

Petroleum Prospects under the Lotikipi Basin, North-Western Kenya

Rop, Bernard Kipsang

Department of Mechanical Engineering

Jomo Kenyatta University of Agriculture and Technology (JKUAT)

drropben@yahoo.com

Abstract

The assumption that sedimentary rock sequences of Mesozoic age, similar in age to the Jurassic-Cretaceous sequence of southern Sudan, where oil pools have been discovered, under the vast alluvial plains of the little known Lotikipi Basin (NW Kenya) formed the premise of the study. A new interpretation of the gravity and seismic data, preserved in the National Oil Corporation of Kenya (NOCK) records, bolster the possibility that under the thick cover of weathered volcanic rocks and alluvium lie sedimentary sequences (~1050-2100 m thick) which may be suitable for hydrocarbon exploration. Since the beginning of the Cretaceous, the Lotikipi Basin seems to have evolved consequent to a complex tectonic activity related to continental drifting and block faulting of the Anza and Central African Rift Systems.

Keywords: Lotikipi, Sedimentary, Hydrocarbon, Basement, Gravity

Introduction

Bounded between the Longitudes $34^{\circ}15'E$ and $35^{\circ}30'E$ and Latitudes $3^{\circ}30'N$ and $5^{\circ}00'N$, the Lotikipi basin is located in the north-western Kenya (Figures 1 and 2). The Lotikipi Basin seems to have evolved consequent to a complex tectonic activity related to continental drifting and block faulting of the Lamu-Anza and Central African Rift Systems. Its geology has drawn little attention because of paucity of surface exposures and a thick cover of alluvial sediments deposited by the fluvial system constituted by the Anam, Natira, Tarach and Nakalale rivers (Figures 3, 4 and 5). These rivers, flowing from south to north, drain the western Songot-Mogila Ranges, the Lomilio-Ngimorutai Hills, the basement rocks along the Kenya-Uganda escarpment and the eastern ranges forming the Lokwanamoru-Lorionetom and Murua Rith Hills. The present course of the rivers seems to have been tectonically controlled, following the N-S fault systems that parallel the main Kenya Tertiary Rift.

