Giving names to features in geology; the choice between subjective listing or researching objective natural divisions

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ABSTRACT

In literature the English playwright Shakespeare proposed that "a rose by any other name would smell as sweet". Many geologists are also flexible about the names they apply to features, and are tolerant of both oversimplification and even making mistakes in the naming of formations or other features. It appears that precision of a single noun is considered subservient to the essence of the narrative, such as evaluating a hydrocarbon prospect, or giving an interpretation of history.

Here it is argued that naming is important, because geology is so rich in names/nouns, and consequently compound errors in the use of multiple, poorly-defined names/nouns rapidly degrade overall meaning. It is argued here that without names that are both natural and consistently applied, and also continually improved, the scientific framework soon falls apart. By this we mean that the geological understanding of exploration risk, or geological history, rapidly becomes too easily accommodating of any new data and thus lose all rigour. Good, natural names are the results of tested concepts and are themselves open to further testing. From such testing comes recognition that in nature there are not only discrete biological, paleontological and geological categories, but there are also many examples of gradational variations between these categories. A search for good names is inexorably linked to a better understanding of the features concerned.

Keywords: *Geologic names, naming convention, fossil names*

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INTRODUCTION

This is the first in a series of essays on SE Asian geology. Rather than focus on specialist or local topics we instead describe some general properties of geological studies. It is proposed that there is a need for discussion and peer review of the subject of geology itself in the unique and dynamic setting of this region. The underlying hypothesis being considered is that workers in this tectonically active area have adopted habits from more passive regions that are based on inappropriate assumptions. Such a situation might be addressed by either a single, grand refutation, or a series of data-rich papers on multiple areas to achieve the same end. However, in attempting this latter path, the present authors have encountered many difficulties that we need to present to our peers for consideration. In particular we have found ourselves out of step with some reviewers who are neither familiar with the poor nomenclature of geological features, the epistemological problems arising from several decades of accumulated miscommunication, nor an appreciation of the complicated geology of the region. In this essay we deal with the first of these topics, how we have historically applied names, but have failed to keep the underlying concepts or context updated.

Review papers on the philosophy of science in geology are rare but not unknown. In particular what is presented here builds on work such as Miall (2004) and Miall and Miall (2004, and their prior papers), with titles such as "*Empiricism and model-building in stratigraphy*". We have decided to split this review into several parts not only to update some of the examples described by Miall and Miall but also to include objective examples of the features described, as applied to SE Asian examples. A discussion of process, based on Miall and Miall, is in the second essay (Lunt and Luan, *submitted*).

Precision and accuracy in naming of all things in geology

A fundamental point to both reviews is that many observations in geology are based on proxies that have uncertainty in multiple, independent dimensions, yet these aspects of reliability are usually not documented, and this can have important consequences. To explain this is best done by using examples. There are simple ones, such as strontium dating that is reported with high machine precision, implying an age to within a hundred thousand years, and such data can have accuracy (repeatability in re-analysis of adjacent samples), but locally the data fails tests of trueness. For example, results may have shifted away from true age proportional to the sample proximity to a locally contaminating source of ^{86}Sr (such as andesitic volcanics, see Figure 4 in Luan and Lunt, 2022). We will attempt to show that an evaluation of precision, accuracy and trueness of proxy observations is an important factor in applying Miall and Miall's "hermeneutic circle" of rational investigation.

Our first essay considers precision, accuracy and trueness in the naming of things in geology. In SE Asia we have excellent tropical microfossil fauna, highly diverse lithofacies, and complex stratigraphic patterns that require a careful consideration of the naming of all things. If we assume what is colloquially called

"layer-cake" stratigraphy, we apply names that do not seek to test this assumed simplicity. For instance, lower clays can be given one labelling noun, the overlying sandy coastal facies another name, and the uppermost coaly fluvial deposits a third (in Sarawak outcrops, an example of such a succession is the Setap Shale, Nyalau Formation and Kakus Member respectively). If we stop with only acknowledging minor aspects, such as that there are gradual boundaries, we are committing what is called "estimator bias" in statistics. This is an initial subjective appraisal of a topic that guides later investigation. If we assume layer-cake conditions in sedimentary geology, the associated terminology can either lead to confirmation bias, or it can stall any more detailed appraisal of what, in this example, is obviously a regressive sedimentary unit. We need to better use the full range of tools available to us rather than just use a definition based on lithology, as in this particular example we have known for forty years that immediately offshore Sarawak two or more major interruptions to this simple broad regression (the Cycle boundaries; Ho Kiam Fui, 1978) need to be included in the geological history. We need better names for interlinked views of stratigraphic concepts to allow for advances in geological understanding. We might never give up the name Setap Shale, because most marine clays in the region look the same, but we can bring in new observations such as contrasting bedding dip (an angular unconformity; Brondijk, 1962; top Cycle I, Levell and Tan, 1986) or a climatic shift reflected in fossils (Hageman et al., 1987; Morley, 2000), to allow subdivision(s) of the monotonous shale, and we need names that can accommodate this complexity. This is not just a pedantic "lumpers versus splitters" naming problem, but the construction of a new hierarchy of names with better definitions that overcomes the original estimator bias assumptions. For this we need to investigate what it is that we are naming; gradual series or distinct features? Distinct features cannot be subject to lumpers vs splitters pedantry, as they have a test of distinction. This review attempts to demonstrate this point; that better names lead to better geology.

THE NAMING OF FOSSILS

The traditional view of taxonomy is that it comprises the rules and jargon for the naming of organisms, and in geology of fossils. This would include features such as the syntax of names, such as zoological families having the suffix "…*idae*", the capitalisation of generic names, as well as the fundamental basis that species are based on an ideal type specimen. From these come the rules on how to deal with synonyms, and so on. This is the bureaucrat's view of taxonomy. People concerned with correct form and procedure. It has an underlying assumption that each species is distinct, and can be represented by an ideal type (a healthy adult specimen), – a view that was not seriously challenged in the 18th century when the Linnaean system of zoological nomenclature was proposed.

However, it is suggested here that the most valuable role of taxonomy is logically deciding what deserves a name; a topic that by the early 20th century had become well known as the "species problem in biology" (Mayr, 1942). The roots of the word taxonomy come from the Greek *taxis* 'arrangement' + -*nomia* 'distribution', which alludes to a natural distribution of forms. This basic premise, of looking for natural

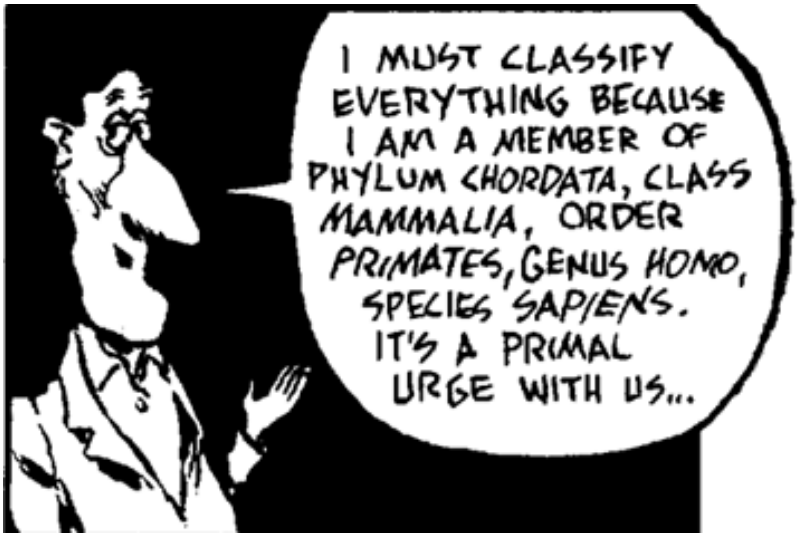


Figure 1: *A very old cartoon reproduced under copyright fair-use for educational purposes, comically illustrating an underlying bias for scientists to use technical names.*

distinction as opposed to gradual variation, also applies to all other examples of naming things in geology given here, so some well-studied examples from palaeontology are a good introduction to the subject.

