Structural and Stratigraphic Evolution of the Gulf of Papua, Papua New Guinea: New Insights from a Modern 3D Seismic Survey*

Andrew Botsford[1], Larry Endebrock[1], and Amanda Harrington[1]

Search and Discovery Article #10456 (2012)
Posted October 29, 2012

*Adapted from extended abstract prepared for poster presentation at AAPG International Conference and Exhibition, Singapore, 16-19 September, 2012

[1]Petroleum Geo-Services Asia Pacific Pte Ltd. Singapore (andrew.botsford@pgs.com)

Geological Setting

The Gulf of Papua (GoP), part of the Papuan Basin, has undergone a complex and varied structural and stratigraphic evolution relating to its position on the NE edge of the Australian plate. The current basin configuration is a NW-SE-trending foreland basin to the SW of the uplifted Papua New Guinea (PNG) mountain ranges of the Papuan fold belt (Figure 1).

Uplift of the Papuan fold belt has resulted from the collision of Pacific island arcs with the Australian plate. Over 3.5km of siliciclastic sediments have been deposited in the GoP in less than 5 My from the Pliocene to the present day (Figure 2). Prior to this rapid influx, a period of tectonic quiescence persisted during which an extensive carbonate system developed over 30 My, throughout the Oligocene and Miocene. Several areas of reef development occurred; greatly influenced by eustatic sea level changes (Tcherepenov et al., 2008). Understanding basin evolution and tectonic setting prior to the Eocene to Miocene carbonate development is challenging. Well data and seismic surveys in the GoP show that erosion of up to 1.8km of Mesozoic sediment occurred between approximately 63-38 Ma (Gordon et al., 2000; Parsons and Bowen, 1986). To the SE of the Papuan Basin, rifting and extension from about 62 to 56 Ma formed the Coral Sea (Weissel and Watts, 1979). It has been suggested that uplift occurred in the Papuan Basin during this period (Home et al., 1990; Struckmeyer et al., 1993). Prior to the Coral Sea rifting period, extensive Mesozoic marine sediments were laid down as part of the regionally extensive Gondwana syn- and post-rift megasequences. Prior to Gondwana rifting, the pre-Triassic (>250Ma) basin is likely to have been in a continental setting with some development of Permian and older sediments.

Petroleum Exploration

Most PNG exploration to date has focused on the onshore region of the Papuan fold belt, where a number of commercial oil and gas discoveries have been made. There is now increasing focus on the offshore area. Although there are fewer wells offshore, there have been three significant gas and condensate discoveries (Figure 3). The Uramu and Pasca discoveries were made in 1968, and Pandora was discovered in 1988. The three discoveries contain hydrocarbons within lower Miocene Darai limestone reefs. These discoveries were made using 2D seismic surveys, which helped identify structural highs capped by reefs that are sealed by extensive Pliocene to Recent siliciclastic infill.

In addition to the proven Eocene to Miocene carbonates, plays analogous to onshore discoveries have potential in the GoP. Most onshore discoveries were charged by a Mesozoic source rock, which has also been drilled in the Gulf (Gordon et al., 2000). Additional source potential lies in Cenozoic deposits. Plant material in the Pliocene-Pleistocene deltaic sediments may source a biogenic gas system, Miocene and older mudstones provide potential for a thermogenic hydrocarbon system. Gas composition of discoveries made at Pasca and Pandora are very different. The Pandora gas was nearly 100% methane, indicative of a biogenic source, whereas the gas at Pasca contained 80% methane plus a significant proportion of heavier hydrocarbons.

Clastic reservoir potential is possible throughout the sedimentary section of the GoP. The Pliocene-Pleistocene deltaic siliciclastics are generally fine-grained and have poor reservoir potential, owing to mineral provenance of uplifted island-arc volcanic rocks in the Papuan fold belt. Periods of coarser-grained sediment input was likely when sediment provenance switched to exposed granites and quartzites, and were worked into the GoP as basin floor fans. A massive fan lacking volcaniclastic fragments crops out in north PNG, and 20-25% porosity in thin sand layers has been noted in Pasca C-1 well (Jablonski et al., 2006). Where coarser sandy deposits are present, there is good potential for sealed reservoirs, such as the Flinders Prospect (Schmidt, 2000). Cretaceous sandstones have provided good quality reservoirs onshore and may be present offshore beneath the Cenozoic carbonates; examples drilled and exposed onshore include the Upper Cretaceous Pale Sandstone and the Lower Cretaceous Toro Sandstone. Mesozoic rift deposits may contain localised coarse clastics, but pre rift continental sediments are likely to be deeply buried and metamorphosed; therefore, porosity preservation is unlikely. There are a number of larger structures that remain undrilled in the GoP. The current tectonic configuration of the Australian and Pacific plates pressing together has formed thick skinned structures in the hanging wall of the deformation front. Four-way-dip-closed anticlines containing Mesozoic clastic reservoirs are proven onshore in several discoveries within the Papuan fold belt.

Seismic Acquisition and Interpretation

PGS acquired 6300km² of MultiClient 3D seismic data from 2010 to 2011.Ongoing interpretation has greatly improved imaging and mapping of the offshore area surrounding the Pasca gas condensate discovery and the NE-SW-trending Pasca Ridge (Figure 3). The seismic data is composed of three sections covering part of the fold and thrust belt, the foreland basin section and the Pasca discovery. Another smaller area has been acquired to the SW of this area. This article focuses on the insights obtained from the region of greatest continuous coverage (Figure 3).