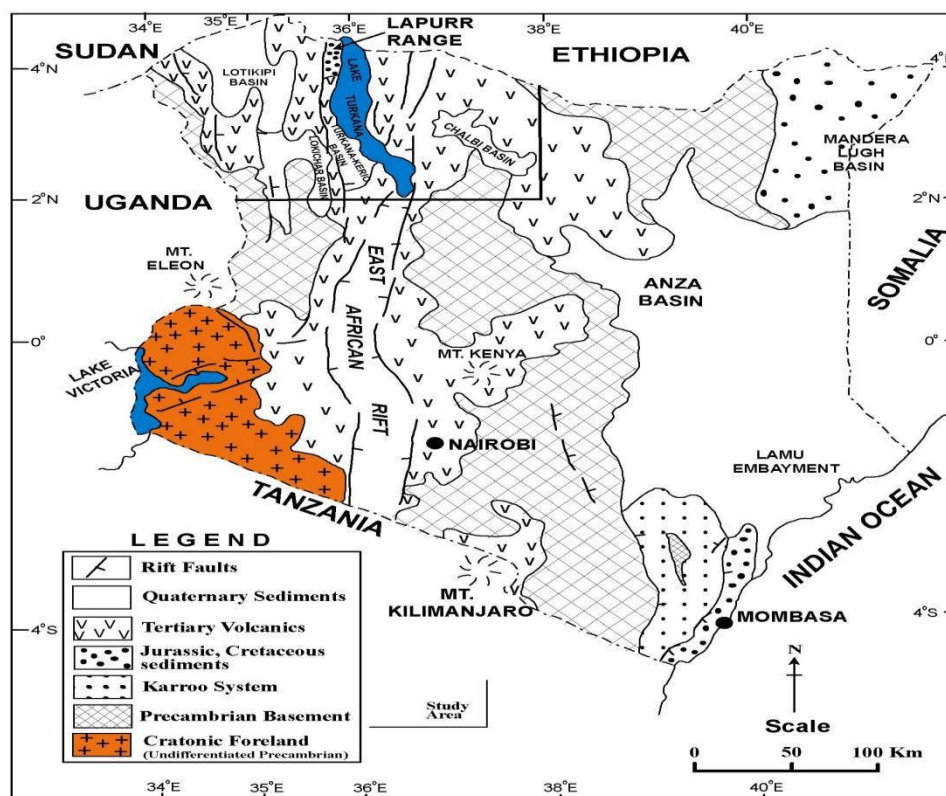


Figure 1. General geological map showing the study area in north-western Kenya

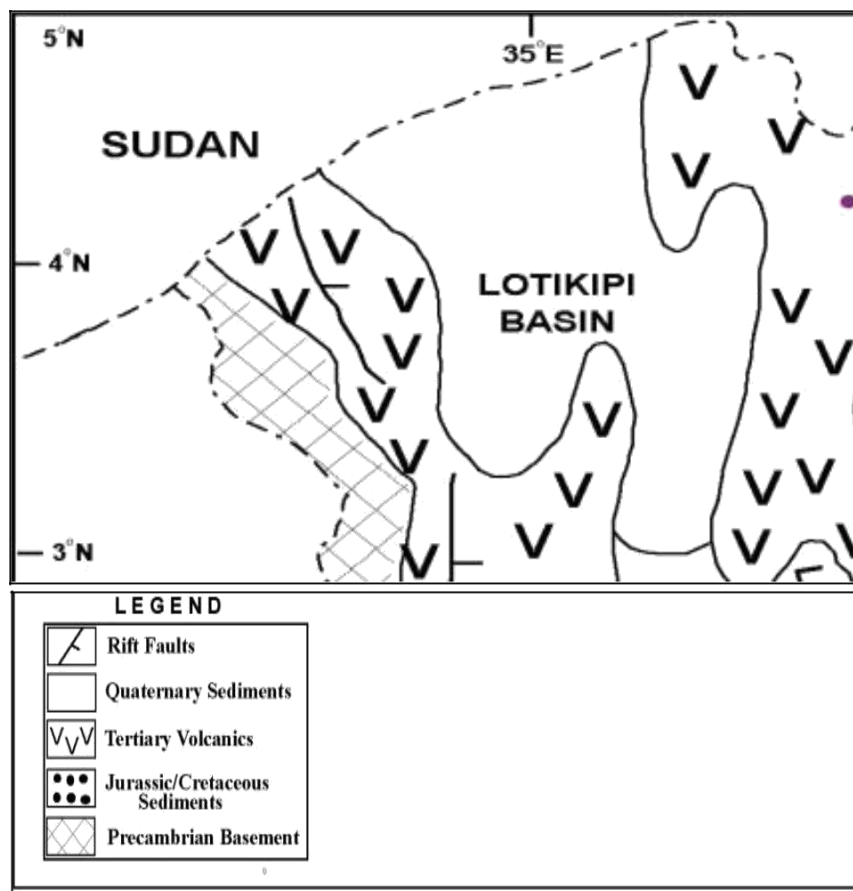
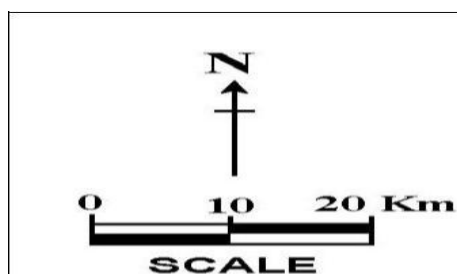


Figure 2. Map showing geology of the Lotikipi basin in north-western Kenya

The two river systems (Anam-Natira and Tarach-Nakalale) are joined by tributaries draining the southern edges of the basin (the Muruasingar-Pelekech Ranges). It is highly possible that much of the drainage pattern was directed earlier to the major depression of the Lake Turkana, controlled by NW-SE trending faults sympathetic to the Anza-Abu Gabra Rift systems. It was reoriented by the younger rifts governed by an E-W extensional stress system that became active in the early Miocene (Davidson & Rex, 1980; Girdler, 1983; Key *et al.*, 1987; Green *et al.*, 1991). The landscape of the entire basin indicates an active tectonic control over the courses of rivers cutting through both the Precambrian basement rocks as well as the volcanic rocks of Oligocene-Miocene age (Morley *et al.*, 1992). The basin forms an isolated terrain surrounded by high ranges but, in spite of the active tectonism, the rivers do not form deep gorges but follow a gentle gradient at present (Plates 1 and 2).



