Palaeocurrents and provenance: uplift history of the Meratus Complex, SE Kalimantan

Duncan Witts
NPA Satellite Mapping, CGG. www.npa.cgg.com
Corresponding author: duncan.witts@cgg.com

INTRODUCTION

The Barito Basin in southeast Kalimantan contains a thick sedimentary succession of Middle Eocene to Pleistocene age. The basin is separated from the much smaller Asem-Asem Basin by the Meratus Mountains (Figure 1) – a complex of metamorphosed arc and ophiolitic rocks that record the accretion of East Java-West Sulawesi to Sundaland in the mid-Cretaceous. The complex was later uplifted during the Neogene. The uplift had a profound effect on the basin architecture, developing a foredeep along the emerging mountain front, and creating the present-day hydrocarbon plays of the basin. Thus, understanding the history of the Meratus uplift not only provides insight into the tectonic evolution of the basin, but also the development of the hydrocarbon system. Previous estimates of the age of uplift range from Middle Miocene (e.g. Letouzey et al., 1990; Satyana et al., 1999) to Late Miocene (e.g. Panggabean, 1991; Hutchison, 1996). Consequently, linking the uplift to regional tectonics has remained speculative. This article gives a very brief summary of palaeocurrent and provenance data, and makes reference to palynology results, that collectively aid our understanding of the Meratus uplift. The data were collected along the western flank of the Meratus Mountains during field and provenance studies between 2009 and 2011, as part of a PhD at Royal Holloway University, London. Additional data were collected during recent fieldwork with BP Indonesia, in association with Institut Teknologi Bandung (ITB), Indonesia.

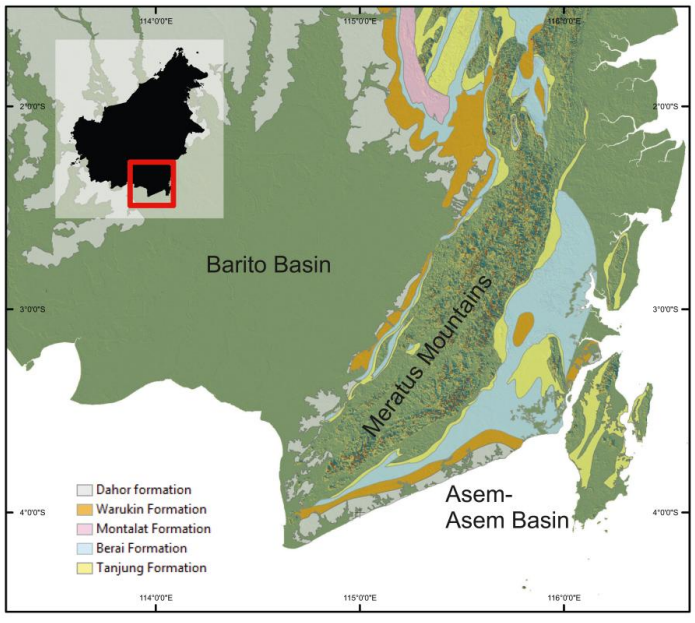


Figure 1. *Location of the Meratus Mountains and adjacent Basins. The Cenozoic sedimentary succession is also shown.*

A revised stratigraphy for the Barito Basin was published by Witts et al. (2012). Palynology showed the oldest part of the succession (Tanjung Formation), to be no older than Middle Eocene. The Berai and Montalat Formations overlie the Tanjung Formation conformably. They are laterally age equivalent (Upper Oligocene to Lower Miocene), but lithologically different. The Berai Formation comprises a near basin-wide shallow marine carbonate succession, whereas the Montalat Formation which is restricted to the northeast corner of the basin, comprises marginal to clastic shallow marine deposits (Bentot Member), followed by sandy and pebbly braid-delta deposits of the Kiwa Member. The Warukin Formation spans the Middle and Late Miocene, and probably extends into the Plio-Pleistocene locally. It overlies the Berai Formation conformably, and is thought to overly the Montalat Formation in a similar manner – although this latter relationship was not observed in the field. The formation comprises marginal marine (Barabai Member) to fluvio-deltaic (Tapin Member) deposits, recording a return to terrestrial deposition across the basin. The formation is overlain unconformably by, and locally interfingers, the latest Miocene to Pleistocene Dahor Formation, comprising alluvial material shed from basement rocks of the Meratus Complex. In my view, the Montalat and Warukin Formations contain evidence for a much earlier phase of Meratus uplift than previously speculated. They also suggest that the northern end of the Meratus was uplifting first. A brief summary of the results considered pertinent to this discussion is presented here.

