Making the Most of Biostratigraphic Data; Examples from Early Cretaceous to Late Jurassic Shallow Marine Sand Units in Papua New Guinea and Australasia

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ABSTRACT

A fundamental task in the exploration workflow is the mapping of reservoir sand units within a broader paleogeography. Such maps help, for example, to predict reservoir extent and link sands back to likely sediments sources thereby helping to improve reservoir quality predictions. If these sand units are multiple bodies within a relatively narrow time-stratigraphic interval, mapping of individual sands can be difficult if we rely on simple lithostratigraphic differentiation, or chronostratigraphic terminology ("ages") for correlation.

An example of this is shown from the Early Cretaceous to Late Jurassic shallow marine sands of southeast Papua New Guinea and Australasia. Previously correlated only on a broad timescale and often with overlapping age-range for individual lithostratigraphic units, it can be difficult to determine the precise stratigraphic position of each of these sands (e.g. the important Toro Sandstone reservoir) which in turn can affect interpretations regarding their exploration and production characteristics.

The evaluation of large, public-domain, biostratigraphic datasets has allowed for the construction of a detailed "synthesis biozonation" for the area which permits more reliable identification and stratigraphic placement of individual sand units and which further allows for improved correlation at local and regional scale and improved mapping.

INTRODUCTION

The Toro Sandstone is an important hydrocarbon reservoir rock in southeast Papua New Guinea (the "Papuan Basin – Shelf Platform" USGS basin) – Figure 1 – and is *generally* considered to be of Late Jurassic to Early Cretaceous in age. Related sand bodies of similar general age include units labelled variously as Alene, which occurs stratigraphically above the Toro Formation, and the Digimu, P'nyang, Hedinia and Iagifu units together with an informal unit known as "X" all of which occur stratigraphically below the Toro. The literature shows much disagreement as to the lithostratigraphic definitions and relationships between many of these units (see Davey, 1999 and below for a brief discussion), particularly the status of the Toro unit itself and its internal subunits. Discussions as to the correct lithostratigraphic assignment of bed, member or formation status to these units is beyond the scope of this work and – notwithstanding such assignments given in the general descriptions below – they are treated here as separate informal "units".

The main Toro unit has been subdivided into three subunits; in descending order Toro A, Toro B and Toro C (Madu, 1996; De Vries *et al.*, 1996 and Azizi-Yarand and Livingstone, 1996) with the "B" unit being somewhat shaleier than those above and below it. The status of the "C" unit is particularly debateable with Davey (1999) seemingly equating it with sands previously assigned to the Digimu unit (upper Imburu Formation) in the Toro's type section. This has led to the concept of a so-called "Digimu lobe" of the Toro Formation and a degree of uncertainty as to its status.

Overall, these various sand units are believed to be shallow marine shelf sands as determined mainly by their palynological content (organic-walled microplankton, spores and pollen).