Cenozoic Insights

Cenozoic siliciclastic deposits have undergone intense deformation in response to the ongoing compression of the Pacific Plate with the NE margin of the Australian Plate. Interpretation of an intra-Pliocene seismic horizon reveals the NW-SE-trending offshore extension of the Papuan fold belt; these NW-SE-trending compressional thrust faults mark the modern-day thick-skinned deformation front (Figure 4).

In the foreland basin, west of the thick-skinned deformation, is an array of NE-SW-trending extensional faults that dip to the SE. These faults detach in sediments overlying the Miocene Pasca carbonates, and have been accommodated by NE-SW-trending, SE-verging fold and thrust structures to the SE (see Figure 7). These thin-skinned structural features are likely to represent a gravitational response to rapid sediment loading, as they have a separate trend to the regional tectonic regime. The features are confined to a region north of the Pasca Ridge. A ductile detachment surface is likely to have been deposited north of the ridge, but may not be present farther south.

The Miocene Darai Limestone occurs as reefal buildup on pre-Cenozoic structural highs (Figure 5). The 3D seismic dataset images two separate pinnacles, a crescent shaped elongate feature to the SE and a much smaller isolated pinnacle to the NE. The larger pinnacle contains gas (Pasca A-1, A-2 & A-3), whereas the smaller pinnacle contained no commercial hydrocarbons and is underlain by quartzite (Pasca C-1 & C-2). The PGS 3D dataset has imaged a previously undiscovered pinnacle reef to the NE of the Pasca reef complex.

Pre-Cenozoic Insights

Seismic interpretation beneath the Cenozoic carbonate unit reveals a thick sedimentary section segmented by an ENE-WSW-trending inverted extensional fault system. These extensional faults generally dip northwards, north of the Pasca Ridge, and southwards, south of the ridge. The inverted compressional system verges to the SE (Figure 6). This inverted sedimentary package appears to have been overthrust by a seismically less coherent section (Figure 7).

The Pasca C-1 well of 1968 drilled an undated quartzite directly underneath the Darai limestones. This quartzite unit is represented on the seismic section as incoherent reflectors. This may be attributed to the presence of overlying carbonates dissipating seismic energy, or to the lack of resolvable bedding within the metamorphosed section.

Two hypotheses for the origin and age of these units are proposed:
1. The moderately deformed sedimentary section is part of the Mesozoic sedimentary sequence present in the onshore Papuan basin. A significant Early Tertiary (65-38 Ma) deformation event resulted in uplift of the Gondwana rift section, thrusting older metamorphic rocks over the younger sedimentary section and emplacing the Pasca Ridge to its present position. Significant erosion of the Mesozoic section occurred after this event and exposed the deep metamorphic rocks encountered in the Pasca C-1 well.
2. The sedimentary units described above pre-date the Mesozoic rift section, and are composed of Triassic or older sediments. The deformation event occurred prior to Mesozoic rifting; and this location has been a passive margin since the Early Mesozoic.

Of the two models put forward, the former is considered most likely by the authors. The NE-SW-trending deep extensional faults have the same orientation as would be expected when viewed in a regional context, with Mesozoic extension along the North Australian margin. In addition, the Dibiri-1 well has significant volume of Mesozoic section missing, and source-rock maturity data suggest the removal of sediment between approximately 65-38 Ma. This trend has also been observed in other wells across the region (Gordon et al., 2000). Uplift during this period may have been driven by transpressional-fault movement related to the strike-slip fault marking the boundary between the eastern margin of the Northern Australian continent and the western margin of the proto Coral Sea Basin (Struckmeyer et al., 1993; Pigram and Symonds, 1993).

Conclusions

New 3D seismic data has allowed improved imaging of the offshore Papuan fold belt, the Papuan foreland basin and the Pasca gas condensate discovery. A proven petroleum system is in place across the area, as indicated by hydrocarbon discoveries and shallow gas anomalies. Two structural regimes have been observed on the seismic data. An ongoing Cenozoic compression related to the convergence of the Pacific and Australian plates has formed thick-skinned NW-SE-trending structures, whereas sediment loading has formed thin skinned NE-SW trending syn-sedimentary structures. An earlier NE-SW structural trend has deformed and uplifted older sedimentary rocks and led to the exposure of quartzite beneath the Miocene carbonates of the Pasca discovery. The Pasca reefal carbonates have been imaged in great detail and indicate two build-ups, a larger crescent form and a smaller pinnacle.

It is likely that the pre-Miocene uplifted sediments are Mesozoic rift sediments, which contain moderate to good quality source rocks. This source may be responsible for charging the Pasca discovery and provides encouragement for charging additional prospects in the area. These units have been rapidly buried over the last 5 My and are likely to be overmature for oil generation in many areas at the present day. Additional thermogenic source potential is present in the Eocene to Recent clastic deposits and from the buried organic carbonate deposits. Several Late Cenozoic structural closures have been identified, which have the potential to hold large volumes of hydrocarbons. It is anticipated that future discoveries could be made where reservoir sands are in place and top seal has not been breached by tectonic stresses.