MONTALAT FORMATION

Palaeocurrents recorded from cross-bed foresets through ~200 stratigraphic metres of the Lower Miocene Kiwa Member, indicate flow was directed towards the NW (Figure 2). We know that marine conditions were established to the east, north and southwest of where the measurements were recorded, which implies an uplifted source area to the SE. The only candidate for such an area is the Meratus. If this were the case, one would expect the material being supplied to the Kiwa Member to be reworked sedimentary rocks of the underlying Tanjung Formation.

This hypothesis was tested by comparing heavy mineral (HM) assemblages and zircon age populations of the Kiwa Member with those of the Tanjung Formation. The Kiwa and Tanjung datasets reveal a strong positive correlation in HM species and their relative proportions (Pearson Correlation -

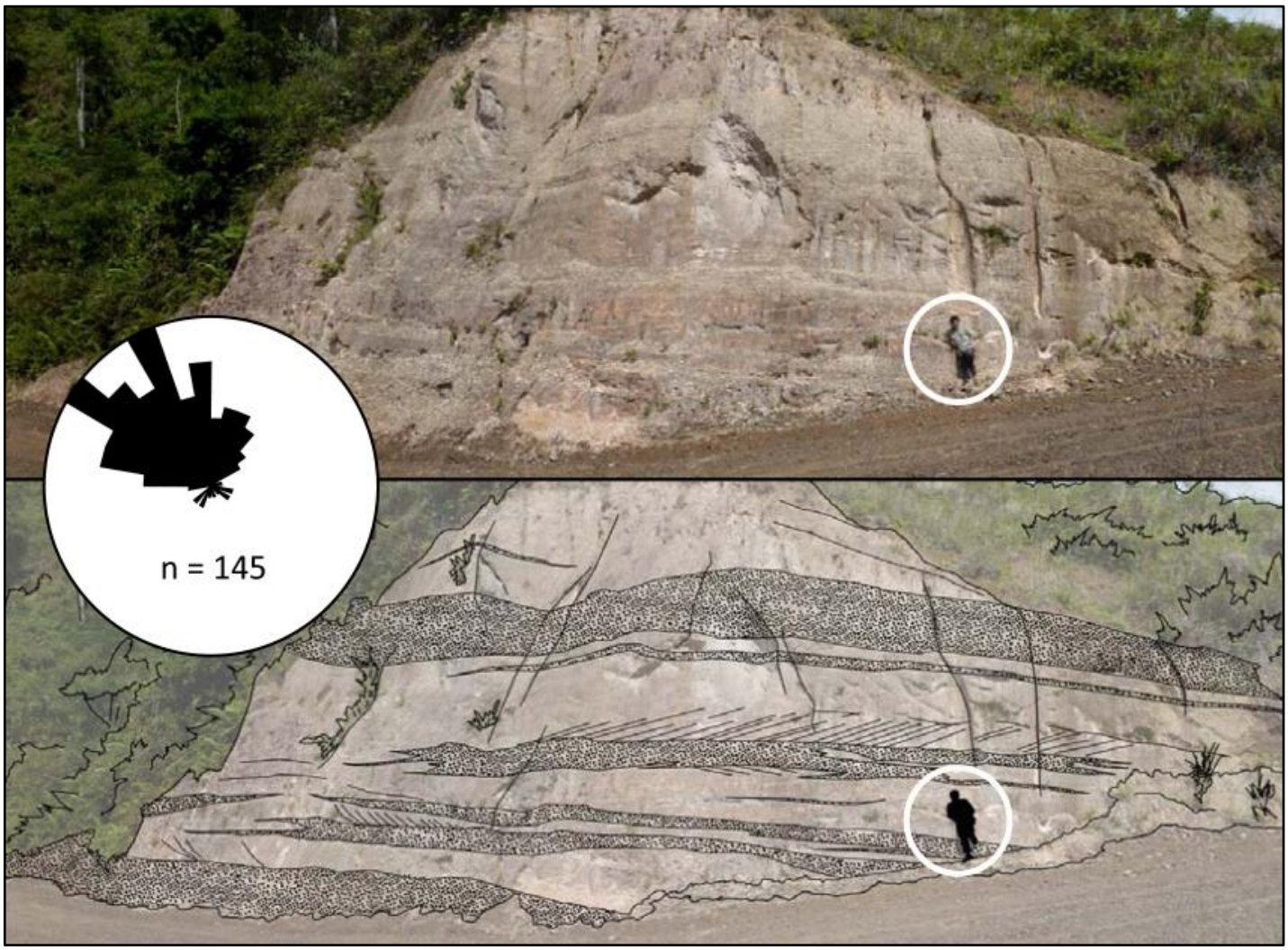


Figure 2. *Typical exposure of sandstones and pebbly sandstones of the Kiwa Member. Inset shows total palaeocurrents recorded from cross-bed foresets.*

between 0.7 and 0.9). In addition, the oldest HM samples from the Tanjung Formation most strongly correlate with the youngest sample from the Kiwa Member, and vice versa. If the Tanjung Formation was reworked into the Kiwa Member, this inverse relationship would be expected. This interpretation is also supported by zircon geochronology (See Figure 3). When zircon age populations of the two units are compared statistically, using the degree of overlap and similarity (OS) test (Gehrels et al., 2006), the data correlate positively at 0.94.

WARUKIN FORMATION