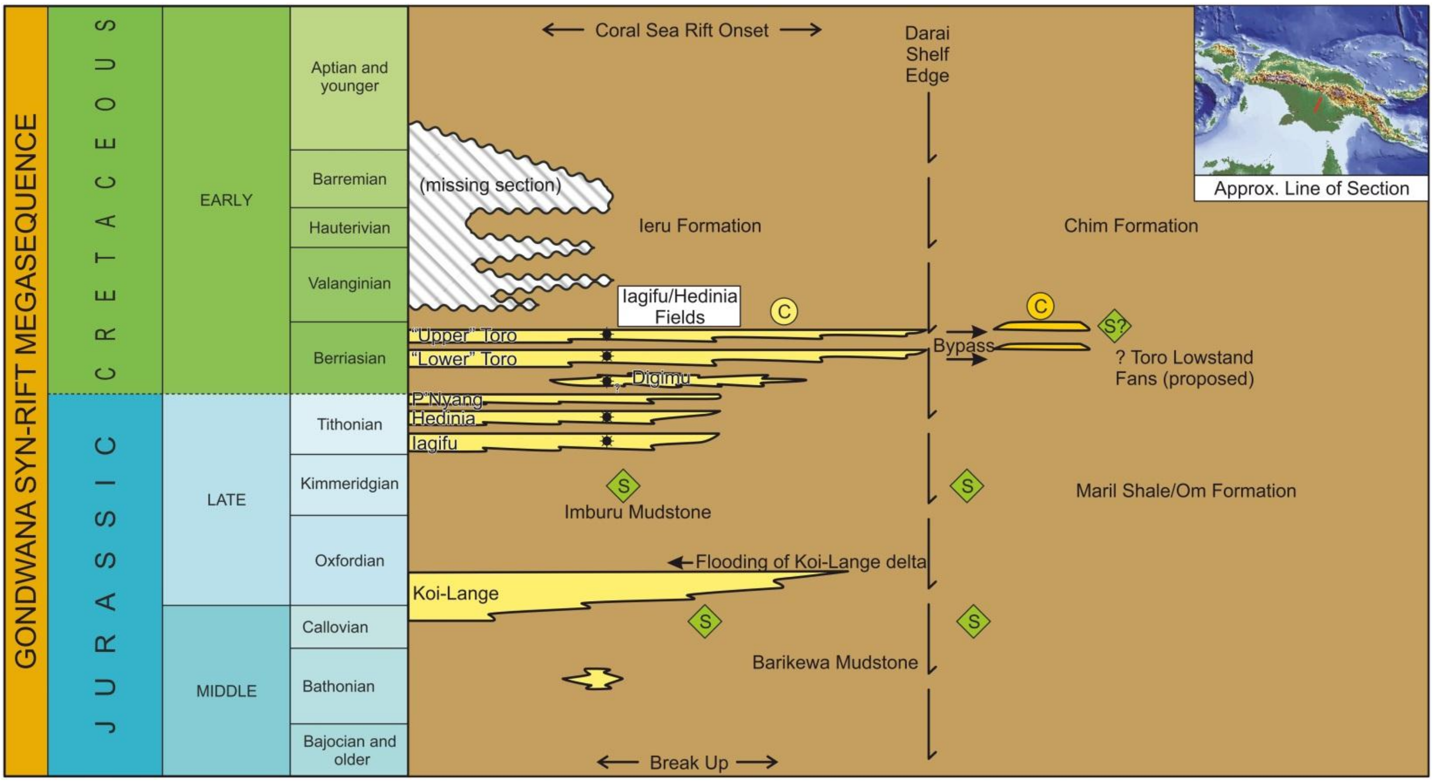

Figure 1. *Generalised stratigraphy of the Late Jurassic to Early Cretaceous of Papua New Guinea (based on Hill et al., 2000) and location of the study area. Chronostratigraphic timescale is approximate, but based on biozones from this study.*

In a regional context, these sediments form part of the Middle Jurassic – Early Cretaceous Gondwana Syn-Rift Megasequence and were deposited in a passive margin setting on a relatively stable marine shelf, which progressively deepened towards the north-east. Across the more proximal south-western portion of the basin, a series of interbedded sandstones and shales comprising the Koi-Lange Formation were deposited unconformably above the Barikewa Formation. These sandstones represent potential hydrocarbon reservoirs, whilst interbedded shales become increasingly organic-rich towards the north-east where they may have source potential with TOC of 1-1.5% (Burns & Bein, 1980). The Koi-Lange Formation is overlain conformably by the Imburu Formation which is typically divided into 4 members. The Lower Imburu Member comprises mainly shales with some source potential, whilst the younger Iagifu, Hedinia and Digimu members comprise some important blocky coarsening upward reservoir sandstone bodies.

Early Cretaceous sediments continued deposition in a passive margin setting as the upper part of the Gondwana Syn-Rift Megasequence. The Toro Sandstone represents one of the most important hydrocarbon reservoirs within the basin and is capped by thick regionally extensive shales of the Ieru Formation, which form the principle seal. These formations are overlain by thick shales and siltstones of the chronostratigraphically equivalent deeper water Maril Shale across the distal north-eastern part of the passive margin. The linear distribution of productive hydrocarbon fields in the frontal part of the Papuan Fold Belt marks the distal limit of sandstone deposition within this megasequence.

Distally, beyond this limit (the "Darai Shelf Edge" of Hill *et al.*, 2000), shales and mudstones of the Maril Shale or Om Formations ("Jurassic") and the Chim Formation ("Cretaceous") are deposited. Using sequence stratigraphic principles, Hill *et al.* proposes the existence of Toro equivalent lowstand fans beyond the shelf edge derived from cannibalised Toro shelf sands (Figure 1).

RELATIVE AGES OF THE SAND UNITS

Many authors, with or without biostratigraphic data, have assigned various age or biozone labels to the sand units forming this study (e.g. Davey, 1987, 1999; Denison and Anthony, 1990; Granath and Hermeston, 1993; Hill *et al.*, 2000; Hirst and Price, 1996; Johnstone and Emmett, 2000; Madu, 1996; McConachie and Lanzilli, 2000; McConachie *et al.*, 2000; Morton *et al.*, 2000; Phelps and Denison, 1993; Powis, 1993; Varney and Brayshaw, 1993; Welsh, 1990; Winn *et al.*, 1993). A summary of these composite age/zonal ranges is shown in Figure 2.

