Stratigraphic record of continental breakup, offshore NW Australia – Discussion

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Abstract

Reeve et al. (2022) address the stratigraphic record of continental breakup by focusing on a set of stratigraphic unconformities from a proximal sector of the NW Australian continental margin, inboard from the Exmouth Plateau. They suggest that such unconformities can potentially document a well-defined three-stage process: end of the syn-rift phase, formation of a wide continent-ocean transition zone (COTZ) and generation of 'true' Penrose-type oceanic crust. We counterargue that continental breakup is a protracted event that can only be understood via seismic- and chronostratigraphic correlations of strata, and their composing sequences, across and along rifted margins. Tying proximal stratigraphic unconformities to magnetic anomalies outboard from the study area in Reeve et al. (2022) is

open to question. In parallel, we suggest that age resolutions of c. 1 Ma are not achievable using the micropaleontological data presented in Reeve et al. (2022), with important reworking of microfossil assemblages potentially occurring during the erosional process forming local and regional unconformities. Our discussion addresses these points in more detail.

1. Problem statement

The recent paper by Reeve et al. (2022) focuses on sedimentary basins offshore NW Australia to consider, based on the published literature, that continental breakup separates a phase of (syn-rift) extension in discrete sub-basins, and synchronous deep-offshore rift axes, from a broader thermally induced phase of lithospheric subsidence, the so-called drift stage (see Ravnas et al., 2000; Manatschal et al., 2004; Peron-Pinvidic et al., 2007, 2013). We welcome their approach insomuch as new data from the continental margin of Australia provide important detail concerning the tectono-stratigraphic evolution of rifted margins (Fig. 1). However, a fundamental aspect of the Australian literature is that emphasis has thus far been given to the recognition of *Breakup Unconformities* on proximal margins as representing the *de facto* continental breakup amongst conjugate continental margins (Falvey et al., 1974) or, as suggested by Görür and Şengör (1992), the successive 'stripping of thin crustal segments calved off Australia to create successive ocean basins behind them'. Such an emphasis on identifying and accurately dating *Breakup Unconformities* as markers of continental breakup seems to contrast with new information from West Iberia-Newfoundland, Brazil-West Africa and young rifted margins such as the Gulf of California, to cite a few examples (Alves and Cunha, 2018; Alves et al., 2020).

Based on the published literature, Reeve et al. (2022) extrapolate data from the proximal continental margin near the Exmouth Plateau and Exmouth Sub-basin to the deeper rift axes of the Culvier and Gascoyne abyssal plains, where continental breakup occurred in discrete, but successive, phases. Reeve et al. (2022) also consider the syn-rift stage on the proximal margins of NW Australia to be separated from drift deposits by *Breakup Unconformities*. It is true that, in other parts of their study area, a thin sequence (reaching 500-600 ms, corresponding to ~500 metres) of breakup-related strata was deposited in between syn-rift units and a thick drift succession. However, they later suggest that syn-rift faults and major basin-bounding structures do not propagate, or develop, above the *Breakup Unconformity*, without specifying which of their three unconformities they are referring to (Fig. 2). Finally, Reeve et al. (2022) tie regional unconformities formed on the proximal margin of NW Australia to major geodynamic events such as the end of the syn-rift phase, the formation of a wide continent-ocean transition zone (COTZ), or the generation of 'true' Penrose-type oceanic crust, later proposing two models to explain full continental breakup in the Cuvier and Gascoyne abyssal plains (Fig. 1).