Palaeocurrents from the Warukin Formation form two distinct trends. The first, directed towards the ESE (i.e. towards the present-day Meratus), indicates the Meratus were not yet elevated (rivers flow out of highland areas, not into them). The second trend records flow directed towards the WNW (i.e. away from the Meratus). This second trend was recorded from channel sandstones in the uppermost ~500 m of the formation. The 180° switch in palaeocurrents is clearly seen in Figure 4. I interpret this reversal to record the early stages of Meratus uplift – perhaps only to a few metres elevation – and the initiation of a new drainage system.

HM assemblages throughout the Warukin Formation showed very little variation (Witts, 2011). The same was true for zircon age populations. The sandstones were originally derived from the Schwaner Complex and the Central Kalimantan Ranges (Witts, 2011), located to the west and northwest respectively. Such a provenance is consistent with ESE-directed palaeocurrents, but inconsistent with those directed towards the WNW (away from the Meratus). Thus, it seems probable that the Warukin Formation essentially cannibalised itself when the Meratus was being uplifted.

DISCUSSION

Palaeocurrents and sandstone provenance of the Kiwa Member suggest the northern part of the Meratus was uplifting during the Lower Miocene. To the south, a reversal in palaeocurrent direction indicating the onset of Meratus elevation does not appear until the uppermost strata of the Middle – Late Miocene Tapin Member (Warukin Formation) – Figure 5. Due to limited age-diagnostic fossils in these coal-bearing Warukin strata, it was not possible to determine their exact age. However, some deductions can be made from palynology. We know from palynomorphs that the Tapin Member was deposited from between 16 Ma and 7.4 Ma (Witts, 2011).