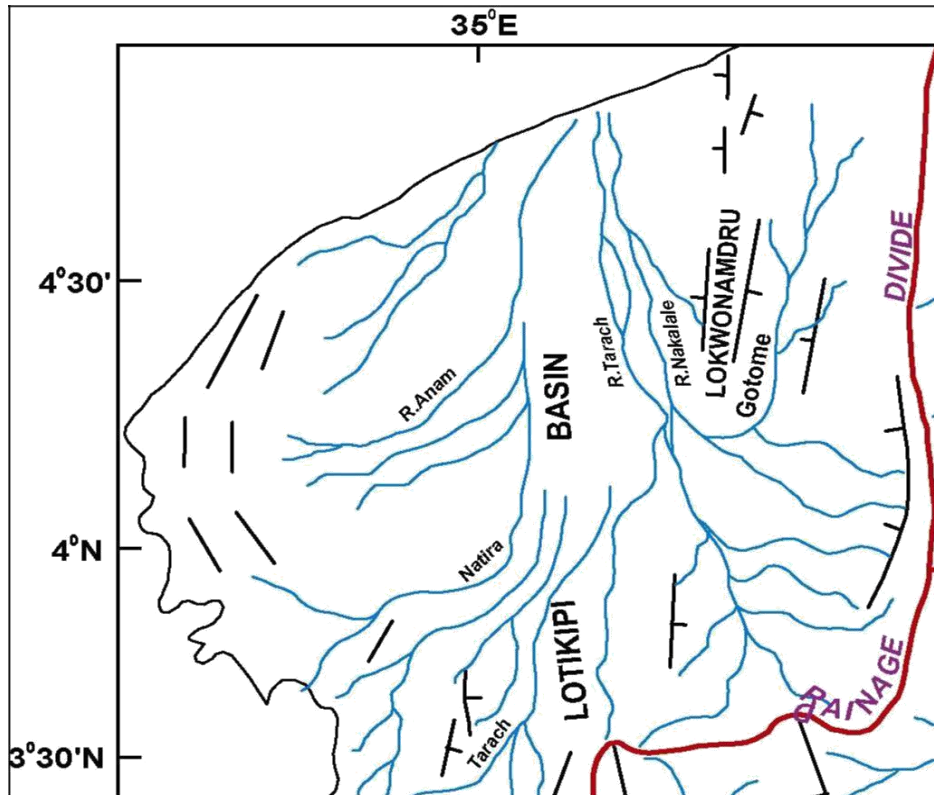


Figure 3. Map showing Lotikipi basin drainage system in northwest Kenya

As surface exposures of older sedimentary sequences are scanty and rare, and since no exploratory wells have so far been drilled in this basin, there is an incomplete understanding about what lies below the thick alluvial cover (Holocene). Walsh and Dodson (1969) and Rop (1990) mention that the lava flows overlies directly the Precambrian basement and are overlain in turn by post-volcanic sediments and alluvial deposits. Barker *et al.* (1972) referred to the Lotikipi plain as a weakly faulted, big swampy area that was dominated by gently dipping lavas (38-17 Ma age), forming a 'synclinal structure' with no underlying rift section. Later work (Morley *et al.*, 1992) undertaken to the south of the Lotikipi basin was based on gravity and seismic data that revealed horst and graben structures below the alluvial plains. It seems that the Tertiary faulting and rifting facilitated speedy erosion in the central part of this basin which was left with very little thickness of the volcanics below the alluvium. But, no surface sections or exposures of volcanics or sedimentary rocks occur in the river channels (Rop, 2003).