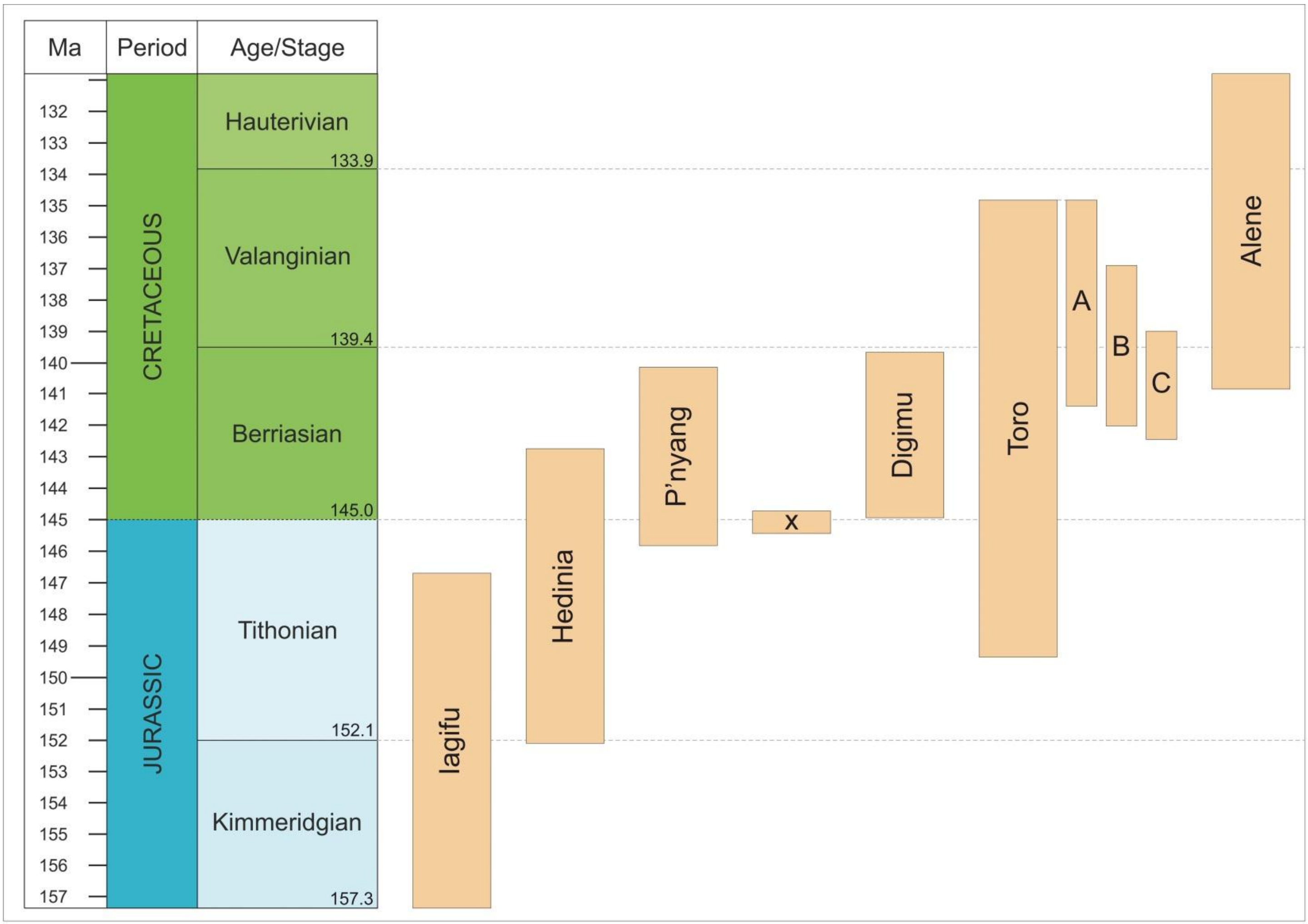

Figure 2. *Summary of the range of maximum and minimum age assignments conferred on sand units by various authors, shown against the Gradstein et al., 2012 time scale.*

These composite age ranges are clearly unrealistic and have no practical value for correlation purposes. Therefore how do they come about? One of the most likely sources is the over-reliance on using interpreted ages as a basis for correlation. Chronostratigraphic (age) interpretations as derived from calibration of biostratigraphic zones and events can and do change, sometimes frequently and often significantly. The reasons for this are many-fold and include iterative re-definitions of stage boundaries and improved techniques (biostratigraphic, magnetostratigraphic, radio-isotopes, geochemical excursions, orbital calibration etc.) for recognising them. Traditional European-based stages, many of which were defined in proximal settings and separated by significant unconformities, are being replaced by new subdivisions based on marine sections with continuous deposition which allows easier global correlation. The four chronostratigraphic stages that are of interest to us here have lower boundary ages which have varied between the following values since the 1980's alone:

Valanginian	128.0 – 140.7
Berriasian	133.0 – 145.6
Tithonian	140.0 – 152.1
Kimmeridgian	145.0 – 157.3

This also means the *duration* of stages can vary considerably. It is easy to see why a worker using one timescale might regard a section as Berriasian, while another worker using a different timescale would attach a Tithonian label.

These chronostratigraphic changes can have two significant adverse effects – the first, by incorrectly correlating separate strata given a similar chronostratigraphic age by two separate workers one of whom has made an incorrect *interpretation* because definitions may have changed (see, for example, the redefinition of the boundary between the Campanian and Maastrichtian stages; Odin, 2001 and Ogg, Hinnov and Huang, 2012; pp. 806-808). For example, a stratigraphic section of the Phanerozoic of Papua New Guinea in McConachie *et al.*, 2000 shows the Toro unit placed (incorrectly) within the Valanginian chronostratigraphic stage without any apparent justification for that age interpretation. Subsequent workers using this information may miss-correlate the Toro with other local sand units of a proven Valanginian age, or believe genuine Toro sands are not, in fact, Toro due to them *not* having a Valanginian age.

The second main source of error arises by not correlating separate strata given different chronostratigraphic ages by two workers who each has a different "concept" of the chronostratigraphy but who are, in fact, talking about the same stratigraphic section. An example of this concerns the lack of formal definition of the Jurassic – Cretaceous system (Berriasian – Tithonian stages) boundary where there are no fewer than 14 separate candidate markers for the boundary spread over a 3-4 million year time-span (see Ogg, Hinnov and Huang, 2012; pp. 795-797). Therefore it seems one person's concept of "early Berriasian" may in fact be the same as another's concept of "late Tithonian" but the two sections would normally never be correlated, or may be incorrectly thought of as being diachronous. Such errors are frequently perpetuated in the literature thus further compounding the problem.