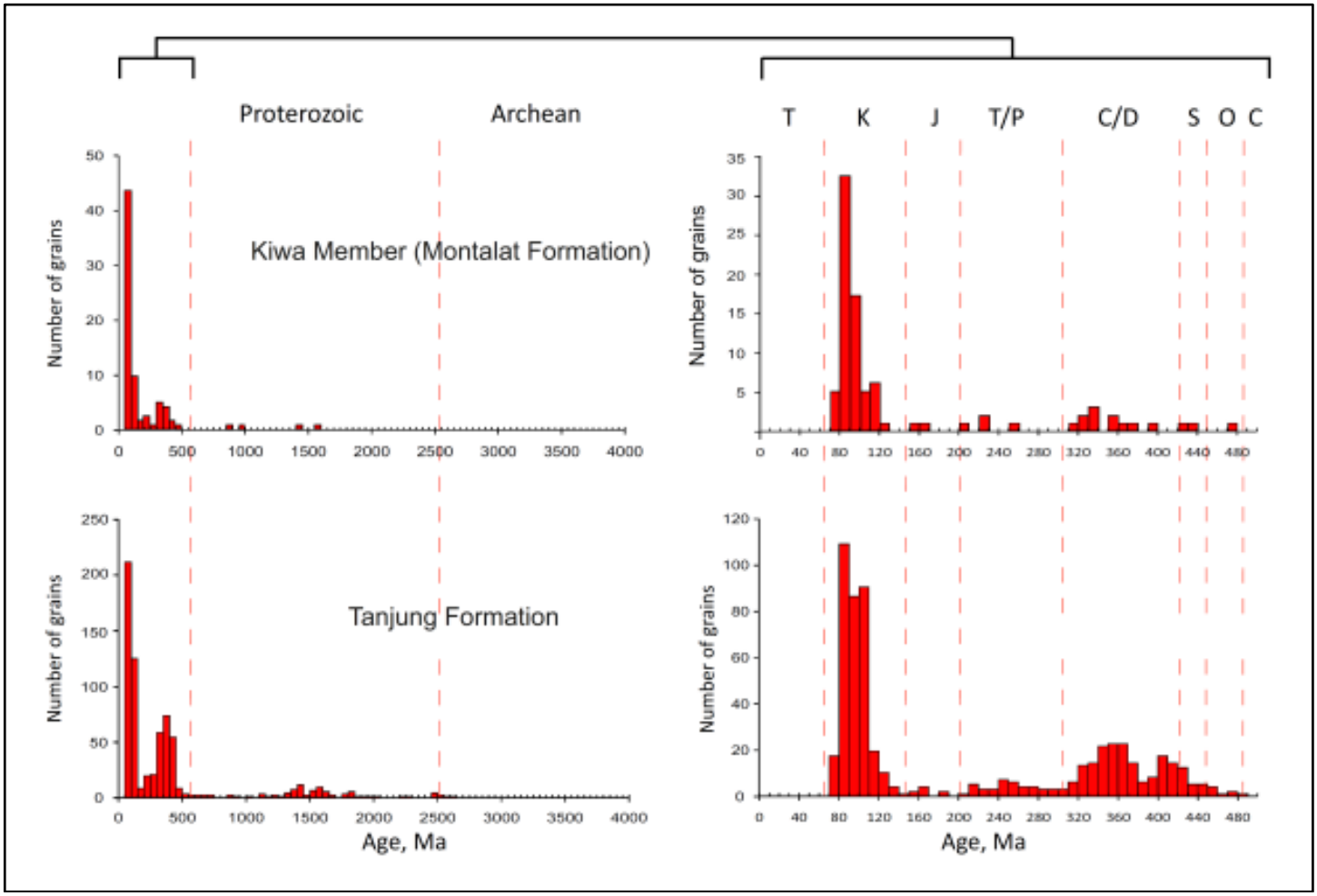


Figure 3. *All concordant U_Pb ages of zircons analysed from the Kiwa Member (top) and the Tanjung Formation (bottom). Left histograms show complete range of ages. Right histogram is an expanded view of Palaeozoic and younger ages. T: Cenozoic, K: Cretaceous, J: Jurassic, T/P: Triassic and Permian, C/D: Carboniferous and Devonian, S: Silurian, O: Ordovician, C: Cambrian.*

