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A NEW TECTONIC MODEL FOR THE EVOLUTION OF THE V- SHAPED SEDIMENTARY BASINS

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Abstract

West and northwest-trending transcurrent faults divide Australia into blocks and belts. The Canning-New England Block that encompasses the Canning Basin at its northwestern end was more mobile than the adjacent blocks. Sinistral and dextral faults bound the block from the north and south respectably. Intermittent and major activity of these faults could trigger along strike decompression zones in the lower crust. The V- shaped sedimentary basins flanking the Canning-New England Block were created by multi-stage ductile movement of lower crustal material from the adjacent blocks towards the decompression zones and their offshore extension. The lower crustal flow was contemporaneous with wrenching in the overlying brittle cover, with sinistral and dextral strike-slip faults, that are orthogonal in trend to the major transcurrent faults. Along the basin lateral channel flow of lower crustal material and associated thermal perturbation is likely to account for subsidence and deformation along and across the V-shaped sedimentary basins. These transcurrent faults extend eastward to the Pacific subduction zone. The Cook and Vening-Meinesz Fracture Zones are likely to represent the most eastern extension of the proposed faults that defined the Canning-New England Block. They are displaced northeast because of anti-clock wise rotation of the Tasman Sea. The proposed lateral lower crust flow is self-induced mechanism and stress related and facilitated by low viscosity of mafic and ultramafic rocks that is inconsistent with hotspot and classical plume models. Similar tectonic setting is proposed for the Basin and Range Province. The seismicity in Australia and western USA are consistent with the proposed model.

Introduction

The thermal results of both pure shear and simple shear models have been tested in the Red Sea (Buck et al., 1988). It was found that topography across the Red Sea does not match any of the proposed models and that only a narrow region of pure shear extension could satisfy the observed topography and heat flow data. Hence, the role of ductile flow of the lower crust has been emphasized in many extensional models of sedimentary basins (Bott, 1999; McKenzie et al., 2000). A suitable model for the evolution of sedimentary basins needs to involve a mechanism that is capable of predicting a relatively large number of stretching phases and migration of depocentres (Van Wees et al., 1998; Reemst and Cloetingh, 2000). The model should explain contemporaneous wrenching and volcanic activity (Van Wees et al., 2000). A new model needs also to address the role of basement and major strike-slip zones in the evolution of sedimentary basins (McBride, 1998), changes in plate motion, plate-interaction and the evolution of rifted basins (Cloetingh et al., 1998). A new tectonic model for the evolution of Northern Carnarvon Basin, Western Australia was proposed, Daim and Lennox, 1998. The model suggested that the basin was created by multistage ductile movement of lower crustal material, in a general northerly direction from the Exmouth Plateau, towards the assumed decompression zones along the southern bounding fault of the onshore and offshore Canning Basin, Figure-1.

The V-shaped features in Mafic dykes of the Pilbara Region, eastern Carnarvon Basin, Western Australia, described by Semeniuk & Brocx., 2019, indicate that this lateral lower crust flow is self-induced Mechanism in contrary to hotspot and classical plume model. Contrary to the symmetrical Geometry assumed in pulsing plume models, Hey et al. 2010 proposed a propagating rift model for the V-shaped ridges south of Iceland, and suggested the possibility that a pulsing Iceland plume might not be necessary to explain the Reykjanes V-shaped gravity ridges and troughs south Iceland.