Palaeontology, especially micro-palaeontology with its abundant faunas, has the advantage over other biological sciences in that it can apply a simple test to species concepts; namely does a morphotype have an initial evolution and an extinction datum? If it does, then it appears to fit the biological species concept (BSC) of Mayr (1942). If not, then the morphological characters can be suspected to be ecophenotypic variation. This is how dimorphic pairs of haploid and diploid foraminifera are identified. For example, after the end Eocene mass extinction, some forms of *Nummulites* appeared in the Early Oligocene, which had very distinct reticulate sutural traces. These tests came in two very distinct sizes and were given two species names (*fichteli* and *intermedius*), but they are now considered to be haploid and diploid generations of the same species, as they share the same stratigraphic range (and are found together). It is also how examples of convergent or iterative evolution are identified (*cf.* Banner and Hodgkinson, 1991; Lunt and Renema, 2014); where homeomorphic characters (or even whole test types) can be demonstrated to have occurred at more than one time, separated by a substantial and genuine (not facies controlled) absence from the fossil record.

The following account illustrates two approaches to giving names to larger foraminifera, which are important rock-forming fossils in SE Asia, and the resulting implications for biostratigraphy and evolutionary studies. The first method establishes species concepts based on stratigraphic distribution, and even offers a way to avoid Linnaean names in biostratigraphy by recognising simpler morphological groupings. It should be remembered that larger foraminifera are usually studied in random thin sections of hard limestones, so in most views important features such as the embryonic chambers, or the external expression of septal traces, may not be visible, or are hard to determine. In addition, it is well known that there are strong responses of the tests

to environmental conditions (see Hallock, 1999; Beavington-Penney and Racey, 2004). Consequently, there is a subjective element to determining the number of different species in a sample, or a suite of slightly different lithofacies from a small section, and also what form the 'ideal' test for each suspected species has. These subjective ideal forms are then the basis for choosing names. There is a historical abundance of species names for larger foraminifera (see Schaub, 1981; charts reproduced in Racey, 1995). Each species is based on a (subjective) type specimen, as required by the rules of the International Code for Zoological Nomenclature (ICZN), focused on a subjective type specimen, and (under the rules of the ICZN) which excludes consideration of the range of variation, gradation or distinction in form. The structure of these rules explains why it is valid to give different names to the macrospheric embryonic generation *Nummulites fichteli* Michellotti 1841 as well as to the microspheric embryonic generation *Nummulites intermedius* d'Archaic 1846.

Lunt and Luan (2022) re-drew the figures of Morley Davies et al. (1971; presented here as Figure 2), based on Eames et al. (1962), and similar to Schaub (1981) and other sources such as Racey (1995), who all noted that beds of Letter Stage Ta age (Middle Eocene) contained highly diverse, often highly dimorphic larger foraminifera, whereas the overlying Letter Stage Tb (Late Eocene) beds lacked these forms. Adams (1965, 1970), studying samples from SE Asia, including the thick and continuous later Eocene to base Miocene Melinau Limestone, came to the same conclusion. One difference was that Adams did not use the mass extinction of diverse forms at the top of Ta to define this boundary. The Letter Stage Ta assemblage was only present in the lowermost sample out of the 195 he collected from the Melinau Gorge. Instead, he placed the base of Tb at the first evolution of the genus *Pellatispira,* which Leupold and van der Vlerk (1931) and others had already noted to have appeared well before the multi-genera extinction event mentioned above. Morley Davies et al. (1971) noted that this end Ta extinction event in the supergenus *Nummulites* (split into multiple lineages by Schaub) affected all forms that were highly dimorphic, those that had meandrine septal traces, and those that had granules over the septal traces. The microspheric generations of these highly dimorphic species were frequently between 2 and 3 centimetres in diameter and often abundant, rock-forming, bioclasts. In contrast, the largest *Nummulites* in the Late Eocene and Early Oligocene were the *N. intermedius* form of the Early Oligocene and these rarely reached 1 cm (Racey, 1995; Renema et al., 2002).

In SE Asia, un-faulted, continuous Middle to Late Eocene sites such as at Melinau, Batu Gading, Nanggulan (Adams, 1965; Adam and Haak, 1962; Lunt, 2013a; Coxall et al., 2021) and the lower Tonasa Limestone and underlying beds in Sulawesi (Crotty and Engelhardt, 1993; Wilson, 1995), plus wells drilling this unit offshore, saw the same succession in *Nummulites* and other larger foraminifera observed by Morley Davies, Eames and Adams, along with planktonic foraminifera for age control. In wells in the southern Makassar Straits, and outcrops in Central Java, planktonic foraminifera are found within or immediately above larger foraminifera-bearing limestones (Lunt, 2013a; Lunt and van Gorsel, 2013). The extinction of three distinctly ornamented genera of planktonic