Plate 1. West Lotikipi basin showing highlands of Kenya/Uganda escarpment



Plate 2. Lotikipi basin showing the Eastern Mountain ranges

For subsurface exploration of possible hydrocarbon bearing strata and structures, it was necessary to ascertain geophysically the thickness and lithological succession in sedimentary units. The BEICIP (1984) report did assume that during the Mesozoic rifting, structures similar to the NW-SE trending Anza basin (graben), formed and extended (Figure 1) even across the Lotikipi basin. Sedimentary sequences equivalent in age (Jurassic-Cretaceous) to those of southern Sudan (Rop, 2002; Schull 1988) might be discovered overlying the Precambrian basement in these structures.

Materials and Methods

Gravity anomalies map and the basement depth map (Figure 4 and 5) helped in determining the limits of the weathered profile and volcanic cover, in determining the depths up to which sedimentary sequence might extend and even the depth configuration of the mantle below the basement. The Bouguer gravity contours (Figure 4) over the Lotikipi basin showed a distinct north-south strike, indicating that the Tertiary rift tectonics affected even the crust-mantle interface. Sections across these contours have been examined along the latitudes $4^{\circ}00'N$, $4^{\circ}15'N$, $4^{\circ}30'N$ and $4^{\circ}45'N$ (Figure 6a, b, c, d), at regular intervals in order to delineate the subbasins. The Bouguer gravity anomaly values (-50 to -90 mgal) over the basin indicate a thin volcanic cover, a deep upper mantle and the probable surface presence of low-density sedimentary rocks over the Precambrian basement. The cross-section along Lat. $4^{\circ}00'N$ (Figure 6a) showed that the gravity anomaly became increasingly negative westward from Murua Rith Hills (about -60 mgal) towards the Songot Mountain (about -90 mgal) near the Kenya/Uganda border escarpment. It appears that the upper mantle downwarped in that direction, the Precambrian basement should be thicker, although the depth to the basement shallows from east to west (e.g. -2 km at the immediate east of the Pelekech horst like structure to 0 km at the Songot Mt.). The basement deepens from 2.5 km to 3.5 km towards north, indicating a plunging structure (Figure 5). The Bouguer gravity and basement depth between Pelekech Range and Murua Rith Hills do not vary much, in spite of the faults that affected both the basement and the upper mantle. The undulatory basement profile in the southern part of the basin has been caused by the deep mantle-reaching fault systems.

