Introduction and Methodology

The structural mapping of major faults and folds in offshore stretches of NW Borneo has revealed a wealth of information about the structural development and kinematics of faulting in the region (Tan et al., 1999; Shuib, 2003; Morley et al., 2003; Kessler, 2009; Wannier et al., 2011; De Rosa et al., 2018). However, such data are limited on the onshore portions, and therefore this study shows new structural mapping in Miri at the Miri Hill, Malaysia, which houses the oldest drilling site for petroleum exploration in the region. The prominent topographic expression of Miri Hill was previously interpreted as a simple anticlinal ridge and later workers showed that faulting plays a key role in the formation of this structural high in an otherwise flat region (Sandal, 1996; Hutchison, 2005). The mapping of regional strike-slip fault system in Borneo and the active tectonic structures in NW Borneo have led to major disagreements on the formation and evolution of geological structures in Borneo.

Miri Hill structure has been interpreted as a part of the West Baram Delta that contains ~10 km thick deltaic sequences of Middle Miocene to Recent (Tan et al., 1999; Shuib, 2003; Kessler, 2009; Wannier et al., 2011; De Rosa et al., 2018). The sediments are dominantly composed of inter-bededded sequence of thicker coastal - fluviomarine sands and marine shale intervals. The presence of organic rich shale and clear sandstone reservoirs have contributed in exploration of the producing reservoirs at the Miri oil field (Tan et al., 1999). The antiformal structure is the most prominent landform in the region (Fig. 1), and it was mapped as a NE-SW trending asymmetrical anticline by the initial works of Anglo Saxon Petroleum Company (Hutchison, 2005). Later works have shown (Kessler, 2009; Wannier et al., 2011) that the anticlinal structural is bounded by a number of faults, and both extension and compression have contributed to the overall structural configuration of the region (Suish, 2003; Wannier et al., 2011). However, it is still largely unknown as to what really controls the formation of the Miri Hill structure, and why it has both extensional and compressional faults although the total extent of the exposed structure is less 10 km on plan view.

Herein we shown by using satellite data and detailed geological fieldwork (Figs. 1 and 2) that Late Miocene gravity-driven extensional structures (e.g. Shell Hill fault) and the ~NW-SE Pliocene compression (Miri Hill) have developed during sinistral strike-slip faulting, and therefore tectonics and not gravity is the driver of deformation in the NW Borneo. Gravity plays a role but it is not the driver. The mapping was done by recording structural parameters (e.g. dip, dip-direction of bedding and faults) and transposing the information on the satellite image to accurately map the Miri Hill structure. The detailed field notes, outcrop shots and traversing details are available, and some are shown here (Figs. 1 and 2).

Geological Settings of Miri Hill Structure

The abrupt topographic high of Miri Hill structure has invited many earlier investigators to understand the cause of the formation of the structure and in particular the petroleum geology of the region (Haile, 1962; Levell, 1987; Sandal, 1996). It hosts a number of textbook quality geological exposures that largely expose shallow marine and deltaic sequences of interbedded sandstone and shale lithologies, and that has attracted a new wave of researchers (Kessler, 2009; Wannier et al., 2011; De Rosa et al., 2018). The rocks range in age from Miocene to Recent, and the Miri Formation (Middle to Upper Miocene) can be subdivided into Lower and Upper Miri (Hutchison, 2005). The upper Miri Formation consists of arenaceous deposits with irregular alternation of sandstone and shale while the lower Miri Formation consists of argillaceous deposits (Jia and Rahman, 2009). Therefore, the depositional environment ranges from littoral non-marine to inner neritic shallow marine environment (Hutchison, 2005).

Results and Discussion

Miri Hill structure is part of the Northwest Borneo, and traditionally the deformation in the region is largely attributed to the young gravity-driven forces that have produced a sequence of normal growth
The Shutter Radar Topographic Mission (SRTM) image shows the regional topographic expression of landforms where Lambir Hill (blue triangular region on left) and Miri Hill (rectangular area) structures are clearly visible. B) The detailed structural data obtained in the field are mapped on the Miri Hill structure. C) Evidence of westward dipping thrust fault that has displaced a number of sedimentary beds with a dextral sense that range from >2 m to < 0.3 m. D) Steeply NW dipping normal fault with ~50 cm of net downdip displacement.

faults, which are mostly rooted on the mobile shale strata, that has also produced a sequence of toe thrusts (Morley et al., 2003). At Miri the Late Miocene gravity driven extension is attributed to a set of listric normal faults, and the Shell Hill fault, with an offset of 750 m (Hutchinson, 2005), is the major structure that has accommodated the regional extension (Fig. 2A). A series of ~ENE-WSW trending normal faults have been interpreted as antithetic normal faults (Hutchinson, 2005) that do not extend beyond the Shell Hill fault (Fig. 2A). These normal faults are interpreted to represent the crustal extension in the region, which was followed by ~NW-SE directed Pliocene compression that possibly formed the Miri anticline (Tan et al., 1999; Morley et al., 2003; Hutchinson, 2005; Wannier et al., 2011).
Figure 2 The geology map and tectonic model Miri Hill structure, NW Borneo are shown. A) Field data were incorporated into the existing geology map of Miri Hill structure (after Wannier et al., 2011). B) The 3D structural model of Miri Hill structure made by incorporating field data on the STRM image. C) NE-SW cross section profile showing the structural details of the Miri Hill structure (Van der Zee and Urai, 2005).

However, our fieldwork (Figs. 1 and 2) has shown that Miri Hill structure is not a typical anticlinal structure where both the limbs are observable and could be mapped for the entire extent of the structure. And instead, we found that the SW portion of the structure has a steeply dipping (>60°) SE limb and a gently dipping (~16°) NW limb. These limbs do not show continuity of the structure and at the NE portion of the Miri Hill structure the dip direction of the bedding dramatically changes from being ~SE to ~NE and the amount of the dip also changes from (>60°) to just ~05-13°. Similar changes are observed on the ~NW extent of the structure. Therefore, our structural mapping has shown that Miri Hill structure is not a typical anticlinal structure, and instead we propose that it was formed by the major regional sinistral strike-slip fault system (Shah et al., 2018), and the Miri Hill is located at the releasing bend geometry of the fault (Fig. 2A and 2B). We therefore propose that the structural orientation of normal and reverse faults measured and observed at Miri have formed simultaneously (Fig. 2A and 2B). This means that the previous interpretation of regional extension and compression as two separate events is not compatible with our work, and we propose that the regional oblique compression have produced both the extensional and compressional structures simultaneously. A sequence of inferred major thrust faults (e.g. Inner and outer Kawang thrust; Fig.
2A) were not observed in the field, and therefore the structural geology of these faults remains an unknown.

Conclusions

The detailed structural mapping shows above has revealed new insights into the formation and deformation of the Miri Hill structure where regional left-lateral strike-slip faulting is causing the formation of extensional and compressional structures observed at Miri Hill. The mapped structural configuration of faults, fold, and bedding is consistent with a releasing bend geometry of the major sinistral strike-slip fault and could have formed together during the progressive deformation in the region. Therefore, Miri Hill structure is not a typical anticline but a fault controlled small scale structure that should not extend beyond the curvature of the strike-slip fault.

References


