the termination of the Melinau limestone agree with those of Adams (1965, 1970) and Wannier (2009), with an initial event near the Oligo-Miocene boundary (Te4 to Te5 boundary) and the youngest limestones dated as Te5, about 20.3 Ma.

INTRODUCTION

The foraminiferal biostratigraphy of the Middle Eocene- latest Oligocene Melinau Limestone, which outcrops on the flanks of the Mulu Anticlinorium in north Sarawak (Figure 1), was first described by Adams (1965).Additional work by Adams in 1966 lead to modifications described in Adams (1970). In 2009 Wannier reviewed the geological setting of the Melinau Limestone, suggesting a tectonic model that would allow deposition of very thick (~5260'/1600m; Adams 1965) shallow marine carbonates, with minimal coralline boundstone, in about 15 million years. Wannier carried out some foraminiferal analysis to map the otherwise indistinguishable strata, but did not detail his palaeontological work, apart from a few noteworthy points.

The author made a visit to the Melinau Gorge and some surrounding outcrops in 2007 in order to clarify the observations of Adams. As noted by Wilson (2002) and Wannier (2009), the Melinau limestone is exceptional, being one of just two carbonates in SE Asia with a thickness of more than 2200 m (as some of the carbonates cited by Wilson have limited published thickness but are known to be much thicker in unpublished well data, such as the Kais Limestone of West Papua, this statistic is not strictly true, but it does correctly emphasise the exceptional thickness of the Melinau Limestone). As the Melinau Gorge section is unfaulted and has possibly only one significant unconformity, it is an important reference section for later Eocene through Oligocene foraminiferal biostratigraphy.

The stratigraphic record of the *Heterostegina* (*Vlerkina*), *Tansinhokella* to *Spiroclypeus* lineage was a key objective of this visit and some of the details of this study are in the accompanying paper (Lunt and Renema, 2014).

THE MAIN CONCLUSIONS OF ADAMS

The Melinau Limestone was an important contributing section in the widely cited Adams (1970) review of larger foraminiferal biostratigraphy. No other tropical Tethyan or Pacific section known to Adams had the virtually complete later Eocene and Oligocene section present. The Melinau Limestone includes about 15 or 16 million years of almost unbroken stratigraphic record. Only the Asmari Limestone and subsequent formations in Iran cover a similar, virtually unbroken, time span (Td- later Tf, about 21-23 Ma; GTS2004, Lunt & Allan 2004). The composite Bikini and Eniwetok atoll cores were noted by Adams to cover a longer period (Cole 1954, 1957; Todd & Post, 1954), but as Cole noted, it is questionable if the Tc/Td stages are present in these holes.

The Tb to Tc (Eocene - Oligocene) transition and the entire Oligocene part of Adams' major review of the Letter Stages was therefore dependent on observations at Melinau Gorge. However it should be noted that Adams' observations paralleled, and drew upon, the earlier work of Leupold & van der Vlerk, 1931 and Rutten (1947, in van Bemmelen, 1949), that were developed on more fragmentary outcrops in Java and east Kalimantan (see Lunt & Allan, 2004.

The ranges of most taxa are therefore well documented in the references above and will not be repeated here. The important new observations of Adams 1965 (see Figure 3) and 1970 were as follows:

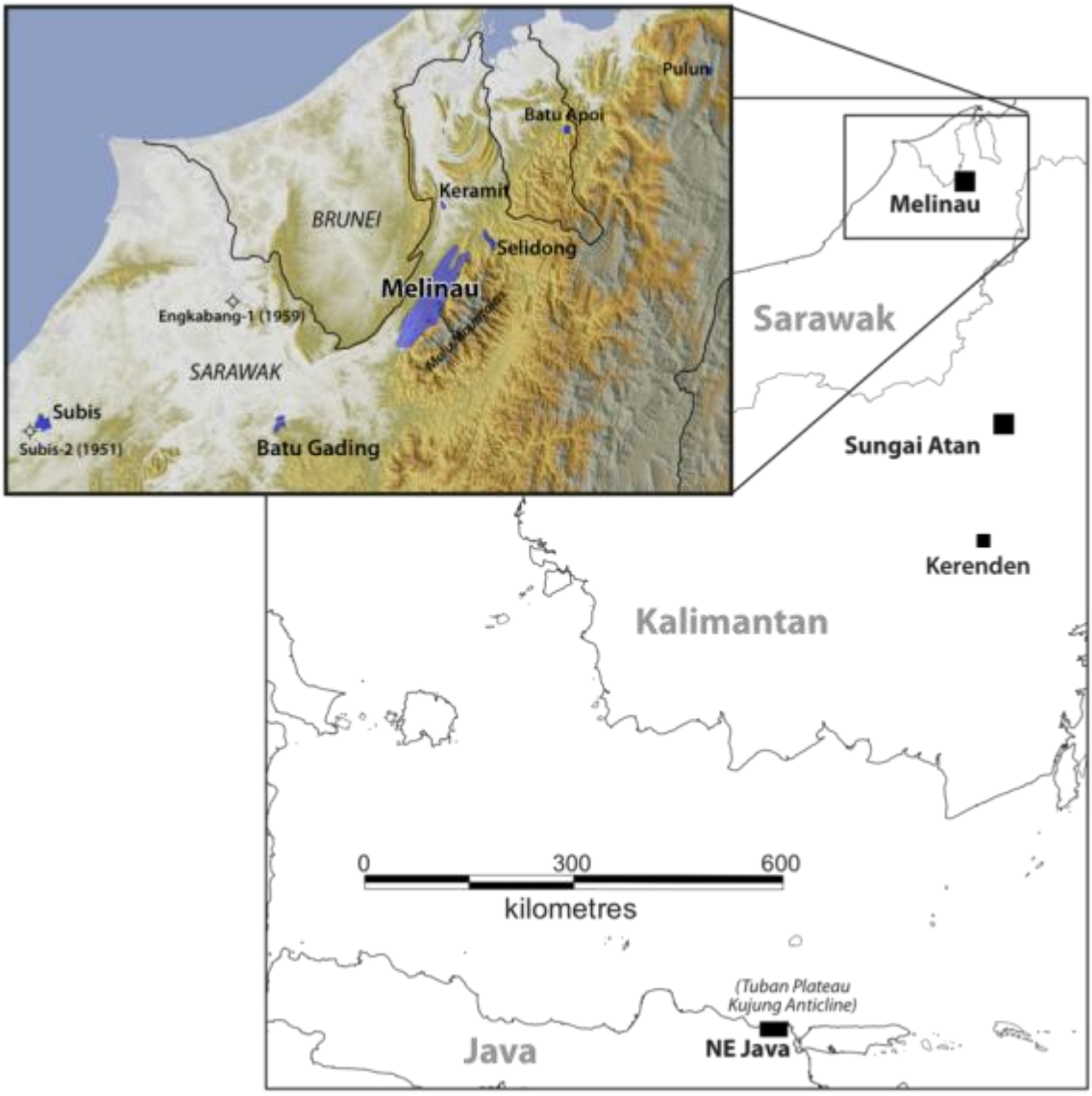


***Figure 1**. Location map of Melinau and other carbonate sites mentioned.*

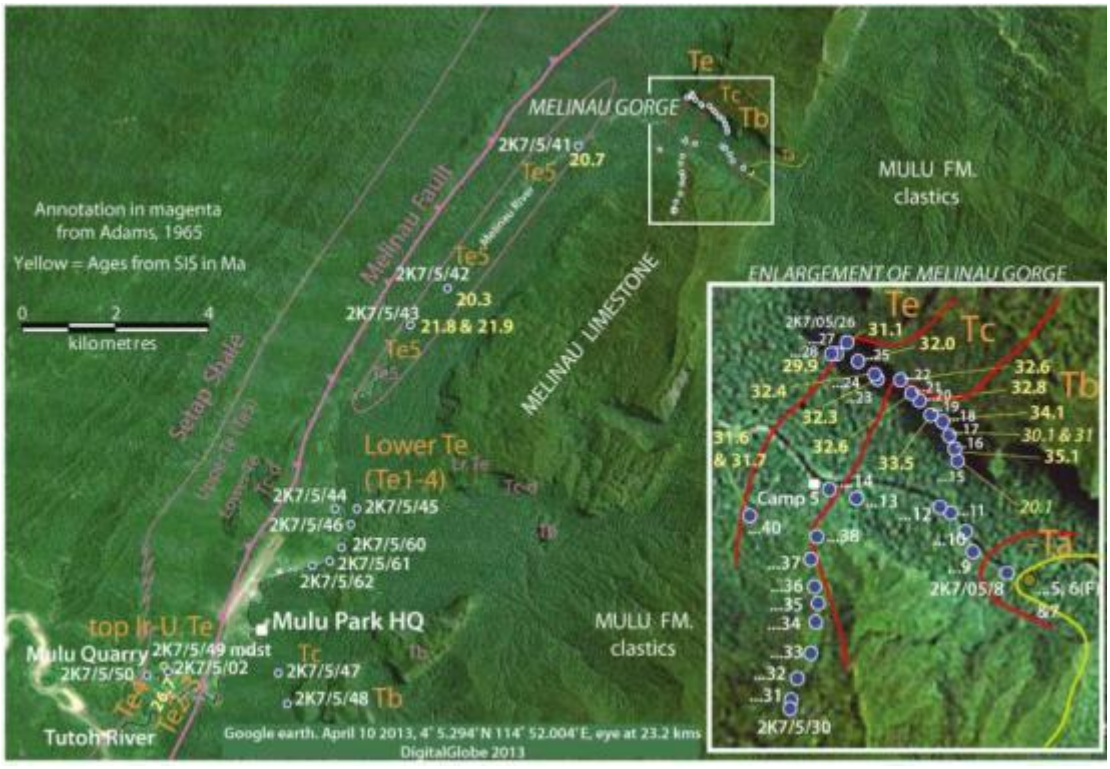


***Figure 2**. Location map of Melinau outcrops. SIS ages in yellow, in Ma (see also Table 1.*

***Table 1**. A summary of Strontium Isotope Stratigraphy [SIS] data. $^{87}Sr/^{86}Sr$ ratios normalised to $^{86}Sr/^{88}Sr$ =0.1194. Ages calculated from McArthur & Howarth (2004; GTS04)*

Sample and location	Ratio & error (%)	NIST 987	Age & measurement precision and key marker foraminifera
2K7/5/41 114.873933E, 4.135083N	**0.708387** ± 0.0015	0.710235	**20.7** (20.3 to 21.1) **Ma** Te5 fauna present
2K7/5/42 114.84700E, 4.10800N	**0.708408 ± 0.0011**	0.710235	**20.3** (20.0 to 20.7) **Ma.** Te5 fauna present
2K7/5/43 114.84005E, 4.09975N	**0.708318** ± 0.0015 **0.708315** ± 0.0011	0.710235	**21.8** (21.5 to 22.1) **Ma** **21.85** (21.6 to 22.1) **Ma**. Te5 fauna present
2K7/5/50 114.790988E, 4.033222N	**0.710106** ± 0.0015 **0.709648** ± 0.0012	0.710235	Invalid result, analysed twice
2K7/5/02 114.79624E, 4.03446N	**0.708088** ± 0.0012	0.710235	**26.72** (26.1 to 27.3) **Ma**. Te2-3 fauna present
2K7/5/27 114.89515E, 4.144366N	**0.707973** ± 0.0011	0.710235	**29.86** (29.5 to 30.4) **Ma**. Te1 fauna present
2K7/5/40 114.87585E, 4.136550N	**0.707916** ± 0.0011 **0.707919** ± 0.0012	0.710235	**31.65** (31.2 to 32.05) **Ma** **31.57** (31.0 to 32) **Ma**. Td fauna present
2K7/5/26 114.895933E, 4.145066N	**0.707933** ± 0.0015	0.710235	**31.11** (30.5 to 31.7) **Ma**. Td fauna present
2K7/5/25 114.896533E, 4.1439917N	**0.707903** ± 0.0013	0.710235	**31.98** (31.5 to 32.4) **Ma**. Td fauna present
2K7/5/24 114.897621E, 4.142919N	**0.707885** ± 0.0015	0.710235	**32.37** (32 to 32.75) **Ma**. Tc fauna present
2K7/5/23 114.89790E, 4.142650N	**0.707893** ± 0.0013	0.710235	**32.22** (31.8 to 32.6) **Ma**. Tc fauna present
2K7/5/22 114.89926E, 4.142700N	**0.707872** ± 0.0013	0.710235	**32.64** (32.3 to 32.9) **Ma**. Tb fauna. Sample slightly young if compared to other data on Tb to Tc boundary (34.8 Ma)
2K7/5/21 114.899817E, 4.141933N	**0.707873** ± 0.0011	0.710235	**32.62** (32.3 to 33.0) **Ma**. Tb fauna. Sample slightly young if compared to other data on Tb to Tc boundary (34.8 Ma)
2K7/5/20 114.90030E, 4.141417N	**0.707864** ± 0.0014	0.710235	**32.78** (32.4 to 33.1) **Ma**. Tb fauna. Sample slightly young if compared to other data on Tb to Tc boundary (34.8 Ma)
2K7/5/19 114.900917E, 4.140533N	**0.707821** ± 0.0012	0.710235	**33.51** (33.2 to 33.8) **Ma**. Tb fauna. Sample slightly young if compared to other data on Tb to Tc boundary (34.8 Ma)
2K7/5/18 114.90165E, 4.140166N	**0.707791** ± 0.0010	0.710235	**34.07** (33.8 to 34.5) **Ma**. Tb fauna. Sample slightly young if compared to other data on Tb to Tc boundary (34.8 Ma)
2K7/5/17 114.902117E, 4.1139317N	**0.707966** ± 0.0013 **0.707936** ± 0.0017	0.710235	**30.11** (29.6 to 30.7) **Ma** **31.01** (30.4 to 31.7) Ma. Both falsely young, sample strongly dolomitized
2K7/5/16 114.902633E, 4.138560N	**0.707761** ± 0.0013	0.710235	**35.Ma** (CSIRO tables, no error range given in Ma)
2K7/5/15 114.902917E, 4.137750N	**0.708421** ± 0.0012	0.710235	**20.07** (19.8 to 20.4) **Ma** Falsely young, sample strongly dolomitized