Differences of opinion between paleontologists is another factor, both by workers within the same fossil group and workers between different fossil groups. For example, four important biozonation schemes based on palynology applicable to the Papua New Guinea region which cover the Late Jurassic and Early Cretaceous interval are those of Davey, 1987 and 1999; Helby, Morgan and Partridge, 1987 and Welsh, 1990. Each has similarities with, and differences from, the other (see Figure 3).

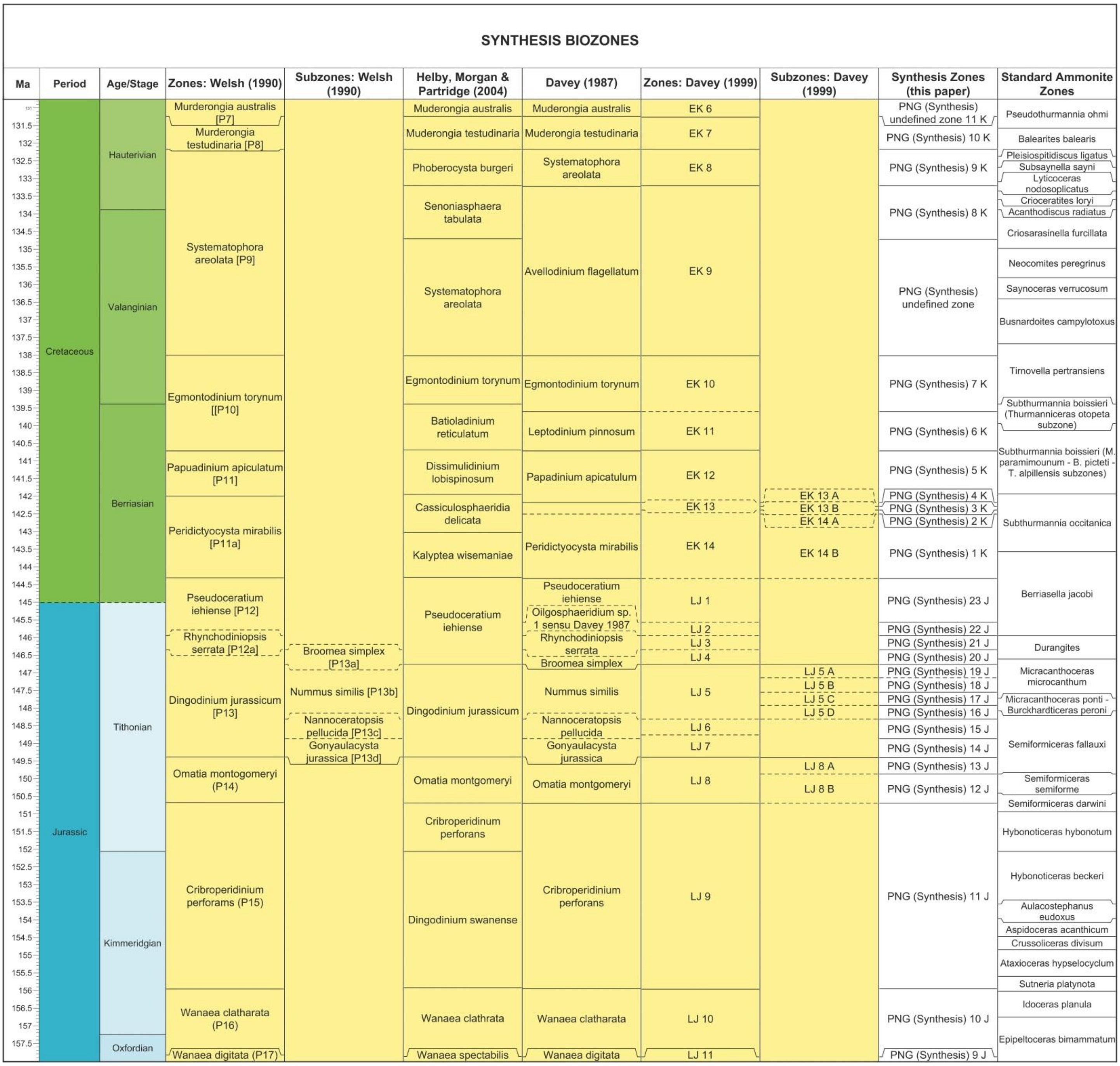

***Figure 3.** Synthesis Biozonation scheme for the Late Jurassic – Early Cretaceous interval in the Papua New Guinea region, including some of the important palynological schemes used in its construction. Standard Chronostratigraphy is based on Gradstein* et al.*, 2012. Chart constructed using TSCPro©.*