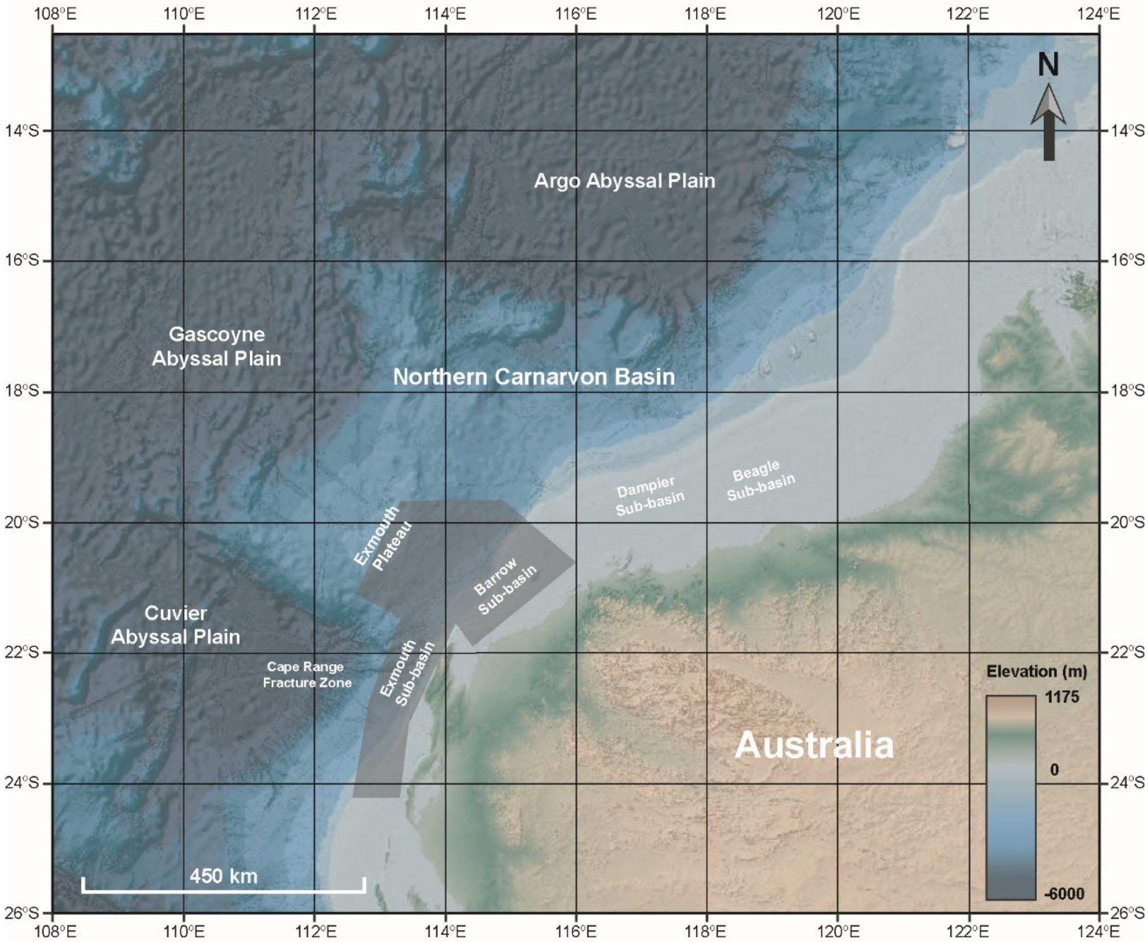


Figure 1 – Regional map of NW Australia with the shaded area highlighting the study area considered in Reeve et al. (2022). Note the relative location of the Exmouth and Barrow sub-basins on the proximal margin of NW Australia, inboard from the regions experiencing hyperextension and the formation of continent-ocean transition zones.

This discussion will review an important issue in basin analysis, and a significant aspect in the work of Reeve et al. (2022): stratigraphic unconformities formed on fully rifted continental margins reflect diverse depositional and tectonic settings. However, there is a tendency, which we believe to be erroneous, from interpreters to extend similar-looking stratigraphic surfaces across and along these margins. This tendency is derived from the 'syn-rift' literature, in which interpreters strive to recognise rift-related tectonics systems tracts, separated by unconformities with seemingly regional expression, in contiguous extensional half-grabens and grabens (see Prosser et al., 1992; Nøttvedt et al., 1995; Ravnås and Steel, 1998 as pioneer articles, but also Muñoz-Barrera et al., 2021 for a more recent analysis of syn-rift basins in deep-offshore basins). The recognition of such systems tracts as being deposited during the continental rifting stage of margin evolution is valid, but many breakup-related unconformities on distal continental margins reflect distinct geological settings, or have different ages to those where they were first defined on the continental shelf (e.g., Lei et al., 2019; 2020). Thus, seismic-stratigraphic boundaries identified on the proximal margin, as those boundaries defined in Reeve et al. (2022), cannot necessarily be tied to what are essentially protracted geodynamic processes happening near the loci of continental breakup. Recent IODP drilling at the loci of continental breakup of the northern South China Sea, has also demonstrated that single seismic markers (breakup-related unconformities) associated with continental breakup comprise local stratigraphic features, cannot be linked to the protracted opening of the South China Sea, and are relatively older in the basins located inboard of the IODP drilling sites (Zhao et al., 2016; Lei et al., 2019; Zhang et al., 2021; Chao et al., 2022).