Selected References

Carman, G.J., and Z. Carman, 1993, Petroleum Exploration and Development in Papua New Guinea: PNG Chamber of Mines and Petroleum, Port Moresby, Papua New Guinea, 687 p.

Gordon, S.A., B.J. Huizinga, and V. Sublette, 2000, Petroleum potential of the southern Gulf of Papua: Petroleum exploration in Papua New Guinea: Proceedings of the Fourth PNG Petroleum Convention, p. 205-218.

Home, P.C., Dalton, D.G. and Brannan, J., 1990, Geological evolution of the western Papuan basin, *in* G.J. Carmen, and Z. Carmen, (eds), Petroleum Exploration in Papua New Guinea: Proceedings of the First PNG Petroleum Convention, Port Moresby, p. 107-118.

Jablonski, D., S. Pono, and O.A. Larsen, 2006, Prospectivity of the deepwater Gulf of Papua and surrounds in Papua New Guinea (PNG) - a New Look at a Frontier Region: APPEA Journal, p. 1-22.

Nelson, A., 2004, Acquisition and preliminary impressions of airborne gravity gradient and aeromagnetic data in the Eastern Papuan Basin, Papua New Guinea, Airborne Gravity 2004: Abstracts from the ASEG-PESA Airborne Gravity 2004 Workshop, Geoscience Australia.

Parsons, G.L., and E.A. Bowen, 1986, The tectonic evolution and petroleum potential of the Papuan Basin, Papua New Guinea: Proceedings of the Southeast Asia Petroleum Exploration Society, v.7, p. 96-110.

Pigram, C.J., and P.A. Symonds, 1993, Eastern Papuan Basin- A new model for the tectonic development, and implications for petroleum prospectivity: Petroleum exploration and development in Papua New Guinea: Proceedings of the Second PNG Petroleum Convention, Port Moresby, p. 213-231.

Schmidt, D., 2000, Seismic attribute studies of the Flinders Amplitude Anomaly- Gulf of Papua, *in* P.G. Buchanan, A.M. Grainge, and R.C.N. Thornton, Papua New Guinea's petroleum industry in the 21st century: Fourth PNG Petroleum Convention, Port Moresby, Papua new Guinea, p. 469-474.

Struckmeyer, H.I.M., M. Yeung, and C.J. Pigram, 1993, Mesozoic to Cainozoic plate tectonic and palaeogeographic evolution of the New Guinea Region, *in* G.J. Carman, and Z. Carman, (eds.), Petroleum exploration and development in Papua New Guinea; based on the Proceedings of the Second PNG Petroleum Convention: Proceedings of the Second PNG Petroleum Convention, v. 2, p. 261-290.

Tcherepanov, E.N., A.W. Droxler, P. Lapointe, and K. Mohn, 2008, Carbonate seismic stratigraphy of the Gulf of Papua mixed depositional system: Neogene stratigraphic signature and eustatic control: Basin Research, 2008, v. 20/2, p. 185-209.

van Ufford, A.Q., and M. Cloos, 2005, Cenozoic tectonics of New Guinea: AAPG Bulletin, v.89/1, p.119-140.

Weissel, J.K., nd A.B. Watts, 1979, Tetonic evolution of the Coral Sea basin: Journal of Geophysical Research, v. 84/B9, p. 4572-4582.

Williamson, A., and G. Hancock, 2005, The Geology and Mineral Potential of Papua New Guinea: Papua New Guinea Department of Mining, 152 p.

