Tectono-stratigraphic evolution constraints derived from integration of 2D structural restoration and sandbox analogue modelling: case-histories in extensional, transcurrent and compressional settings

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By combining 2D structural restoration of an appropriate number of differently oriented geological cross-sections and a series of 3D sandbox analogue models, the structural evolution of three case-histories, namely, in extensional, transcurrent and compressional settings, have investigated with particular emphasis on exploration issues. 2D structural restoration was conducted on selected regional transects and was used to support the 3D analogue modelling. This combined approach and integrated workflow aimed at resolving, at both regional- and local-scale, the structural details and timing of observed deformation.

Extensional setting case-history: West Africa rifted continental margins

The integrated workflow was used to investigate the pre-salt tectono-stratigraphic evolution of the Central segment of the South Atlantic Ocean with emphasis on the West Africa rifted continental margins, characterized by the presence of a large evaporitic basin, developed during Aptian time. Seafloor spreading in this segment of South Atlantic occurred at the Aptian-Albian boundary 112-116 Ma, corresponding to the last salt deposition. Recent studies and sub-salt seismic images show that in spite of the volcanic activity occurring during the breakup phase, the low amount of magmatic products observed together with the absence of seaward dipping reflections (SDRs) and the presence of an intermediate/transitional crust between the continental and the oceanic crust, all suggest a "magma-poor" margin. The extensional sandbox analogue models were performed at full lithospheric setup-scale, including the entire pre-salt sedimentary succession (pre-rift, syn-rift, and late syn-rift/sag sequences), and a series of different rheological layering (strength-depth functions) with their inferred initial thicknesses representing upper crust, lower crust and upper mantle. In order to reproduce a realistic geodynamic evolution, various stretching factors were tested. The study elucidates the structural elements and features reflecting the syn-rift basin evolution and the processes that governed the pre-breakup extension of the continental crust. In addition, the study refines and constrains the structural architecture and nature of the continent-ocean transitional domain.

Transcurrent (transpressional/transtensional) setting case-history: northern Nile Delta area

A series of sandbox analogue models was used to investigate the pre-Messinian structural, kinematic and tectono-stratigraphic evolution of the Nile Delta area. The study area is bounded to the south by the E-W trending Nile Delta Hinge Zone, to the east by the NW-SE Bardawil (Temsah) fault system and to the west by the NE-SW Rosetta fault (Qattara-Eratosthenes). Several parameters were evaluated and elucidated in the course of the conducted sandbox models: among others, passive versus active deformation, effects of décollement/detachment levels, quantification of the interaction between well-constrained vectors of relative motion and deformation at the Hinge Zone and along the boundary fault systems/lineaments. The integrated study has successfully

reconstructed and refined a coherent kinematics evolution of the Nile Delta area, from Late Mesozoic to pre-salt Messinian times, by taking into account the different regional structural lineaments; provided insights on the interaction between deformation and sedimentation, outlining the tectono-stratigraphic evolution of the area; and finally, resolved specific details, in time and space, of the structures in the vicinity of the three main regional structural lineaments/features. Close combination of structural restoration and sandbox analogue modelling in the Nile Delta area was able to provide valuable support in decreasing the exploratory risk.

Compressional setting case-history: upper Assam valley, NE India

The integrated approach has been also applied to investigate the geological and structural evolution of a region located in the upper Assam valley, NE India. The Assam Basin represents the foreland of both the Himalayan and Burma convergent boundaries, with their advancing foredeeps and thrust–fold belts. The SE part of the Assam valley is bounded by the thrust-and-fold Assam-Arakan Belt, in which mainly Tertiary sedimentary successions are involved, overlaying a Pre-Cambrian metamorphic basement. The latter is characterised by extensional faults inherited during the pre-Tertiary rifting stages, and overprinted by the compression in the Neogene. The study focused on the structural evolution of the Naga Thrust, the youngest structure located in the frontal part of the Assam-Arakan Belt. The Naga detachment consists of coals and mudstones deposited during the late Eocene-Oligocene Barail Formation which represents the source rock of one of the two petroleum systems that characterises this region. Through the analogue modelling we investigated the geometry and the rheological behaviour of the detachment level related to the Naga Thrust development. Modelling has also addressed the possible interaction between the deeper extensional structures and the nucleation of the Naga Thrust, and the effects of syn-tectonic sedimentation in the foreland. Also in this case, the integrated use of 2D restoration and analogue modelling allowed to better constrain the geological model for the area: defining the relative chronology of the main tectonic structures (Naga and previous thrusts) and the geometry and role of the source rock as detachment level during the deformation, allowing some considerations and hypotheses about both timing of hydrocarbon maturity and hydrocarbon charge migration routes.