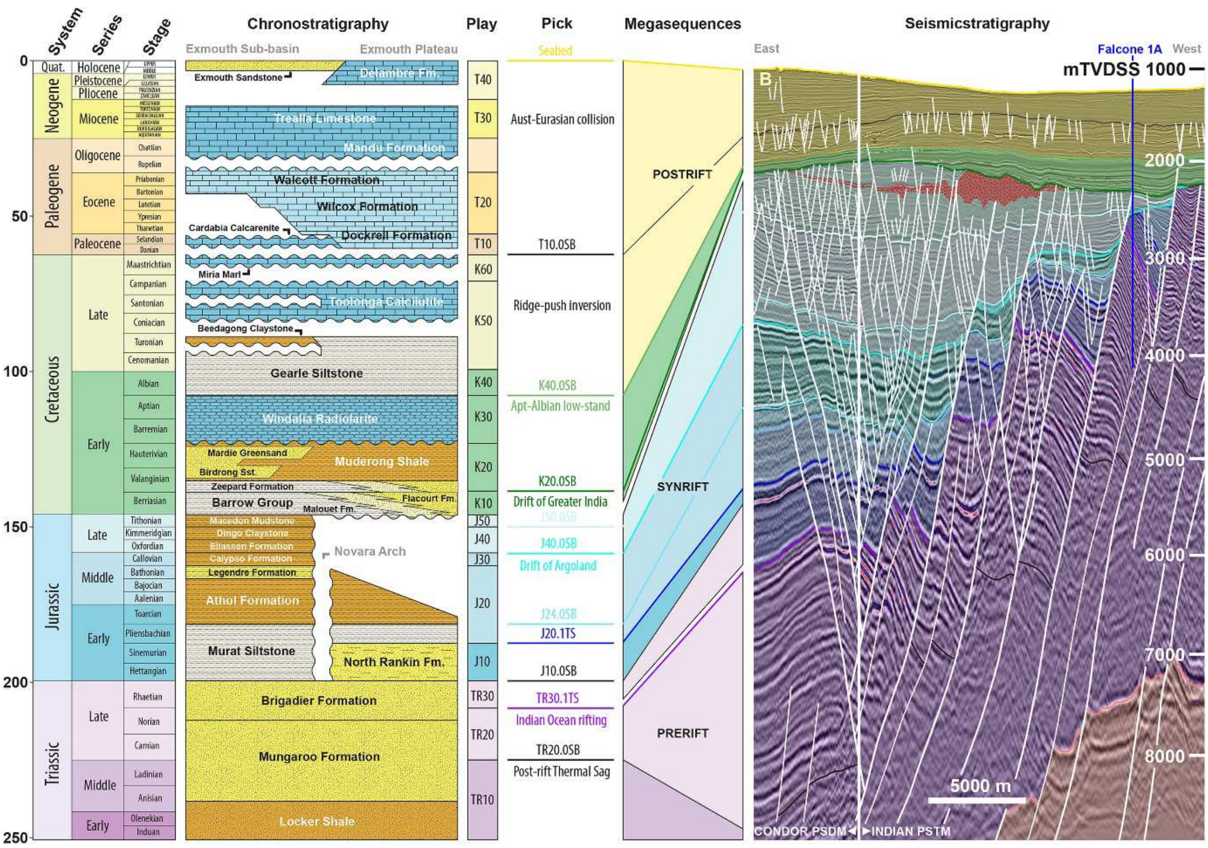
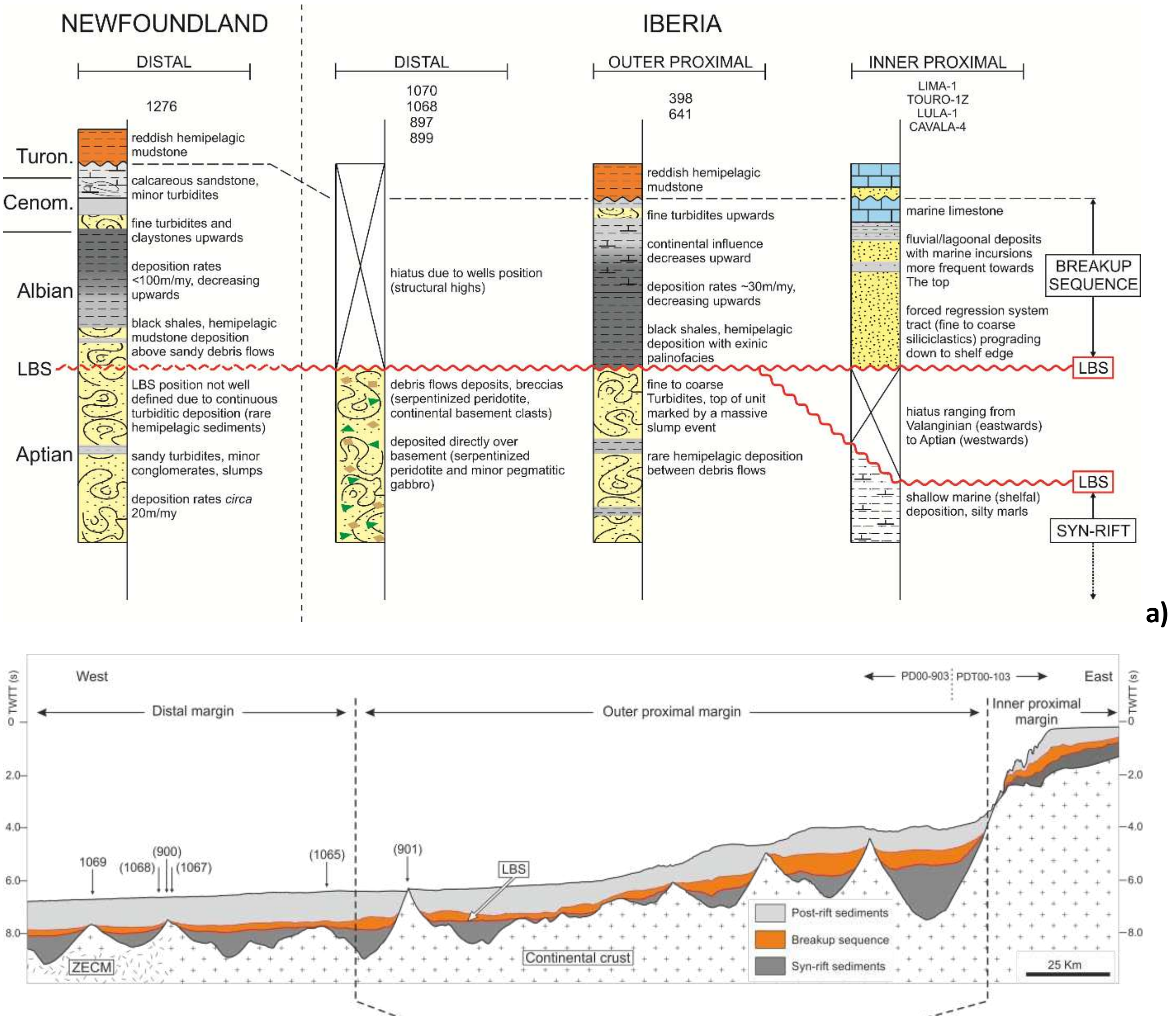


Figure 2 – Seismic-chronostratigraphic chart for the southern Exmouth Sub-basin highlighting the main tectonic events described in Longley et al. (2002), the sequence stratigraphic nomenclature from Marshall and Lang (2013), and seismic interpretation tied to well Falcone 1A in Black et al. (2017). The stratigraphic interval assessed by Reeve et al. (2022) is shown in dark green in the figure. Figure modified from Black et al. (2017).

2. *Breakup Unconformities vs. Breakup Sequences* as distinct concepts

The *Breakup Unconformity* as originally defined in Falvey et al. (1974), and further described in Soares et al. (2012) and Alves and Cunha (2018) offshore West Iberia, is a major surface of erosional truncation in the proximal regions of rifted margins. Not uncommonly, it forms an angular unconformity of regional expression. However, one seldom finds such an angular unconformity in sedimentary basins formed in the necking zone of continental margins, outboard of the proximal margin. Furthermore, the *Breakup Unconformity* usually reflects a broad depositional hiatus on the proximal margin, and is difficult to correlate with specific geodynamic events occurring in the distal sectors of continental margins during continental breakup, i.e., the onset of COT formation, widespread magmatism in SDRs, or the generation of 'true' oceanic crust. In fact, the *Breakup Unconformity* putatively marks the onset of COT formation in West Iberia, but the stratigraphic response to the initiation of continental breakup is complex and widely variable inboard from the necking zone.

Still referring to the proximal parts of rifted margins, Alves and Cunha (2018) and Alves et al. (2020) have shown that the classical *Breakup Unconformity* correlates with the base of *forced-regressive strata* accumulated above syn-rift units in the Lusitanian Basin, the North Sea Central Graben, or the Jeanne d'Arc Basin, to provide examples from three distinct basins. This forced regression in depositional facies results from the abrupt tectonic subsidence, margin-shoulder uplift, and accommodation-space creation that accompanies the onset of the continental breakup process on the distal margin (Fig. 3). Hence, in our opinion, for magma-poor *Type I margins* such as NW Australia's (Huismans and Beaumont, 2011), the *Breakup Unconformity* should preferentially be called *Lithospheric Breakup Surface (LBS)* as it represents the rupture of the crust and brittle (upper) continental lithosphere - and the (presumed synchronous) onset of mantle exhumation - before oceanic lithosphere is emplaced during 'final' continental breakup (Huismans and Beamount, 2011; Soares et al., 2012).