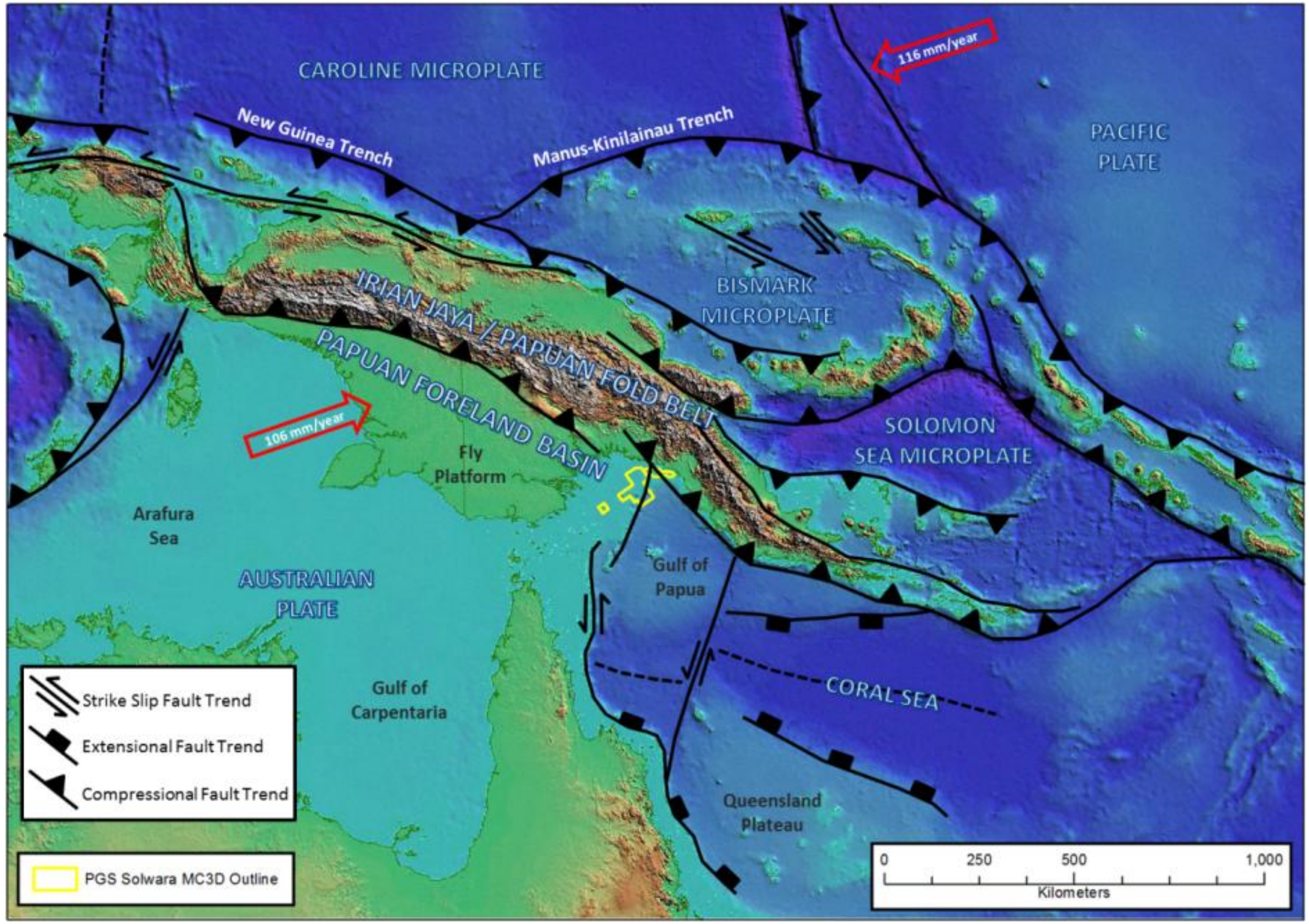

Figure 1: Major structural components surrounding the Gulf of Papua, overlain on topography and bathymetry derived from GEBCO data. (Compiled and adapted from van Ufford and Cloos, 2005, Struckmeyer et al., 1993, Pigram and Symonds, 1993, and USGS, 2012.)

