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The Brunei fold-and-thrust belt: Tectonically- or Gravity-driven?

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The present-day activity of the NW Borneo Margin is a matter of debate. Traditionally, this margin is considered as inactive mainly because of the absence of seismicity. However, recent GPS studies (Socquet, 2003; Simons et al., 2007) show a relative motion between the NW Borneo coastline and fixed Sunda Plate in the order of 6mm/yr, attributed to a convergence located in the NW Borneo Trench (fig. 1).

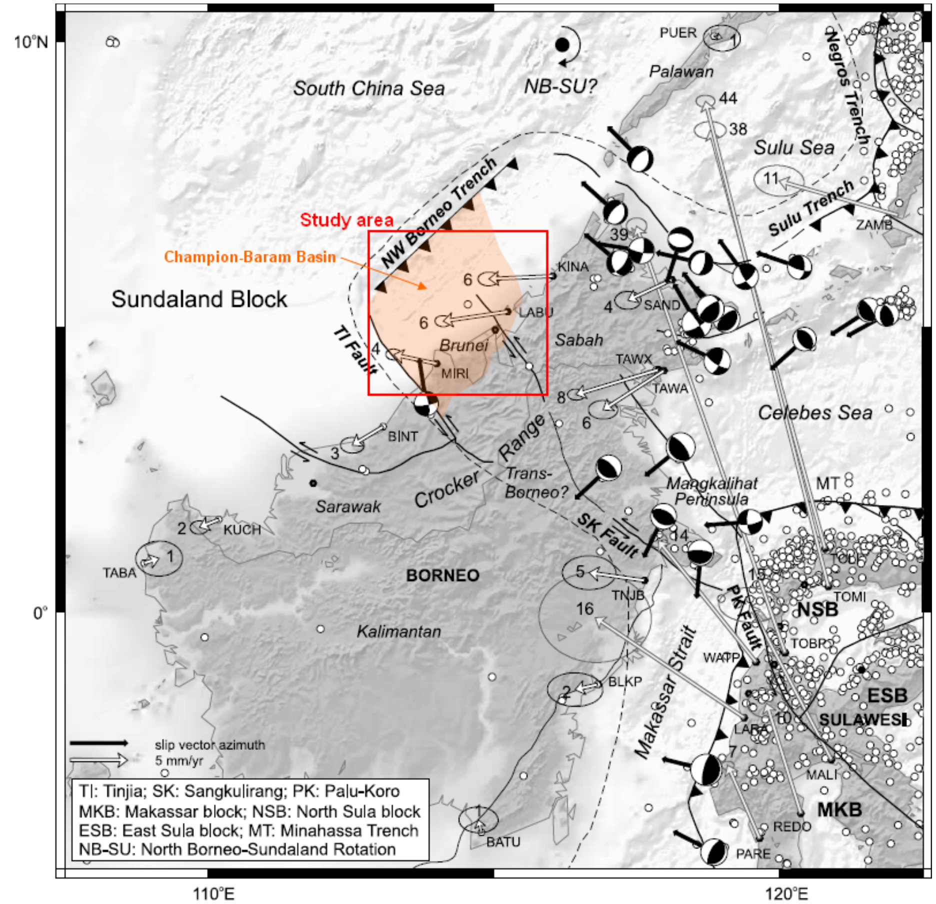

Fig. 1 Borneo Island geodynamic settings and Champion-Baram Basin location (modified from Simons et al., 2007).

Velocities in Borneo are with respect to Sundaland. The dashed line illustrates the boundaries of the undeformed Sundaland block. Faults on Borneo are based on Moss and Wilson (1998), Hall and Nichols (2002), and satellite images are accessible through Google TM Earth. The historical seismicity (1973–2006) and the available moment tensor solutions (each included with preferred slip vector azimuth and slip direction toward Sundaland) (USGS, 2004) support the absence of active deformation in the NW Borneo Trench. A small clockwise rotation of North Borneo can be deduced from the velocities (with the possible location of the NB-SU rotation pole west of Palawan Island (Simons et at., 2007) or east of Sumatra Island (Socquet, 2003)).

The Present-day frontal fold-and-thrust belt of NW Borneo is related to a long history of convergence between the Borneo Island and the Sunda Plate, leading to the complete closure of the Proto-South China Sea (Holloway, 1982; Taylor and Hayes, 1983; Rangin et al., 1999). The convergence seemed to begin in the Paleocene, and developed mainly in deep-water environment (shales, flysch and turbidites), until the Lower Miocene when some deltaic provinces began to develop (Mazlan, 1999; Mazlan et al., 1999) in the Brunei area.

The prolific hydrocarbon province of the Champion and Baram deltas of the northwestern coast of Borneo Island, mainly located in Brunei Darussalam and adjacent parts of Sabah and Sarawak is hosted in Middle Miocene to recent deltaic sedimentary rocks. It shares many structural similarities with what is encountered in large deltas controlled by gravity tectonics (growth faults, shale diapirs, toe thrusts, e.g. James, 1984; Sandal, 1996). However, because the Champion-Baram deltaic province is located at the front of an accretionary wedge (fig. 1), some of its structures have been inverted and/or modified by the growth of compression- or strike-slip-related folds and thrusts (Bol and van Hoorn, 1980; James, 1984; Levell, 1987; Bait and Banda, 1994; Sandal, 1996; Morley et al., 1998). Most large deltaic provinces described in the literature are developed on passive margins (e.g. Mississippi, Nile, Niger deltas).

