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Petroleum generation and migration modeling, Rawat Central sub-basin, Sudan

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ABSTRACT

The petroleum generation, expulsion and migration histories have been studied in the Rawat Central sub-basin, in Sudan. The Upper Cretaceous Galhak formation source rock in the Central sub-basin was evaluated using the Rock Eval and Vitrinite Reflectance Data. 1D and 3D Basin and Petroleum System Modeling (BPSM) were conducted to determine the burial and thermal histories of the sub-basin, and their implications for the hydrocarbon generation and expulsion. Four wells and nine depth structure maps have been used in this study.

Rawat Central sub-basin experienced two rifting phases: The first phase commenced at the Late Cretaceous time. It was characterized by high subsidence rate and resulted in the deposition of the source rock sequences. This phase was followed by a gradual with decreasing subsidence intensity during the Paleocene-Eocene. The second rifting phase started during the Early Oligocene. Subsequently, significant erosion took place during the Late Oligocene. The thermal history reveals that, the Upper Cretaceous source rock layers in the central Rawat sub-basin primarily lie within the oil window.

The hydrocarbon generation and expulsion started at the mid Oligocene postdating the trap formation.

All the discovered hydrocarbon in the Rawat Central sub-basin were encountered in thin sandstone layers intercalated with the Upper Cretaceous Galhak Source rock. So far, most of the exploratory drilling targeted structural traps. Considerable yet-to-find oil volumes are believed to be accumulated in potential combination and stratigraphic traps and small structural closures.

EXTENDED ABSTRACT

Introduction:

The Rawat basin, 350 Kms south of Khartoum, is a northwest–southeast trending Late Cretaceous to Tertiary rift basin in Sudan (**Figure 1**). The basin lies adjacent and to the northwest of the hydrocarbon prolific Melut Basin that hosts sizeable oil fields in the Republic of South Sudan. The Rawat basin is structurally divided into five half grabens (sub-basins). This paper is focused on basin modeling of the Central sub-basin. The Sub-basin is filled with Late Cretaceous to Quaternary fluvial, lacustrine sandstones and mudstones sedimentary section. The petroleum system is proven in this basin as several structurally trapped discoveries were encountered.

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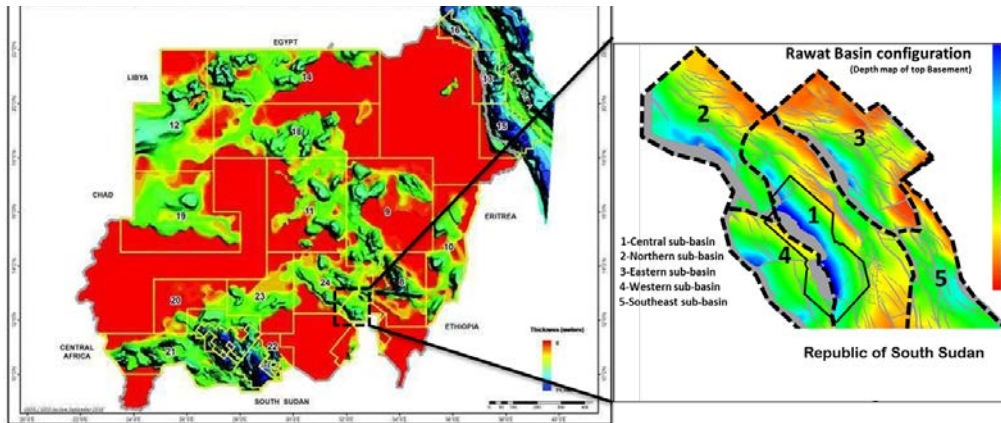


Figure 1: (Left) Sudanese Rift basins in yellow, green, and blue colors. (Right) Top Basement depth structure of the Rawat basin and the distribution of the five sub-basins.

Objectives and methodology:

The objectives of this study were to define the level of the source rock maturity and to estimate the temperature and timing of hydrocarbon generation and expulsion. To achieve these objectives, 1D and 3D basin and petroleum system models (1D and 3D) were constructed utilizing data from four wells.

Petroleum System Elements:

The main petroleum system elements in the sub-basin are summarized below and in (Figure 2).

Source Rock

The main source rock in the Central sub-basin of the Rawat lies in the Upper Cretaceous Galhak formation. It is composed of thick grey-dark mudstone layers primarily deposited in a lacustrine environment. The richer parts of the source intervals were found mainly in the middle and upper part of the formation. The source rock quality varies from excellent to good with the Total Organic Carbon (TOC) weight percent ranges between 1 to 6.

Reservoir

The main reservoirs in the Rawat Central sub-basin are of Late Cretaceous (Campanian to Maastrichtian) age interbedded within Galhak source rock. They comprise fluvio- deltaic sandstone layers and lacustrine fan deposits within the upper Galhak Lacustrine organic-rich shale. The reservoir quality is good to excellent with porosities ranging from 13-27%.

Seal

Shales of the Galhak source layer represents a competent and effective top, bottom, and lateral seals.

