Interplay between Submarine Depositional Processes and Recent Tectonics in the Biak Basin, Western Papua, Eastern Indonesia

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ABSTRACT

The offshore Biak Basin between Biak and Yapen Islands is a transtensional pull-apart basin. Deposition along basin margins is strongly influenced by active faulting. The bathymetric map of the basin shows submarine depositional processes occurred during relatively recent tectonic activity.

Introduction

The Biak Basin is located in Eastern Indonesia, Papua Province, between Biak and Yapen islands. The area is characterised by a complex tectonic history, being located in the oblique collision zone between the Australian and Pacific Plates. A major strike-slip system, the Sorong – Yapen Fault Zone, bounds the basin to the south (Figure 1).

The basin is a frontier area for oil and gas exploration and offshore data are very limited. As a consequence, the origin and evolution of this basin is still poorly known. Recently acquired offshore data can help constrain the history of this basin. In this study, we use suite of high-resolution bathymetric data acquired in the area by TGS (2007). These data allow detailed seabed imaging and thorough mapping of the various morpho-structural surface features observed in this tectonically active area (Figure 2).

On the seabed, fault lineaments and fold axes have been identified, together with submarine depositional features and their generating processes. The deformation is dominated by the presence of the Sorong-Yapen fault zone. Modern earthquake activity revealed by public domain data on focal mechanisms (Ekstrom, 2006) highlights remarkable consistency among earthquake mechanisms and some of the morpho-structural features mapped on the seafloor.

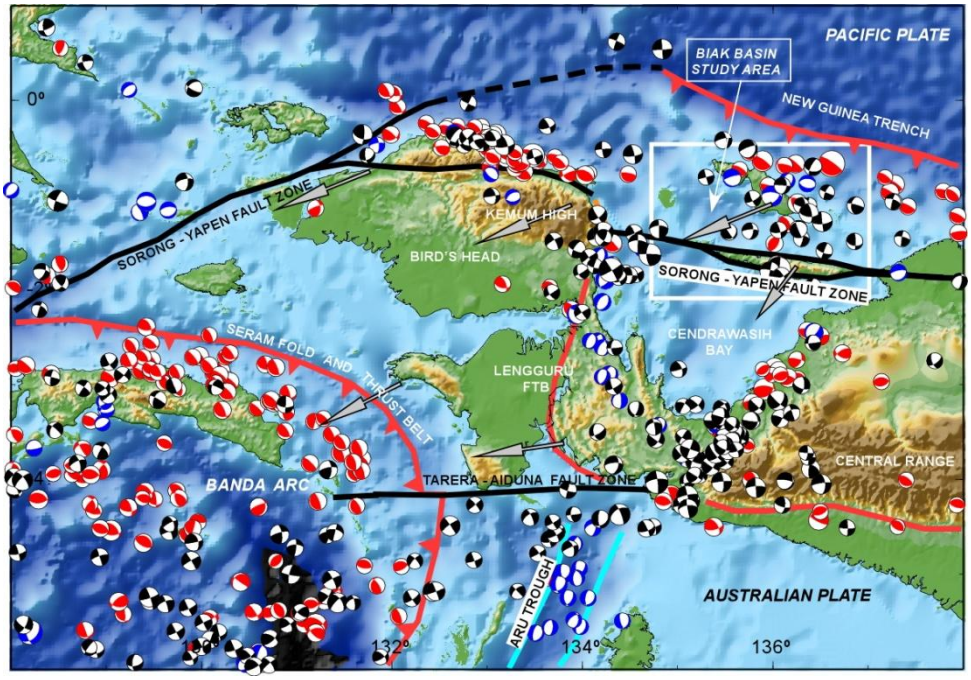


Figure 1. Tectonic setting and structural elements of the West Papua area. Seabed and digital elevation model are from Gebco database (http://www.gebco.net/). Public domain data on earthquake focal mechanisms show recent seismic activity (from Ekstrom, 2006 http://www.globalcmt.org/). Color keys: black represents strike-slip, red and blue represent compressional and extensional mechanisms, respectively. The main fault zones are color-coded in the same way as the earthquakes focals. Grey arrows represent GPS motions relative to Australia (from Stevens *et. al.*, 2002).