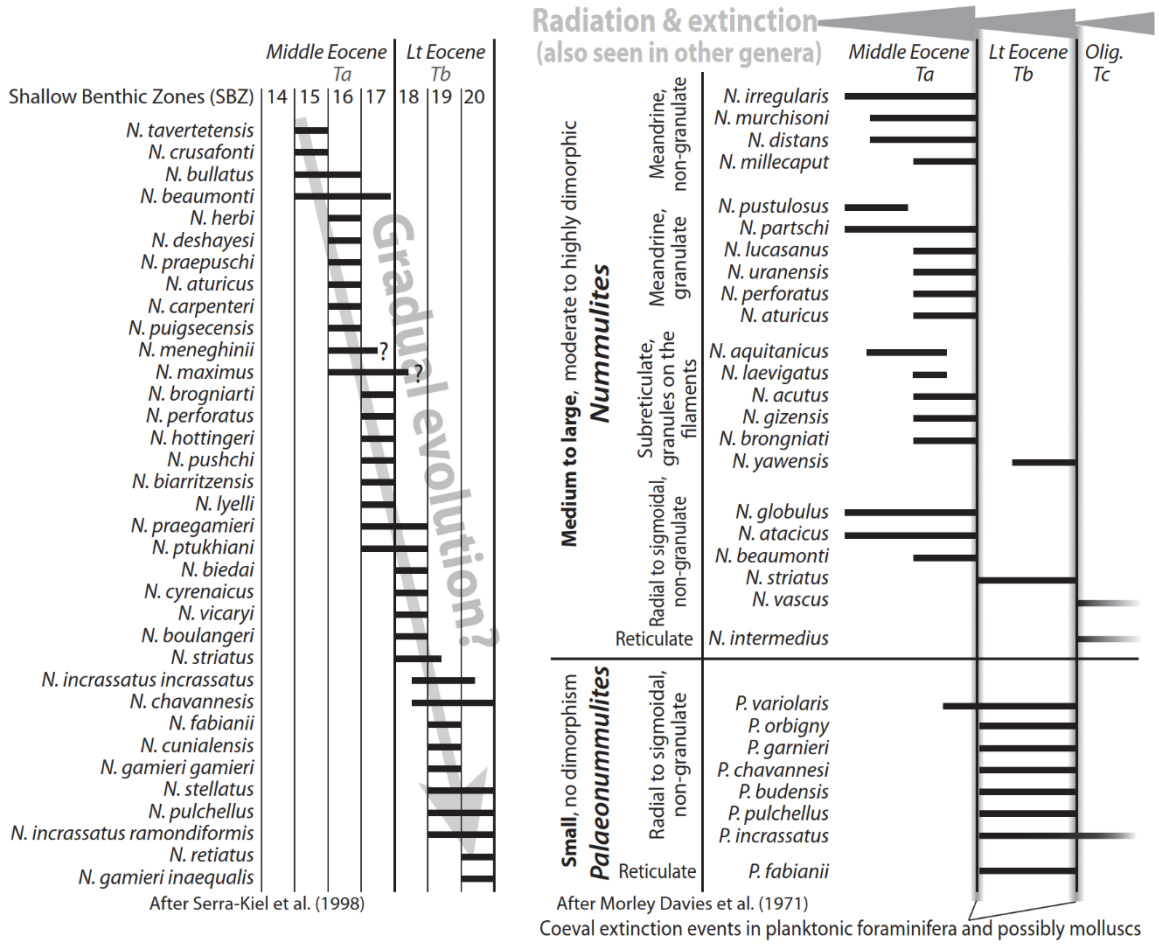


Figure 2: *Summary of Nummulites taxa over the Ta to Tb boundary, from Lunt and Luan (2022). Left; an arguably pedantic approach to Nummulites taxonomy that implied a gradual trend in Nummulites evolution and overlooked the fundamental radiation and extinction of forms observed by many other workers. Right; the Middle Eocene Letter Stage Ta saw increasing complexity of morphology to the acme of Nummulites diversity, abundance and size in upper Ta, but was abruptly terminated (along with several other larger and planktonic foraminifera, and possibly macrofossils) and then replaced by much simpler forms in the Late Eocene Tb, which can be recognised from basic morphological categories. A further extinction occurred at the Eocene-Oligocene boundary. The difference between these approaches is based on the application of independent stratigraphic checks on the identification of natural species, which must have consistent evolution and extinction datums.*

foraminifera at the end of Zone E13/P14, namely *Acarinina* (muricate tests), *Morozovelloides* (muricocarinate tests) and *Truncorotaloides* (spinose with supplementary apertures), appears to have been at the same time as the end Ta extinction of many larger foraminifera. These muricate / muricocarinate tests are often identifiable in thin sections of limestone that also contain larger foraminifera (e.g. Lunt and Allan, 2004), important observations even if only the generic names can be given to such records.

Consequently, a synthesis of the foraminiferal record over this period, with

good age control, from several independent workers, indicates that *Nummulites* had undergone gradual radiation to forms with highly dimorphic haploid/diploid generations and specialist morphologies such as meandrine sutures and granules, and all these became extinct at the same time as other genera disappeared, such as *Alveolina, Assilina/Planocamerinoides*, and *Orbitolites*, apparently also the planktonic genera *Acarinina, Morozovelloides* and *Truncorotaloides*. Amongst the surviving larger foraminifera, forms such as *Pellatispira* then underwent rapid expansion in abundance as well as radiation in morphotypes (hence its usual association with Tb faunas), being ancestral to *Biplanispira* and *Vacuolispira*. Also during Tb, *Heterostegina* (of the "*Vlerkina*" types of Banner and Hodgkinson, 1991) evolved from *Operculina*, and then rapidly evolved into the complex *Tansinhokella* and *Spiroclypeus*. The Letter Stage Tb was terminated by another mass extinction at the Eocene-Oligocene boundary. In planktonic foraminifera Wade (2004) also noted the global turnover in multiple genera at the end of zones E13 (=top Ta) and the end Eocene top E16 (=top Tb). Even in American molluscs, two extinctions seem to correlate with the end Middle and end Late Eocene (Haasl and Hansen, 1996; Hansen, 1987). This has been attributed to stages in the prolonged growth in the Antarctic ice sheet (e.g., Prothero, 1994).

This is a framework or hypothesis of data, based on multiple sites, that is predictive and testable. The extinction events, which appear to correlate across different groups of organisms, appear to be significant datums. There may be exceptions, but these should be rare and have context. For example, one of the present authors has found a single sample in the lower part of planktonic Zone E14 of West Java, with a few large *Nummulites* having rare and weakly developed granules (locally called *N. hoogenraadi* Doornink, 1932). However, many other Late Eocene and Tb samples in the same area contained common *Nummulites* without dimorphic variation, granules or meandrine septal traces (Lunt, 2013a). Also the "Grande Coupure" ("Great Break") extinction of metazoans and molluscs in Europe is thought to be slightly above the marine Eocene extinctions, and probably correlates with slightly delayed terrestrial climatic changes that occurred in the earliest Oligocene (Hooker, 1992; Prothero, 1994).

The method of using a time-line, of evolutions and extinctions, to test natural species concepts begins to fail where continuous stratigraphic sections are rare or short. Adams (1970; his Figure 2) summarised the best Cenozoic carbonate sections around the remnants of the Tethys Ocean. He noted that the most continuous sections in the Middle and Late Eocene were in SE Asia. The sections in Assam, eastern India, have the Sylhet Limestone of Ta age terminated by a major transgression of open marine clays of the Kopili Formation. This latter formation lacks larger foraminifera, and the contact with the Sylhet Fm. is still within Middle Eocene Letter Stage Ta (Biswal et al., 2021). Racey (1995) documented a number of sections in Oman that, in total, covered most of the Eocene as well as Early Oligocene, but of mixed carbonate and (larger foraminifera poor) clastic facies. In European studies, the Shallow Benthic Zones [SBZ] were proposed by Serra-Kiel et al. (1998) as a simple concurrent range bio-zone scheme for the Paleocene and Eocene of "West Tethys". This was based on discontinuous outcrops, mostly exposed due to the Alpine

Orogeny, and usually with no independent age control in indurated limestones (rocks of this age cannot be dated from strontium isotopes; *cf*. McArthur, 2010). The sites of Racey (1995) are on the southeastern edge of the Alpine fold and thrust belt and, due to uplift that began in Early Miocene times, lacks carbonate outcrops younger than Late Oligocene.

The SBZ scheme was based on a large number of proposed species, based on the standard ICZN typological approach, but the range charts based on these species concepts failed to identify the major extinction event near the end of the Middle Eocene; i.e. the collapse in morphological diversity followed by new radiation from different ancestral stock that was recognised by Morley Davies, Eames et al., and many others over a much wider area, and with better stratigraphic control (see Figure 2). Even in later iterations (Serra-Kiel et al., 2016), where the SBZ scheme was extended into the Oligocene, while the terminal Eocene event was recognised (even though some important new Oligocene genera such as *Cycloclypeus* were omitted), the Ta to Tb mass extinction event was still not discernible. In this 2016 SBZ scheme, over 80 larger foraminifera species were listed, and the scheme appears to be highly technical, but one has to question either their validity as natural species, or the arrangement of the sample sites in time, if they do not fit the Morley Davies, Eames, Adams etc. evolutionary framework discussed above.

Biostratigraphers feel they need to give fossils names to the level of species, perhaps to demonstrate professional competence, but this is not necessarily the best approach, especially as so few species concepts have had stratigraphic checks applied. The Indonesian Geological Survey (?) manual on larger foraminifera by Mohler (1946), and the book by Morley Davies (1971; see Figure 2), working at generic level with minimal species names, can reliably identify the basics of the Letter Stages, which have now been correlated to a standard time scale (van Gorsel et al., 2014). This Middle Eocene to Pliocene biostratigraphic zonation framework, based on stratigraphically tested generic or subgeneric taxa, has been used by numerous field workers over decades, and it was later independently tested by planktonic foraminifera and nannofossils.

It was this stratigraphic testing of species concepts that saw the planktonic foraminifera and nannofossils develop as important biostratigraphic tools (*cf*. Bolli and Bermudez, 1965; Blow, 1969; Postuma, 1971; Stainforth et al., 1975). Prior to this research, in 1949, van Bemmelen reported that "*The Discoasteridae, Coccolithinae and Radiolaria are of little value from a stratigraphical point of view*", citing the erroneous view of palaeontologist Tan Sin Hok. This was before the pioneering work of Martini (1971) in establishing proper nannofossil species and giving them names based on natural (stratigraphically tested) differences. An insistence on using subjective (untested) species names can sometimes be a backward step.

