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Analysis of deformation features using integrated field methods and aerial drone imaging on the Bach Long Vy island, Gulf of Tonkin, Vietnam

Hoang Bui[1,2], Michael Fyhn[3], Tuan Nguyen[1], Toan Do[1], Jussi Hovikoski[3], and Long Hoang[1]

[1]Vietnam Petroleum Institute, Petroleum Geology, Ha Noi, Viet Nam (hoangbh.epc@vpi.pvn.vn)
[2]Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Voldgade 10, DK-1350, Copenhagen K, Denmark
[3]Geological Survey of Denmark and Greenland, GEUS, Øster Voldgade 10, 1350-Copenhagen K, Denmark

Situated in the junction between the Song Hong Basin and the Beibuwan Basin, the Bach Long Vy island exposes Paleogene syn-rift rocks not seen elsewhere in the Gulf of Tonkin. The island underwent a complex geological history related to the Cenozoic SE-ward tectonic escape of Indochina, recorded as deformation features along the outstanding, continuous coastal exposure. To analyze these deformation features in detail and relate them to the regional events, we acquired a high-resolution Unmanned Aerial Vehicle (UAV) dataset covering about 635,000m^2 of the 3.5 km long coastal outcrop. In addition, 656 strike and dip measurements were made and 390 photos were taken using smart phone apps, thus on-the-ground data were rapidly acquired and georeferenced. Strike and dip measurements from smart phone apps were periodically checked against traditional Brunton compasses for their reliability. The ground photos were correlated with the UAV image during interpretation. QGIS allows both datasets to be overlain on one another for detailed analysis and interpretation.

We interpreted 2236 deformation features from the dataset, which can be divided into three major types: sand injectites, NW-SE faults, and NE-SW faults. Sand injectites can be divided into three main types: linear dikes, irregular dikes, and massive remobilized sands. Linear dikes trend dominantly N80-100E.

NW-SE faults are closely spaced and have high dip with N110-130E trend. They consistently left-laterally offset sand dikes while most of the time left-laterally offset the gently dipping beds. Apparent right-lateral separation of beddings probably resulted from variation of the slip vector from horizontal pure strike-slip. Occasionally, sand dikes fill in these NW-SE faults. The offsets are small, mostly less than 1 m.

NE-SW faults are larger scale than the NW-SE faults, and are associated with drag folding of the strata. No fault surface kinematic indicators were found, probably due to wave erosion. The drag folds are consistently right-lateral, while the bedding separation can be either left-lateral or right lateral. Left-lateral separation is inferred to indicate a second phase of movement along the same

fault. Sand dikes cross-cut the drag folds, thus sand dikes formed after the drag folds and the right-lateral motion on NE-SW faults.

The orientations of these deformation features are consistent with the regional stress field associated with the End-Oligocene inversion, which affected the northern Song Hong Basin and the western Beibuwan Basin due to transpression along the junction between the two basins. The inversion caused regional tilting and NE-SW right-lateral faulting, followed by the main phase of sand injection, and finally the left-lateral NW-SE faults that offset sand dikes. Previously the inversion event was characterized at large scale using industrial seismic and well data. This study provides further evidence of the inversion at the outcrop scale, well below the resolution of the seismic data.