1. A new genus *Wilfordia sarawakensis* was discovered at the top of Tb, and Adams predicted this distinct form would become an important new marker. However it has never been seen outside Melinau Gorge, and some possible reasons are given below;

2. The new species *Dictyoconus melinauensis* was described and is distinct in being early Oligocene (Tc) and a simple form, whereas the other members of this genus are older. This species was also found by Adams in Tc limestones in the Bukit Sarang Limestone, a small biohermal complex some 250 km to the southwest in Sarawak;

3. *Biplanispira* was only recorded in the youngest part of Tb, well above the appearance of its ancestor *Pellatispira*. On his often cited range chart (Adams 1970 Figure 3) the range of *Biplanispira* is shown to be as old as near base Tb (and *Pellatispira* erroneously to base Tb; see Leupold & van der Vlerk, 1931), but later work in Java (Lunt & Allan, 2004; Lunt 2013) agrees with Adams' written observation, that *Biplanispira* is restricted to later Tb;

4. *Tansinhokella vermicularis* (assigned to a broader taxon; *Spiroclypeus* by Adams) was stressed to also be a later Tb marker. No *Tansinhokella* was found in the early and mid-Oligocene;

5. In 1970 Adams stressed that he was in error in ranging *Miogypsinoides complanatus* throughout Lower Te (Te1-4) in his 1965 work. He says the species is unknown from Melinau, but it has been observed and photographed by Wannier (2009, his Figure 15D, in outcrops shown here to be uppermost Lower Te) and observed by myself in latest Oligocene (Te4) and basal Miocene, Te5, samples;

6. Adams noted that "*Heterostegina* (*Vlerkina*) *borneensis* van der Vlerk appears well below the first occurrence of *Miogypsinoides* (*M.* cf. *bantamensis*) and *Tansinhokella*. This has been confirmed by careful collecting at close intervals in the Melinau Gorge." [modern taxonomy substituted for clarity]. This follows observations in NE Java (Figure 1) by Muhar (1956) and Lunt and Allan (2004) which re-established the Te2/3 to Te4 boundary based on the latest Oligocene evolution of *Miogypsinoides* from *Neorotalia mecatepecensis* - a species not recorded by Adams except as "rotalids indet." but seen in correct stratigraphic position in new samples described here;

7. Not in his 1965 work but in his 1970 paper, Adams noted in the Melinau Gorge "A disconformity, visible in the field, occurs between Tc and Td. This accounts for the relative thinness of Td, the lower part of which is missing".

OBSERVATIONS OF WANNIER

Biostratigraphic observations in Wannier's paper stress the amount of reworking in the Melinau Limestone, viz: "*The pervasive faunal reworking, known to occur in parts of the Melinau Limestone Formation, further complicates the age dating.*" (p. 181), "*In the field, the application of the above subdivision is fraught with difficulties, owing to the occasional absence of index larger foraminifera and the often widespread reworking of older faunas in younger strata.*" (p. 185), "*the eroded northern flank leading to widespread reworking of Late Eocene faunas are diagnostic criteria for deposition in a wedge-top basin"* (p. 191). While such reworking is seen in the uppermost (latest Oligocene) part of the nearby Batu Gading outcrops (50 km from Mulu Park Lst; Figure 1) and in the Keramit and Selidong outcrops about 10 km to the north (in more precisely dated Te4 latest Oligocene beds), such reworking is not observed in the main Melinau Limestone in the Gunung Mulu National Park. It was not noted by Adams or the new work here (although Te4 beds are under-represented in both Adams' study and the new samples described here), nor is the reworking specifically shown in the data of Wannier. Both Ta and Tb markers are reworked into latest Oligocene at Batu Gading and elsewhere, but Te5 age limestones, which are only found surviving in the Melinau area, have no obvious reworking, but do have common downslope transport of olistoliths. On the whole, as the work of Adams has shown, biostratigraphic control in the Melinau Limestone is excellent and not complicated by reworking.

Wannier noted *Glomalveolina ungaroi*, determined by L. Hottinger, from a small site in the SW near the Mulu airport and this alveolinellid was correctly determined to be a Ta index species (translated by Wannier to be "Bartonian", although this European Stage ranges to basal Tb (Lunt & Allan 2004). What Adams (1965) and Wannier had not noted was that Ta (*de-facto* Middle Eocene) had already been recorded in the data of Adams, but Adams was influenced by the incorrect assumption that the evolution of *Pellatispira* defined the Ta to Tb boundary, when it was actually the mass extinction of *Nummulites javanus*, granulate *Nummulites* and all Alveolinellids (see Umbgrove 1928, Leupold and van der Vlerk 1931, and Lunt & Allan 2004), which occurred slightly after the evolution of *Pellatispira*.