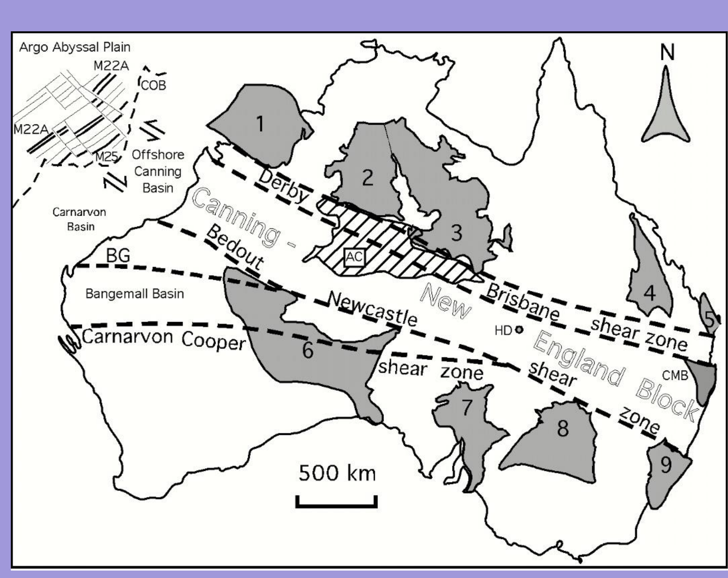

Figure 1 The proposed continental scale shear zones and the adjacent sedimentary basins. 1=Kimberley, 2=Wiso, 3=Georgina, 4=Bowen, 5=Maryborough, 6=Officer, 7=Adelaide, 8=Darling, 9=Sydney basin and 10= Clarence-Moreton Basin, BG=Barrow-Gibson shear zone, AC=Arunta Complex (diagonal lines pattern), and HD=Haddon Downs Well -1, COB= Continent-Ocean boundary. The magnetic lineations (M16-M26) of the Argo Abyssal Plain are revised according to Mihut and Muller (1998).

The observation of the V-shaped ridges south of Iceland that showing southward pointing V with a tip near 57°N considerably different from that to north, which shows northward pointing V with a tip near 69°N. They explained the above-mentioned discrepancy because of lithospheric discontinuity of the Tjornes Fracture Zone. It is difficult to see why deep radially symmetric plume pulses should produce the observed north-south VSR asymmetry. Adding that the narrow transform zone offsets of the propagators suggests a shallow driving mechanism. Hey et al. (2010) realized it is not the pattern expected from radial plume pulses interacting with an existing axis, which should produce structures symmetric about that axis.

General tectonic setting

The Mesozoic breakup of the Western Australian continental margin that started in Argo Abyssal Plain in the north, then in Gascoyne and Cuvier to the southwest, and later in Perth abyssal plains farther to the south, was associated with widespread lower crust / upper mantle extension and magmatism, (Symonds. et.al. 1998). They divided the western Australian margin into four main segments, the Argo margin to associate with the Browse and offshore Canning Basins, the Gascoyne margin with the Northern Carnarvon Basin, the Cuvier margin with the Southern Carnarvon Basin, and the Perth margin with the Perth Basin. They concluded that the evolution of these sedimentary basins extended for over more than 500 million years.

The Carnarvon Basin is a Palaeozoic to Cenozoic depocentre at the southern end of the North West Shelf of Western Australia. The basin is divided into the mainly onshore Southern Carnarvon Basin and the offshore Northern Carnarvon Basin. The Northern Carnarvon Basin consists of four sub-basins namely the Exmouth, Barrow, Dampier and Beagle from south to north. These en echelon sub-basins are striking to the northeast. The Barrow sub-basin is displaced and bended to the east. The sediments may reach 20 km in thickness. Most of the onshore sediment is Paleozoic, while the offshore sediment is mostly Mesozoic and Cenozoic. North and northeast-trending faults that are cut by west and northwest-trending faults characterize the Exmouth Plateau.

Interpretation of seismic data

Vertical and sub-vertical strike-slip faults that dominated the basin are inconsistent with classical models whereas normal faults are expected. A migration of fault activity and structuring has been seen along and across the basin revealed by the dip lines (Figure-2). The Rankin Trend shows Early Cretaceous to early Late Cretaceous tilting in Line 10, whereas in Line 12, Early Cretaceous tilting and folding continued into the Late Cretaceous. The pre-Miocene folding evident in Line 10 on the Madeleine Trend shifts to Late Miocene - Pliocene over the Legendre Trend in line 12. This folding continued until the present as is evident from the seabed topography on the Legendre Trend in Line 14. Local folding and unconformities also points to non-regional unconformity that is required by plume models.