		DISTAL	OUTER PROXIMAL	INNER PROXIMAL	
Seismic Character	Earliest syn-rift	Transparent reflectors onlaping structural highs and LBS	Transparent reflectors onlaping structural highs and LBS	donwlaping (with toplap) reflectors on the LBS	
	Latest post-rift	Chaotic, divergent, strong reflectors	Chaotic, parallel and divergent reflectors	Parallel reflectors	
Depositional environment	Earliest syn-rift	Pelagic deposition below CCD	Pelagic deposition below CCD	Deltaic to fluvial deposition	
	Latest post-rift	Pelagic deposition below CCD	Pelagic deposition below (distally) and above CCD (proximally)	Neritic	
Lithology	Earliest syn-rift	Black shales (in starved depocentres)	Black shales (in balanced depocentres)	Fine to coarse siliciclastics (overfilled depocentres)	
	Latest post-rift	Mass flow deposits (hemipelagic background.)	Mass flow deposits (hemipelagic background)	Marls to fine siliciclastics	
Stratigraphic contact		Diastem?	Diastem/conformable (probable short hiatus or condensed level)	Unconformity (hiatus less expressive basinwards)	Composite subaerial unconformity
Sequence stratigraphic surface		Correlative conformity	Correlative conformity	Erosive basal surface of forced regression	Subaerial unconformity
				OFFSHORE	ONSHORE

b)

Figure 3 – a) Schematic lithological and stratigraphic correlation between wells drilled across the West Iberian margin and Newfoundland that crossed *Breakup Sequence* B. b) Schematic section across NW Iberia highlighting the different zones of the margin and the relative

position of the *Lithospheric Breakup Surface (LBS)* and *Breakup Sequence* (Soares et al., 2012). Data from the inner proximal margin taken from Soares et al. (2012) and Alves and Cunha (2018). Data from the outer proximal margin taken from Sibuet et al. (1979) and Boillot et al. (1987b); distal margin Sawyer et al. (1994), Whitmarsh et al. (1998) and Tucholke et al. (2004).

As the loci of first lithospheric rupture can vary spatially and temporally across a continental margin, *Lithospheric Breakup Surfaces* may be better preserved 100s kilometres away from the crustal segment where the mantle exhumation first started, near the continent, where sediment sources are readily available. Moreover, in the distal part of *Type I margins*, in the necking zone, long-lasting degradation complexes, lava flows and magmatic edifices emplaced during the continental breakup event usually mask the true significance of stratigraphic unconformities near structural highs, on newly formed continental slopes, and near exhumed basement units (Alves and Cupkovic, 2018). While it is true that episodes of uplift and erosion occur within *Breakup Sequences*, these episodes relate to local phenomena that cannot be correlated across and along a rifted continental margin. In fact, Thompson and Parsons (2016) have used geodetic surveys to demonstrate that footwall unloading and uplift – as documented in many parts of the Reeve et al. (2022) study area, located on the proximal margin – occurs over a broader region (+/- 100 km) than the subsidence along a particular fault, and that such a phenomenon is not plate-margin scale and may not be linked to breakup. As a result, most unconformities recorded within *Breakup Sequences* are diachronous and of local expression. In our opinion, they cannot therefore be correlated across and along a vast continental margin such as NW Australia's. In summary, the top and base of *Breakup Sequences* are often clear on geophysical data, but local unconformities within *Breakup Sequences* are diachronous (Fig. 3a).

To illustrate the latter point, Figure 4 shows an example from the distal margin of NW Iberia where a well dated Aptian-Turonian *Breakup Sequence B* is underlain by an older 'transitional' interval representing an older phase of continental breakup in SW Iberia (*Breakup Sequence A*). The base of *Breakup Sequence B* does not form an unconformity in the centre of the basin – likely reflecting continuous deposition from *Breakup Sequence A* – and syn-rift basins occur much lower in the succession. Figure 4 also shows that the half-graben basin to the east of the syn-rift succession directly underlies *Breakup Sequence B* and there is no *Breakup Sequence A* as such. This demonstrates the degree of variability in the evolution of discrete half-graben and graben basins during continental breakup. It also shows the variable development of *Breakup Sequences* across distinct half-graben and graben depocenters. In comparison, Figure 5 shows a seismic line from SW Iberia where the two *Breakup Sequences A and B* are also observed and form a complex set of degradation complexes and local unconformities that cannot be correlated across or along the Iberian margin, nor reflect major geodynamic events related to continental breakup. On some continental margins, such as those dominated by evaporites, the *Breakup Sequence* is also tectonically deformed, structurally decoupled from basement thick-skinned tectonics, and not recorded by any change in evaporite content or rank (Alves et al., 2020). Magma-rich continental margins record *Breakup Sequences* dominated by Seaward Dipping Reflectors (SDRs), interfingering clastics, volcanic tuffs and carbonates, in a setting dominated by accelerated tectonic subsidence (Norcliffe et al., 2018).