Wannier discovered some important sites at the upper transition of Melinau Limestone to overlying mudstones, which Wannier called the Temburong Formation. After Brondijk (1962) the Temburong Formation was a name applied only to mudstones of latest Oligocene Te1-4 [Lower Te] age, including the Batu Apoi debris limestone shown on Figure 1. Above this Temburong Formation there was a significant unconformity (see Figure 10 of Liechti et al. 1960, Figure 4 of Wilson 1964) and the succeeding Te5 [Upper Te] mudstones were assigned to the Setap Shales (including the thin Pulun Limestone on Figure 1). Wannier (his Figure 3) follows the common mistake in assuming the Temburong to Setap unconformity was the mid Miocene Deep Regional Unconformity (DRU), even though the field work references above and Levell

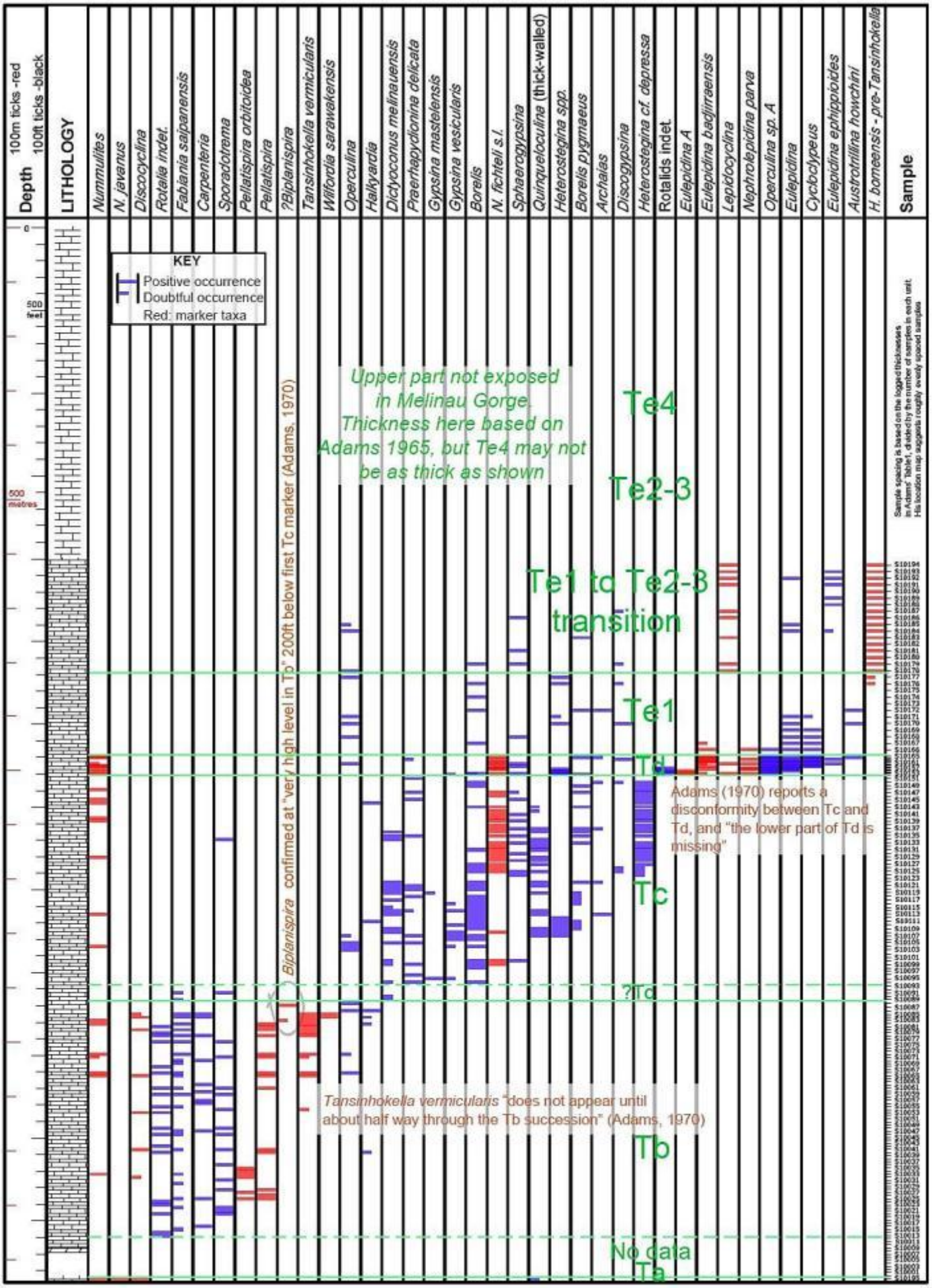


Figure 3. *The Melinau Limestone in the Melinau Gorge section, from Adams (1965, mod. 1970).*