The member is ~2 km thick, and the thickest coal-bearing horizons (which contain the palaeocurrent reversal) form the uppermost ~500 m. The up-section increase in coal bed thickness indicates conditions were becoming optimal for peat productivity. This most likely corresponds to the Miocene thermal maximum – between 15 Ma and 13.8 Ma (R. Morley, pers. comm., 2011) – when conditions were at their hottest and wettest for the Neogene. Therefore, it is unlikely that these horizons are older than 14 Ma. Secondly, the palynomorph assemblages from the youngest coal beds suggest the climate may have started to become more seasonal (R. Morley, pers. comm., 2011). Seasonal and drier climates began to develop across southern Sundaland from Late Miocene through Plio-Pleistocene (Morley, 2000). Therefore, it seems reasonable to suggest that the thick coal-bearing strata that contain the west-directed palaeocurrents were deposited during the Late Miocene.

These interpretations point to strongly diachronous uplift of the Meratus, initiating in the north during the Early Miocene, but not until the Late Miocene in the south. This corroborates many observations other than the data presented in this article. For example, thinning of the Lower Miocene marls of the Berai Formation over the 'Meratus ridge', reported from subsurface data by Bishop (1980); and the presence of reworked Eocene foraminifera (e.g. *Pellatispira* sp.) within those marls (Witts, 2011), that were probably reworked from marine-influenced horizons of the uplifting Tanjung Formation. In addition, the deepest/most developed part of the Meratus foredeep is at its northern end, suggesting longer lived uplift and loading in that area. Unfortunately, seismic coverage along the Meratus front is extremely limited, thus extrapolating subsurface observations is inherently problematic. Nevertheless, subsurface data do suggest a general thinning of the Warukin interval towards the Meratus flank in the north, with relatively constant thickness of the same interval to the south (BP Indonesia Exploration Team, pers. comm., 2013).

Such a strongly diachronous uplift history suggests the Meratus Complex is, or has previously been, segmented; permitting piecemeal elevation of individual blocks at different times. NW-trending faults dissecting the Meratus, NW-trending stream alignments in the lowlands of the Barito Basin, and a similarly oriented basement fabric underlying the basin (BP Indonesia Exploration Team, pers. comm., 2013) all support this hypothesis. It could also explain the NW-trending 'Tanjung Line', which delineates an abrupt change in deformation style