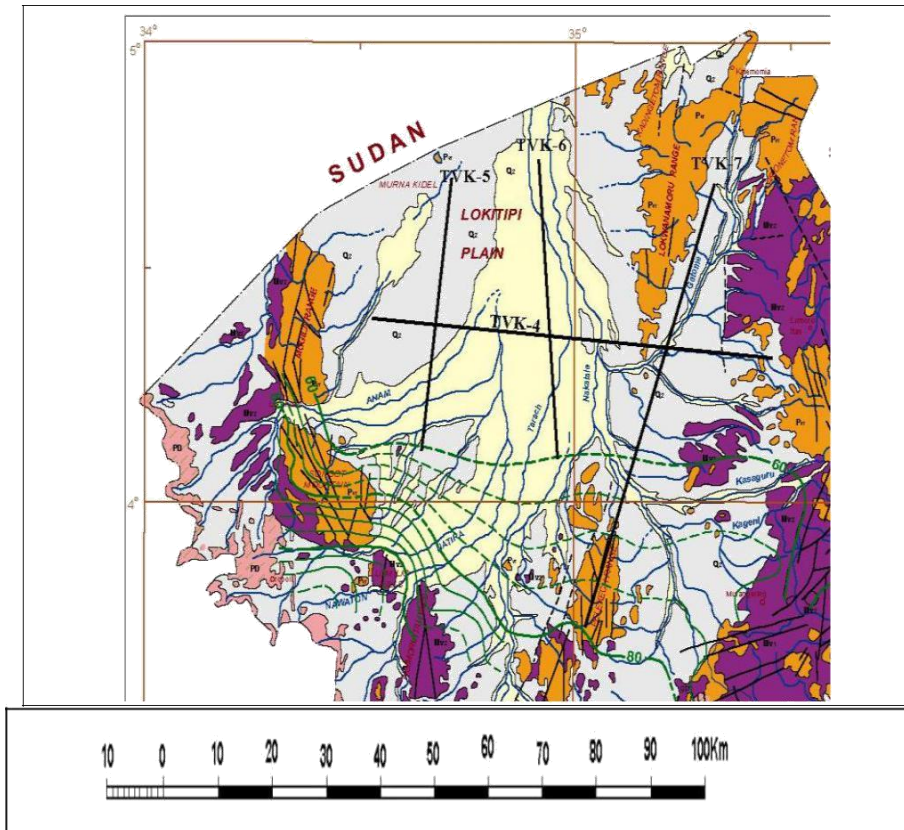


Figure 4. Bouguer gravity contour map showing seismic lines TVK 4-7

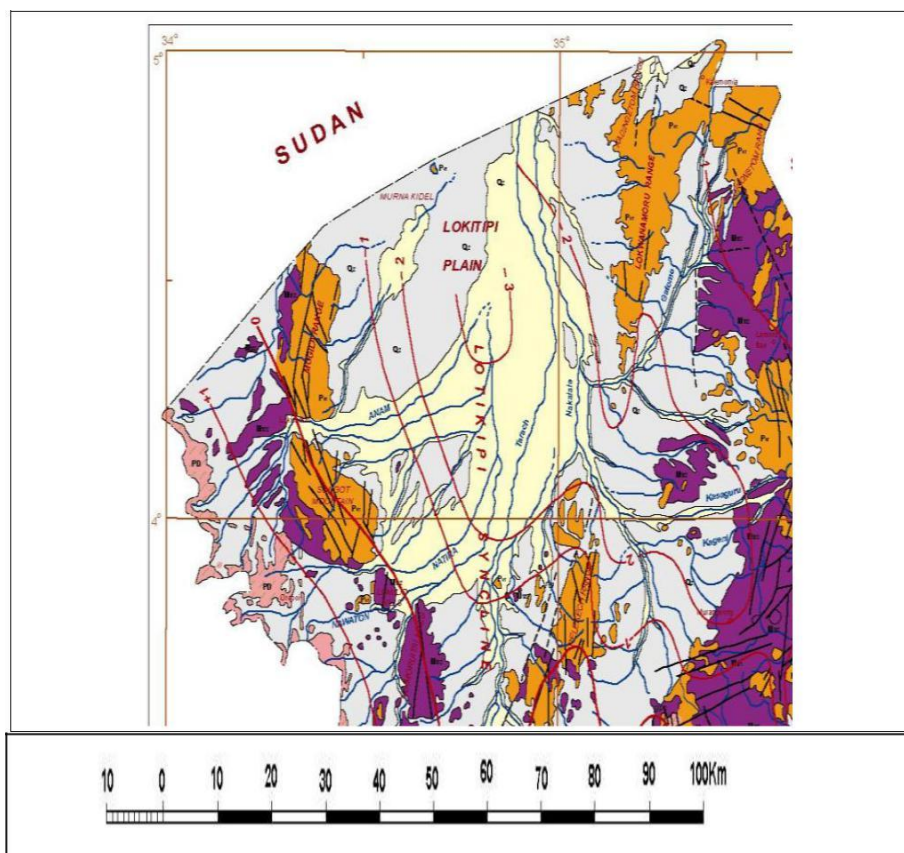


Figure 5. Basement contour map showing depths

The positive gravity anomalies (Figure 4) define the limits of the horst structures where the basement is overlain mostly by the lava flows. The cross-sections (Figure 6b, c, and d) between Lat. $4^{\circ}15'N$ up to Lat. $4^{\circ}45'N$, are not much different than that along the Lat. $4^{\circ}00'N$ except that the depth to the basement increases towards north, indicating also that the thickness of the sedimentary sequence increases in that direction. The basin deepens gradually between Lat. $4^{\circ}00'N$ and $4^{\circ}30'N$, but the gradient becomes suddenly steep further beyond. The negative Bouguer anomaly over the central deeper basin (-80 mgal) becomes relatively positive (-65 mgal) towards west (Mogila Range) as well as towards east (Lokwanamoru Range). This part of the basin formed by the NE-SW Mesozoic rifting and was later affected also by the E-W Tertiary rift. The basin deepens steeply eastwards, but the displacement along the western N-S (Tertiary) bounding faults is greater. In the deepest part of the basin, lying between Long. $34^{\circ}30'E$ and $35^{\circ}E$ and Lat. $4^{\circ}15'N$ and $4^{\circ}45'N$, a thick Mesozoic (Cretaceous or still older) sedimentary section is expected to underlie the few hundred kilometre thick cover of