Earthquake activity seems to be focused in the N and E flanks of the basin, where a series of fault scarps and associated deposits are observed. In other areas, where no earthquake activity has been registered (especially to the W and SW), deformation could be accommodated by plastic processes (e.g. seabed creeping). This allows us to draw conclusions on the general tectonic setting of the area, and eventually lead to a better understanding of the evolution of the Biak basin.

Submarine Depositional processes

The Biak basin is a semi-enclosed basin covering an area of *ca.* 4000 sq km in its central part, with water depth reaching over 1100m (Figure 2). The basin is connected to the Yapen Strait through a narrow corridor to the south-east and to the Pacific Ocean to the west, through a broader seaway, between the Biak and the Numfor Islands (Figure 1). The basin appears relatively sediment-starved with dominant deep water clastic deposition; carbonates develop on its margins and volcanic deposits are also locally observed and they outcrop on the nearby islands. The basin margin slopes are variable and range from few degrees in the W and SW, to relatively steep (5 to 15 degrees) on the NE and

E slopes. Sediment accumulation patterns in the basin vary and are normally associated with the different slope angles. The main deposits and processes observed are:

- Well-defined mounded bodies with lobular shape in plan view, either in isolated or coalescent configuration, located at abrupt decrease in gradient from the high angle slopes to the basin (Figures 3 and 4). The mounded bodies are interpreted as clastic lobes originated by re-sedimentation processes. Clastic lobes (Figure 3) are constructional depositional bodies developed downstream of points where laterally confined flows from the feeder channels expand (e.g. Stow *et al.*, 1999). The shape and direction of the lobes suggest that they are fed from the north, where they are bounded by a series of semi-circular NW-SE scarps (Figure 3). The scarps represent major erosional features in the basin. Erosional activity is also documented by incisional episodes on top of the lobes and large blocks deposited in their most marginal parts (blue dashed lines in Figure 3).

  Figure 4 shows a belt of multiple adjacent lobes, forming a linear, slope-parallel apron, 20km long and between 3km (lateral) to 8 km (central) wide from scarp to base of slope. The described slope apron is directly associated with a series of parallel linear features observed on the seabed. These morphostructures are interpreted as terraced fault scarps and represent the likely linear source for the apron. The overlapping and coalescing series of lobes composing the apron suggest different phases of fault scarp activity that seems to be concentrated in the central part of the apron.

- An aerially extensive circular crater-like structure (Figure 4) rimmed by an arcuate, crescent-moon shape feature, open to the N and bounded at the flank by small scale circular scarps. The maximum relief observed at the centre of this crater is *ca.* 300m, and diameter reaches nearly 10km. The typically concave-upwards subcircular shape and associated curved scarps resembles that of collapse structures (e.g. Stewart, 1999). Analogous arcuate-shaped escarpments interpreted as repeated slope failure episodes at the edge of a carbonate platform have been described by Ten Brink *et al.* (2006) offshore Puerto Rico. Possibly, this structure is associated with subcropping carbonate units and differential compaction of overlying deep-water sediments. Additionally, we observed a series of straight slope gullies, V-shaped in section, on the slope to the west of the circular collapse structure.

- A subtle wavy surface morphology is evident on the N-NW slope of the basin and is associated with low slope angles (Figure 2). This morphology is a typical expression of seabed sediment creep, i.e. a process of slow strain due to the downslope weight of sediment (Reading, 1999). Although creep might be a precursor to creep rupture and slope failure, normally it suggests the predominance of plastic deformation.