Traps

The main trapping styles are structural related to faults associated with the rifting phases. Recent drilling proved presence of combination structural stratigraphic traps and stratigraphic ones. Additional exploration concepts pursued are lacustrine channels, Sub-lacustrine fans, and Sub-unconformity stratigraphic traps.

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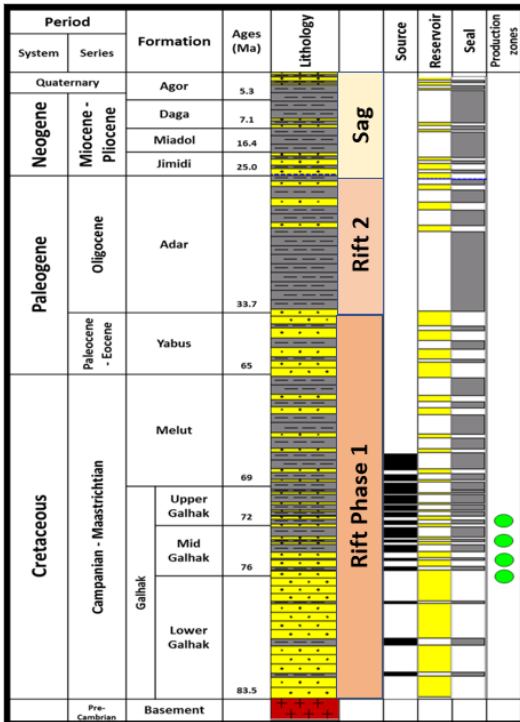


Figure (2): Rawat Stratigraphy and Petroleum Systems

Basin and petroleum system modeling results:

The burial and thermal evolution in the Rawat Central sub-basin were investigated through construction and calibration of 1D models at well locations. The basin experienced a rapid sedimentation rate during the late Cretaceous (the first rifting phase) resulting in deposition of Galhak formation, that contains the source rocks. The subsidence rate decreased gradually from the Late Maastrichtian to the late Eocene during the deposition of Melut, and Yabus formations (**Figure 2**). The second rifting phase commenced in the Early Oligocene with deposition of Adar formation. During and after this time, the eastern periphery of the Rawat Central half-graben was uplifted and eroded, resulting in a regional angular unconformity surface as seen at the top of Adar formation. The sub-basin witnessed a thermal subsidence sagging phase from the Late Oligocene to present day resulting in deposition of the Neogene clastic sequences.

The thermal history experienced in the Rawat basin matured the Late Cretaceous source rocks of the central sub-basin. Note the areas represented by the 4 wells are either in or about to enter the oil window. (**Figure 3**). The thermal maturity is consistent with the structural trends. This indicates that source rock maturation was predominantly controlled by burial.

Transformation Ratios (TR%) curves indicate that, oil generation commenced in the Rawat Central sub-basin at the Mid Oligocene. The Oligocene uplift has minimal effect on the hydrocarbon generation and expulsion, this is because the greatest uplift occurred along the sub-basin periphery while the deep kitchen areas were less affected. The timing of the oil generation and expulsion postdated the formation of structural traps. Upper Galhak source rock represents an efficient top seal extending all over the sub-basinal area. Although vertical migration through faults could be happening, most of the hydrocarbon migration pathways appeared to follow lateral route through the Upper Cretaceous sandstone carrier beds to the shallower sub-basin peripheries. Since sands of lacustrine fans dominate in the bottom of the lacustrine shales of Galhak

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formation, this provides a likely setup for potential stratigraphic traps due to encasing of sands within source shale intervals. Both the generation and expulsion of hydrocarbons in the Rawat central sub-basin almost commenced simultaneously. This is attributed to the deep and rapid burial as a result of the second rift phase. Figure 4 shows the petroleum system event chart in the Rawat Central sub-basin.