Tertiary and Quaternary volcanics and alluvium. This subsurface basin is not far from the NNW-SSE faults system of the Kenya/Uganda escarpment and its structure is more like a half-graben, which deepens also northwards. It does appear that the series of faults that have affected the deeper basin configuration should have been initiated sometime in the Mesozoic. It is possible that northwards this basin extends into Sudan. As such, the interpretation bolsters the optimism to discover subsurface sediments of even Lower Cretaceous age, similar to those in Sudan, which could be petroliferous.

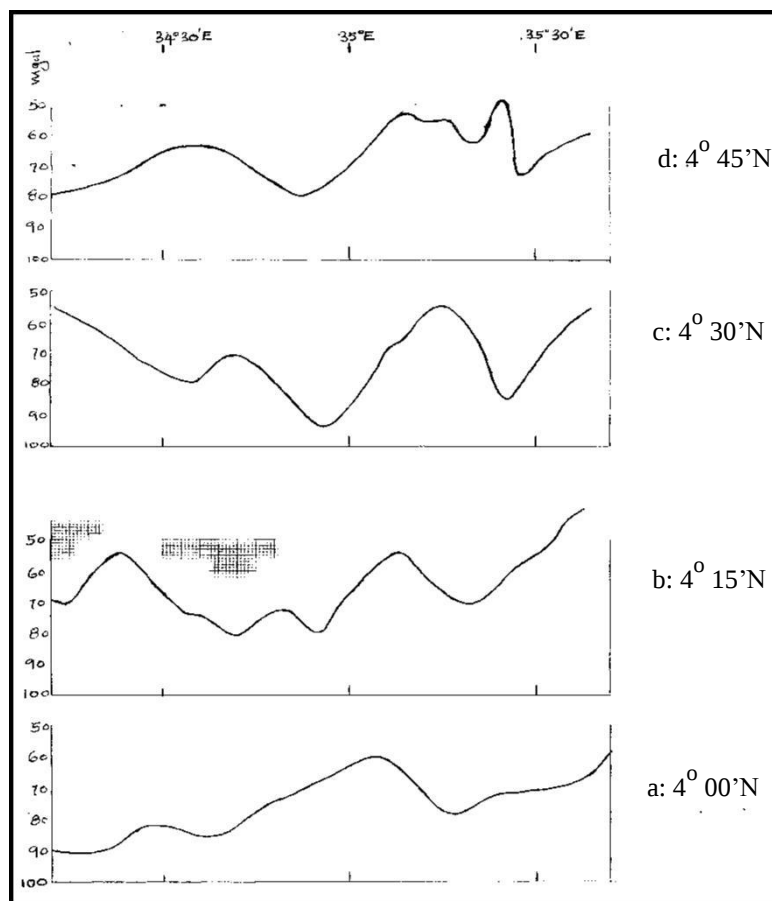


Figure 6a, b, c, d. The gravity cross-sections of Lotikipi basin along $4^{\circ}00'N$ to $4^{\circ}45'N$

The positive gravity anomaly, along the eastern margin of the Lotikipi basin, is interpreted as due to the uplift of the basement as well as the mantle upwarp. Faults bounding some of the horst and graben structures (Figure 6) should/could be 'active faults' that also controlled the courses of the rivers and their tributaries, later in the Quaternary. A minor fault inferred at the banks of Nakalale River, to the north of Pelekech Range, represents the N-S striking end of the Turkwel Fault (Morley *et al.*, 1992), which branched from the Elgeyo escarpment bordering the Lotikipi basin to the south. These faults should have been intermittently active affecting the basin structure and controlling the fluvial sedimentation.