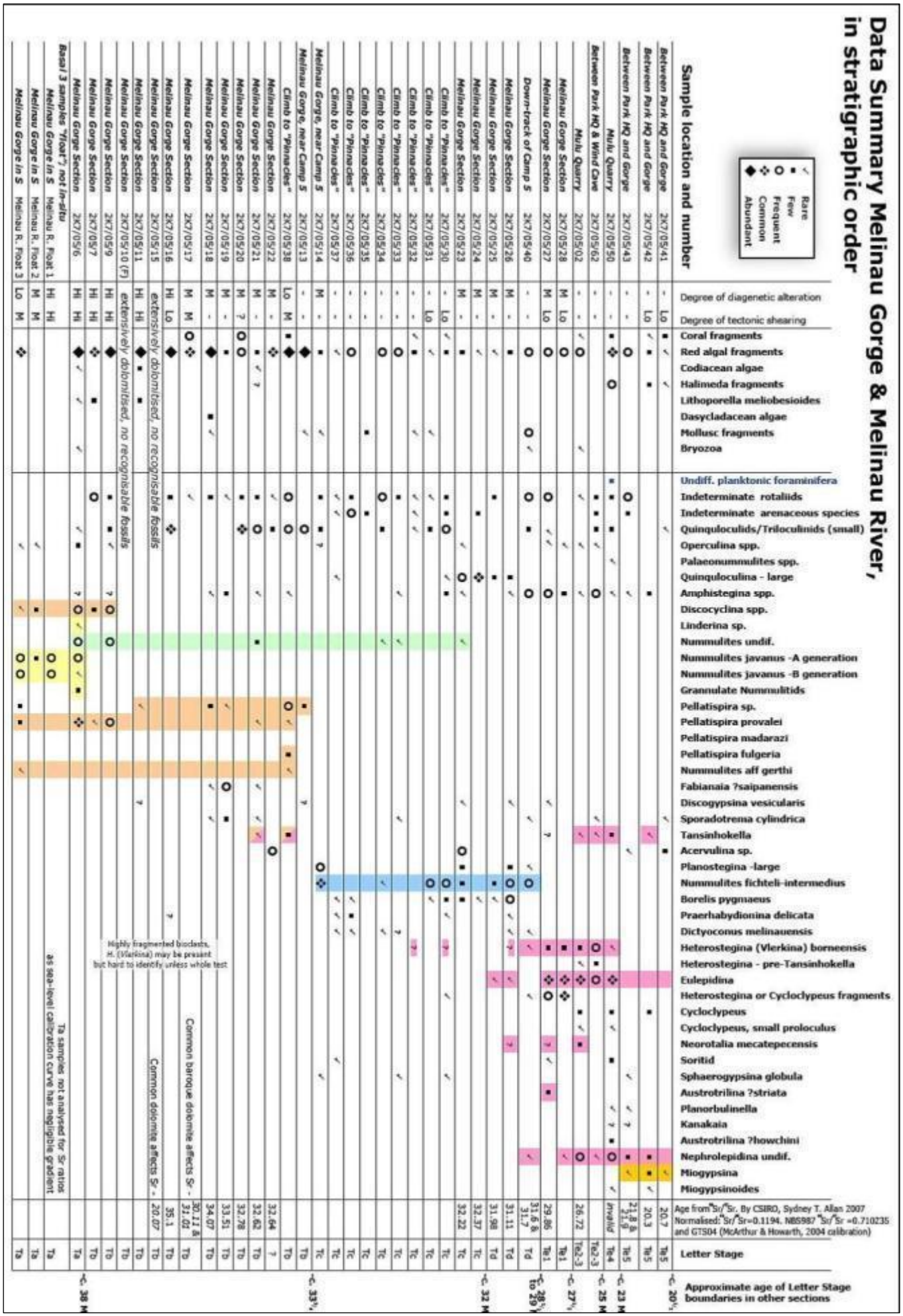


Figure 4. *New biostratigraphic data.*

(1987) made it clear that these were very distinct events. Even though it had been recognised long before, Hall et al (2008) gave this unconformity the apt name of "Top Crocker Unconformity". In this strict sense the mudstones overlying the Melinau are the Setap Shales, and the regional unconformity at Te4 to Te5 is one of the events that led to the demise of the Melinau Limestone (see also Figure 2 of Adams 1970, who places an unconformity at Te4 to Te5). This point of nomenclature aside, the sites at Mulu Quarry (Wannier 2009, Figure 13, 14, 15), and west and above the quarry where there are mudstones with carbonate debris flows and olistoliths (Wannier, Figures 16-18), are important sites covering the termination of the Melinau Limestone. Wannier studied only the carbonates and not the mudstones, although the mudstones are highly indurated and at first glance would not be expected to yield good microfossil faunas. The large limestone olistolith in the lower Mulu Quarry section was noted to have *Miogypsinoides* but no *Miogypsina* (an observation duplicated by this author's field visit), the slightly higher section known to Wannier as Mulu Olistoliths contained both *Miogypsina* (Te5) and *Miogypsinoides dehaartii*, although the defining parameters of *M. dehaartii* were not given. This indicates that close to the Te 1-4 to Te 5 boundary (Lower to Upper Te) the Melinau Limestone underwent a drowning, but survived locally to source the Te5 olistoliths. This event was also observed in Adams (1965, 1970), and both Adams and this work have found clean carbonates of Te5 age that survived this event (samples 2k7/05/41 to 43, Figure 2).

OBSERVATIONS FROM THIS REVIEW

The biostratigraphic observations of the sites visited (Figure 2) are summarised in Figure 4, which are displayed in approximate stratigraphic order.

Samples from the south-east of the Melinau Gorge confirmed the presence of Ta Letter Stage, but the contact with the underlying Mulu Formation was not seen. Both A and B forms of *Nummulites javanus* were recorded (the A generation sometimes called *Nummulites bagelensis,* Renema et al 2003), and some small granulate *Nummulites* were noted as well as rare *Linderina*.

The thick Tb section parallels observations by Adams (1965, 1970), with *Tansinhokella vermicularis* appearing high in Tb, but no records of the ancestral *Heterostegina*. Given the low abundance of the morphologically distinct *Tansinhokella*, some fragments of Heterosteginid ancestors might be present in low number but do not stand out in random thin sections due to their simple morphology.

Both *Wilfordia sarawakensis* and *Biplanispira* at the top of Tb were not observed in the new samples, which are more widely spaced than Adams' work. However paratype material of *W. sarawakensis* was examined in archived material at the British Museum. The highest Tb samples are just east of the Camp 5 accommodation on the south side of the river, although best exposure and Adams' samples are from the cliff on the north side of the river.

Letter Stage Tc assemblages were found in samples on both the north side of the Melinau River and on the path up to "The Pinnacles" karst scenery south of Camp 5. The miliolid form *Praerhapydionina delicata* is found in low numbers throughout Tc. This species is rare in other Tc sections in SE Asia. Large *Planostegina* species, similar to those found in Tc sediments of Cimanggu of West Java, are found throughout Tc, and these seem to have the same range as some of the *Heterostegina* cf. *depressa* of Adams (1965). These are illustrated in Lunt and Renema (2014). Adams shows *H.* (*Vlerkina*) *borneensis* appearing near the lower part of Te, an observation paralleled by the wider spaced samples studied here.

The Tc to Te transition was not well sampled in this study. This section occurs near the northwest end of the Melinau Gorge where the main cliff section begins to diminish, and outcrop is poorer and overgrown. Only a few samples of Td age were collected by me, emphasising the observation of Adams (1965, 1970) that Td is anomalously thin here.

The lowest Te, the Td and highest Tc samples were analysed for strontium isotope stratigraphy, which date the Td to Te transition at between 29.86 and 31.11 Ma, and Tc to Td at about 31.98 to 32.22 Ma. The disconformity of Adams (1970) at the Tc-Td boundary was not seen. The clean cliff-face outcrop continued to sample 2K7/5/25 (lowest Td), and no obvious events were seen in outcrops to this point. Above this, outcrops deteriorated in quality, and from this study it is suspected that the disconformity might be within Td rather than at the base of Td.