3. Why breakup-related unconformities do not correlate with protracted geodynamic events

Recent data from West Iberia, Newfoundland and the South China Sea reveal the pinching-out, onlapping and eventual lateral disappearance of the *Breakup Sequence* towards the loci of continental breakup, where oceanic crust is first formed, as the main seismic-stratigraphic feature marking continental breakup – see Figure 1c,d in Alves and Cunha, (2018), Figure 10 in Lei et al. (2019), Figures 7 and 9 in Zhao et al. (2021) and Figure 8 in Chao et al. (2022). The stratigraphic pinch-out of *Breakup Sequences* towards the loci of continental breakup can be gradual or abrupt, but is usually difficult to identify when approaching the continental slope. This is where most borehole data are available (as in Reeve et al., 2022) but here sediment bypass predominates. Acknowledging this limitation, *Breakup Sequences* were classified in Alves and Cunha (2018) and Alves et al. (2020) in three main types, composed not of abrupt unconformity-bound sub-units and members, but rather reflecting a gradual change from a forced-regression depositional setting towards the progressive aggradation of sediment on fully separated continental margins, again accompanying a setting of generalised tectonic subsidence (Figs. 4 and 5). A deepening-upwards trend in depositional facies occurs in most *Breakup Sequences*. In their model, Alves and Cunha (2018) and Alves et al. (2020) stress that only the very top and bottom of the *Breakup Sequence*, which represents a 1st-order sequence per se, can be identified and tied to data from the proximal margin and exhumed aulacogen basins. The top of the *Breakup Sequence* may also be a paraconformable surface with evidence for contourite drifts, marking the onset of deep geostrophic currents on a fully rifted continent (Soares et al., 2014), and has a regional expression all over West Iberia. Between this upper 'onset of drift' unconformity and the lower *Lithospheric Breakup Surface* are deposited thick stratigraphic sequences (*Breakup Sequences*) with distinct ages and areal distributions. We believe the recognition of these *Breakup Sequences* is the correct approach to follow when interpreting seismic data from distal continental margins, near the loci of continental breakup, with changes in the provenance (and nature) of sediment derived from multiple sources comprising the key aspect that documents the eustatic, geodynamic, and climatic changes that accompany continental breakup *per se*.

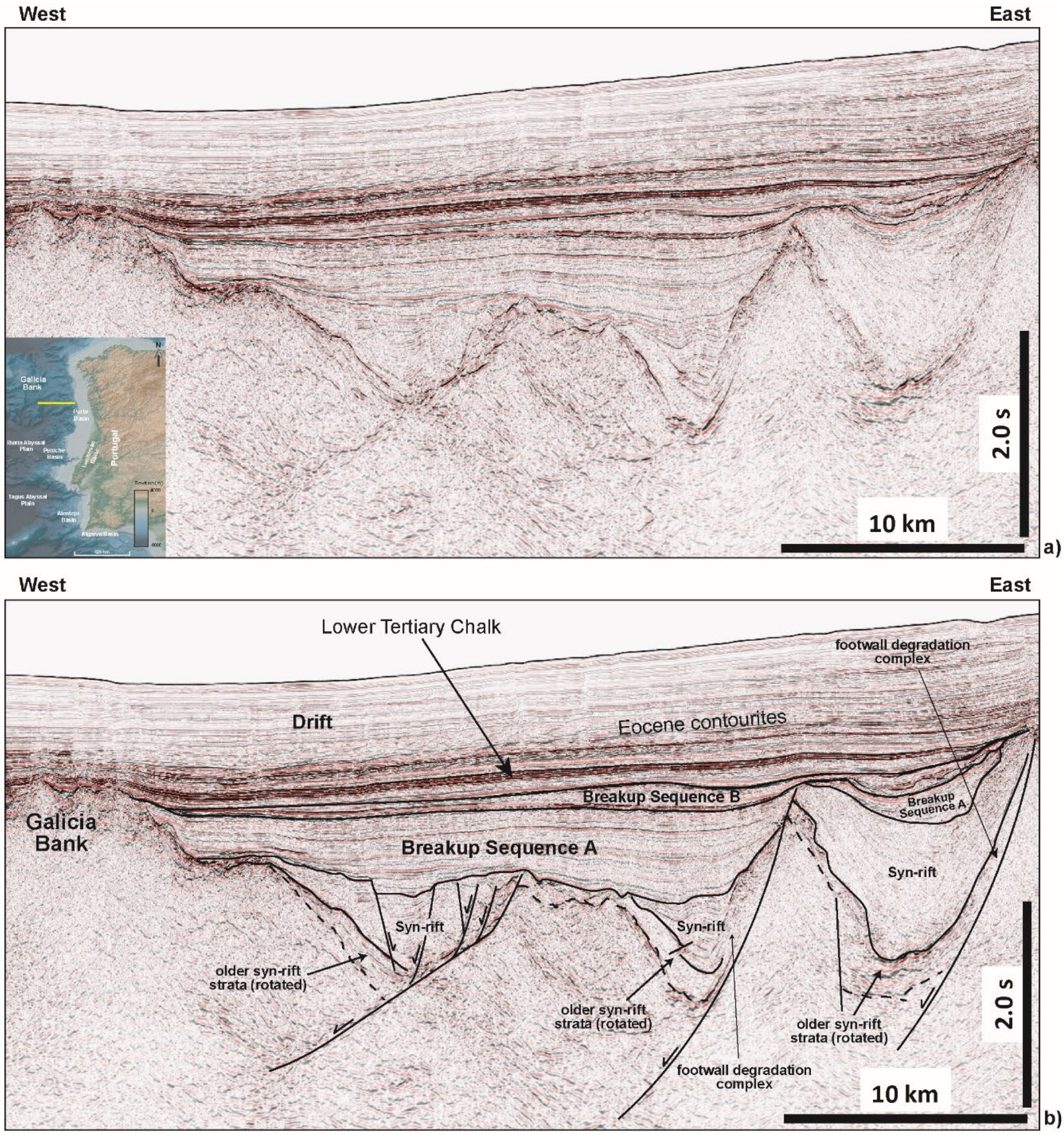


Figure 4 – Seismic profile from Northwest Iberia with the putative locus of continental breakup on its western edge. Note the presence of an older *Breakup Sequence* A, reflecting

continental breakup in the Tagus Abyssal Plain, and the overlying *Breakup Sequence* B, correlated with continental breakup on the Iberia Abyssal Plain. *Breakup Sequence* B has been dated by DSDP/ODP wells on the distal margin, and by industry boreholes on the proximal continental margin. Of significance is the passive draping (and filling) of *Breakup Sequence* A in the centre of the seismic line, while it is deformed and perhaps syn-tectonic in the east part of the line. Footwall degradation complexes along significant fault also show that syn-rift highs are capable of delivering sediment into the adjacent half-grabens for prolonged periods of time (i.e., after continental breakup). Inset map shows the relative location of the seismic profile offshore NW Iberia.