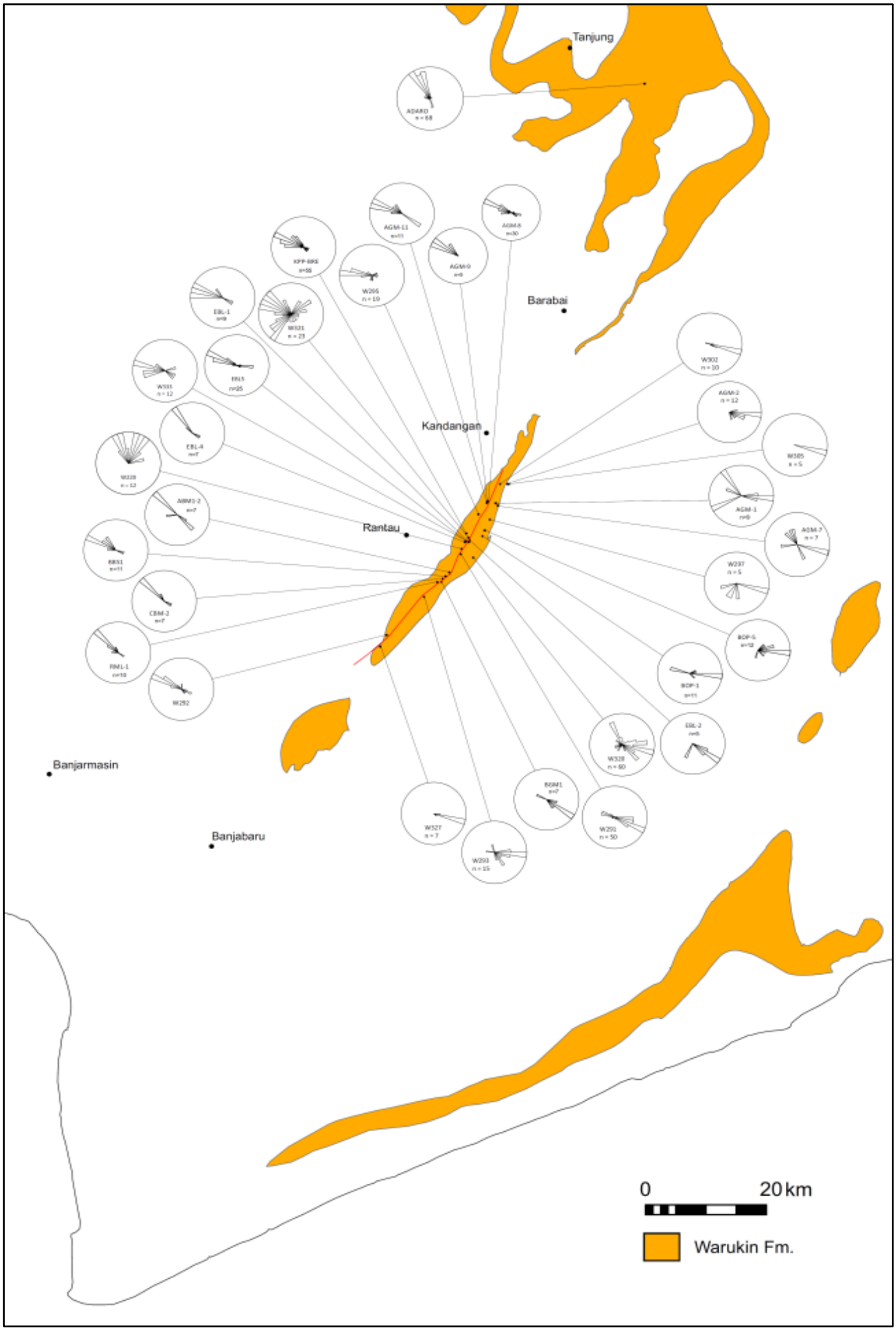


Figure 4. *Palaeocurrent data from the Warukin Formation, recorded along the western flank of the Meratus. Warukin Formation outcrop is rendered orange, coastline shown as solid black line. Palaeocurrent data is divided into two sets. Those of the left are predominantly directed towards the WNW. Those on the right are predominantly directed towards the ESE.*