Artificial (Informal?) fossil names

The example given above seeks to demonstrate that strict adherence to the procedures of ICZN taxonomy can result in subjective names, and consequently questionable stratigraphic or palaeontological observations based on those names. Simple names (i.e. just to

generic or subgeneric level) can be better than specific names simply because they have concepts that have been tested. Therefore, taxonomy should be concerned most with discovering what is worth giving a name, not just compliance with an established standard. This chapter looks at an alternative method of simple microfossil names, but one which still lacks testing of its concepts and therefore remains of very limited scientific value.

In the past few decades a movement away from the confusing lexicon of names in the benthic foraminifera has been attempted. This was brought on by a problem described by Boltovskoy (1965) as the "*Twilight of foraminiferology*", due to a "snowballing" of species names. Few smaller benthic foraminifera have useful evolution / extinction datums, because their simple morphologies show as much response to facies controls as to their evolutionary history (*cf*. van Morkhoven et al., 1986). Beginning in about 1985, workers such as Jones and Charnock (1985), studying the very simple arenaceous foraminifera dominant in very deep marine faunas, simplified the classifications into morphogroups, noting association of some body plans to certain benthic conditions. It was just proposed as a simple short-hand to examine particular aspects of facies relationships without being distracted by the confusing Linnaean taxonomy. The method expanded far beyond the intention of these workers, as it sidestepped Boltovskoy's snowball of names and sped up both logging and training of students. In the past two decades some commercial consulting groups in SE Asia have issued well reports where the foraminifera and nannofossil data charts have columns annotated "Total count Morphogroup A" and even "Total count (Zone) N5 markers" for the planktonic foraminifera (see Figure 3). This forms a poorly considered 'taxonomy of convenience' that may appear technical and precise, but actually creates highly inaccurate categories.

The morphogroup approach to logging benthic foraminifera, while convenient in samples with poor preservation, usually degrades their use in palaeontological studies. For example, in the scheme used for Figure 3, morphogroup C1 contains the bathyal index forms *Martinotiella* and *Gaudryina*, but also the estuarine *Ammobaculites*. Morphogroup B2 contains *Glomospira* (another bathyal index), which in the 1950s and 60s included the "*Glomospira* 4" of Shell in Sarawak and Sabah, but which was eventually recognised to be the morphologically similar but brackish water *Miliammina fusca*. Note that arenaceous foraminifera are concentrated in assemblages from very deep marine and also very shallow marine-brackish settings that are both hostile to taxa with calcareous tests. A key differentiator is that estuarine arenaceous taxa use inorganic cements, while the bathyal forms have weak calcareous cements. The artificial, un-natural classification used in Figure 3 has many such caveats and it should be replaced with a revision based on tested concepts. In SE Asia most genera and some species found in the young fossil record are extant and a large number can be highly ranked as restricted to specific environments, especially water depth (see a partial listing of such studies in Lunt, 2013a). Not all benthic fossils can be ranked this way, which means a messy summary rather than an attractive new classification scheme.

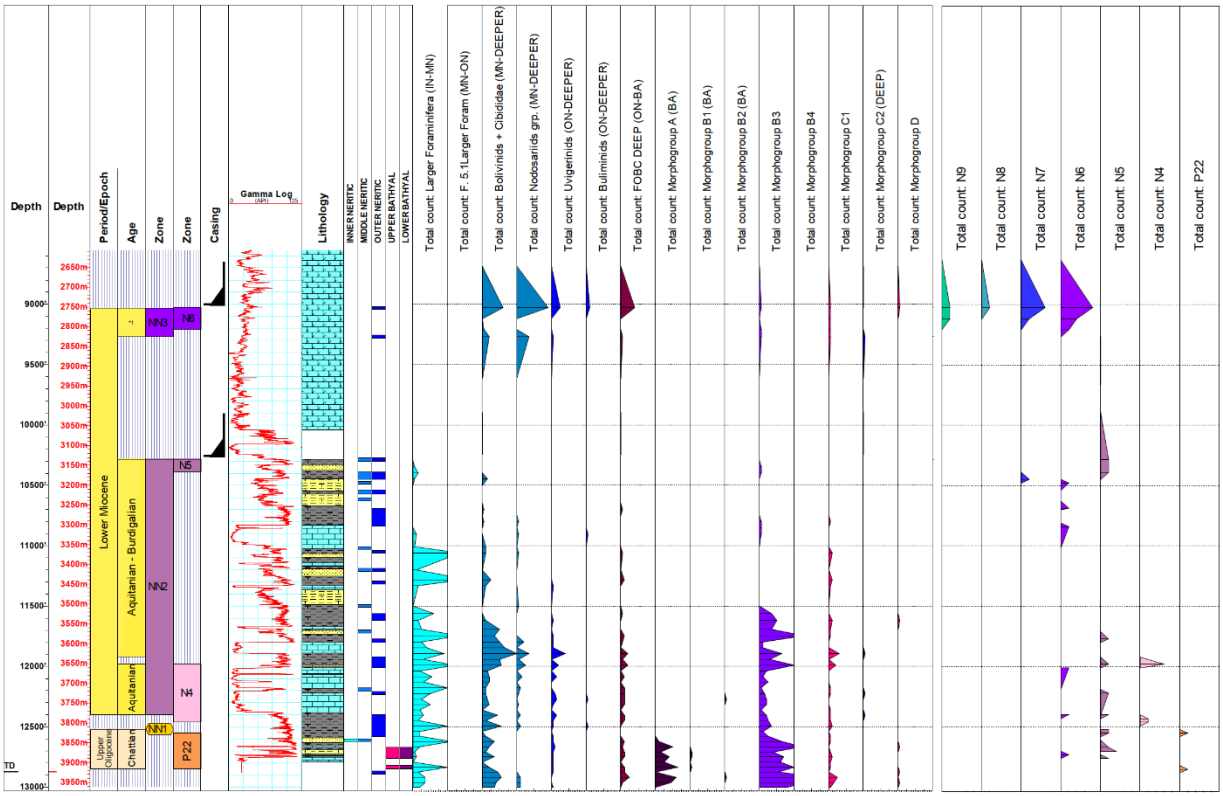


Figure 3: *A disguised section of an actual well analysis chart from SE Asia drilled in the last ten years. The benthic foraminifera are reported by morphogroups and the planktonic foraminifera un-named in columns as zonal markers. Data has not been changed.*

Similarly, the classification of age-index forms appears to be technically solid in Figure 3, but it is also unnatural and degraded. An example is Zone P22, which is defined solely on the absence of younger N4 and older P21 species. So what markers might have been logged as the “Total Count of P22 markers”? Similarly, Zone N5 is another empty set above the extinction of *Paragloborotalia kugleri* and below the evolution datum of *Globigerinatella*. Even worse, as noted by Bolli and Saunders (1985),: "*even in optimum latitudes the distribution of the genus [Globigerinatella] can be irregular, necessitating the use of other taxa to verify the stratigraphic level.*", a view repeated by Gradstein et al. (2012). So what were the N5 markers logged in multiple samples? They might be *Globigerina binaiensis*, which is a minor but consistent member of SE Asian faunas. This morphologically distinct species became extinct at about 19.4 Ma. However there is no way to verify this from the above well report (including the accompanying text). The two implied records just below casing near the base of the limestone would be significant and, if accompanied by a photograph, would help to reliably date the youngest siliciclastic sediments below the limestone. Note that the left hand data column of “Total count larger foraminifera” is not accompanied anywhere by a summary of what those larger foraminifera are. This group of fossils has been the mainstay of biostratigraphy in SE Asia since the 1920s, but this data summary, produced in the last ten years, has them all lumped together in a morphogroup of no use whatsoever.