Australian shear zones:-

The map of Australian sedimentary basins revealed the interpreted continental-scale crustal features. Two sets of V-shaped sedimentary basins are evident in this map. The sedimentary basins in both of these sets are open towards the Canning New-England Block (Figure 1). This arrangement is not mere coincidence; a northwest-trending crustal feature is suggested to control the development of these basins, (Daim & Lennox, 1998). The shape of the Darling Basin does not seem to reflect this arrangement, but its gravity and the structural elements mapped by Scheibner (1996) show a V-shape configuration. The thickness of sediments increases in each of these basins towards their open end, based upon interpretation of their gravity anomaly, and the basins are progressively younger to the east. Sinistral movement in the Amadeus Basin, Central Australia, documented by Veevers et al. (1982), may represent younger reactivation along the Derby-Brisbane shear zone. While dextral movements documented along the Musgrave Block in the Ediacarian (Petermann Ranges Orogeny), during the Late Carboniferous in the southern Cooper Basin and the Lachlan Transverse zone (Glen and Walshe, 1999), are consistent with dominant dextral movement on the Bedout-Newcastle shear zone. Another two shear zones which influenced the evolution of the adjacent sedimentary basins are represented by the west-trending Barrow-Gibson and Carnarvon-Cooper shear zones (Daim & Lennox (1998, Figure 1). Based on the left-handed overstep of the aligned continent-ocean boundary, sinistral strike-slip movement is interpreted to dominate the Barrow-Gibson shear zone (see figure 1). Krapez (1999) has interpreted sinistral and dextral strike-slip faults that could be associated with this shear zone. A dextral sense of movement is interpreted to dominate the Carnarvon-Cooper shear zone. Figure 3 shows eastwards displacement of the Ajana-Wandagee basement ridge that coincides with the Wooramel River in the Carnarvon area. The eastwards displacement of the segmented Weedarra Ridge relative to the Yallalong Ridge, and an eastward displacement of the boundary between the Precambrian deposits and younger strata, also supports a dominate dextral movements in this area. Krapez (1999) confirmed the location and the trascurrent movement of all the mentioned shear zones in Western Australia.

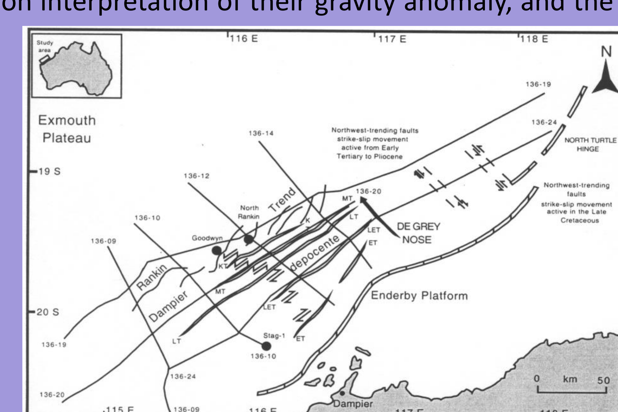

Figure 2 Location map of the studied seismic lines of AGSO 136 Survey and the tectonic model of the Dampier Sub-basin showing dominantly sinistral strike-slip movements on the western flank and dextral strike-slip movements on the eastern flank, KT=Kendrew Trough, MT=Madeleine Trend, LT=Lewis Trough, LET=Legendre Trend and ET=Enderby Trend.

Seismicity and Topography in Australia

Seismicity and the topographic map of Australia have been integrated to locate the proposed shear zones (Figure 4). Many earthquakes coincide with the offshore Canning Basin and occur southeastwards along the margins of the Canning Basin.