Near the top of the Gorge section sampled here Lower Te limestone was exposed, with frequent *Eulepidina, Nephrolepidina* and *Neorotalia mecatepecensis* in each sample. *Heterostegina* (*Vlerkina*), with well developed, but simple, alar prolongations, had been found in very rare instances from Td but increases in abundance within lowest Te. This matches the observation of Adams. No instances of *Tansinhokella* are found in the Gorge. The Mulu Quarry site near the airstrip was visited and found to have frequent *Tansinhokella* and would qualify as Te2-3 in age but, as noted by Wannier (2009), the upper part of the 15m olistolith slab contains rare *Miogypsinoides* and hence is here Te4 in age. The SIS age for the lowest limestone in the quarry is 26.7 Ma, consistent with other sites of Te2-3 age. The SIS analysis on the upper Te4 sample gave erroneous Sr ratio values, of no use in age dating.

Outcrops of younger Te5 limestones are scattered and rare. Three samples with *Miogypsina* were found between Melinau Gorge and the Park Headquarters,

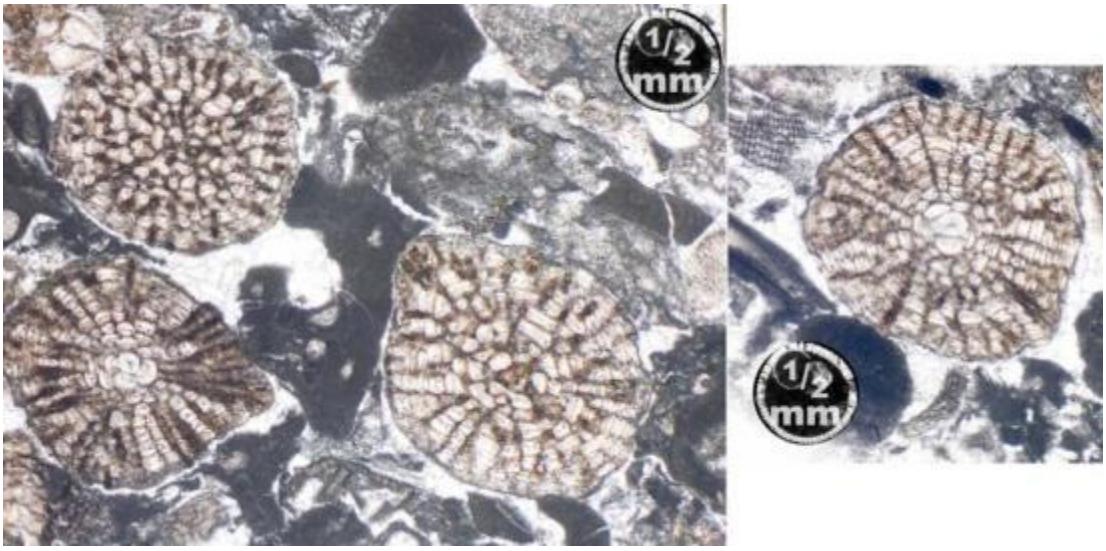


***Figure 5**. One of Adams' (1965) thin sections, stored at the British Museum [sample S10085], from the top of Tb Letter Stage, showing topotypic material of* Wilfordia sarawakensis *Adams.*

and all these gave SIS ages less than 22 Ma (as young at 20.3 Ma, close to the upper limit for Te5 in other areas, see Lunt & Allan 2004).

Mudstone samples overlying the Melinau samples were taken and analysed but the strongly indurated nature of the rock made extraction of microfossils very difficult. It should be noted that the limestone has no primary porosity and is also very strongly indurated, suggesting the whole section had been deeply buried before uplift. In the mudstones common planktonic foraminifera are seen as well as some small benthic foraminifera indicative of deep marine conditions, but with compaction and overgrowth it could not be said with certainty if the key index marker for this age, *Globigerinoides*, was present. One specimen with the distinct profile of *Globigerina binaiensis* was noted above the rafted limestone block in the Mulu Quarry, but this just confirms an age older than about 19½ Ma (Wade et al., 2011).

CONCLUSIONS

An important conclusion from this study is almost self-evident, but its magnitude needs stressing, and that is that intense sampling and analysis, such as that carried out by Adams, gives much better data than the widely spaced sampling of this new work. More thin sections (as archived by Adams in the British Museum) of each sample also helps considerably. Small-scale facies control on faunal record can be overcome, and often rare markers, such as *Miogypsinoides*, can be found. Also transitional forms such as *Heterostegina* (*Vlerkina*) to *Tansinhokella*, which require particular views through the test to be identified, can be more accurately recognised if there are more thin sections.
The method of SIS dating has several sources of error and non-obvious inaccuracy. In Melinau a high degree of dolomitization strongly affected SIS results, and the derived ages were well out of order from the surrounding sequence of samples. Other data, such as the in-order SIS data on Tb samples in the Gorge samples, appears valid until compared to control Tb ages from other sites and the SIS ages of these Melinau samples must be slightly, falsely, young. This study technique has limits and the best results come from SIS complementing biostratigraphy.

The new data supports the 1970 observation of Adams that there is a mid-Oligocene disconformity within the Melinau limestone, but rather than being at the base of Td it may be within Td. A quantitative indication of this disconformity based on modern GPTS data shows that the Tb and Tc carbonates measured by Adams accumulated at rates close to 200m/Ma, but the thin Td is represented by only 11m/Ma, suggesting a significant hiatus and possibly erosion. The succeeding Lower Te Stage was deposited at a rate of over 100m/Ma.

Based on SIS data, the age of this disconformity is older than 29.7 Ma and younger than a cluster of three dates close to 32 Ma. The current best estimate for the major eustatic sea-level fall is at about 29.6 Ma (Haq et al. 2005), so this remains a candidate to have been the cause of this event.

Saller et al. (1992, 1993) gave the age for the drowning of the Berai carbonate platform in Central Kalimantan, 500 km to the south (Figure 1), as 28.0 Ma based on the strontium isotope ratio versus time curve of Miller et al. (1988). However, as noted by Wannier (2009), the lack of species-specific data on the foraminifera limits the value of their strontium age. Questions about the validity of this SIS data also come from the author's knowledge that in three wells referred to in the Saller andVijaya (2002) study of the particular Kerendan carbonate buildup, with suggested drowning age of about 28.6 Ma, the well K 3 had good specimens of *Tansinhokella* (illustrated in thin sections from core close to the top of the carbonate). The same genus is in core petrographic images from K-1, and in K-2 in core about 300' deep into the limestone. As *Tansinhokella* did not evolve until base Te2-3 (about 27 ½ Ma; Lunt & Allan 2004) there is reason to doubt some of the Saller et al. SIS ages. The Kerendan area remains an important reference section for understanding carbonate and general sedimentary stratigraphy of the region, but new work is required before it can be incorporated.