The Brunei Margin, where the Champion and Baram Deltas (respectively known in Malaysia as the East and West Baram Deltas) lie, results from the joint evolution of gravity and compression tectonics (Morley et al., 2003, 2008). Out of these processes, gravity-driven tectonic is expressed by very particular structural features, the Counter-Regional Normal Faults (CRNF). These listric normal faults have kilometric offsets and dip landward, whereas the commonly observed normal faults of a gravity-driven basin dip seaward.

Indeed, compression on the Brunei Margin is evidenced by inversion of CRNF (e.g. Ampa, Seria Faults) and seaward normal faults (e.g. Menchanai, Miri Faults) and uplifts onshore, until the Late Pliocene.
At least since the Late Pliocene, reconstructions of cross-sections of the Brunei Margin on the bases of the Upper Champion and Baram Units show a negligible global shortening (< 1%), arguing that the frontal compression in the Outer Thrust Zone is balanced by the extension in the shelf area. The coexistence of active convergence and gravity tectonics during a certain bracket of time on the Brunei Margin results from a very particular structural and geodynamic history (Morley et al., 2003, 2008; fig. 2).

By the end of the Middle Miocene (1) the first CRNF (Seria Fault) initiated above the FTB. The convergence jumped toward the back of the NW Borneo Wedge (Belait Anticline, etc.). (2) We observed the initiation of a second CRNF (Ampa Fault) as the deltaic system prograded. The shortening remained restricted landward, inverting the earlier Seria CRNF. (3) The delta-front continued to move rapidly and a third CRNF (Fairley Fault) developed. The Ampa CRNF was in turn inverted. (4) The delta-front reached an area devoid of any early fold and large seaward normal faults developed. The lithospheric convergence is not active anymore and typical gravity-driven basin development is observed.

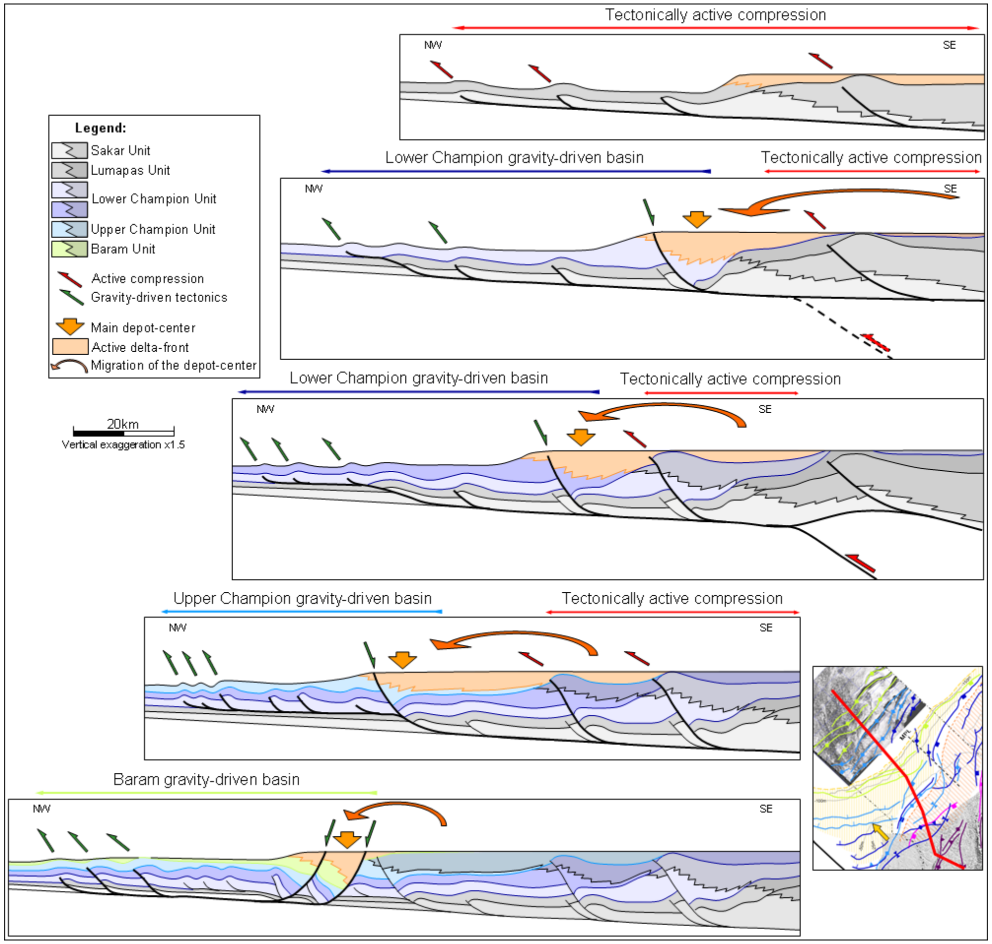

Fig. 2 Schematic tectono-stratigraphic evolution of the Brunei Margin: Interactions between gravity and compressive tectonics.

The Brunei margin is an active margin on which a large deltaic province developed. Schematically, the Champion deltaic province prograded over an active FTB. This led to the formation of a gravity-driven basin controlled by large CRNF (Seria, Ampa and Fairley Faults) initiated on the top of the early folds of the FTB, and migrating seaward, parallel to the delta-front progradation. The tectonic compression is still active but restricted in the backing the landward part of the wedge and inverted some of the CRNF (Seria and Ampa anticlines). In the last stages of the evolution, convergence is no longer active. The Baram gravity-driven basin is controlled by large seaward normal faults, as there are no more early folds to initiate CRNF.

Basically, the Brunei deepwater fold-and-thrust belt, active since the Middle Miocene, is mainly gravity-driven, at least since the Late Miocene, the lithospheric convergence being accommodated in the Brunei onshore area. However, the earliest folds (Middle Miocene) of the FTB may be tectonically driven by this convergence between the NW Borneo and the Sundaland.

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