In eastern Australia, the earthquakes associated with the Canning-New England Block are aligned in a northwest trending line close to the margin. An orthogonal trend of seismicity is represented by roughly northwards alignment of earthquakes seen along the western margin of the Adelaide Fold Belt and east of Perth. This trend of seismicity is probably created by forces acting orthogonally to the west and northwest-trending shear zone and related to the evolution of adjacent sedimentary basins. In general the topography is consistent with the proposed shear zones and specially the high altitude area (> 600m) in western and central Australia, in terms of location and trends. The map also shows that the area between Sydney and Brisbane is displaced eastwards that is consistent with similar displacement of the 300 m contour in the Canning Basin (Figure). In central Australia, the Tertiary accommodation space of the Lake Eyre Basin shows a V-shaped pattern that is open to the north (Moussavi-Harami and Alexander, 1998), towards the proposed Bedout -Newcastle shear zone (Figure 4).

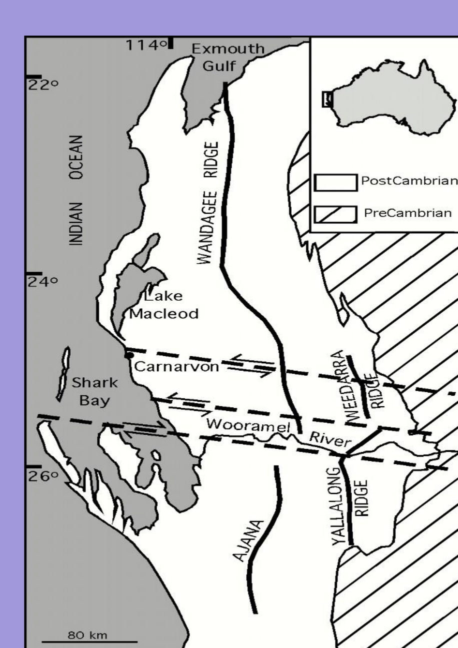

Figure 3 Detailed map of the western part of the Carnarvon-Cooper shear zone, reinterpreted after Condon, 1968, showing diffuse strike-slip movements in the Carnarvon area.

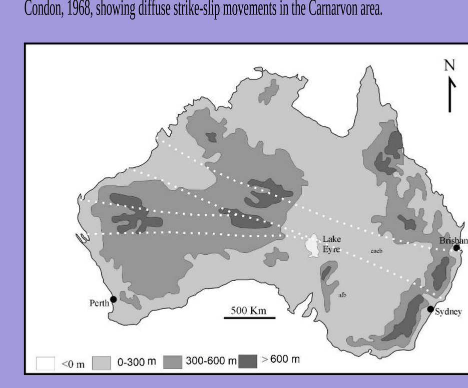

Figure 4 Topography map of Australia showing the relationship between elevation and the proposed Australian Transcurrent faults, cneb=Canning-New England Block, afb=Adelaide Fold Belt.

The current morphology of the shoreline in Western Australia represented by Exmouth Gulf and Shark Bay as well as Lake Macleod, indicates that the V-shaped pattern continues to dominate recent sedimentation. Recent movement on these faults is likely as indicated by sharp jogs in the shoreline along the proposed shear zones and the associated seismicity.

General V-Shaped model

Daim and Lennox (1998) proposed a conceptual model for the evolution of the Northern Carnarvon Basin. This model is based on the idea that the Australian Plate is subdivided on a large scale by WNW-trending shear zones into blocks and belts. Differential movement of these belts creates pull-apart basins along their borders. Major pull-apart basins are associated with decompression zones in the lower crust. The decompression zone always propagates in the direction of the absolute plate motion. Decompression may melt mafic rocks at the base of the lower crust and /or top of the upper mantle, causing magma upwelling.