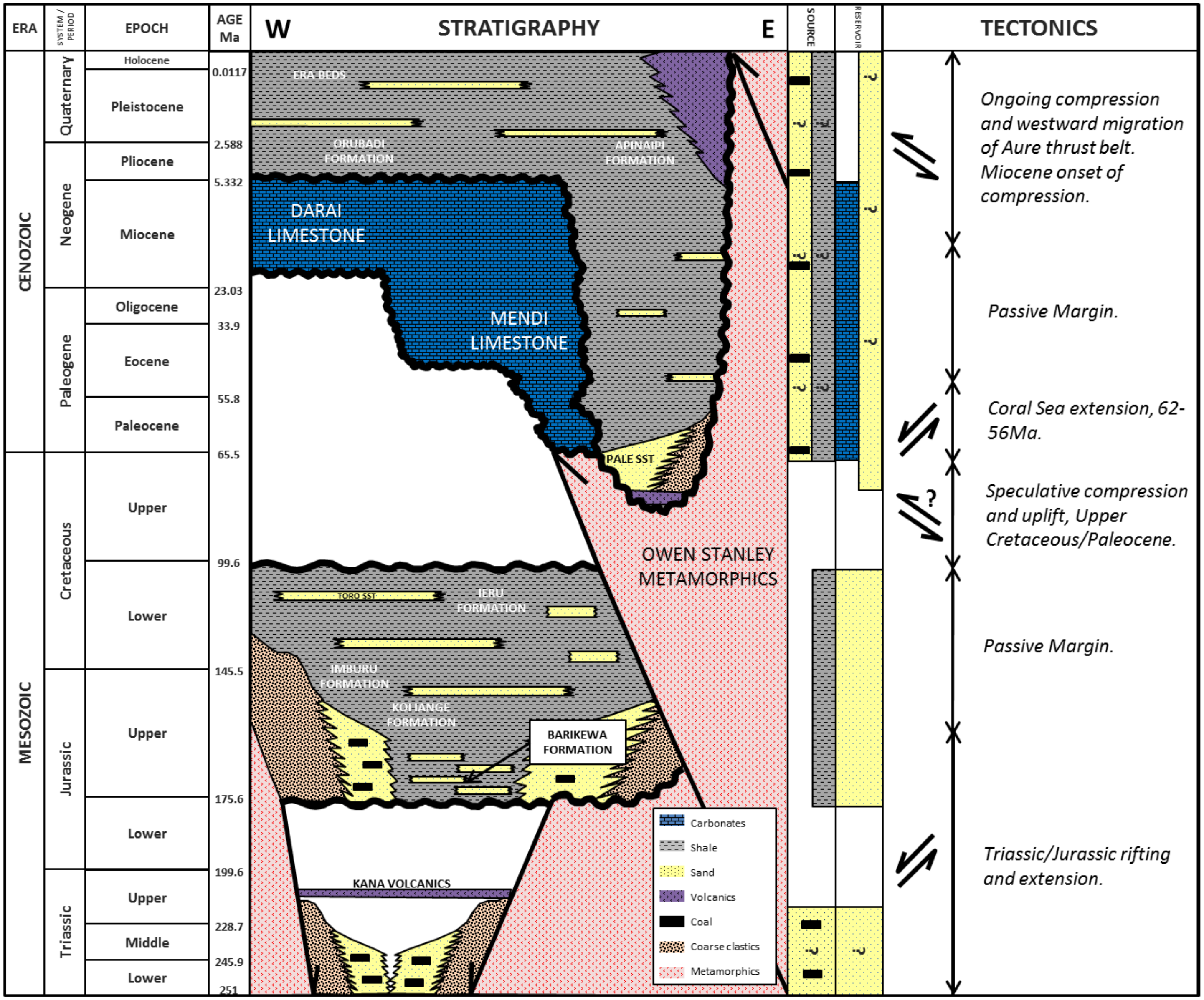

Figure 2: Stratigraphy, petroleum systems and tectonics of the Gulf of Papua in the region surrounding the Solwara MC3D seismic survey. (Compiled and adapted from Struckmeyer et al., 1993, Jablonski et al., 2006, Gordon et al., 2000, Nelson, 2004, and Carman, 1993.)

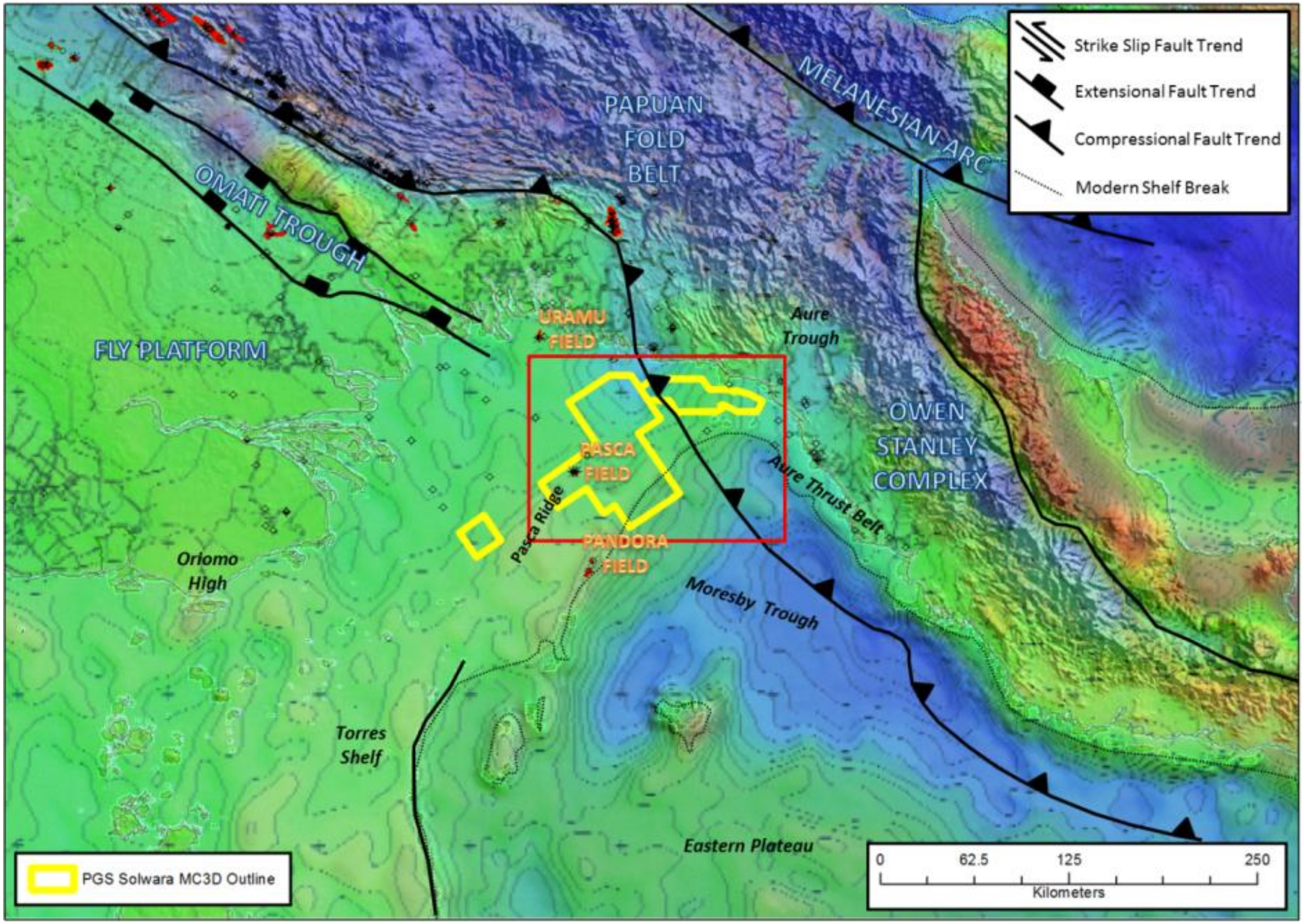

Figure 3: Major structural components. Gravity (Red=High, Blue=Low). Petroleum Discoveries (labeled offshore) and exploration wells of the Gulf of Papua Region. Topography and bathymetry are derived from GEBCO data, with a 50% transparent gravity overlay. The study area lies within the red box. (Compiled and adapted from Jablonski et al., 2006, Parsons and Bowen, 1986, Williamson and Hancock, 2005, and other industry sources.)