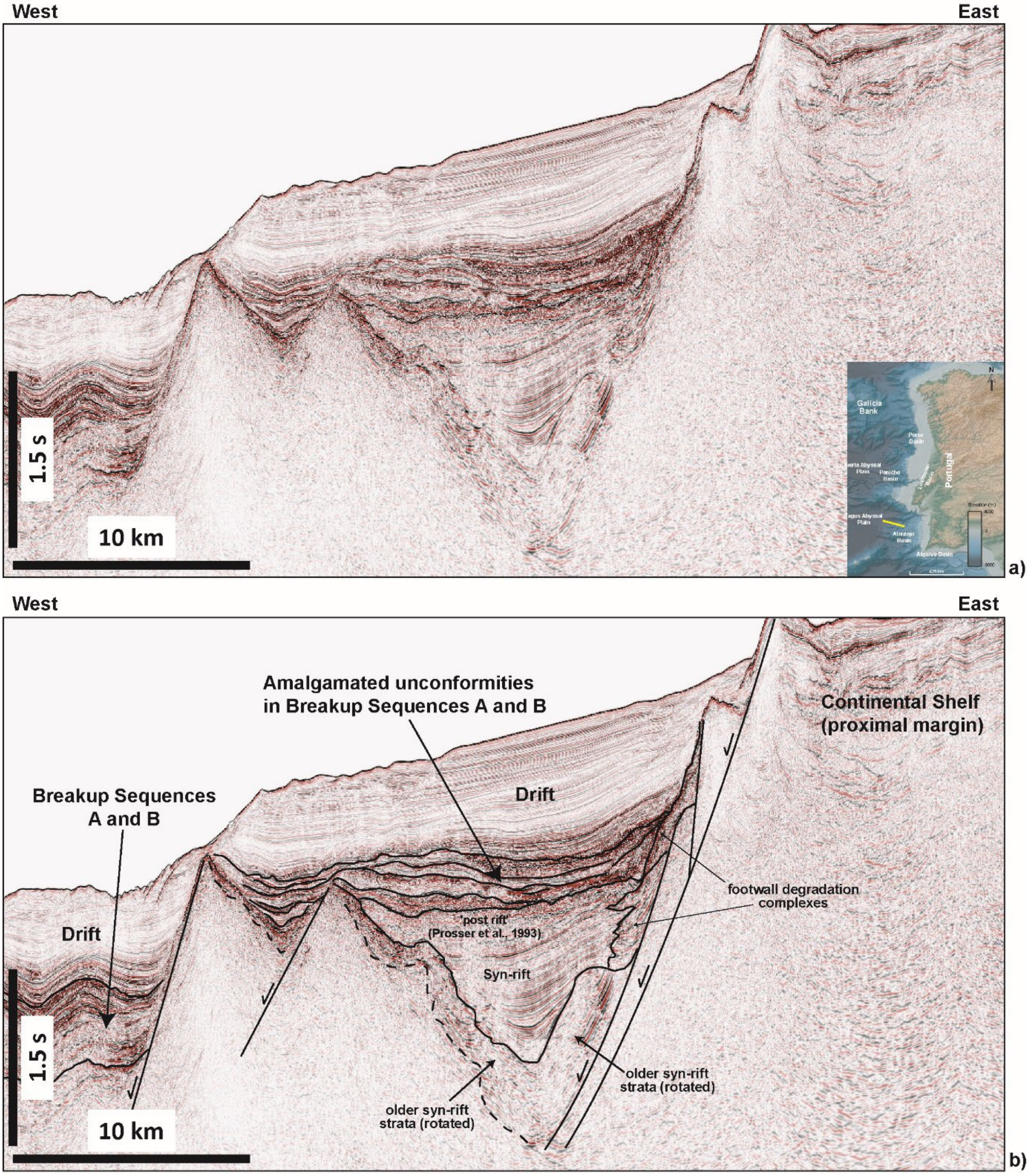


Figure 5 – Example of amalgamated unconformities within the break-up related strata of SW Portugal. In this part of the Iberian continental margin, *Breakup Sequences* A and B overlap to form a complex set of forced-regressive strata with amalgamated unconformities. None of these unconformities can be identified further outboard towards the locus of continental breakup. On the continental shelf, they merge into a pronounced basal unconformity/*Breakup*

Unconformity and a thin breakup related package. Inset map shows the relative location of the seismic profile offshore SW Iberia.

5. *Breakup Sequences* and continental breakup offshore Australia

A few other issues arise from the interpretation presented in Reeve et al. (2020) interpretation. First, the first *Breakup Unconformity* in NW Australia is constrained to be Oxfordian in age (Marshall and Lang, 2013) and is often tied to the M26 (156 Ma) magnetic anomaly in the Argo Abyssal Plain, the oldest preserved and documented magnetic anomaly along the North to West Australian margin. As lithospheric breakup precedes the final (post-mantle exhumation) breakup of the mantle on *Type I margins* such as NW Australia's, with subsequent formation of 'true' oceanic crust (see Huismans and Beaumont, 2011), the mantle exhumation process is protracted in time and variable in terms of its velocity and spatial distribution along a margin. This means that the so-called *Lithospheric Breakup Surface* that forms at the base of the *Breakup Sequence*, not at its top, does not necessarily correlate with the precise initiation (nor the end) of the subsequent stages of COTZ and 'true' ocean-crust formation in successive margin segments (compare this concept with the two scenarios from Figure 9 in Reeve et al., 2022). Such a caveat is best recorded in West Iberia by the well-known 'J Anomaly', which has been recently recognised as representing the onset of oceanic crust formation but is markedly diachronous along the margin (Grevemeyer et al., 2022). Such a diachroneity is recorded in West Iberia by successive, and often interfingering, syn-rift and breakup sequences (Alves et al., 2009; Alves and Cunha, 2018).