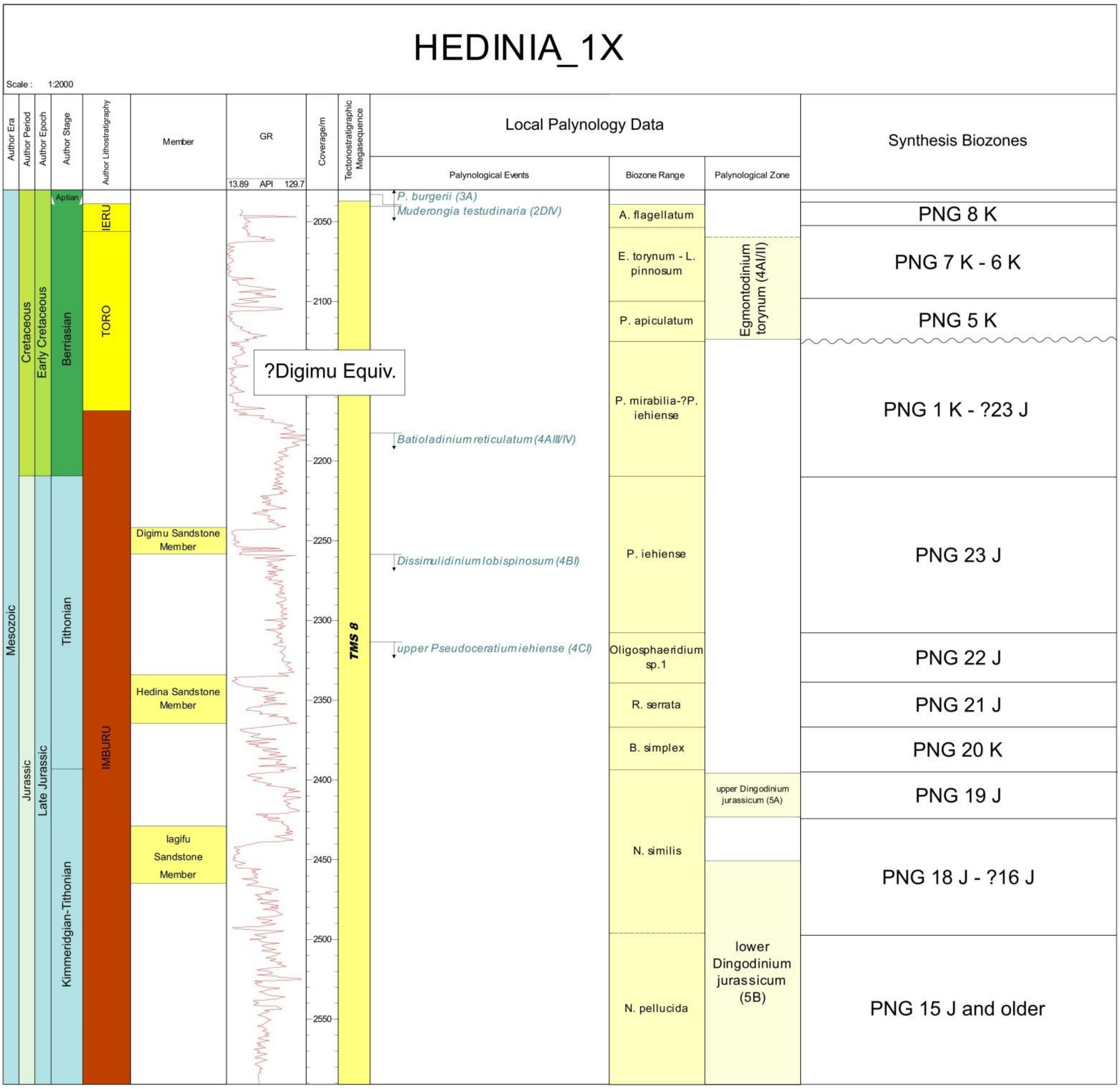

Figure 4. *Synthesis biozones applied to the Hedinia-1X well allowing the biostratigraphic fingerprinting of sand units and the strata between them. Note that the synthesis biozone PNG 1K identified in the lower part of the Toro unit beneath a clear biostratigraphic hiatus suggests this should be reinterpreted as a Digimu equivalent. (Well data from Winn et al., 1993 and Denison and Anthony, 1990).*

Further sources of error may include the incorrect application of lithostratigraphy and possibly even simple counting errors such as… "*This is the fourth sandstone unit encountered, therefore it must be the P'nyang unit*" without independent confirmation.

Ensuring that the various biozonation schemes are correctly calibrated to global standards is a vital step in being able to correlate the different schemes together. This involves the screening of all available palynological data throughout the region to identify those fossil extinction and inception horizons which are the most consistently and confidently recorded. This only works as long as the (in this case palynological) data itself has been consistently recorded and calibrated against global standard biozonation schemes and timescales. This workflow applies equally to other fossil groups.

Note that in some instances (as in Figure 3) it can be seen that the same stratigraphic zonal interval is given different species names by the different authors and occasionally the boundaries between the zones do not match up. This is, of course, scientifically correct especially if different fossil groups are used (i.e. spores & pollen versus dinoflagellates) but is potentially very confusing for a non paleontologist. Correlation of different stratigraphic sections zoned by different workers using different fossil groups is only possible if this type of diagram – a "*Rosetta Stone*" – is properly calibrated and available.