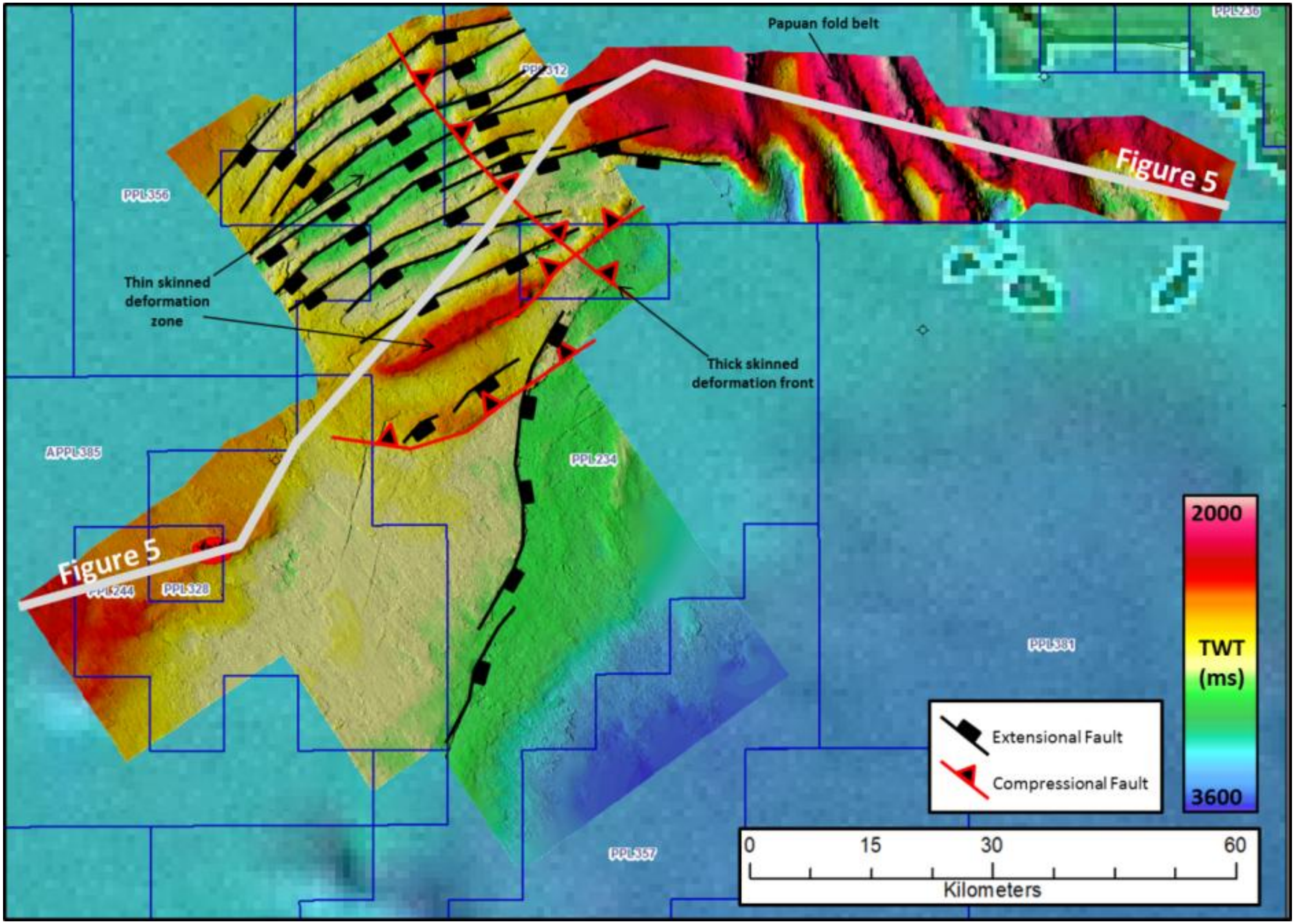

Figure 4: Intra-Pliocene (~3Ma) TWT structure map. The location of profile in Figure 5 is highlighted.