The ductile movement of the lower crustal materials toward a decompression zone is associated with wrenching in the brittle upper crust, oriented almost orthogonal to the transcurrent faults. Both dextral and sinistral strike-slip faulting develops in the upper crust. Plate that is moving eastwards, sinistral faulting starts first associated with the ductile movement of the lower crust as the decompression zone grows, for basin located to the south of the transcurrent fault. Whereas, dextral faulting is associated with the declining stage of the decompression zone, (Figure 5). The evolution of the Northern Carnarvon, Officer and Sydney Basins is likely to be controlled by such a mechanism, (Figure 5a). However, for basins located to the north of a transcurrent fault, dextral strike-slip faulting starts first, then followed by sinistral faulting. Examples are the Browse, Wiso and Bowen Basins , (Figures 1 & 5a).

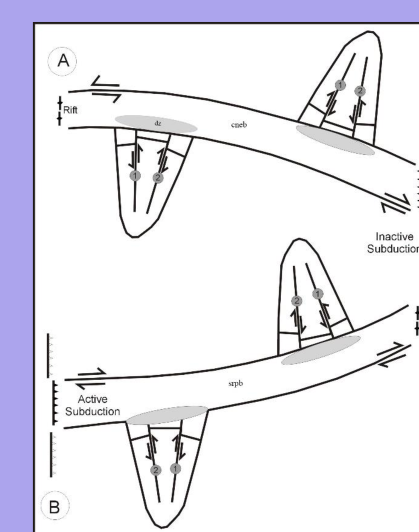

Figure 5 A crustal blocks diagram showing the evolution of a general V-Shaped sedimentary Basin. (a) Along the Canning –New England Block (cneb) (b): Along the Snake River Plain Belt (srpb) showing the various strike-slip mechanisms.

This is not a general rule, because the type of the strike-slip faulting depends on the direction of the block's movement and the location of the basin in regard to the shear zone. Plate that is moving westward, such as western America, dextral faulting starts first for basin located to south of the belt as the decompression zone grow and then sinistral faulting associate with the declining phase of the decompression zone, (Figure 5b). The Northern Basin and Range Province is consistent with such a mechanism. Opposite sense of mechanism for basins located north of the belt. Thinning is presumably proportional to the contemporaneous upper crust extension at every stage. This model is applicable under a very wide range of crustal stretching parameters. It is even applicable for V-shaped sea floor spreading as in Cuvier Abyssal Plain and Tasman Sea. It is intriguing to sea that every ridge in these basins and in offshore western United States has its own characters and they did not show any kind of symmetry. So, it is likely that this model is applicable as long as lower crust and upper mantle is involved.

Conclusions

Multiple lines of evidence suggest that V- shaped sedimentary basins can be explained in terms of sub-rigid block tectonics.

The Cook and Vening-Meinesz Fracture Zones are likely to represent the most eastern extension of the proposed transcurrent faults that defined the Canning-New England Block.

They are displaced northeast because of anti-clock wise rotation of the Tasman Sea.

The V- shaped sedimentary basins flanking the Canning-New England Block were created by multi-stage ductile movement of lower crustal material from the adjacent blocks towards the decompression zones and their offshore extension.

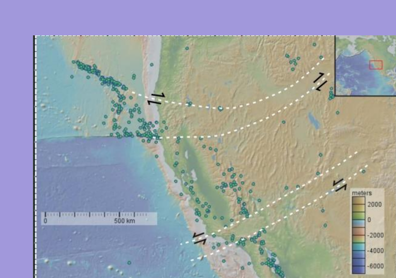

Figure 6 A crustal blocks map of the Northern Basin and Range Province showing major strike-slip faults superimposed on topographic map, focal mechanism are green dots.

The proposed lateral lower crust flow is self-induced mechanism and stress related and facilitated by low viscosity of mafic and ultramafic rocks that is inconsistent with hotspot and classical plume models.

Two dextral and sinistral mobile belts, from the north and south respectively, confine the Northern Basin and Range.

All the powerful earthquakes in western USA are likely triggered by faults that are orthogonal to the San Andreas Fault.

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