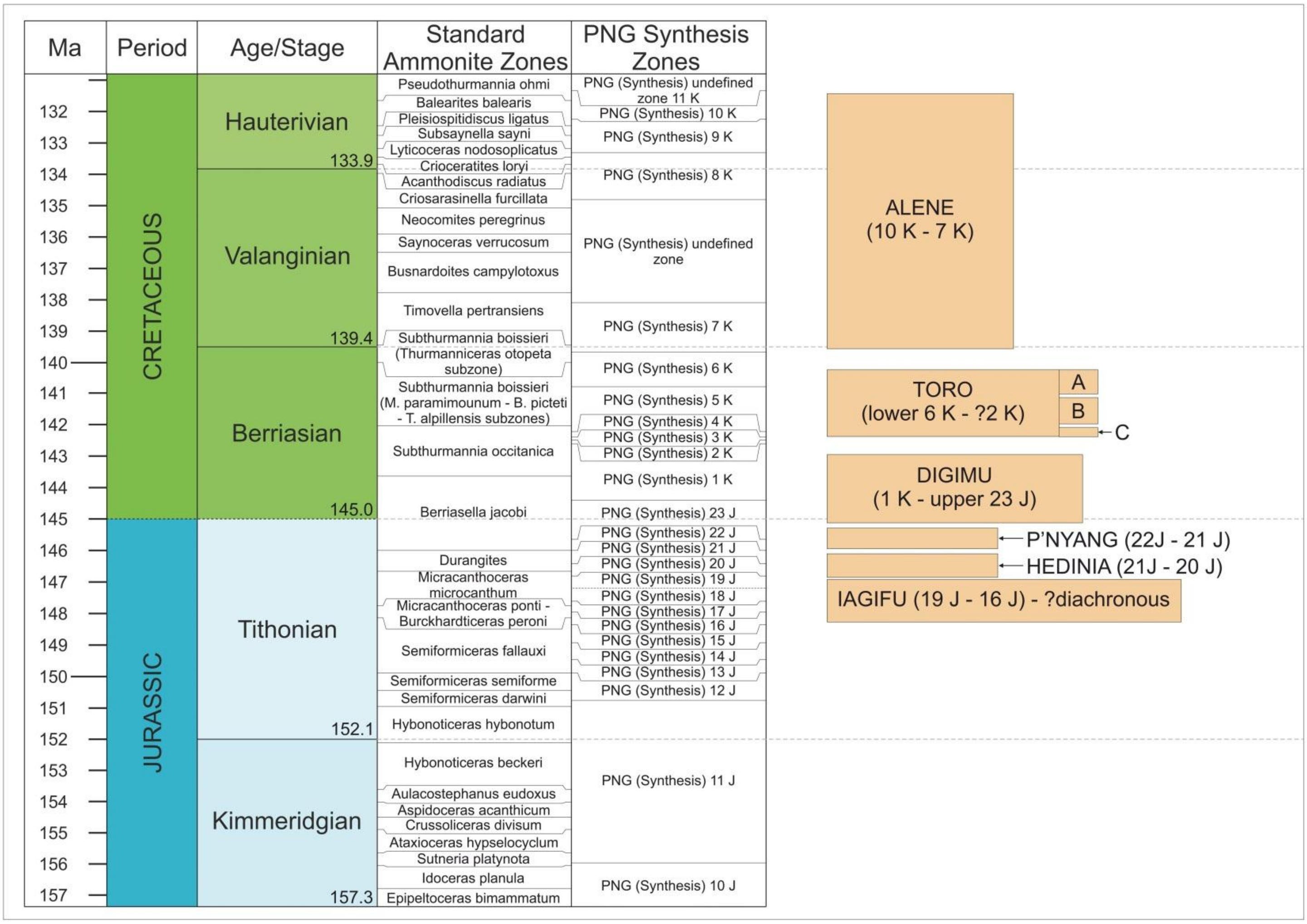

Figure 5. *Biozonal assignment of individual sand units from the PNG area. Standard Chronostratigraphy is based on Gradstein* et al.*, 2012.*

The next logical step would be to further integrate the (calibrated) zonation schemes and bioevents from additional fossil groups and to construct a full "synthesis biozonation" based on the most reliable, widespread and confident bioevents. "Synthesis biozones" allow correlation at local and regional scales independent of current or past timescales and avoiding the need to communicate with potentially confusing and/or obsolete fossil names.

Figure 3 shows the results of such a process for the Kimmeridgian to Hauterivian stages of the Papua New Guinea area and four of the more important individual palynological schemes used in the construction. The full data set which was used comprises many more schemes from palynology and many other fossil groups and is not shown here.

The "synthesis biozones" are calibrated against a series of standard, global biozones – in this case Tethyan ammonites.

Applying these synthesis biozones to well data we can biostratigraphically "fingerprint" observed lithological units such as these various sand bodies (Figure 4).

By applying this technique to multiple wells, all of which were previously zoned to a greater or lesser degree by different workers using different local schemes, it is possible to arrive at a clearer idea of the exact stratigraphic levels upon which these sand units lie (Figure 5). Compared to the initial age assignments shown in Figure 2, this shows considerable improvement in resolution which enables much greater confidence in correlating these sand bodies across the region.