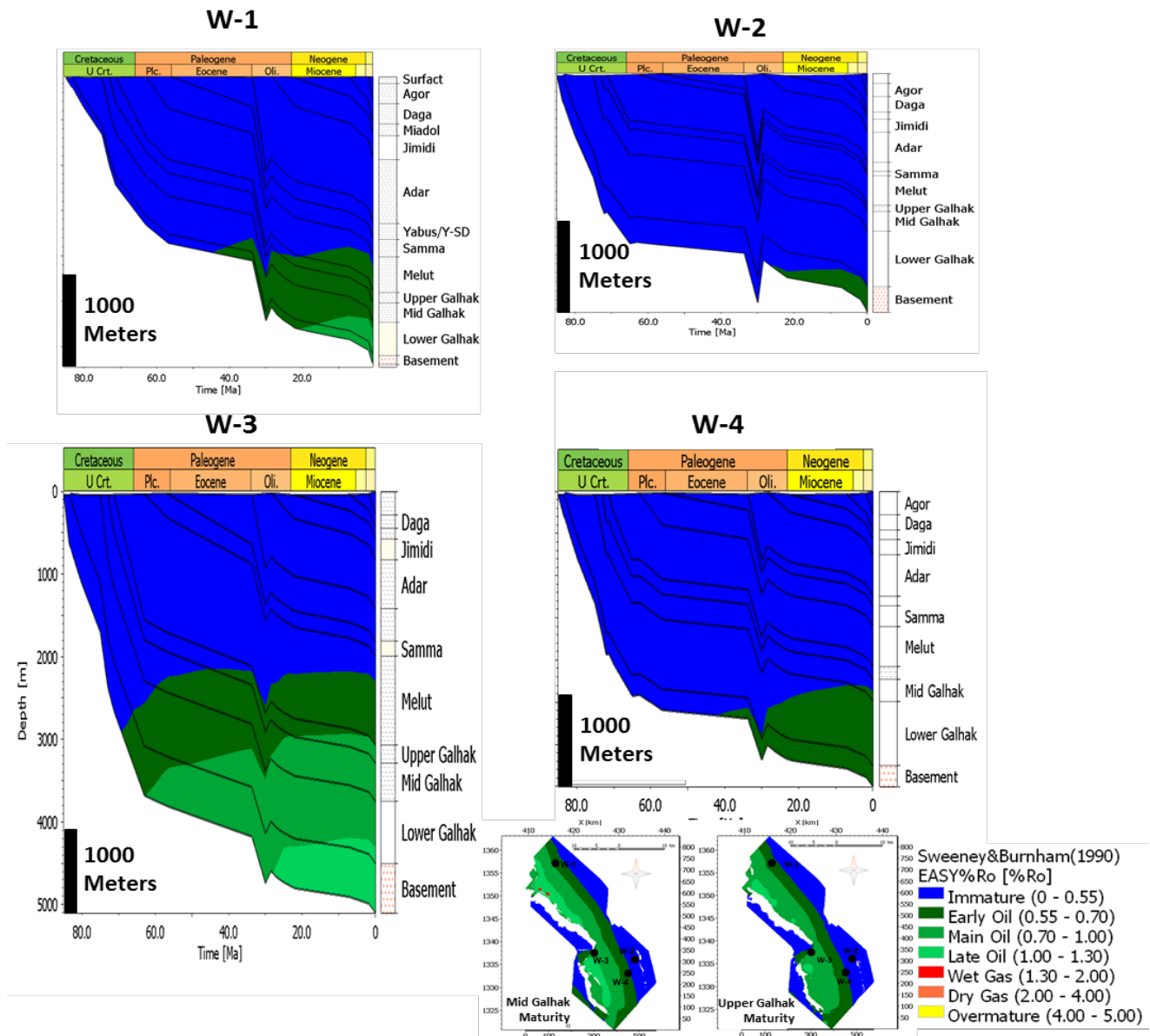


Figure 3: The Burial history plots with Maturity overlay at the four well locations. (Down) Maturity maps for Upper and Mid Galhak source rock layers.

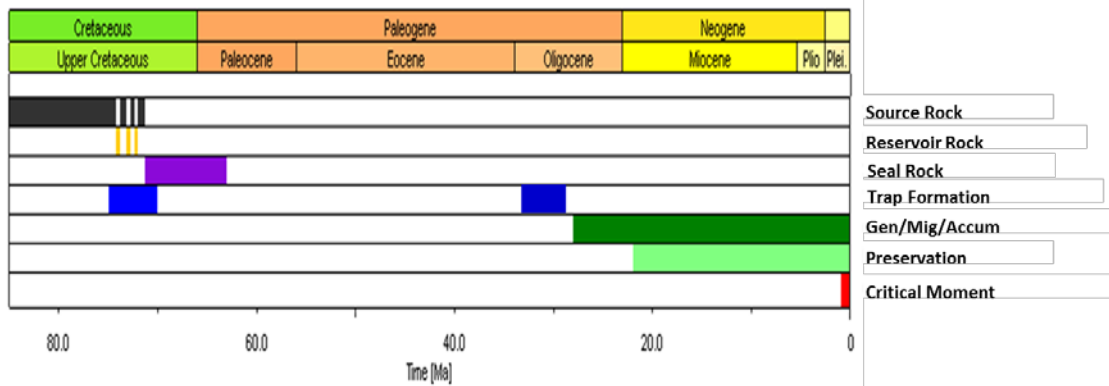


Figure 4: The Petroleum system event chart of the Rawat Central sub-basin

Conclusions:

- Two rift phases occurred in Rawat Central sub-basin, at the Late Cretaceous and Early Oligocene. (Oligocene uplift has an insignificant effect on the petroleum system processes).
- The Galhak source rocks in central sub-basin were mostly buried and entered the oil window during the Paleogene.
- Petroleum system modeling technique ideally reveals the combination between the thermal and the burial histories of the Rawat central sub-basin .
- The reservoir layers are encased within the Late Cretaceous organic-rich source rock layers.
- All the discovered hydrocarbons so far, were encountered in structural traps within the Late Cretaceous sequences. Additional potential is likely to exist in combination and stratigraphic traps.

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