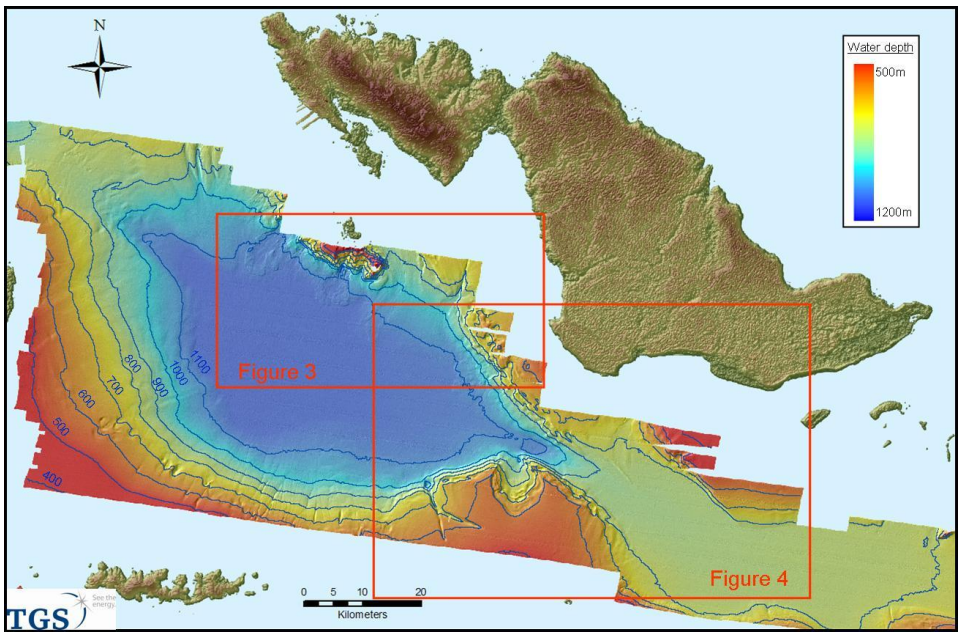


Figure 2. Gridded multibeam data showing details of seabed morphology in the Biak Basin (data from TGS). Contour interval is 100m. Digital elevation model is from Aster Global Digital Elevation Model (GDEM) (http://www.gdem.aster.ersdac.or.jp/)

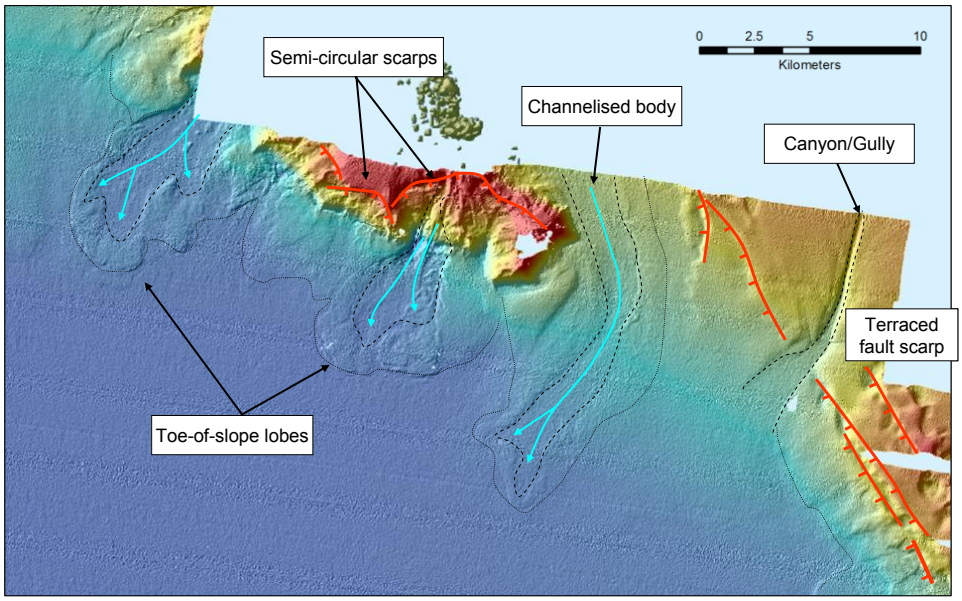


Figure 3. Details of morphostructural interpretation of seabed in the northern part of Biak Basin (See Figure 2 for location). Note the presence of clastic lobes adjacent to semi-circular scarps, and toe-of-slope deposits developed at the end of a channelised

Tectonic Setting

West Papua represents an area where at least 3 major tectonic plates converge, with smaller terranes acting as buffers along the edges of the main plates (Figure 1).
The Biak Basin is located within the northern edge of the collision zone between the Australian and Pacific plates, in an area which can be interpreted as a crustal sliver bounded by the New Guinea Trench to the north and the Sorong-Yapen fault zone to the south. The crustal configuration of this area is the result of the collision and accretion of terranes of complex origin (volcanic arcs, rotated forearc terranes, submarine plateaus, etc.) that were dragged by a south facing subduction zone and collided against the Australian margin during Tertiary (Hill and Hall, 2003). This subduction seems to have ceased and relative plate motion is now oblique, as revealed by dominant strike-slip earthquake activity at Yapen Island along the left-lateral Sorong-Yapen Fault Zone (Figure 1).