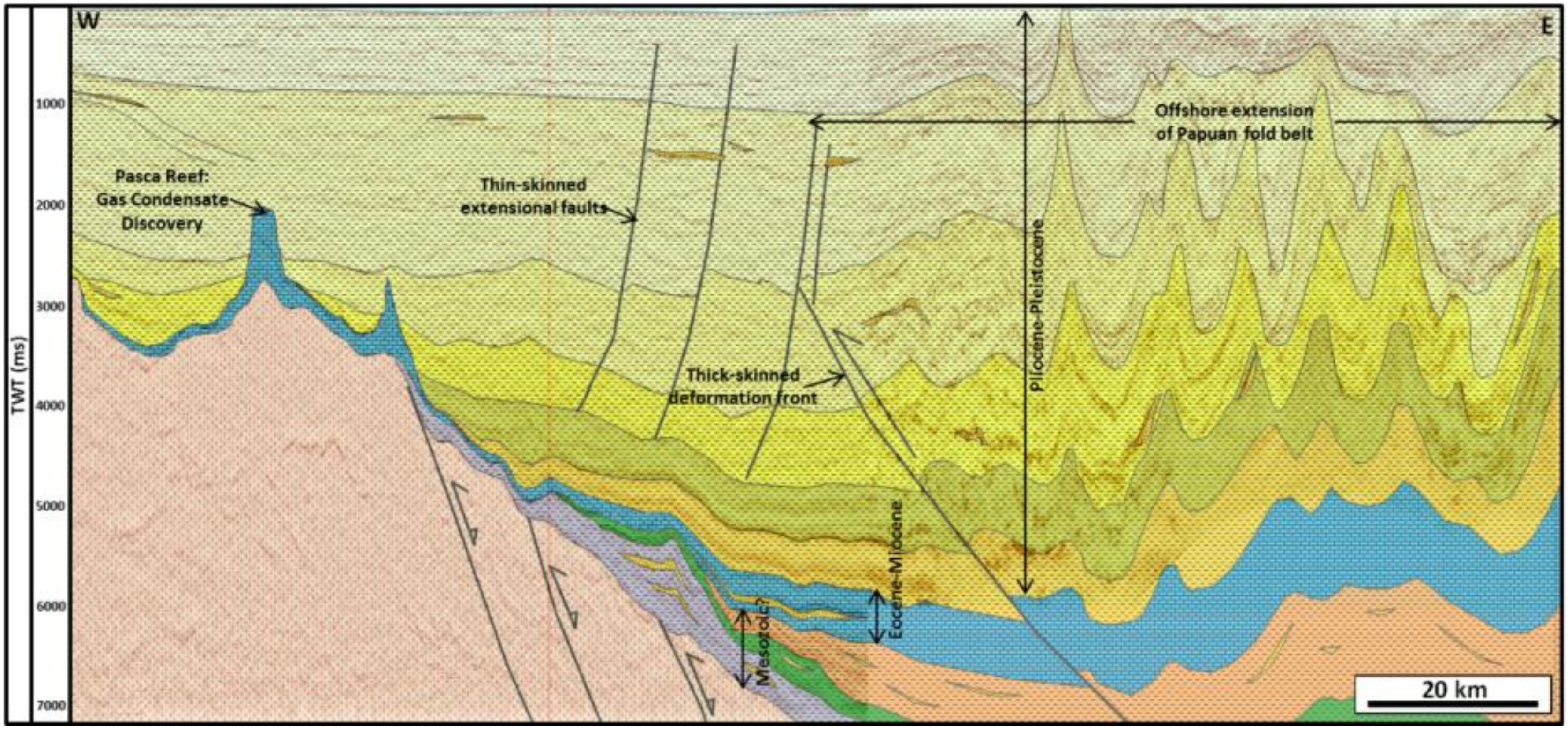

Figure 5: Interpreted west-to-east profile of PGS Solwara MC3D dataset; for location see Figure 4.