On the scale of NW Australia, the horizon Reeve et al. (2021) termed the IVU (intra-Valanginian unconformity) is well defined and accepted in the literature as being present in the southern Exmouth Sub-basin, with most associating its genesis with tectonic activity in the Curvier sector of the margin as opposed to the Gascoyne sector, which includes the Exmouth Sub-basin and nearby Plateau (Smith et al. 2002, Tindale et al. 1998; Arditto et al. 1993; Longely et al. 2002; Smith et al. 2015; Marshall and Lang 2013; Black et al. 2017). In contrast, the evidence presented by Reeve et al. (2021) for their TVU (Top-Valanginian unconformity) and IHU (Intra-Hauterivian unconformity) does not fit with the overall development of the Early Cretaceous succession in the Exmouth Sub-basin. In our opinion, the seismic based evidence presented by Reeve et al. (2021) for truncation at the IHU is inconclusive. Furthermore, they do not present definite information about the time-span of the depositional hiatuses materialised by the IHU, and the TVU, although an exception occurs where IHU and TVU merge to the south with the IVU, across which there is well accepted time missing as evidenced by angular truncation and biostratigraphic data. It is worth noting that Figure 5a and 5b in Reeve et al. (2021) is perpendicular to depositional dip and cuts prograding clinoforms that may give the impression of truncation.

Regionally, the package bounded by IVU and IHU represents a series of back-stepping successions (Zeepard and Birdrong) deposited overlying the Lower Barrow Group (see Smith et al. 2003; Marshall and Lang, 2013), which comprises the most regressive Early Cretaceous shorelines in the Exmouth Sub-basin. The Zeepard and Birdrong successions are separated by a flooding surface with no evidence for missing time. Similarly, the Birdrong is separated from the overlying time transgressive Mardie Greensand by another flooding surface. The top of the Mardie Greensand is marked by horizon K30.2_MFS (Marshall and Lang, 2013), which is a regional flooding surface across the North West Shelf. In summary, the Early Cretaceous succession in the Exmouth Sub-basin is widely interpreted to comprise progradational sequences with the younger three back-steeping relative to the underlying Lower Barrow Group and bounded by flooding surfaces. This stacking pattern resembles the deepening-upwards trend recorded within discrete *Breakup Sequences*, as documented in Soares et al. (2012), Alves and Cunha (2018) and Alves et al. (2020).

The aspects discussed above may cause issues when correlating magnetic anomalies in thinned continental or transitional crust to proximal unconformities putatively marking fully established continental breakup. The Zeepard and Birdrong are not separated by unconformities in vast parts of the Reeve et al. (2022) study area. Moreover, correlating discrete stratigraphic surfaces to large-scale geodynamic processes poses a particular problem on margins as NW Australia's, where a complex and variable Mesozoic evolution along and across a 4000 km long margin (including failed rift basins inboard), culminating in the final separation of Australia and India, requires an in depth understanding of many an individual basin and sub-basin.

6. Concluding remarks

We acknowledge that the approach presented in Reeve et al. (2022) may have been driven by mathematical models suggesting regional stratigraphic unconformities as representative of the geodynamic processes causing continental breakup. There are several examples of these models in the recent literature (Pérez-Gussinyé et al., 2020, Korchinski et al., 2021, Nehuarth et al., 2022). Such models are often formulated assuming sedimentation rates that are relatively constant across and along continental margins, and sediment sources that are homogeneous in nature. They also do not consider the significant progradation of sediment from hinterland sources that occurs during continental breakup, nor the sediment bypass observed near newly formed continental slopes and palaeo-topographic highs, some of which may be inherited from the early stages of continental rifting (Figs. 4 and 5). In our opinion, the Reeve et al. (2022) article lacks important stratigraphic data, including depositional facies maps, detailed structural maps, tectono-stratigraphic restorations, plus geochronological data proving the age and precise loci of continental breakup along SW Australia. Clearly, this is not always possible as such data are only very recently being gathered on distal continental margins across the world, with an emphasis on the Iberian margin (Eddy et al., 2017; Grevemeyer et al., 2022). However, given the available, we suggest that Reeve et al. (2022) do not provide a coherent stratigraphic analysis of continental breakup and its constituting sequences (Fig. 6). The diachroneity of hyperextension at the COTZ (lithospheric breakup), mantle exhumation, and subsequent oceanic-crust formation, is expressed within 1st-order stratigraphic sequences formed under a primary tectonic setting lasting 10-15 Ma, and dominated by enhanced tectonic subsidence, ultimately generating *Breakup Sequences* (Soares et al., 2012; Alves and Cunha, 2018; Alves et al., 2020).

We interpret the IVU unconformity in Reeve et al. (2022) as documenting the base of forced-regressive strata in the first of the Cretaceous *Breakup Sequences* formed in the Exmouth sub-basin, reflecting lithospheric breakup - and the *de facto* initiation of the continental breakup process – in the Cuvier Abyssal Plain. The intricate tectonic evolution of the loci of continental breakup implies that the 'classical' concepts used in syn-rift sequence stratigraphy - considering the formation of well-defined tectonic systems tracts in evolving sub-basins - cannot be readily applied to the distal margins of continents after the continental breakup process is initiated under a dominant setting of generalised tectonic subsidence. They can be applied near local faults, or structures, but their geodynamic significance is limited across and along the areas of continents approaching breakup. Also, because *Breakup Sequences* are deposited in a tectonically active setting dominated by subsidence, crustal and mantle extension, and basement reactivation, it is not true that breakup unconformities broadly separate faulted, syn-rift rocks from overlying, largely un-faulted post-rift rocks (Soares et al., 2012; 2014, Alves et al., 2020).

We postulate that continental breakup in NW Australia was only fully achieved in the Aptian (Fig. 2); until then, the margin was pinned to Antarctica and India (Espurt et al., 2009; Ball et al., 2013; Harry et al., 2020). Only after the Aptian was the study area in Reeve et al. (2022) overlain by a 'true' drift succession – placing the top of their green Barremian-to-Aptian strata (not Albian, compare with the interpretation in Black et al., 2017) as the top of a *Breakup Sequence*. Until the Aptian, Australia was not fully separated from India and Antarctica and breakup-related tectonics was still affecting their deep-offshore basins. This represents a setting similar to West Iberia insomuch as the establishment of a free, fully movable continental plate separated from Eurasia and North America is recorded by a late Cenomanian-Turonian unconformity identified all over the Iberian Plate (Saspiturry et al., 2020). *Breakup Sequences* were deposited throughout deep-offshore Iberia until continental breakup was finally achieved in the Pyrenees, by the Cenomanian-Turonian. Finally, we believe that the points presented in this discussion letter have important implications for the interpretation of sequential faulting, related depositional settings, and to the overall recognition of the loci of continental breakup on continental margins.