To the west of the Biak Basin, in the Bird's Head area, present day seismicity together with GPS data suggest that this region is moving at the same pace as the Caroline Plate, at a rate of 7.5–8.0 cm/yr in the direction of 252° relative to northern Australia (Stevens *et al.*, 2002; Decker *et al.*, 2009). Considering these kinematic indicators, the Bird's Head area is interpreted to be a product of escape tectonics resulting from the oblique collision between the Australian plate and the remnants of volcanic belts and accreted terranes carried by the Pacific Plate (Pubellier and Ego, 2002). The escape movement is accommodated by two broad left lateral strike-slip fault zones, the Sorong-Yapen Fault Zone to the North, and the Tarera-Aiduna Fault Zone to the South (Figure 1).

Based on the above tectonic framework and interpretation of high resolution multibeam bathymetry, earthquake focal mechanisms and GPS data (Figure 5), we interpret the Biak Basin to be a transtensional pull-apart basin which developed in an oblique direction to the left-lateral Sorong-Yapen Fault Zone (Figure 6).

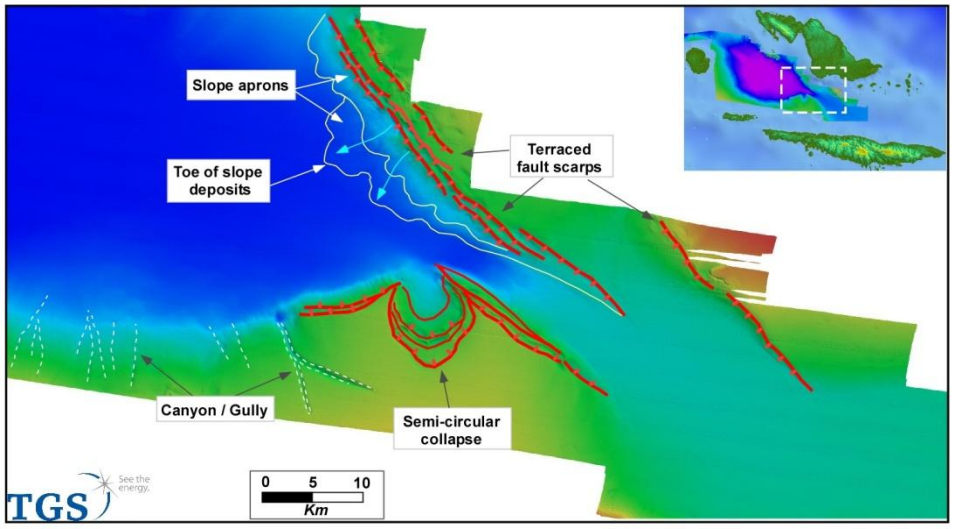


Figure 4. Details of morphostructural interpretation of seabed in the eastern part of Biak Basin (see Figure 2 for location). Note the multi-episode slope aprons adjacent to terraced fault scarps.