In Figure 3 the 'near top Oligocene' (Zone "P22") stratigraphic level has sediments implied to be of much deeper marine origin based on Morphogroup A. This morphogroup consists of tubular or branching arenaceous forms such as *Bathysiphon* and *Rhizammina*, but there are other non-foraminiferal fossils or trace fossils with fine tubes that resemble *Bathysiphon*, etc. If such a fauna contained just a single *Melonis* or *Sphaeroidina bulloides* , both with highly distinct morphologies and specific deep marine palaeobathymetric ranges, then confidence in a bathyal environment of deposition would greatly increase.

Confidence in data reliability is as important in the geological sciences as the estimation of error bars that are compulsory in reports on the experimental sciences, yet it is so often overlooked. To continue the example in the last paragraph, if we could be confident in the age (top Oligocene/base Miocene) or the change from deep to shallow marine environment of deposition in the well in Figure 3, this would be an important observation. This site is surrounded by areas where the Base Miocene Unconformity (BMU) is a regional subsidence (deepening of facies up-section). If there really was uplift at the same time in this location (next to a postulated basement fault zone) it would be a notable contribution to geological studies; an exception that proves (*probare*; tests) the rule. This is the difference that good names, based on validated natural categories, can make; as opposed to poor, ambiguous names that, in Figure 3, leave an investigative dead end.

So, fossils give good examples of the importance of actively investigating the quality and objective nature of names. Yet, too often workers do not question underlying principles, and stop with the established standards that are derived from ideas that are centuries old (and based on metazoan fossils, not the microfossils used in SE Asian palaeontology). This reluctance to re-examine basics also occurs with the names for age units, which have a long history as well as international standards, and the often pedantic insistence of their usage in the international journals.

NAMING IN CHRONOSTRATIGRAPHY AND LITHOSTRATIGRAPHY

It is likely that the jargon-rich subjects of chronostratigraphy and lithostratigraphy are intimidating to the non-specialist, not because of the scientific complexity of the subject matter, but mostly because of the naming of its parts, in the overlapping dimensions of depth/area and time. Such overlapping terms are further complicated by a long history of evolving techniques to measure time and determine facies. In this chapter there is a slight shift in emphasis from the naming of fossils described above, because in chronostratigraphy and lithostratigraphy there are also gradational scales of time and facies settings, and the problem is more of a choice of what makes a better name. By "better" the choice should be for a name that is easy to identify consistently, and also reliably reflects the potential errors bars in the determination of the observation.

Naming units of time

In 1833, Lyell divided what was then called the Tertiary of Europe into four parts, namely Eocene, Miocene, Older Pliocene and Newer Pliocene (the latter pair revised

in 1839 into Pliocene and Pleistocene). As with the slightly younger term Cainozoic (from the Greek *kainos* = new and *zoon* = life), these were biostratigraphy-based units, which is reflected in the roots of the names, viz.: Eocene = "dawn of the new", Miocene = "less new", Pliocene = "more new", Pleistocene = "most new". Lyell defined his Eocene as strata with less than 5% of mollusc fossils still living, the Miocene as strata with about 17% extant forms, and the Pliocene as strata with 35-50% extant forms. The Paleocene and Oligocene were added in 1874 and 1854 respectively as workers discovered significant sections of sediments at the base of the Eocene and between Lyell's Eocene and Miocene.

In the nineteenth century, that was all that could be achieved to identify and name units of time/rock in the high latitude sediments of Europe. Since then, the science of chronostratigraphy, and its offshoot biostratigraphy, has come a long way, especially in tropical Cenozoic SE Asia, which is rich in microfossils (Figure 4). It can be argued that we can almost dispense with the multitude of names in the standard charts of International Commission on Stratigraphy (Stratigraphy.org) and date the Eocene and younger rocks on an absolute time scale (with units of millions of years), which has been relatively stable since Gradstein et al. (2004). However, this proposal currently fails due to the poor dating of non-marine beds, and the large amount of historical work that cannot be reliably translated to such a precise scheme.

A good example of the changing definitions of time units affecting geological studies is the reported age of the Kudat Formation in northernmost Borneo. In the 1950s and 60s these rocks were dated as Letter Stage Te1-4 and the unconformably overlying South Banggi Formation contained Te5 foraminifera (this is the regional subsidence of the BMU mentioned in the previous section). At that time the age of the Oligo-Miocene boundary had not been agreed upon, as the nascent science of foraminiferal biostratigraphy was just beginning to clarify the age of type sections of the Chattian and Aquitanian Stages. It was not even clear if the Aquitanian belonged in the Oligocene or Miocene Epoch (*cf.* Eames et al., 1962). By the time of Adams (1970), the boundary between lower Letter Stage Te (Te1-4) and upper Te (Te5) had been tentatively correlated to the Oligo-Miocene boundary, and the work of Berggren et al. (1985) fixed this relationship to planktonic biostratigraphy in ODP cores. For reference, the upper boundary of the Oligocene is now defined by its Global Boundary Stratotype Section and Point (GSSP) at Carrosio, Italy, which coincides with the first appearance of the planktonic foraminifera species *Paragloborotalia kugleri* and with the base of magnetic polarity chronozone C6Cn.2n (and currently dated at 23.03±0.05 Ma; Steininger et al., 2017).

This history means that the papers of Stephen (1956), Clement and Keij (1958) and Wilson (1961) assigned the Kudat Formation to the Early Miocene (they actually used the term Lower Miocene). In many oil company reports and publications, the Kudat Formation is still described as Early Miocene (Madon et al, 1999, van Hattum, 2013) and hence it must overlie the Base Miocene Unconformity-BMU (which defines the base of Stage III in Madon et al., 1999, their Figure 22.4; it was called TCU (Top Crocker Unconformity) in van Hattum et al., 2013, their Figure 2). The