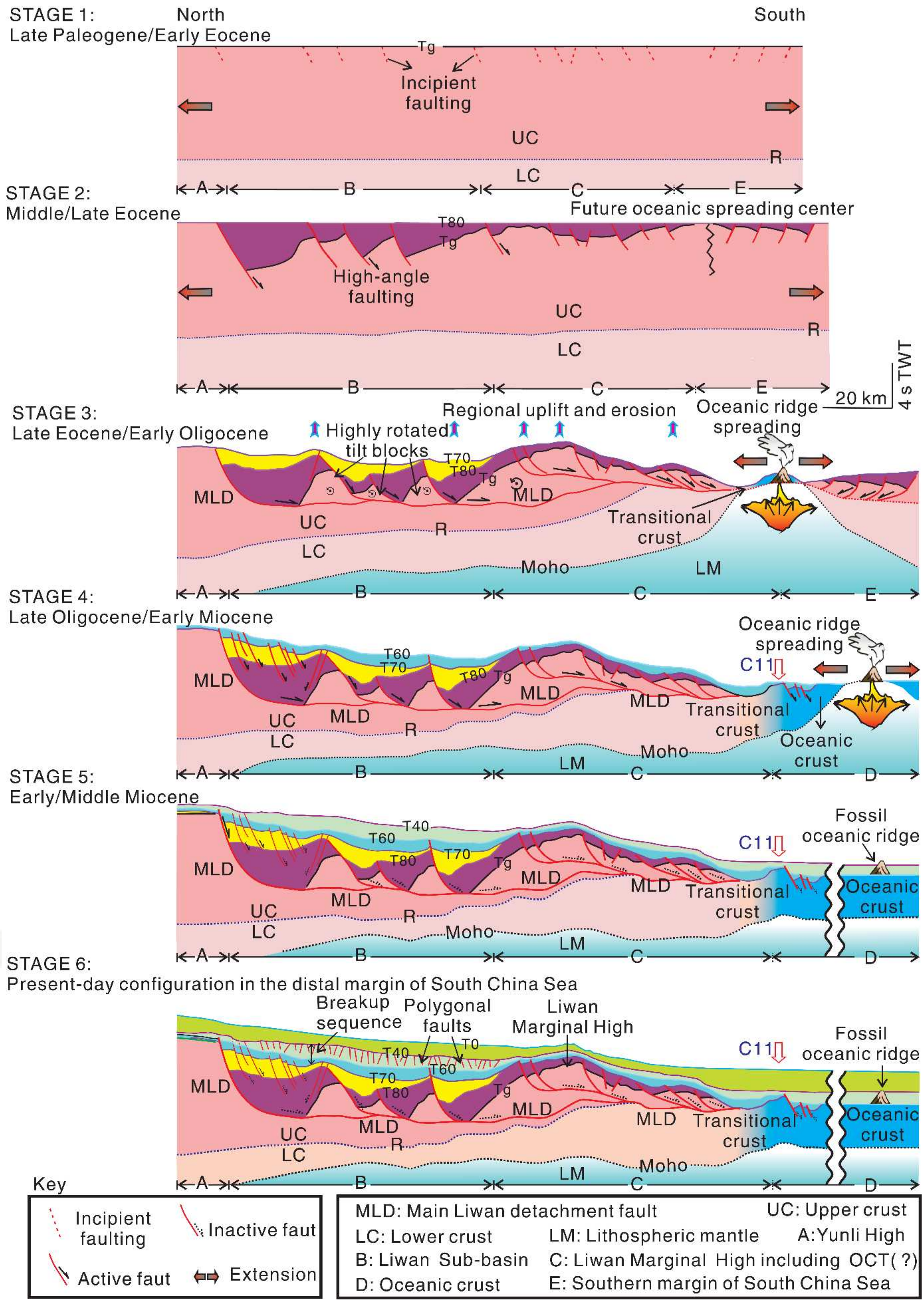


Figure 6 – Diagrams illustrating the evolution of the distal part of the Liwan Basin, South China Sea, near the loci of continental breakup, as published in Lei et al. (2019). Note that no

major unconformities are formed over the Liwan Marginal High, with the overlying strata (and adjacent regional-scale unconformities) indicating that continental breakup occurred between horizons T70 and T60, within a *Breakup Sequence*. Recent ocean drilling in this region has proved the interpretation above - see Zhang et al. (2021) for detailed depositional and chronostratigraphic information from the sites drilled by IODP Expeditions 367/368/368X. Key: TWT—two-way travel time; C11—magnetic anomaly C11; OCT—ocean-continent transition; R—seismic reflector "R".

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Geological term	Formal definition	Key first mentions in the published literature
Breakup Unconformity	Basinwide unconformity separating syn-rift from post-rift strata at the time of crustal breakup and onset of oceanic crust accretion.	Falvey et al. (1974), Ziegler (1975)
Lithospheric Breakup Surface (LBS)	New name for the Breakup Unconformity, representing in its new definition the onset of the breakup process between two future continents, not its end as implied by the Breakup Unconformity. It is also not always developed as an unconformity and represents the involvement of all the lithosphere in the breakup process, not only the continental crust.	Soares et al. (2012). Soares et al. (2014)
Breakup Sequence	Tectonically influenced stratigraphic unit, or sequence, representing the period between lithospheric breakup and the establishment of thermal relaxation as the main process controlling subsidence on divergent (fully-rifted) continental margins.	Soares et al. (2012), Soares et al. (2014)
Forced-regressive strata	Strata deposited when of the seaward movement of the shoreline in response to relative sea-level lowering. This sudden regression occurs during base-level fall, when the shoreline is forced to regress by the falling base, irrespective from sediment supply and type (Catuneanu, 2002).	Mitchum et al. (1977), Hunt and Tucker (1992)
Type I margins	Style of non-volcanic divergent margins in which breakup of the crust occurs before that of the mantle lithosphere. They record wide exhumation and exposure of serpentinized continental mantle lithosphere in the ocean–continent transition zone, and limited magmatism during rifting.	Huismans and Beaumont (2011)

Table 1 - Definition of key geological terms used in this discussion letter.