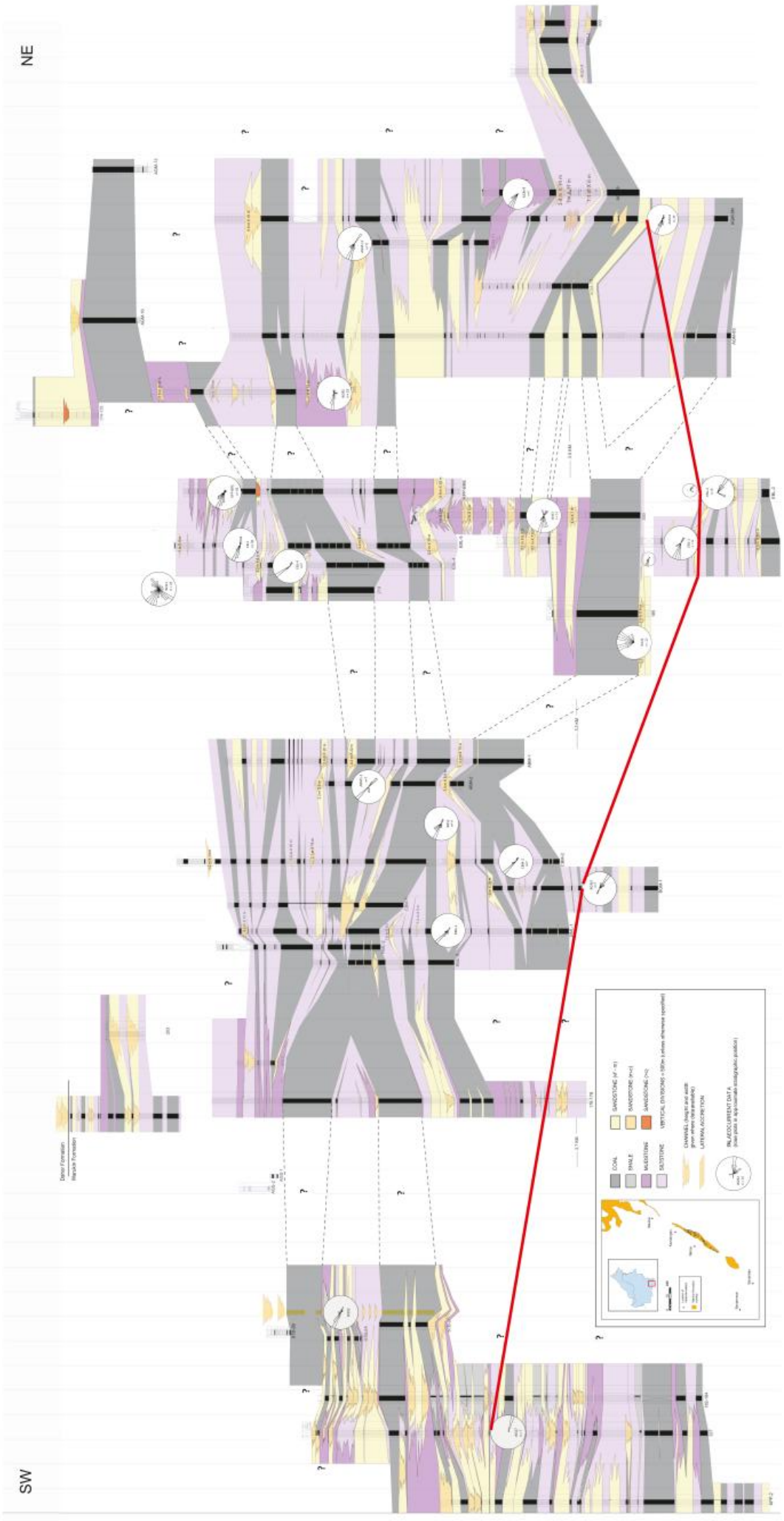


Figure 5. *Correlated sections of the uppermost horizons of the Tapin Member, recorded along the western flank of the Meratus. Palaeocurrents are also plotted. Solid red line indicates approximate stratigraphic position of last occurrence of ESE-directed palaeocurrents*

of the sedimentary succession in the subsurface. This interpretation warrants further study.

Collision between the Banggai-Sula microcontinent and eastern Sulawesi has been suggested as causing the Meratus uplift (e.g. Letouzey et al., 1990; Satyana & Silitonga, 1994). I feel it is highly unlikely that these collisions could have influenced tectonics in east Kalimantan. There is no evidence of collision in the Bone Basin, in West Sulawesi or in the Makassar Basins for this time interval. It seems more likely that uplift was a consequence of regional plate motions. The Miocene – in particular from 20 Ma – was a time of major reorganisation of plate boundaries throughout Southeast Asia, largely driven by the northwards push of the Australian plate against Sundaland (Hall, 1998). Therefore, we would expect most deformation to occur during this time. The Meratus Complex is a suture. Sutures are areas of weak crust that are commonly reactivated during episodes of tectonism (e.g. Busch et al., 1997; Bailey et al., 2000; Tikoff et al., 2001). The Meratus suture resembles a 'flower' structure (e.g. Sikumbang, 1986) positioned between two relatively rigid and undeformed continental fragments. It seems reasonable to argue that uplift of the Meratus merely reflects localised deformation along a pre-existing zone of weakness and controlled by a pre-existing basement fabric, in response to regional plate motions.