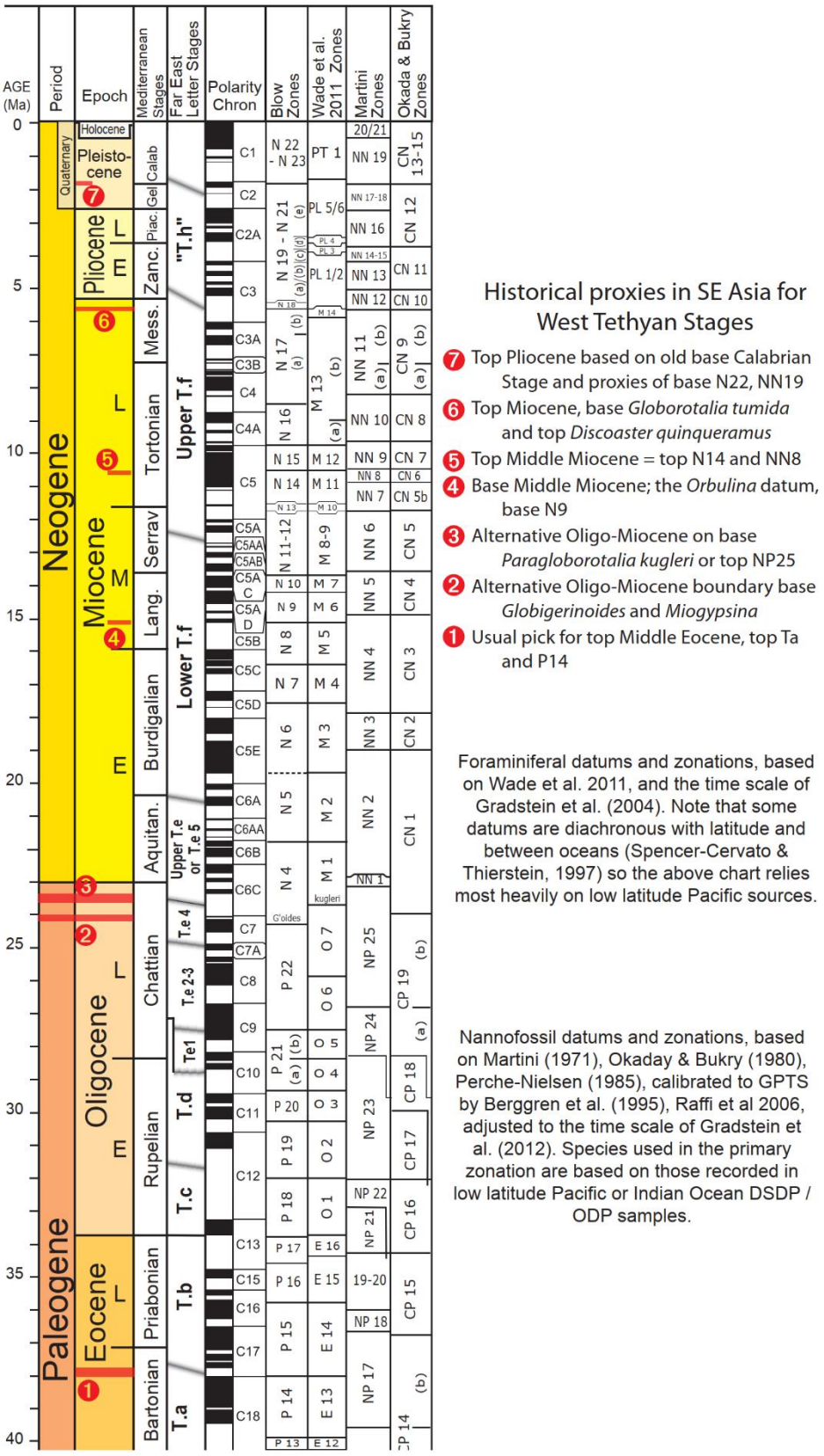


Figure 4: *Late Eocene to Recent time scale with the Leter Stages and biozonations proxies used in SE Asia (after Lunt in van Gorsel et al.; 2014).*

data, however, shows that all the fossils contained within it indicate a Te1-4 age (Clement and Keij, 1958), now considered to signify a Late Oligocene age, and that its deposition was therefore terminated, not initiated, by the BMU.

Applying the wrong age to the Kudat Formation is poor scholarship, but getting its age wrong with respect to the regional BMU, deemed by many workers to be the most important Cenozoic unconformity in north Borneo (see next section), has major geological implications (*cf.* Lunt, 2022a).

Naming of sedimentary rocks

It is grammatically incorrect to use Upper or Lower to describe a period of time, or Early or Late for a unit of rock, and some names have seniority in usage for the sake of consistency, but this is not an important part of lithostratigraphy. Lithofacies grade into different types laterally (and this lateral succession is commonly preserved vertically through Walther's Law), but the generally poor geographic extent of outcrops in tropical SE Asia means that observations of such important grades have to be subordinate to the naming and mapping of basic lithofacies content. Within this record, unconformities can be identified and used to split formations, because it is known that Walther's Law will break-down at unconformities. As a result, unconformities may sometimes be identified within a unit of apparently homogenous lithofacies. Consequently names have to be used that can include gradual change, but with remaining potential for objective subdivision or grouping by an empirically derived stratigraphic framework. Such frameworks

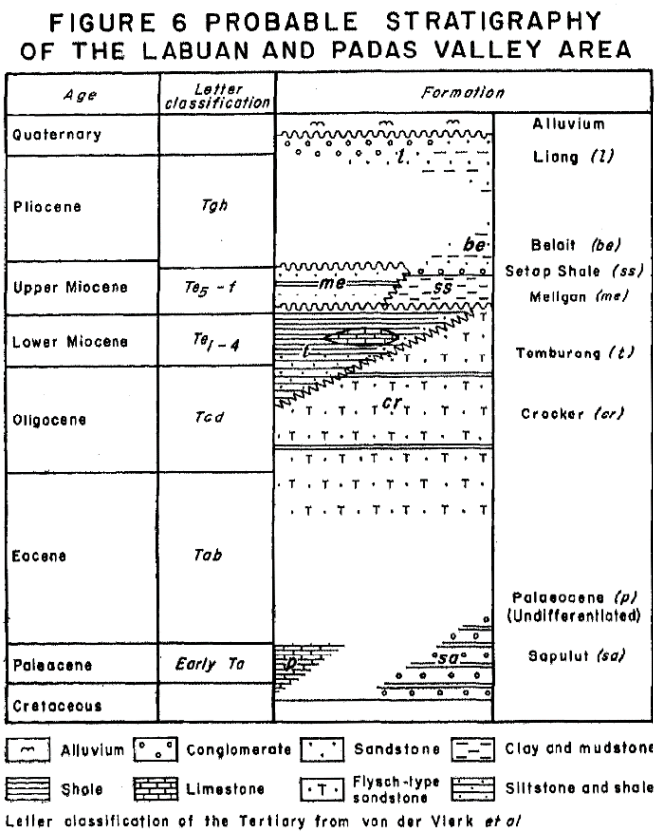


Figure 5: *Stratigraphy of the Labuan and Padas valley, south of the Kudat Peninsula (west Sabah), from Wilson (1964). No schematic stratigraphic summary was drawn for the Kudat area. Clement and Keij (1958) reported ages primarily as Letter Stages, while the mapping quadrangle report of Stephens (1956) noted the Kudat Fm to be "Lower Miocene (Aquitanian, Te1-4)". This highlights the confusion over the shifting overlap in names mentioned in the text. The age observation is of Letter Classification Te1-4 foraminifera; the other names are translations based on out-of-date concepts.*

and the resulting names must always be constrained by Walther's Law.

The application of an empirical framework of facies through time was the reason why the lithologically similar Setap Shale and Temburong Formations were separated across NW Borneo. In this area, the BMU, long recognised as the major Cenozoic tectono-stratigraphic event across all northern Borneo (Reinhard and Wenk, 1951 to Wilson, 1964), was used to split the deep marine Miocene clays (Te5 and younger) from the Late Oligocene (Te1-4) deep marine clays by Brondijk (1962). Around the Temburong River type area (NE Brunei) both formations have minor transported larger foraminiferal limestone interbeds, useful for age dating (the Panggi and Batu Apoi limestones below and the Pulun Limestone above), and the unconformity is identified by a contrast in bedding dip.

Without an empirical framework and an abductive process to bring age, paleontological and other data together to construct that framework, we can only apply basic inductive observation. That was the starting point in west Borneo, where thick, deep marine clays were given the name Setap Shale each time they were encountered. This simple inductive observation might be considered more objective by a pedant, but it is not preferable because it misses the point of why we are carrying out stratigraphy. Workers have long known there was a more active geological history that required study in order to link stratigraphy to other geological disciplines, but clays lack easily observed characters with which to subdivide them. The introduction of the regional BMU by Brondijk (1962) was the first change from simple induction to abduction: he knew there was a division, but additional names were needed to classify which side of the BMU unconformity an outcrop was on. This was a necessary step to understand what happened during this period of change. The shift from pure observation to abductive reasoning included properties that began to build a new framework or cross-discipline hypothesis. Workers began to note that the BMU was strongest in the northwest of Sabah and it faded in expression south and east. There was microfossil reworking in the north prior to the BMU but this reworking stopped at the BMU event. The abductive framework of combining observations to create a new hypothesis and testing it, is the basis of stratigraphy in complex SE Asia. It is this testing of a hypothetical framework that becomes the reality-check on which names for time and rock units are useful. In doing this, we begin to address the question of why is there geographic variation in this regional unconformity, and to predict and test the facies/ palaeogeography on either side of it.

Sequence stratigraphic techniques in tectonically active basins must intentionally embrace an abductive approach, because the ideal passive margin conditions on which deduction is based, do not always apply in SE Asia. That is, we cannot name units only on their geometry compared to a layer-cake, passive margin. There are many times when subsidence and transgression in some areas are coeval with uplift and accelerated erosion in adjacent regions (end of Te5 limestones around Sundaland, Cycle IV to V boundary in Sarawak; Lunt, 2021). Under these circumstances, the passive margin names of transgressive or highstand systems tracts are simply misleading. The landmark paper of Posamentier et al. (1988)

specifically recognised that such tectonically active conditions were outside the base assumptions required for the application of eustatic sequence stratigraphy, yet in SE Asia these often rapid readjustments to basin architecture have been ignored in the haste to apply a "global" model and the associated jargon.