An important conclusion for this review is the apparent extinction of *Tansinhokella vermicularis* at the end of Tb, the absence of both *Heterostegina* (*Vlerkina*) and *Tansinhokella* in a very high number of Tc and Td samples, then the appearance of *Heterostegina* (*Vlerkina*) well before *Tansinhokella* within Te times. This aspect, along with the deliberate search for and failure to find *Spiroclypeus* sensu stricto is dealt with in an accompanying paper (Lunt and Renema, 2014).

The basal part of the Melinau Limestone is confirmed to be within Ta (Middle Eocene, or older than about 38 Ma). The termination of the limestone appears to be in two stages with some indication that within Te4, near the "Top Crocker Unconformity" (Brondijk, 1962; Wilson, 1964; Levell, 1987; Hall et al., 2008; and others), close to the Oligo-Miocene boundary, there was an initial drowning, although some clean carbonates of Te5 were sampled. The youngest limestone, based on biostratigraphy and SIS are not younger than top Te5.

The samples from Tb show that after the extinction of multiple species and genera at the terminal Ta event there was a gradual radiation of new larger foraminifera, with diversity in the *Pellatispira* lineage (leading to *Biplanispira*), evolution of the first *Tansinhokella*, and eventually the appearance of the distinct *Wilfordia sarawakensis*. A mass extinction of many of these forms marks the top of Tb. The fact that *Wilfordia* has never been found outside Melinau may be due to the geological development of Sundaland, with a massive sudden subsidence affecting a large part of SE Sundaland in latest Eocene times (Lunt 2013). The limestone sections on Java and in wells in the east Java Sea, through the Makassar Straits suddenly pass upwards to deep marine clays at about 36 Ma, so there are no records of very latest Eocene shallow marine carbonates (see notes on age determination of sites in Lunt and Renema 2014, this volume). Ongoing work by the author in Sulawesi suggests that the main Tonasa Limestone sequence was initiated by this 36 Ma event and it may be that future sampling might find *Wilfordia* in this formation. The "Tonasa Limestone" drilled in wells offshore south Sulawesi are either Ta age platform carbonates or deep marine Tb marls and therefore this genus has never been recorded there.

