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Systematic assessment of fault stability in the Northern Niger Delta Basin, Nigeria: Implication for hydrocarbon prospects and increased seismicities

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ABSTRACT

Accurate information on fault networks, the full stress tensor, and pore fluid pressures are required for quantifying the stability of structure-bound hydrocarbon prospects, carbon dioxide sequestration, and drilling prolific and safe wells, particularly fluid injections wells. Such information also provides essential data for a proper understanding of superinduced seismicities associated with areas of intensive hydrocarbon exploration and solid minerals mining activities. Pressure and stress data constrained from wells and seismic data in the Northern Niger Delta Basin (NNDB), Nigeria, have been analysed in the framework of fault stability indices by varying the maximum horizontal stress direction from 0° to 90°, evaluated at depths of 2 km, 3.5 km and 4 km. We have used fault dips and azimuths interpreted from high resolution 3D seismic data to calculate the predisposition of faults to failures in three faulting regimes (normal, pseudo-strike-slip and pseudo-thrust). The weighty decrease in the fault stability at 3.5 km depth from 1.2 MPa to 0.55 MPa demonstrates a reduction of the fault strength by high magnitude overpressures. Pore fluid pressures >50 MPa have tendencies to increase the risk of faults to failure in the study area. Statistical analysis of stability indices (SI) indicates faults dipping 50°–60°, 80°–90°, and azimuths ranging 100°–110° are most favourably oriented for failure to take place, and thus likely to favour migrations of fluids given appropriate pressure and stress conditions in the dominant normal faulting regime of the NNDB. A few of the locally assessed stability of faults show varying results across faulting regimes. However, the near similarities of some model-based results in the faulting regimes explain the stability of subsurface structures are greatly influenced by the maximum horizontal stress (SH_{max}) direction and magnitude of pore fluid pressures.

1. Introduction

It will be a great mistake to understate the seriousness of a complete understanding of the fault strength as one of the key determinants of the structural stability in well casing designs, engineering constructions, hydrocarbon and mineral explorations, and predetermining the occurrence of destructive and extensive seismicity of high magnitude scales. We carried out this study in the onshore NNDB, Nigeria (Fig. 1). A map view of wells located in the area is shown in Fig. 2(A). An enlarged view of the portion studied in detail (area AZ1) is presented in Fig. 2(B). Although virtually all the wells have good depth penetrations in most of the locations, but a greater number of them were missing complete log data (density, resistivity and sonic). By implication, detailed study was carried out in 13 wells that have good quality well data, and covered by high resolution (48-fold stack) 3D seismic data. The dominant normal faults interpreted from the seismic data have been modelled using appropriate pore fluid pressures (P_p) and stresses (ratio) constrained from the study area, and also from worldwide basins to simulate pseudo-strike-slip and pseudo-thrust faulting regimes. These approaches have allowed an in-depth assessment of the stability of faults in the three faulting regimes.

Oceanic and continental tectonics are capable of causing temporal changes in both the stress field and faulting regime. For instance, Ziegler (1992) linked a possible change in the stress field of Africa to the conceivable northward movement of the African continent, and ultimate collision with the Europe in the Late Cretaceous.

In this study, we determined the appropriate geomechanical conditions (pore fluid pressure, fault connection, and stress magnitude and direction) that are likely to cause faults to be unstable, and which contemporaneously may favour the migration of structure-bound fluid. This approach is hinged on the apparent determination of the optimum SH_{max} direction that may sustain stable structures in the subsurface. The estimated fault SI shows which part of the fault plane is more likely to slip (reactivate and break a seal), dilate (open and allow fluid to pass along the fault plane or cracks) or be unstable (failure). In this work,