The solution is not to create a new system of names, but a commitment to document and test the framework. Consistency, and if possible precision, in the use of names is important but only in so far as they describe a natural framework of sedimentary geology. In principle, the bounding unconformities are the easiest features to name, but even in these cases there are many naming errors, with the Mid Miocene Unconformity (MMU) of the South China Sea margin being a prime example (Lunt, 2019a, 2022b). Tectonic unconformities are a sum of two movements; the geographically variable tectonic displacement and the movement of the sediment bodies, but these are only loosely linked. For example, in a breakup-type unconformity the subsidence might be initially rapid, decaying to slower, and locally uneven sag (McKenzie, 1978), but the sediment deposition retreat (=transgression) would have been rapid and associated with the initial subsidence, irrespective of any throw on faults mapped later during the tectonic sag. Similarly, the end of compression and erosion at the Deep Regional Unconformity (DRU) in West Sabah was followed by transgression. While some strata may show onlap onto the DRU, as subsidence continued, the event itself and change in sedimentary patterns can be identified at the turnaround from widespread compression and uplift into a rapid subsidence.

Lunt (2019a, b) introduced the term 'Non-Waltherian Contact' (NWC) for a paraconformable contact of a step-like nature in the facies record that is based on facies analysis, irrespective of tectonic movement at that site. Walther's Law only applies to facies, but for paraconformable NWCs this law insists that if the stratigraphic record preserves an abrupt step between two thick or prolonged facies bodies (with no missing section), then there must have been an equally abrupt, step-like change in palaeogeography through time. At a given scale, the facies deposited between two such major sequence boundaries / NWCs must obey Walther's Law and individual facies can be given formation names, with the knowledge that there will be gradual lateral transitions.

At a finer scale, new, parasequence-type, units may be identified due to small scale eustatic or local tectonic change within a "mega-sequence" sedimentary body. Names have a traditional relationship to scale, and formations have an accepted range of sizes (>10s of metres thick – smaller beds are considered to be Members), whereas within a stacked hydrocarbon reservoir, the individual sands units at the scale of a few meters invariably adopt a different naming scheme.

Most of the points in the previous paragraphs seem self-evident, but in spite of this we have entrenched habits that have not yet been abandoned. The name Bampo Formation is still used in North Sumatra (Tampubolon et al., 2018; Muchlis and Elders, 2020), even though the name has two clearly opposing definitions (split by some into non-marine or estuarine Bampo and deep marine Pirak Formations; *cf.* Lunt, 2019b). Even more extreme is the use of the term Ngimbang Formation for a wide

variety of different lithofacies across the Eocene and Early Oligocene of eastern Java, which has reached a state of ambiguity that renders it useless (Lunt, 2019c). These are not exceptions, and many basins in SE Asia have such nomenclatural confusion that is usually ignored, and hence the resolution of stratigraphic studies is degraded.

Other names

Names in geology are given to many real and abstract concepts, from Basins, Provinces and even large sedimentary bodies such as the Champion Delta and Baram Delta of NW Borneo (James 1984, Sandal, 1996; also known as the East and West Baram Delta respectively, see Hutchison 2005). Many basins migrate and change form through time (e.g. Hutchison, 2005, Figure 35 to 37) but basin maps are invariably shown as static geographic polygons, with associated static definitions such as "back-arc" (*cf.* Lunt 2019b). There may be an unhealthy eagerness to give technical names to things, disproportionate to documenting the dimensions of name accuracy, and whether the feature being named can be argued to be a natural unit.

This lack of proportionality is illustrated by the concepts of the Baram and Champion Deltas, which are both large sedimentary systems, weakly implied to have a geographic distinction as well as having different ages (along with the older Meligan Delta suggested from outcrops, but not seen on seismic offshore; see James, 1984; Sandal, 1996 and Schreurs, 1997). Such major sedimentary systems migrating through time should be closely linked to the tectono-stratigraphic *Stages* of Sabah to the north and related *Cycles* of Sarawak to the south, but there is no paper or known report attempting to describe or even hypothesize on this unavoidable link. Some accounts even complicate matters by placing the Champion Delta (East Baram Delta) as a time equivalent to the Baram Delta (West Baram Delta; Tan and Lamy, 1990) in that it "continued throughout Late Miocene to Holocene times". The implication of such fuzzy definitions are described below.

Faults, too, have names, and while faults are usually geographically distinct enough to give them a stable identity they are often not defined in time, which is a key component of any rational geological definition. This can lead to confusion, for example, Zin and Swarbrick (1997; their Figures 3 & 7) mapped the West Baram Line, West Balingian Line, Mukah Line and Igan-Oya Line as parallel structural features, proposed to be causally related dextral wrenches. However, Madon and Jong (2022) show a slightly different orientation for the renamed "Faults" of the Mukah Fault and the Igan-Oya = Sirik Fault. Each of these faults / lines has a different history. The West Balingian Line is an Oligocene extensional fault that inverted during the later part of Cycle I (Lunt and Madon, 2017, reproducing the unpublished work of Barrett and Tan, 1987). The West Baram Line was active only during Cycle II (?into Cycle III). The Mukah and Igan-Oya/Sirik Faults only became active at the base of Cycle III (base T3S of Zin and Tucker, 1999). In this example, the grouping of all these features as parts of one coeval, genetically related tectonic event, modifying the names and assigning a speculative, similar wrench property, is unjustified.

THE IMPLICATIONS OF POOR NAMING CONVENTIONS

Giving poor names to features in geology can lead to accidental "straw-man" arguments. This fallacy is the scholarly discussion of a proposition that is unconnected to any robust geological, or palaeontological, hypothesis. (a deliberate "straw-man" argument is where a similar but irrelevant analogue is deliberately refuted in place of the real hypothesis).

Paleo-delta systems

As with the example of the faults offshore Sarawak discussed above, what is being studied in an accidental straw-man approach is a false idea stemming from the poor definition of terms, rather than the analysis of logically linked components of a geological framework. An example is in the paper of Lambiase and Cullen (2013), which has a central theme that different parts of the "Champion Delta" in Sabah-Brunei have slightly different sand compositions and, unlike the modern Baram Delta, no single river is associated with the Champion Delta system. They conclude, somewhat tautologically, that as the Champion Delta is not a single feature, its multiple smaller rivers therefore have higher diversity in sand composition. The implication from this discussion is that there is a western dominant river (Baram), but in the east there was a suite of small sedimentary systems (Champion system). This implication is a re-definition of the two established names but there is no discussion of how this idea might fit with earlier reports of different ages of each of the deltas. Consequently, any worker is left uninformed on how to combine research that assumed that the Champion Delta is overlain by the Baram Delta (Sandal, 1996) with other data in Lambiase and Cullen (2013) and Tan and Lamy (1990), where the Champion Delta is concurrent with the Baram Delta.

It is not hard to envisage different combinations of ideas that could accommodate most properties from both sets of observations on the Champion and Baram Deltas, but before we can begin to compose such a new hypothesis we need to establish a clear definition of the entities in question, and also ask if they naturally distinct features. That is, could they be like the Gabus Formation in West Natuna and the Cau Formation in Nam Con Son, simply two names for the same thing in different political areas?