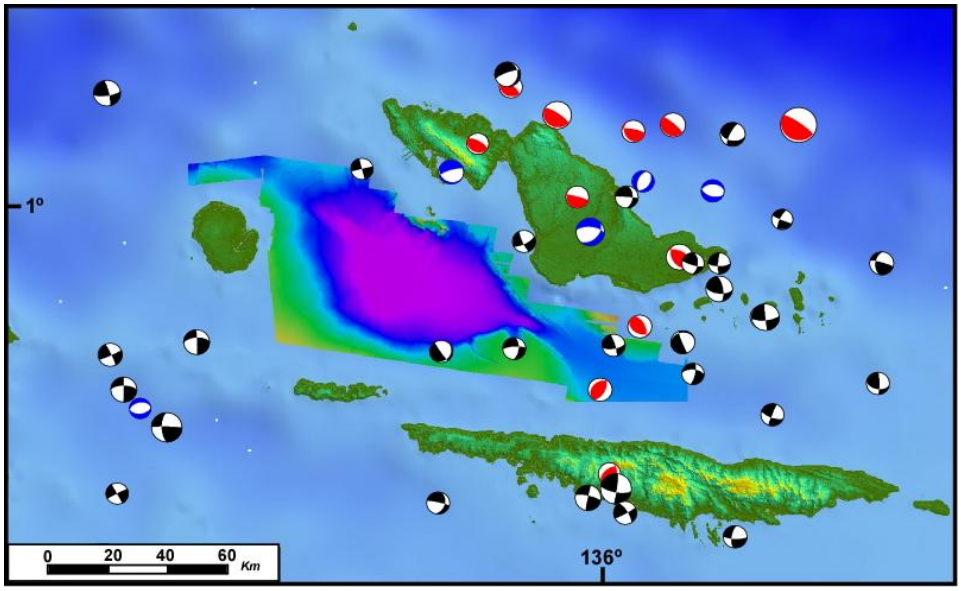


Figure 5. Details of modern earthquake activity in the Biak Basin and surrounding areas, as shown by focal mechanism data (for key to symbols, see Figure 1). Bathymetry data s from TGS gridded multibeam merged with that of Gebco database. High resolution topography is from Aster GDEM database.

The map view of the Biak Basin shows a sigmoidal to rhomboidal geometry oriented in NW-SE direction (Figure 5). Basin boundaries are analogous with terraced oblique-slip extensional sidewall fault systems, connecting laterally offset principal displacement zones (PDZ) of the main strike-slip faults. The basin floor is very flat and tends to be asymmetric where the sidewall faults join the PDZ. The sidewall faults show changes in kinematics from dominantly dip-slip extension in their central sections to oblique slip and strike slip at either end where they connect with the PDZ. Another characteristic feature for interpreting Biak Basin as a pull apart basin lies on the typical narrow ends of the basin, developing in-line horst and graben structures which broaden outward into the basin.

The overall geometry of the basin and its bounding structures seem to be compatible with a right-lateral strike-slip displacement (Figure 7; Dooley and McClay, 1997). Although left-lateral deformation is dominant in the Sorong-Yapen, right-lateral offsets have already been described in the Randaway Fault System (Charlton, 2010), which in fact, seems to be the southward continuation of the southeastern end of the Biak basin (Figure 6).

Analysis of computed focal mechanisms of earthquakes (Dziewonski *et al.*, 1981) shows that some of the sidewall fault systems bounding the Biak Basin are active at present day and are consistent with a strike-slip motion (Figures 6 and 7). This implies therefore that the submarine depositional processes previously described could be controlled by recent strike slip tectonics.

The earthquake data also point out that contractional deformation to the north of the Biak Island is partitioned into strike-slip deformation to the south, towards the Sorong-Yapen Fault system. In addition to the dominant strike-slip and contractional earthquake solutions, we also observed a few normal extensional earthquakes in the vicinity of Biak Island. This fact may be due to stress perturbations caused by pre-existing structures. As the crustal configuration of the area is composed of several fragments, fault block rotations and local extension may exist because changes of slip rates between different crustal blocks. These changes in slip rates could then explain the fact of having right-lateral structures coexisting with a dominantly left-lateral strain.