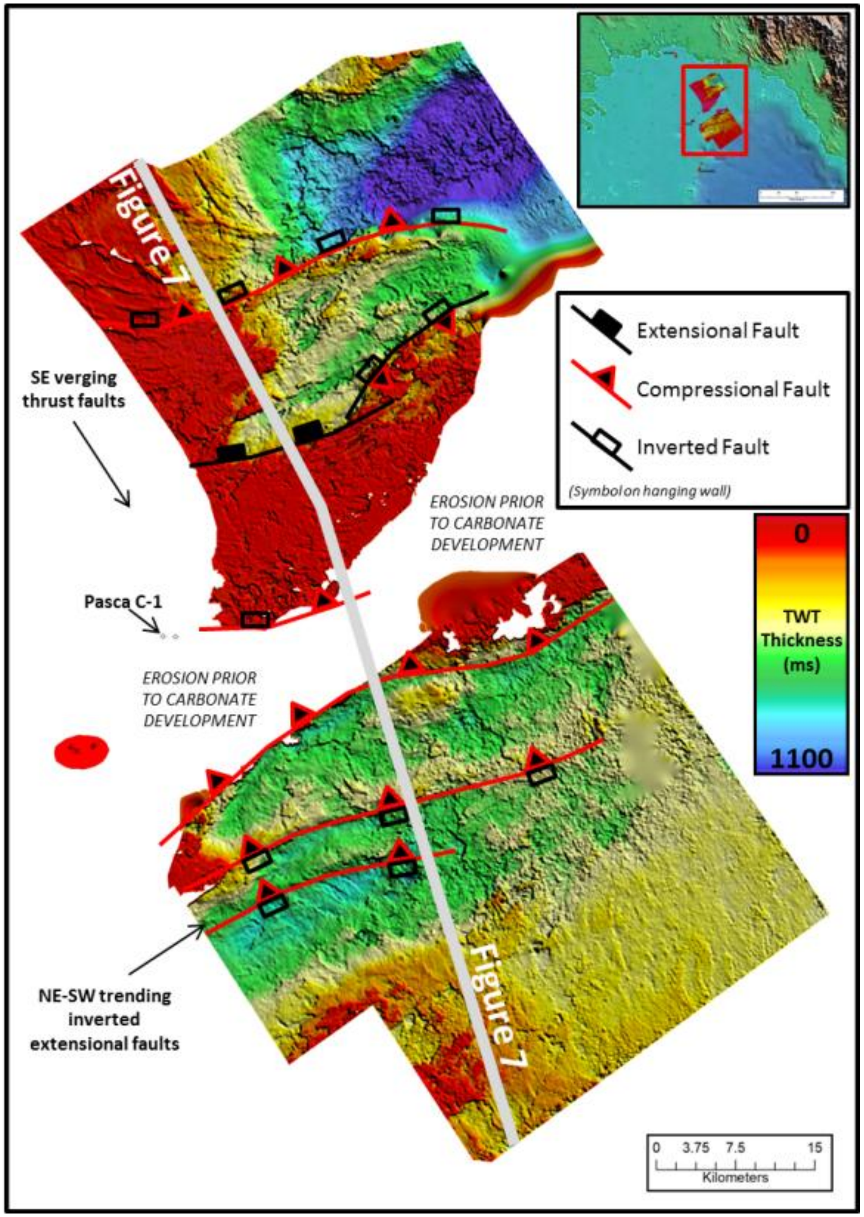

Figure 6: Base carbonate to Intra-Mesozoic isochron (~62-92 Ma).The location of profile in Figure 7 is highlighted.

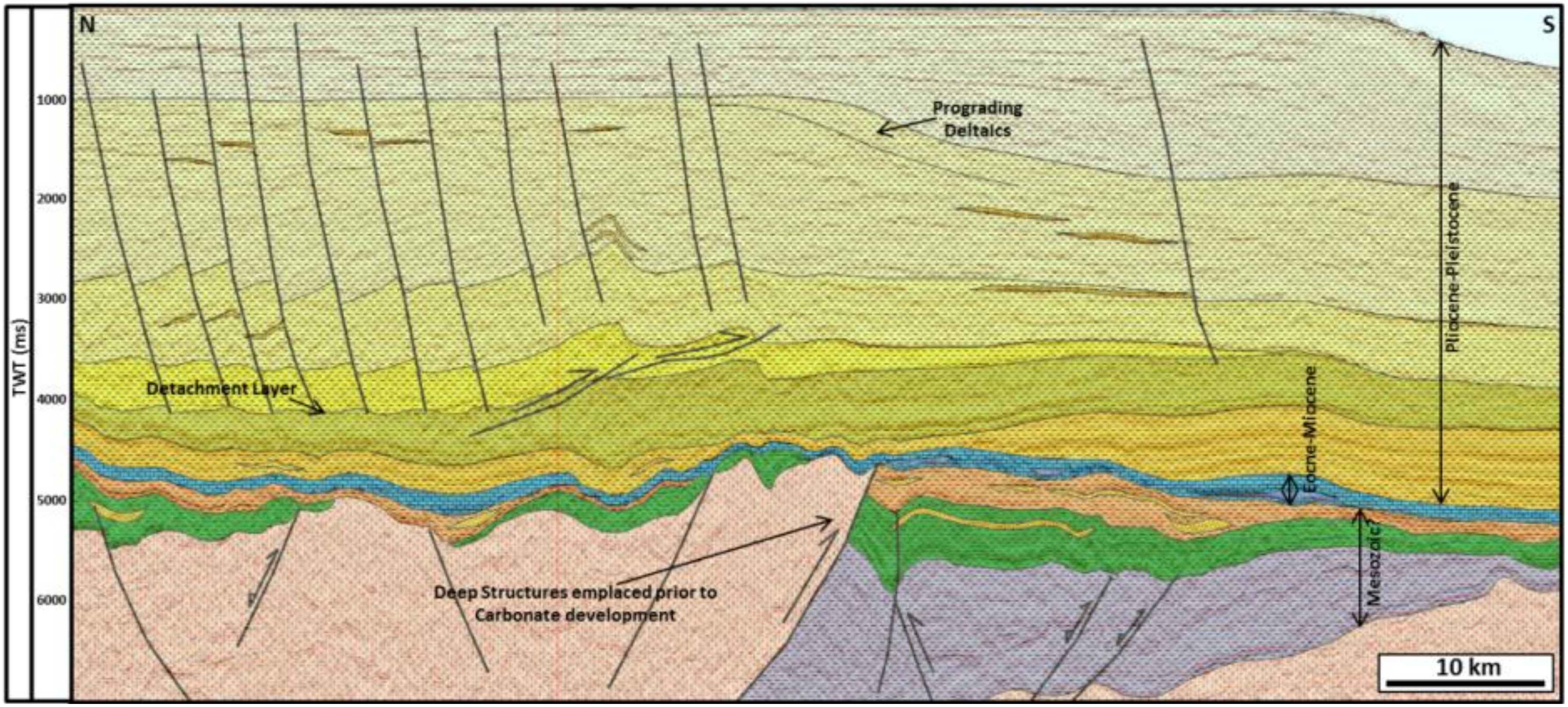

Figure 7: Interpreted north-to-south profile of PGS Solwara MC3D dataset; for location see Figure 6.