Breakup Unconformities

A term that is implied to have a particular tectonic genesis connotation is the noun "breakup unconformity" and its association with a particular cause (breakup; i.e. from plate rift to drift and seafloor spreading). This has led to selective use of the name for only a few of many otherwise very similar features. If we suspend the implied links to plate tectonics and examine the data around these events, using a range of disciplines and methods, we are forced towards a new understanding of both tectono-stratigraphy as well as crustal mechanisms. The term breakup unconformity is mostly used in the South China Sea (SCS), where the distinct form of a buried topography is seen on seismic (*cf*. Morley, 2016) and sea-floor spreading is proven. There are many other examples around Sundaland of more or less well developed buried topography unconformities, and all these have the secondary property of rapid subsidence, as

reflected in highly contrasting depositional facies, such as shallow or even non-marine beds abruptly overlain by very deep marine facies. However, most of these do not have the term breakup unconformity applied to them. The association of a named unconformity type with the singular event of onset of plate drift is further complicated, because many workers have noted that some areas around the SCS have two breakup unconformities (e.g. Ismail et al., 1994, and many others, in the western SCS and Bunguran Trough). Some other areas have a clear topographic form of a breakup unconformity (*sensu* Morley, 2016), but the major subsidence and transgression occurred at a different time (e.g. the Pearl River Mouth Basin, PRMB, He et al., 2017 and others; the T70 and T60 events). In addition, there are many areas showing the same abrupt and high magnitude subsidence and transgression events over a faulted surface that occurred several times, such as in the Makassar Straits (at least three or four times from Middle Eocene to base Miocene; Lunt and van Gorsel, 2013), yet in this area there is no accepted evidence for crustal breakup and rift changing to drift. There is also no evidence for rift to drift associated with the major Doust MMU breakup-type unconformity around the Bunguran Trough and North Luconia.

This record of multiple, abrupt buried topography and subsidence events suggests that a more complex model of crustal extension and episodic failure is required. Any new account of this mechanism will require a change in classification and names. Since at least Driscoll et al. (1995) in the NW Atlantic margin, it has been noted that an event called a rift-onset unconformity can be mistaken for a breakup unconformity, and true crustal breakup (rift turning into to lithospheric drift) came later. Things seem to be more complex in SE Asia. For example, in the PRMB there was early Cenozoic onset of rifting, then a first breakup type event (associated with rift to drift in the so called "Northwest Subbasin"; see Barckhausen et al., 2014) at the Eocene-Oligocene boundary, followed by mid-Oligocene T70 and base Miocene age T60 events, covering at least the northern flank of the new SCS. SE Asia is therefore an ideal place to study the tectono-stratigraphic development of such geological processes, and develop meaningful and natural names. The study of Franke et al. (2014) across the South China Sea was such an initial step, using just seismic data. Generally however, instead of trying to progress, we are simply perpetuating inappropriate jargon developed in other areas.

CONCLUSIONS

The naming of features and concepts describing the dynamic geology of SE Asia remains confused, and the resulting lack of clarity may be holding the science back. Correcting this problem is not simply adopting a more pedantic attitude and arguing for the "correct" name for a feature, but clarifying whether features are either distinct in space and time and deserving of their own name, or if they are part of a gradation of categories.

Some properties such as facies, palaeobathymetry, and time itself, grade along a continuum, and there can be confusion in naming based on imprecise divisions (where does middle neritic become outer neritic?). There are simple ways to work with this, such as basic grammatical constructions (e.g. "deep middle to shallower outer neritic"). More complex

examples include stacked synonyms that have shifted in meaning through time. For example, the Aquitanian Stage is now a part of the Early Miocene, but prior to planktonic biostratigraphy some workers considered it to be latest Oligocene. However, an alternative to the Aquitanian Stage is Letter Stage Upper Te which is defined on observation and is therefore preferable, because the assignation of Aquitanian must be deduced through a potentially imprecise correlation to a master time-scale.

Other properties in geology have naturally distinct sets that may not be obvious, or they may need tests to discover their natural limits. The analysis of these properties is interesting because the discovery and validation of natural distinction can change how we understand the subject. Examples are given from larger foraminifera, where species were originally defined based on different authors' opinions on what constituted an important morphotype, and hundreds of 'valid' species names were established, frequently influenced by environmentally-controlled external ornamentation. Later work on testing which morphotypes have first evolution and extinction datums changed our view of these fossils. This included observing the form or stage of evolution of the embryonic and juvenile stages, which were not usually considered by the early workers (see Haynes, 1981, p. 283-284). This identified a strong evolutionary divergence in the dimorphism of the haploid and diploid generations that is unique among the foraminifera, and was probably not anticipated by the early workers. The evolutionary pattern discerned by such stratigraphically tested studies often matches patterns seen in other fossil lineages, with shared times of radiation and mass extinctions (Figure 2), as well as correlating to changes in other disciplines, such as the multiple isotopic shifts observed at the Eocene-Oligocene boundary.

However, this shift in fundamental understanding of the larger foraminifera leaves us with a major task to clarify and justify replacing the large numbers of proposed synonyms under the rules of the ICZN, which would include new descriptions of a large number of type specimens. The old species names, although legally valid, are a burden and a source of confusion.

Arguably the same problem exists for many other geological features, from concepts such as the Baram and Champion Deltas, to the units we use to describe time and sequence stratigraphy. The bureaucratic nature of the task of revision is off-putting to ambitious youngsters, also un-interesting to research grant committees, and probably of appeal mostly to researchers looking to get a boost their citation index (just as for decades Blow, 1969, and Martini, 1971, were highly cited definitions of zonal schemes). This essay seeks to short-cut this process, and we ask the SE Asian geological community to consider these topics and move together to adopt better schemes of terminology. If we can test, document and adopt a better way, this legally circumvents the rules of the ICZN and other bureaucratic bodies. For example, the term *Camerina* (Bruguiere, 1792) is the senior synonym to *Nummulites* (Lamarck, 1801) but the popular usage of *Nummulites* (e.g. Nummulitique was a popular French term for the Palaeogene) led to its formal adoption over the senior name (nom. conserv.; ICZN, 1945, Op. 192). The International Commission on Stratigraphy

has spent decades refining the time scale and producing standards without including SE Asian Letter Stages (see Lunt, 2013b), yet the unconsidered Letter Stages here are superior observations to standard Stages and they should be included in publications.

This upgrade in terminology can be achieved by simply discussing the names used in reports with qualification, and proposing tests of where each noun is on a spectrum of quality, from subjective to objective. The preference for objective classifications requires that the names have continually refined definitions, and accumulating data on the delimiting boundaries, as well as on the degree of distinction from the related terms. This approach improves with cross-discipline analysis. For example, Morley (2016, p. 66-67) clearly defines a breakup unconformity in terms of geometry and in light of three possible mechanical crustal models. Adding stratigraphic data such as the contrast in environment of deposition across such an unconformity, displayed on a quantitative geohistory plot (van Hinte, 1978) and magnitude of change mapped geographically, can greatly improve our understanding of the three theoretical sub-classes of breakup unconformity (Huismans and Beaumont; 2014 cited by Morley, 2016). So far, we can rule out Huismans and Beaumont's Type I class breakup in SE Asia, as this class involves widespread uplift and erosion during the late synrift stage, which is rare and localised in Sundaland geology.

In this way clarification of a name is directly linked to clarification of the geology behind it, and old subjective names can be tested and improved, or abandoned. In this approach, geology seeks to challenge and test, as opposed as to classify and narrate. The former approach is truly scientific, under the definition of Popper (1963), while the latter approach drifts towards the demarcation limits of a true science. The classify and narrate approach is argued to lead to accidental straw-man arguments. These are logical fallacies that can be found in various grades from trace presence to being the dominant theme of a report. They are studies of a confusion that stems only from the poor definition of the components of the subject. There are some very conspicuous examples of accidental straw-man arguments persisting in SE Asian publications. Narratives based on already demonstrably poorly defined and highly ambiguous subjects such as the Bampo Formation of Sumatra, the Ngimbang Formation of Java, or the Mid Miocene Unconformity, soon become unverifiable, and too accommodating of almost any new data.

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