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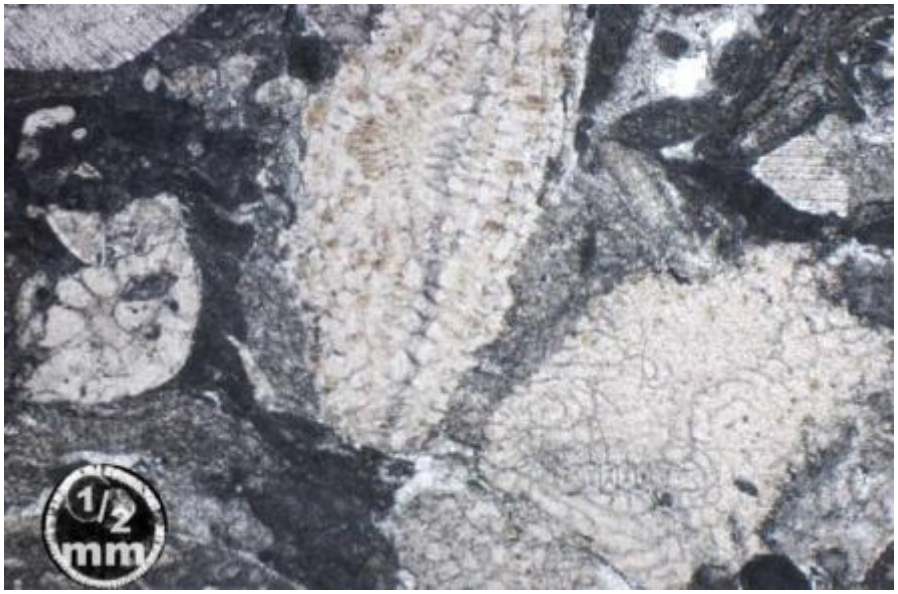
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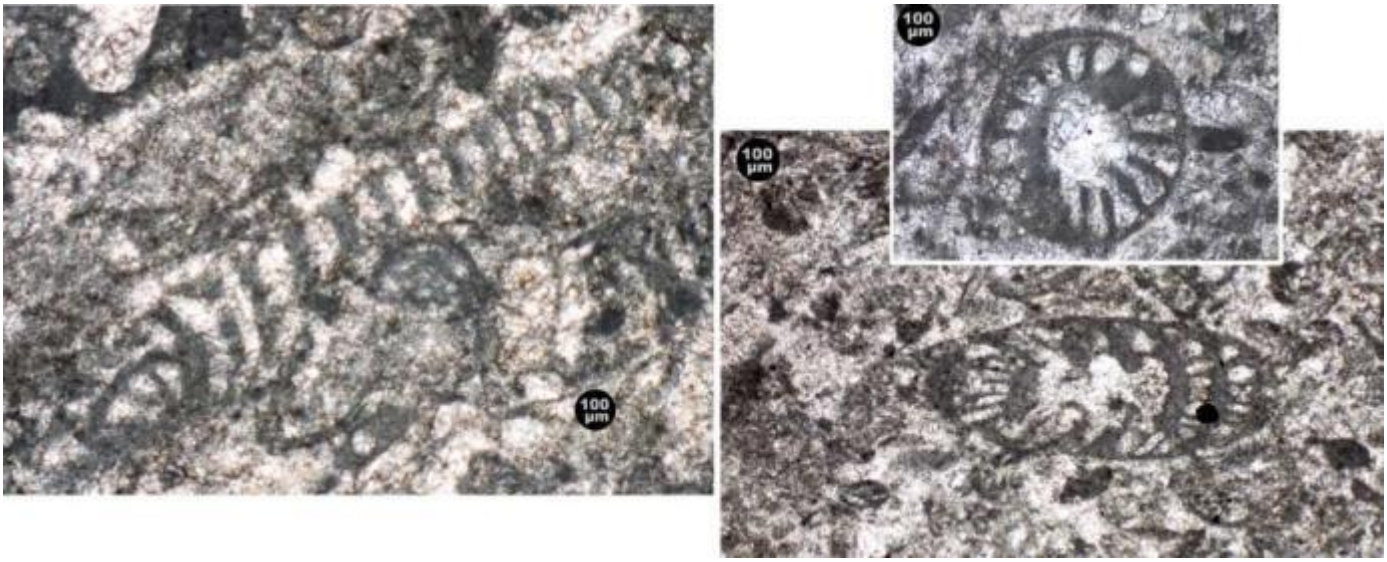
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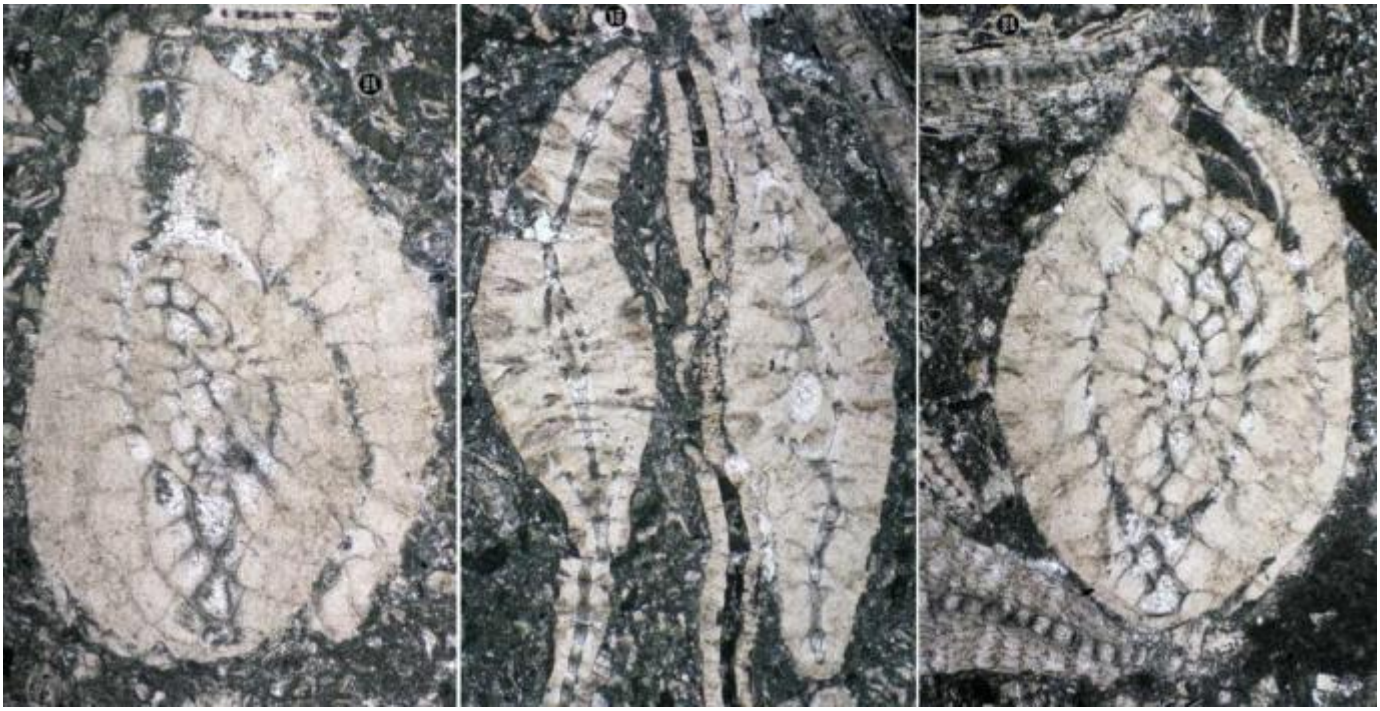
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Template A. One of Adams' (1965) thin sections, stored at the British Museum [sample S10079], from the top of Tb Letter Stage, the genus Tansinhokella - in the oblique section on the right clearly showing the complex "vermiculate" subdivisions within the alar prolongations.



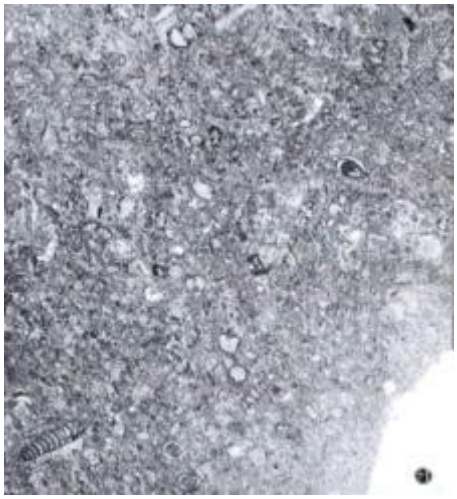
***Template B**. Three views of* Praerhapydionina delicata *Henson in one of Adams' (1965) thin sections, stored at the British Museum [sample S10120], from Tc Letter Stage.*



***Template C.** New sample Melinau 2K7/5/62 (Lower Te, near Mulu park HQ), a sample rich in Heterostegina (Vlerkina) borneensis, but also the earliest Tansinhokella specimens.*



Template D. *Thin section of Adams (1965) sample S-10107, from low in the Tc section.* Heterostegina *with thickening from compound laminar sheets over umbonal area, but with only the very smallest alar prolongations (oblique section cut by fracture shows early chambers with septal traces overlapping earlier whorl). Appears to be slightly maturo-evolute;alar prolongations less visible in adult whorls. The lack of alar prolongations prevents this being included in* Heterostegina (Vlerkina)*. It seems closely related to* Heterostegina *cf.* depressa *recorded by Adams from slightly higher in Tc.*



Template E. *Thin section of Adams (1965) sample S-10121b, from mid Tc: This section shows the overlap of* Borelis pygmaeus *with the Tc restricted* Praerhapydionina delicata *and* Dictyoconus melinauensis



Template F. *Thin section of Adams (1965) sample S-10190, from Te 1 or Te2-3 transition near the top of the Melinau Gorge. Large* Heterostegina (Vlerkina) *with well-developed alar prolongations. Some samples at about this level show the first signs of secondary septa reaching into the alar prolongations, but as can be seen here these samples are dominated by tests morphologically unlike* Tansinhokella *seen higher in the section.*