The calibration of the synthesis biozonation scheme to global standard schemes allows the technique to be carried over into nearby regions and possibly even further beyond. An example from similar-age sand units in the Ichthys Field (Northwest Shelf, Australia) shows how these too can be biostratigraphically "fingerprinted" using the same synthesis zone model as for Papua New Guinea.

Berriasian sand units in Titanichthys-1 (Figure 6) appear to be biostratigraphically equivalent to sands identified as Digimu and Toro in Papua New Guinea.

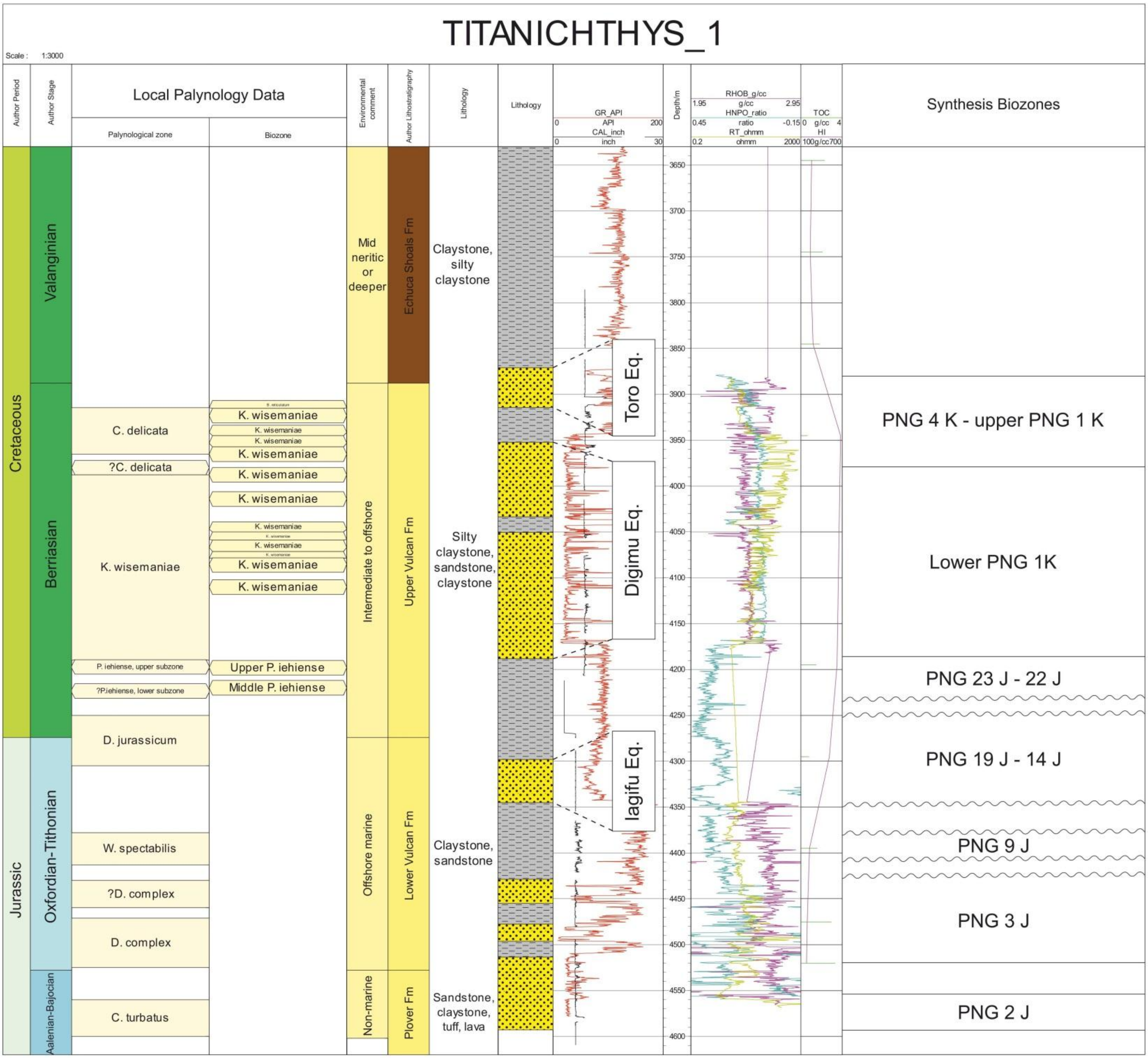

Figure 6. *Biostratigraphic "fingerprinting" of sand units in Titanichthys-1 (Ichthys field, Australian Northwest Shelf). Biozonal correlation with similar units in the PNG Hedinia-1X well show that many of these sand units were deposited during the same sequence cycles. (Well data from WAPINS database, 2008).*

Regional knowledge (Andrew Lavender, *pers. comm.*) indicates that the Ichthys sands are more likely to be deposited in a slope setting and therefore may cautiously support a similar model proposed by Hill *et al.*, 2000, for the presence of lowstand Toro sands in PNG, although such sands have yet to be proved, and the thicker shelf sands in PNG (compared with thinner shelf sands in NW Australia) might indicate lesser degrees of cannibalisation and shelf by-pass. Figure 7 presents a schematic paleogeography.