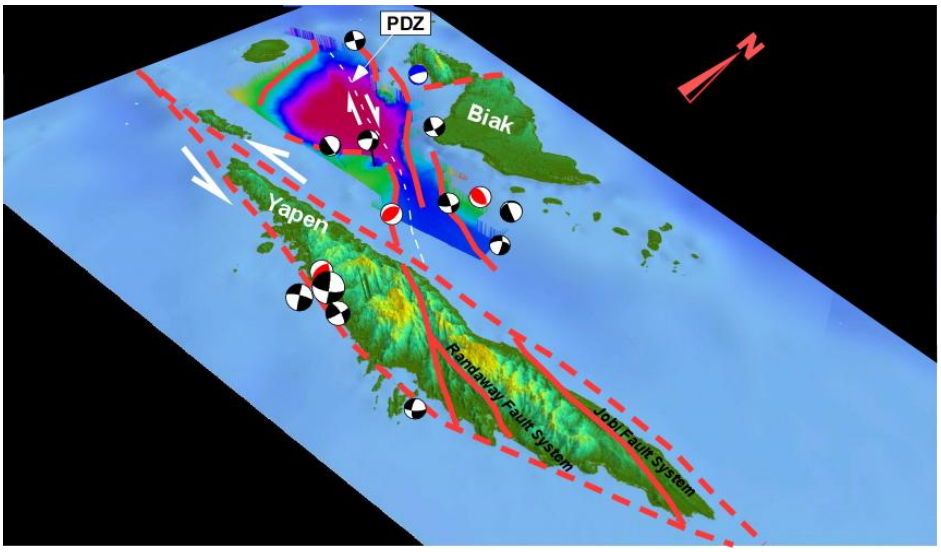


Figure 6. 3 D view of the integration of earthquake focal mechanisms with structural interpretation on the Biak Basin and surrounding areas. PDZ = Principal Displacement Zone (for key to symbols, see Figure 1)

Basin are significantly controlled by seismic activity in the region.

The interplay between recent seismic activity and deformation, erosional and depositional patterns of the Biak Basin is illustrated by the analysis of the circular shaped crater-like collapse located in the southern edge of the basin (Figure 4). This collapse is near a strike-slip focal mechanism solution and it allows us to speculate that the feature is controlled by recent fault activity. A second clear example of this interplay is how the fault scarps associated with base-of-slope depositional lobes are consistent in orientation and location with nearby strike-slip earthquake focal mechanisms (Figures 4 and 6).

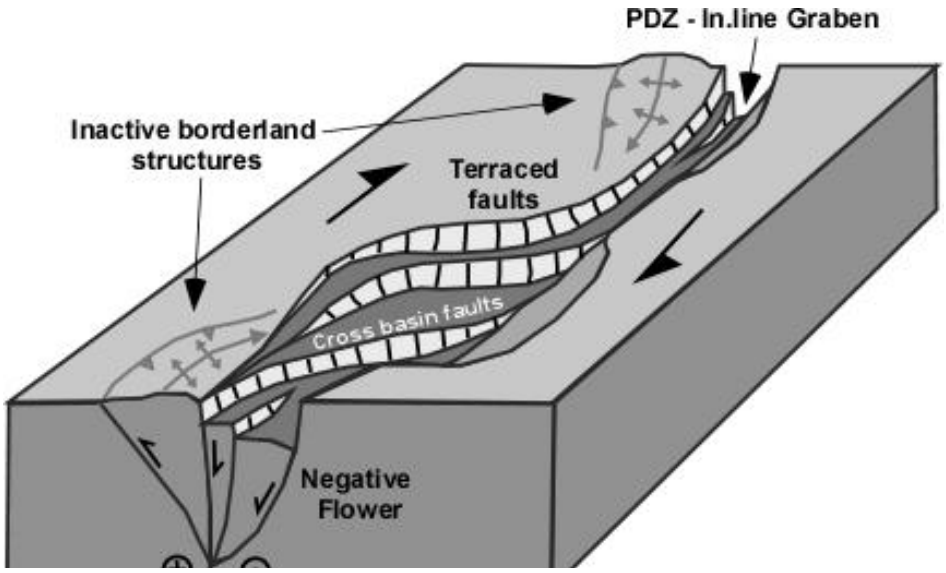


Figure 7. Conceptual right-lateral pull apart basin (after Dooley and McClay, 1997).

Summary and Conclusions

The observations made to date on the seabed depositional and tectonic processes suggest that current basinal depositional processes in the Biak

Based on these indications, we infer that the seabed can be divided in two main zones, based on recent tectonic activity: seismic and aseismic zones. Seismic zones, where focal mechanisms are recorded, show steeper slope flanks and fault scarps with associated depositional lobes. Apron development is seen along one linear fault scarp. The composite character of the associated clastic lobes might indicate repeated scarp activities. It is well known that instability and re-sedimentation processes are favoured by high slope angles and repeated cyclical stress. We consider that this is more likely to be caused by the documented seismic activity, rather than high sediment supply, in this relatively starved basin. Conversely, the aseismic zones correspond to areas of absence of earthquake activity, and are located to the W and SW of the basin. These areas are associated with sediment creep, typical of slow-strain and plastic deformation, and the slopes are prone to erosion by gullies.

