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Two-dimensional geomechanical reconstruction of a deepwater fold and thrust belt: the Baram Delta System, NW Borneo

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Recent GPS measurements demonstrate 4-6 mm y^{-1} convergence across NW Borneo that is not accommodated by plate-scale structures. The only geological structure in NW Borneo, which accommodate on-going shortening is the deepwater fold-thrust belt (DWFTB) associated with the Baram Delta System.

The Baram Delta System is divided into three neotectonic provinces: 1) an inverted onshore and inner-shelf region superimposed on an older extensional deltaic province; 2) an outer-shelf to shelf-edge region of present-day active deltaic extension, and; 3) a compressional delta toe (or DWFTB) located on the slope to basin floor. The inner shelf compressional structures are the result a tectonic inversion due to far-field convergence during the Miocene-Pliocene. However, no active inversion is observed at present-day in the inverted province that can account for the continued convergence suggested by GPS measurements across the margin. Fold and thrust structures in the delta toe are therefore the only compressional structures that might accommodate the shortening from ongoing convergence.

Delta toe fold-thrust belts are commonly thought to be caused by margin-normal compressional stresses generated by margin-parallel upslope gravitational extension. They are considered to be balance systems, where the amount of extension in the delta top directly corresponds to the amount of shortening observed in the DWFTB. Sections of the present-day active Baram Delta System (the extension and compression provinces) have been restored to determine whether the delta toe accommodates far-field convergence (i.e. the amount of extension in the delta top is less than the amount of shortening in the delta toe).

We used a geomechanical program based on the Finite Element Method and conservation of mass and momentum, Dynel 2D, to elucidate the balance between shortening related to the upslope gravitational extension and shortening related to the regional geodynamic frame in the Baram Delta and DWFTB. Computer-based numerical techniques are commonly derived from traditional kinematic approaches. These have led to our improved understanding of the evolution and structure of fold-thrust belts and their associated hydrocarbon systems. However, these tools do not respect the fundamental principles of mass and momentum conservation, and do not allow mechanical interactions between faults. Modelling deformation in delta and DWFTBs remains challenging because the formation of compressional structures in the delta toe, are simultaneous with the formation of extensional structures (margin parallel), on the delta top.

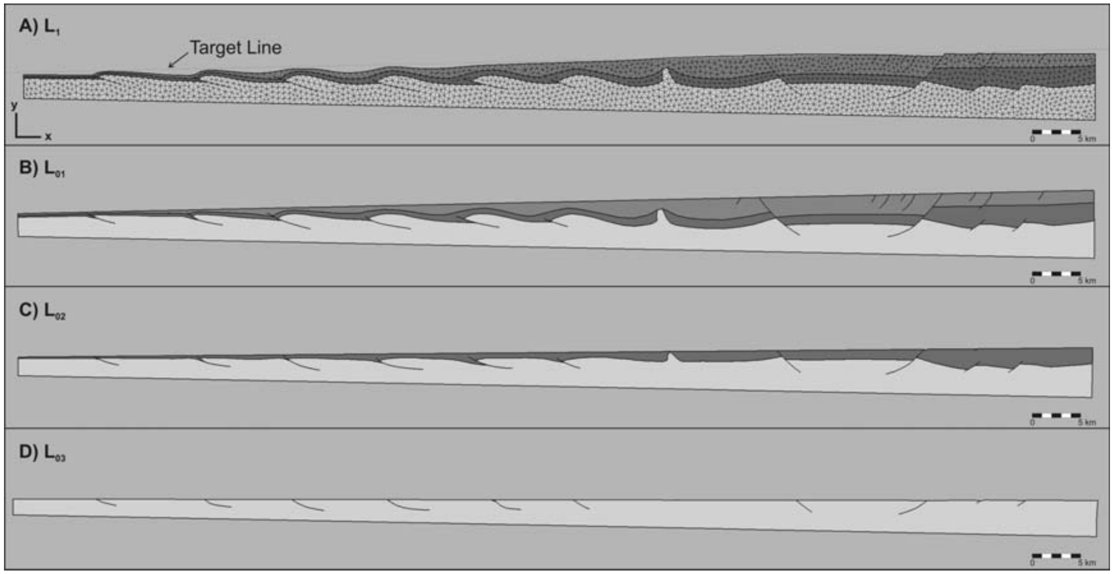

Figure 1: Steps in the backstripping of the Baram delta and DWFTB. A) Initial geometry; B) Section after restoration of the Pliocene; C) Section after restoration of the Late Miocene; C) Section after restoration of the Middle Miocene Setap shale. The model shows an excess of 2.2km of compression in the delta toe, not balanced by extension in the delta top.

We have reconstructed, step by step, the tectonic evolution of the present-day active Baram Delta System in NW Borneo (Figure 1). To do so, we first created a geological cross-section of the Baram Delta System using published geological cross-sections and seismic lines. Sediment packages were assigned petrophysical parameters, which were derived from sonic and density logs (where available). This 2D model demonstrates ~5% additional shortening in the compressional delta toe than would be expected for the amount of extension observed in the delta top (Figure 1). These results suggest that the series of imbricate thrust sheets and associated folds in the delta toe accommodate the far-field compression, in addition to gravity-driven deltaic compression.

In order to test the validity of our results, we evaluated the models sensitivity to the two main uncertainties in the input parameters: 1) the pre-deformed thickness of the pro-delta shale, which forms the main décollement level for the deepwater fold-thrust belt, and; 2) the elastic parameters for each rock package. We first conducted a series of restorations varying only the elastic parameters of the different sediment packages. This first set of models show that the excess shortening is not significantly affected by variations in elastic properties, as the difference in shortening estimates varies only from 0.01% to 0.7% across the total length of the section. We then conducted a second set of back-stripping experiments, varying the pre-deformed thickness of the pro-delta shale. Our models demonstrate that the amount of excess shortening recorded in the Baram Delta System is strongly influenced by the thickness of shale forming the décollement. For example, the shortening estimates vary from 1% to nearly 4% with decreasing thickness of shale. However, these models did highlight that a minimal thickness (~1500m) of shale is necessary to accommodate the deformation that is observed in the Baram Delta System, thus limiting the uncertainties associated with the lack of constraints on the estimated thickness of shale.

Additional shortening was observed in every test carried out. This suggests that this model of the Baram Delta System is accurate, and confirms that the deepwater fold-thrust belt does accommodate far-field convergence in addition to shortening coupled to the extension province.