Results and Discussions

Usually among the geophysical methods used in the exploration of hydrocarbons, the gravity and seismic methods have been more common and effective in delineating prospective subsurface structures. The presence and thickness of sedimentary rock units has to be, however, confirmed further by well inventories and seismic data. Seismic characteristics reveal the physical characteristics like compactness, rigidity, porosity and permeability of the subsurface sedimentary units. It was possible to assess how frequent are the sections containing interlayered shales, compact sandstones, more porous, less compact reservoir quality sandstone and possible carbonate rocks. From the seismic profiles along Lines TVK-4, TVK-5, TVK-6 and TVK-7 (Figures. 4, 7 and 8) it was possible to identify two sub-basins, between longs. $34^{\circ}30'E$ and $35^{\circ}00'E$ and lats. $4^{\circ}15'N$ and $4^{\circ}45'N$ (Figures 6b and 6d), which have been named after the nearest river systems as a) the Anam-Natira Formation and b) the Tarach-Nakalale Formation (Rop, 2003).

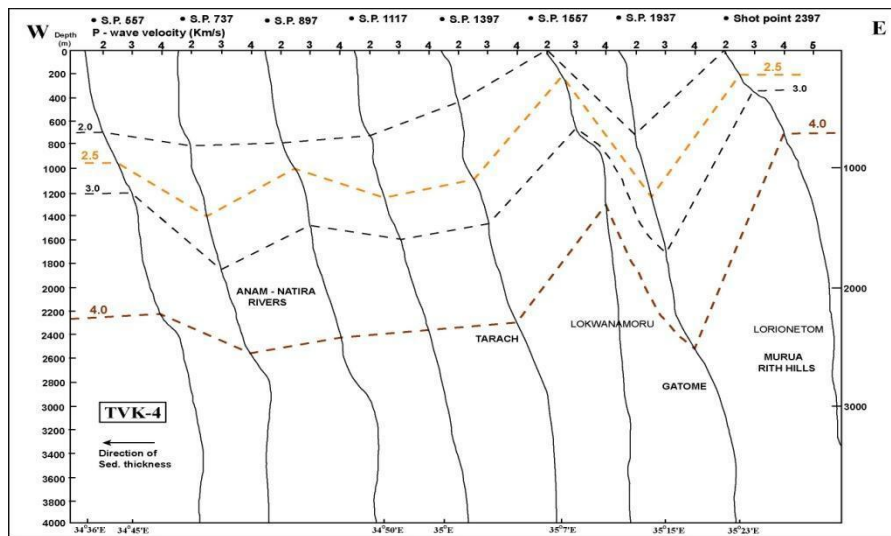


Figure 7. W-E cross section in the Lotikipi along seismic line TVK-4

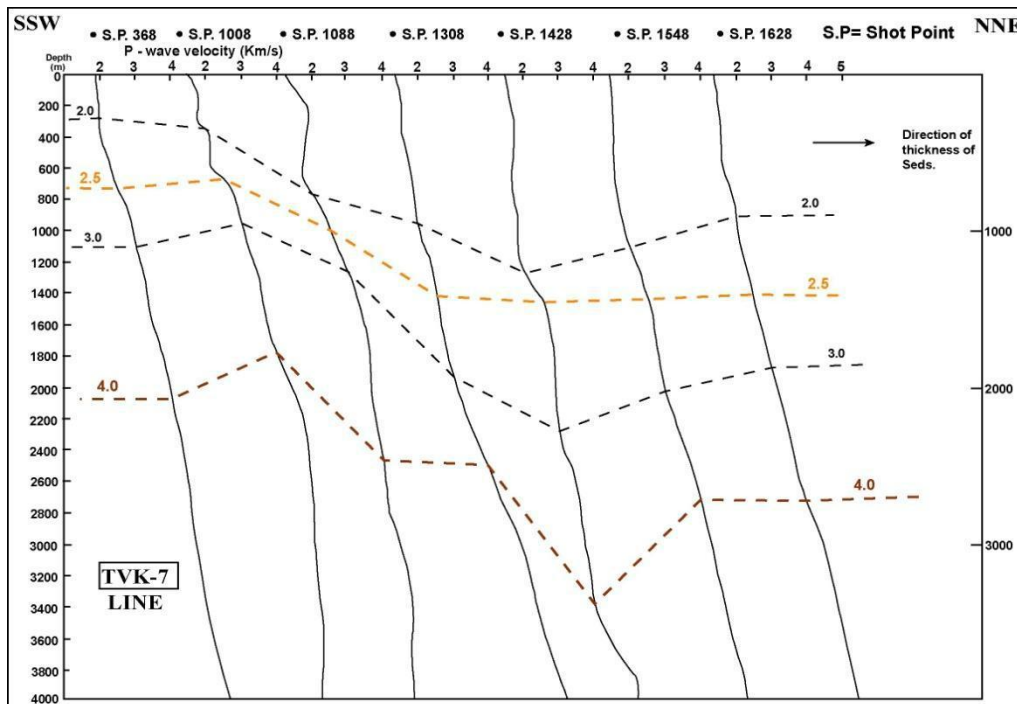


Figure 8. SSW-NNE cross section in Lotikipi basin along seismic line TVK-7

a) Anam-Natira Formation

The anticipated best-developed subsurface sedimentary section, identified on the basis of seismic and gravity studies, under the channels of the Anam and Natira rivers (Figure 7 and 10), has been named as the Anam Natira formation. The 1050 m thick sequence (between long $34^{\circ}30'E$ and $35^{\circ}00'N$), showing P-wave velocity (V_p) between 3.0 and 4.0 km/s on TVK-4 line profile, is interpreted to consist chiefly of sandstones and shales. The lower 350 m section, between 1900 m to 2250 m depth, should contain compact sandstones with frequent thick clay/shale layers, for which the V_p range is between 3.5 to 4.0 km/s. The upper 700 m section, between 1200 m-1900 m depths, should be mainly fine-grained sandstones with minor clay/shale layers, followed upward by mainly coarse-grained sandstones. The upper section is characterised by a lower V_p range between 3.0 and 3.5 km/s, but the intercalated clay/shale or less porous, more compact sandstones layers are marked by higher V_p (3.5 km/s).