As a general conclusion, the uplift and bending recorded in the E part of the basin, and the scarps in the NE flank, are compatible with the basinal strike-slip tectonic setting proposed for the Biak Basin. The results presented here can therefore be used to support a basin evolution model and provide new insights on the regional tectonics of this highly complicated area.

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References

Charlton, T. R., 2010. The Pliocene-Recent anticlockwise rotation of the Bird's Head, the opening of the Aru Trough – Cenderawasih Bay sphenochasm and the closure of the Banda double arc. Proceedings of the Indonesian Petroleum Association 34, p. 203-210.

Decker, J., Bergman, S.C., Teas, P.A., Baillie, P. and Orange, D.L., 2009. Constraints on the tectonic evolution of the Bird's Head, West Papua, Indonesia. Proceedings of the Indonesian Petroleum Association, 33th Annual Convention, p. 491-514.

Dooley, T. and McClay, K.R., 1997. Analog modeling of pull-apart basins. AAPG Bulletin 81, 1804–1826

Dziewonski, A. M., Chou, T. A., and Woodhouse, L.H., 1981. Determination of earthquakes source parameters from waveform data for studies of global and regional seismicity. Journal of Geophysics Research, 86, p. 2825 – 2852.

Ekstrom, G., 2006. Global CMT. Accessed online at http://www.globalcmt.org

Hill, K.C. and Hall, R., 2003. Mesozoic–Cenozoic evolution of Australia's New Guinea margin in a West Pacific context. Geological Society of Australia, Special Publication 22 andGeological Society of America Special Paper, 372, p. 265–289.

Pubellier, M. and Ego, F., 2002. Anatomy of an escape tectonic zone, Western Irian Jaya (Indonesia). Tectonics, 21, 4, p. 1-16.

Reading, H.G. (Ed.), 1999, Sedimentary environments: processes, facies and stratigraphy. Blackwell Science, Oxford,

Stow, D.A.V., Reading, H.G. and Collinson, J.D., 1999. Deep seas. *In*: Reading, H.G. (Ed.), Sedimentary environments: processes, facies and stratigraphy. Blackwell Science, Oxford, p. 395-453.

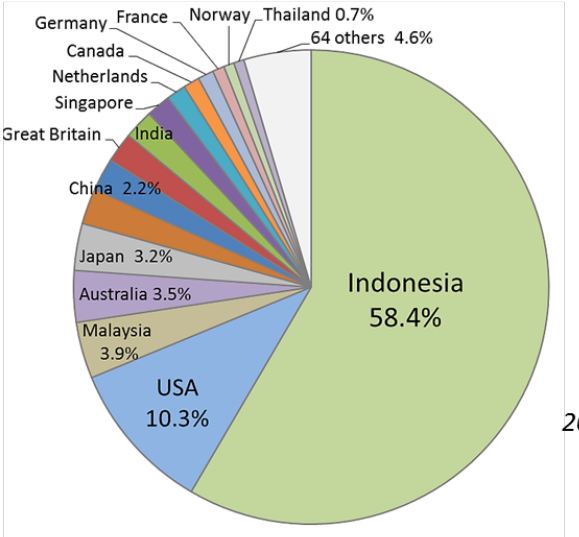
Stevens, C.W., Mc Caffrey, R., Bock, Y., Genrich, J.F., Pubellier, M. and Subaraya, C., 2002. Evidence for block rotations and basal shear in the world's fastest slipping continental shear zone in NW New Guinea. *In*: Stein, S. and Freymeuller, J.T. (eds.), Plate Boundary Zones. American Geophysical Union, Geodynamics Series, 20, p. 87–99.

Stewart, S.A. 1999. Seismic interpretation of circular geological structures. Petroleum Geoscience, 5, 273–285.

Ten Brink, U.S., Geist, E.L., Lynett, P., and Andrews, B., 2006. Submarine slides north of Puerto Rico and their tsunami potential. *In*: Mercado, A. and Liu, P. (eds.). Caribbean Tsunami Hazard. World Scientific Publishers, Singapore, p. 67-90.



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