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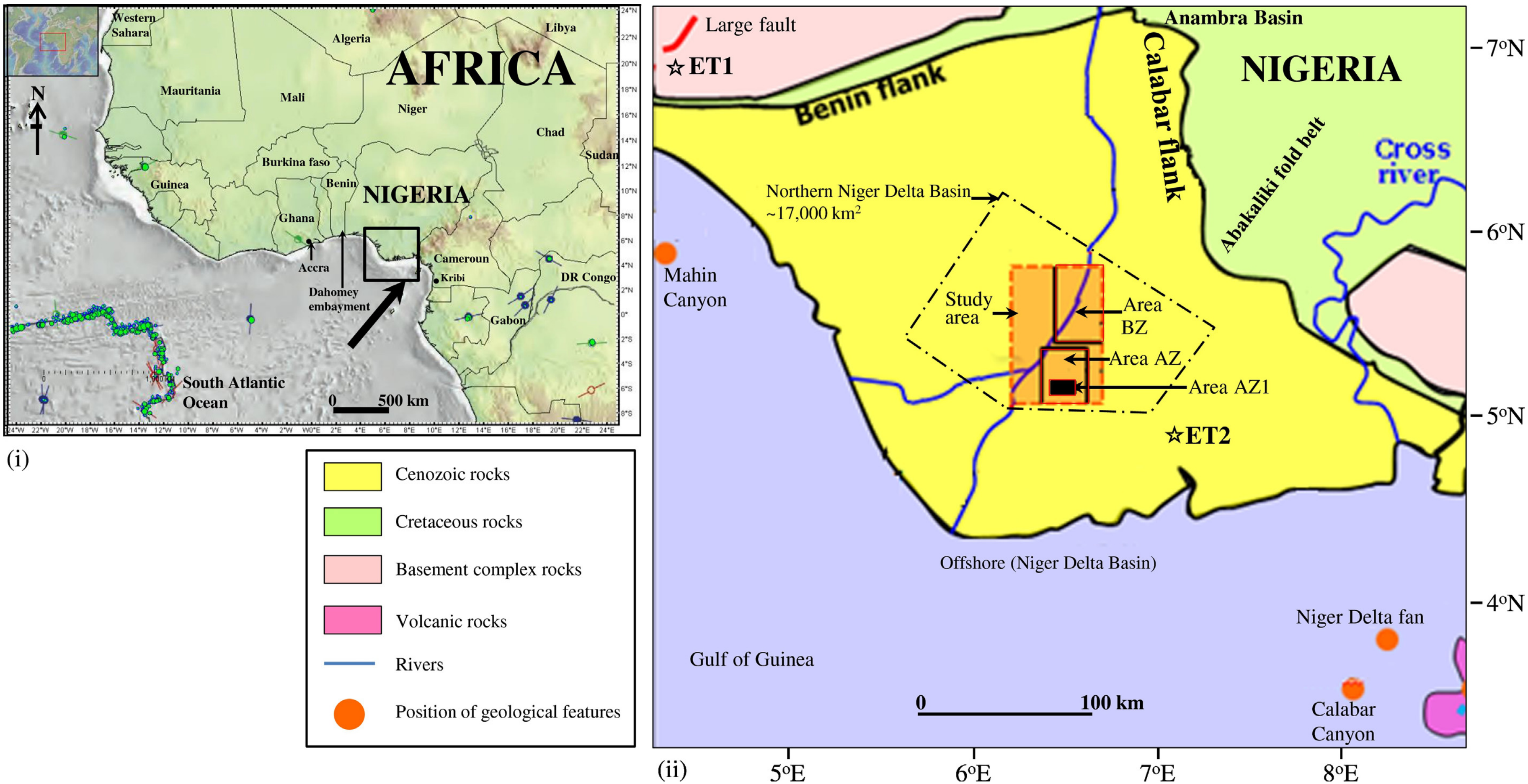

Fig. 1. (i) The position of the Niger Delta Basin, Nigeria is shown in the box (in thick arrow). The stress directions (in green and blue lines) are from Heidbach et al. (2008). Topographic and bathymetric data in the background are taken from GeoMapApp (2014). (ii) The zoom in of the box shown in (i). The pentagon (black long dash dot line) approximates the area referred to as the NNDB. The position of the study area is verged in dash line. Other major sedimentary basins (Whiteman, 1982) are coloured light green and yellow on the map. Geological features in filled orange circles are from GeoMapApp (2014). The 5-Points stars (ET1 and ET2) represent approximate locations of the increased earth tremors referenced in Subsection 5.4. The legend for this map is shown on the bottom left. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)