Introduction

The geological knowledge of South Sudan is quite fragmented. Prior to intense hydrocarbon exploration activities, it was thought that sedimentary rocks in the area were deposited in an extended series of shallow cratonic depressions containing no more than a kilometre of deposits with limited possibility of discoveries. Initially, the major efforts focused over larger Sudan basins like the Muglad and Melut, while smaller sub-basins, like the Tali-Post, remained essentially excluded from exploration activities for years (Figure 1). Following exploration in the second half of 1980s, the new observations indicated that up to 13 km of Cretaceous-Tertiary sediments had accumulated locally in the deepest parts of these rift basins (McHargue et al., 1992).

Figure 1 South Sudan Basins. Left: Study area location. Center: sketched map of Muglad and Tali-Post Basin contextualized within the South Sudan geology. Right: generalized stratigraphy chart of Muglad Basin.

The discovery of two large hydrocarbon accumulations, the Unity and Heglig fields, with combined recoverable reserves of 250-300 million barrels of oil, fuelled interest in the secondary basins (Schull, 1988). Several smaller fields were then discovered as subsidiary plays of major ones, with others intrinsically denoting high potential. A succession of early syn-rift organic-lacustrine shale and mudstone is the dominant hydrocarbon source, which accumulated in fluvial and lacustrine-margin sandstones over time. The Tali-Post Basin is likely to be one of those continental basins.

This study objective is to improve the understanding of the area within South Sudan Block B3 from a regional to a basin scale, from crustal and lithospheric structures to near-surface ones, aiding future exploration activities in this under-explored area.

We accomplished this by integrating proprietary potential field data, public-domain data, and literature information within a coherent and geologically sound regional structural framework. For this, we designed a tailored workflow, encompassing lineament delineation, basement relief computation, and iterative 2.5D and 3D gravity and magnetic data modelling. Finally, the results of the potential field analysis and modeling were reconciled to produce a consistent description of the area’s structural framework and geological history.
Workflow and results

The long-lasting tectonic evolution and the sparse previous exploration campaigns led to numerous unanswered questions about geodynamical evolution, basement relief, and stratigraphy of the Tali-Post Basin. Presumably, this sub-basin experienced similar tectonic and stratigraphic history as the near and larger oil-proven Muglad Basin. At the time of the study, maximum basin depth, depocenters, stratigraphy, geometries, and formation thicknesses were essentially unknown.

To help de-risk future explorations, a tailored workflow encompassing a structural lineament interpretation and a property modelling phase was designed to progressively address the basin from a regional to a local scale.

The first part of the study consisted of mapping possible faulted trends and identifying the strike direction of prevailing geologic features through major lineaments delineation. The second phase led to estimating a basement relief, using a data-driven approach; finally, an iterative 2.5D/3D modelling phase allowed us to revise the deep regional traits and to successively refine the sedimentary package model, with potential identification of sub-basins and high-density areas of interest.

To contextualize the potential field data within the South-Sudan geological framework, the data were merged with public-domain information. The delineation of the tectonic lineaments was performed on the complete Bouguer anomaly (CBA) and the total magnetic intensity anomaly (TMIA) maps, previously filtered and enhanced. Given the wide data coverage, very useful information at the continental scale, was retrieved in terms of predominant regional geodynamical directions: NW-SE, ENE-WSW, and NNW-SSW, consistent with previous authors and known literature (Fairhead, 1988). At a more local scale, anomaly alignment and edge analysis allowed to identify and define locations, directions, and distributions of major normal/strike slip faults being characterized by a predominant N-S direction and several second-order family trends in the background (NE-SW, E-W, NW-SE). Figure 2 summarizes the main stress trends from regional to local scale that have been inferred from the lineament interpretation analysis. These results enabled reconstructing the tectonics and geodynamical evolution of Central Africa Rift System from Barremian to Late Santonian ages.

![Figure 2](image-url)

**Figure 2** Relationship between known regional events and trends identified on filtered gravity maps for the study area. In the top row, reconstruction of the tectonics and geodynamical evolution of Central Africa Rift System from Barremian to Late Santonian ages as proposed by Fairhead (2009). In the bottom pane, regional to basin-scale stress direction reassembled by stress trends resulting from lineament interpretation analysis of gravity data. Left: First vertical derivative of CBA 2.67 g/cm³; Centre: Total horizontal gradient of CBA 2.67 g/cm³; Right: Total horizontal gradient applied on Butterworth high-pass at 35 km of CBA 2.67 g/cm³.
After having properly constrained the main geometries with lineament analysis, the initial 3D geometry of the basement relief was derived through layered gravity inversion (Oldenburg, 1974) of the complete Bouguer anomaly at 2.67 g/cm³. As the survey was located at low latitude, gravity data were preferred to magnetics data to avoid intrinsic problems and numerical instability of both reduction to pole and reduction to equator transformations. Because neither seismic data nor well logs were available within the study area, maximization of the use of public-domain data was crucial to retrieve similarities with adjacent basins.

Information from all previous phases were exploited in the subsequent 2.5D gravity forward modeling stage, aiming to produce reliable geological models properly honoring the acquired gravity data. The final solution was achieved by perturbing the initial bodies geometry and density values towards a better fit of the observed data. However, to take into account the 3D nature of the structures, the 2.5D forward modelling was validated using a 3D approach. For this reason, the regional horizons derived from the 2.5D modelling were upscaled into a 3D grid, and a 3D model was consequently populated with corresponding density values. The 3D gravity forward and its residual analysis with respect to the observed data were then used to assess the regional layers.

After completing the regional deep structure revision, which provided a reasonable data fit of the long wavelengths, the modelling phase evolved towards local-scale assessment and basin characterization. The stratigraphic column for the Tali-Post Basin was reconstructed, leveraging information from the proximal Muglad Basin in terms of stratigraphy, formations, and paleogeography. The following formations were introduced for the modelling: Zeraf-Adok Fm., Tendi-Aradeiba Fm., Bentiu Fm., and Abu-Gabra Fm.

Finally, tectonic lineaments interpreted in the early phases, together with density lateral variations from the modeling stage and literature information, were successfully reconciled in a comprehensive structural framework (Figure 3).

![Figure 3](image-url)
Conclusions

The regional tectonic framework of the Tali-Post Basin, located in the southern part of the Block B3 in South Sudan, has been successfully enforced through integrating potential field data with public-domain and literature information.

The outcome of the analysis resulted to be key in assessing this under-explored geological province, completely lacking structural data and/or quantitative models. This study confirmed how the Tali-Post Basin likely experienced a tectonic and stratigraphic history similar to the nearby larger Muglad Basin; moreover, the maximum basin depth and the formation thicknesses, previously unknown, were investigated and answered.

The resulting multiscale structural framework, validated both from a geophysical and geological perspective, encompasses the full lineaments set, the fault pattern definition, the main sub-basins identification, and the reconciliation of all these items with the final 2D/3D model.

This allowed reconstructing the poly-phase geological history of the area, suggesting the occurrence of the Early Cretaceous extensional phase (Rift Phase I) within the Tali-Post Basin as well.

This represents an important find because, during this period, the Abu Gabra formation, the main source rock in the Muglad basin, developed.

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References