ACKNOWLEDGEMENTS

The data and interpretations presented in this article form part of my unpublished PhD thesis on the Barito Basin, supplemented by field results obtained whilst working with BP Indonesia Exploration Team, 2012. I would like to acknowledge the Southeast Asia Research Group for sponsoring my PhD; and to BP Indonesia for discussions whilst compiling this article, and allowing me to publish Figures 4 and 5. For further discussion, please contact: duncan.witts@cgg.com.

REFERENCES

Bailey, W.R., Holdsworth, R.E., Swarbrick, R.E., 2000, Kinematik history of a reactivated oceanic suture: the Mamonia Complex Suture Zone, SW Cyprus: Journal of the Geological Society, London, 157, p. 1107-1126.

Bishop, W.P., 1980. Structure, stratigraphy and hydrocarbons offshore southern Kalimantan, Indonesia. AAPG Bulletin, 64, 37-58.

Busch, J.P., Mezger, K., van der Pluijm, B.A., 1997, Suturing and extensional reactivation in the Grenville orogen, Canada: Geology, 25, p. 507-510.

Gehrels, G.E., Valencia, V., Pullen, A., 2006, Detrital zircon geochronology by Laser Ablation Multicollector ICPMS at the Arazona Laserchron Centre. In: Olszewski, T. (Ed.), Geochronology: Emerging Opportunities: Palaeontological Society Short Course. 12. The Plaeontological Society.

Hall, R., 1998, The plate tectonics of Cenozoic SE Asia and the distribution of land and sea. In: Hall, R., Holloway, J.D. (Eds.),: Biogeography and Geological Evolution of SE Asia. Backhuys Publishers, Leiden. NL. p. 99-131.

Hutchison, C.S., 1996, The 'Rajang accretionary prism' and Lupar Line' problem of Borneo: Journal of the Geological Society, London, Special Publications. 106, p. 247-261.

Letouzey, J., Jarvis, I., Pearce, M.A., 1990, Fault reactivation and structural inversion. Backarc and intraplate compressive deformations. Example of the eastern Sunda shelf (Indonesia): Tectonophysics, 183, p. 341-362.

Morley, R.J., 2000, Origin and Evolution of Tropical Rainforests: Wiley & Sons, London.

Panggabean, H., 1991, Tertiary source rocks, coals and reservoir potential in the Asem-Asem and Barito Basins, Southeast Kalimantan, Indonesia: PhD Thesis, University of Wollongong, Australia.

Satyana, A.H., Nugroho, D., Surantoko, I., 1999, Tectonic controls on the hydrocarbon habits of the Barito, Kutai and Tarakan Basins, Eastern Kalimantan, Indonesia: major dissimilarities in adjoining basins: Journal of Asian Earth Sciences, 17, p. 99-122.

Satyana, A.H., and Silitonga, P.D., 1994, Tectonic reversal in the East Barito Basin, South Kalimantan: Consideration of the types of inversion structures and petroleum significance: Proceedings of the Indonesian Petroleum Association, 23rd Annual Convention.

Sikumbang, N. 1986. Geology and Tectonics of Pre-Tertiary Rocks in the Meratus Mountains, South-East Kalimantan, Indonesia. PhD Thesis (unpublished). Royal Holloway and Bedford New College, University London.

Tikoff, B., Kelso, P., Manduca, C., Markley, M.J., and Gillaspy, J., 2001, Lithospheric and crustal reactivation of an ancient plate boundary: The assembly and disassembly of the Salmon River suture zone, Idaho, USA, In: Holdsworth, R.E., et al., eds., The nature and tectonic significance of fault zone weakening: Geological Society, London, Special Publication 186, p. 213–231.

Witts, D., 2011, Stratigraphy and Sedimentology of the Barito Basin, Southeast Kalimantan, Indonesia: Unpublished PhD Thesis, University of London.

Witts, D., Hall, R., Nichols, G., Morley, R.J., 2012, A new depositional and provenance model for the Tanjung Formation, Barito Basin, SE Kalimantan, Indonesia: Journal of Asian Earth Sciences, 56, p. 77-104.