CONCLUSIONS

Much valuable local biostratigraphic data, irrespective of publication date, is under-utilised because of a lack of calibration to global standards, reducing their utility for optimum correlation, especially at regional scale. There is a tendency among geoscientists to correlate using chronostratigraphic (age) units rather than biostratigraphic units – this can be potentially misleading if not applied very carefully. Ages are, after all, an interpretation contemporary only to the date of publication. It is the biostratigraphic data that is the fundamental correlation tool.

Critical screening of large biostratigraphic data sets across multiple fossil groups allows consistent and reliable bioevents to be identified to construct a “synthesis biozonation scheme” which permits more confident correlation within a basin, and a “Rosetta Stone” to allow workers to fit their local data within a standard zonal framework for regional studies, which is independent of an ever-changing global timescale and undefined stage boundaries.

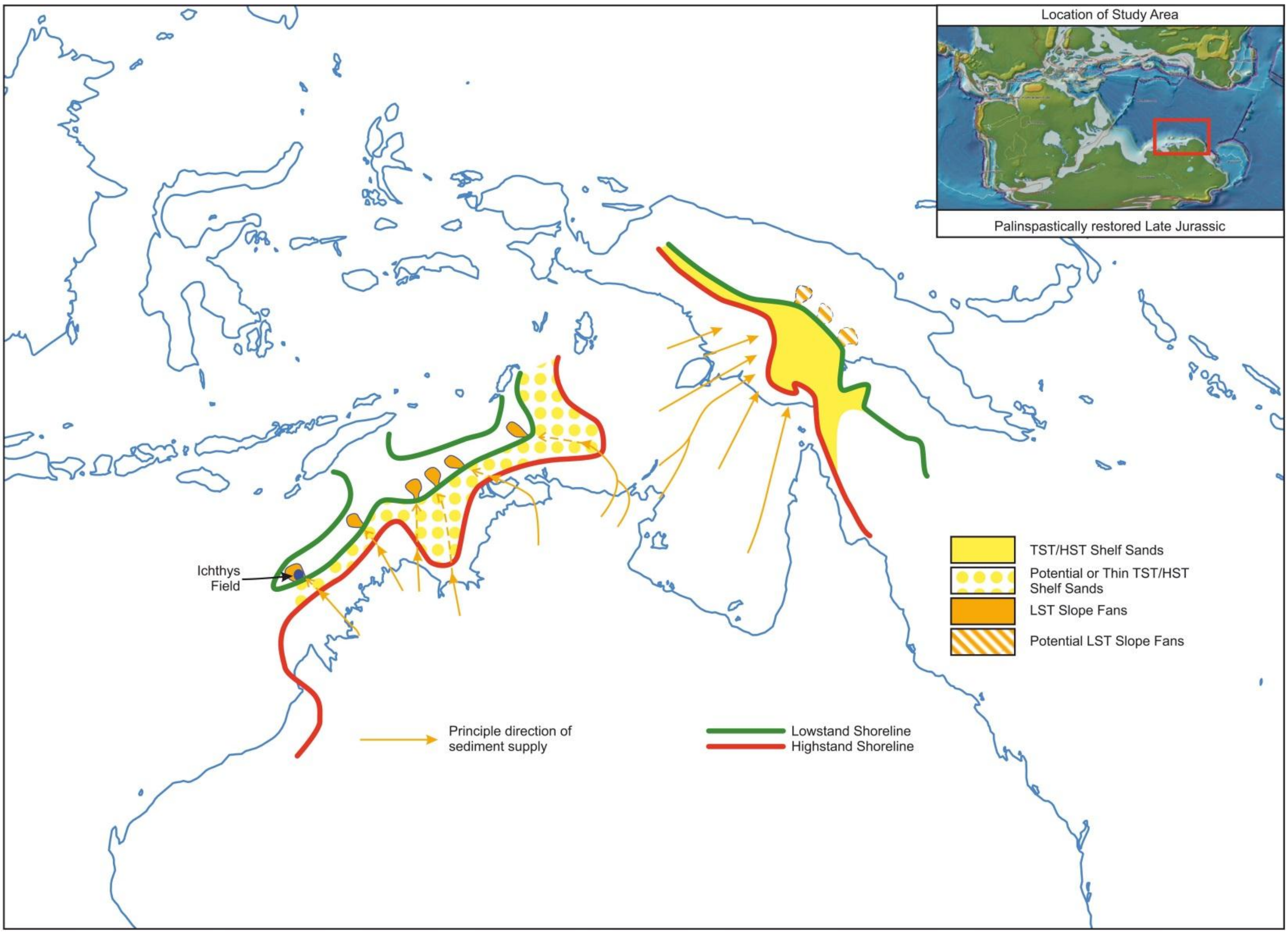

Figure 7. *Generalised Berriasian paleogeography relating to the Toro Sandstone and related units from Papua New Guinea and the Australian Northwest Shelf.*

The technique has been applied in the Papua New Guinea/NW Australia area and increases the power to discriminate between reservoir sand units and place them within the context of a global sequence model.

In appropriate circumstances the technique and zonation scheme may be applied regionally, outside the basin within which it was constructed. This has shown that biostratigraphically equivalent sands have been recorded on the Australian NW Shelf which may be lowstand equivalents of highstand/transgressive sands in Papua New Guinea and lends cautious support to a possible "lowstand Toro" play model in that area.

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