Thus, seismically the Anam-Natira Formation has two subdivisions, which could be recognised as the Upper and the Lower Anam-Natira Members (Figure 11). The section showing the maximum thickness beneath the Natira River (at shot point 1428 - Figure 8) does not show the two members equally well-developed. In this section, the upper member (V_p between 3.0 and 3.5 km/s) is thicker and better developed. Interestingly, in the horst-like parts of the Lotikipi basin (Figures. 4, 6, 7, 8, 9 and 10), under shot points 1557 and 2397 (TVK-4), 542 (TVK-5), 1162 (TVK-6) and 1008 and 1088 (TVK-7) the section shows a better-developed lower member (V_p between 3.5 and 4.0 km/s). The depth of the basement generally shallows in these horst-like parts (1800 m depth). Only in TVK-5 (shot point 782) and TVK-6 (shot point 162) does the basement depth reach beyond 1800 m up to 2100 m. It establishes the non-uniformity of the subsidence experienced by the basin in different parts when the lower member sediments were deposited. It also established that between the end of deposition of the lower member and the beginning of the deposition of the younger member, there has been tectonic episode, which deepened only certain parts of the basin where thicker sequence of the younger member could be deposited. Areas under seismic lines TVK-4 (shot point 1937) and TVK5 (shot point 142), TVK-6 (shot point 1162) and TVK-7 (shot point 1428) show a better developed upper member (V_p between 3.0 and 3.5 km/s), the graben areas of the basin indicating a faster rate of sedimentation. The lower member generally shows a smaller thickness in these parts of the basin, while the upper member shows maximum thickness.

Future drilling and fossil finds will provide additional stratigraphic attributes to these seismically defined divisions.

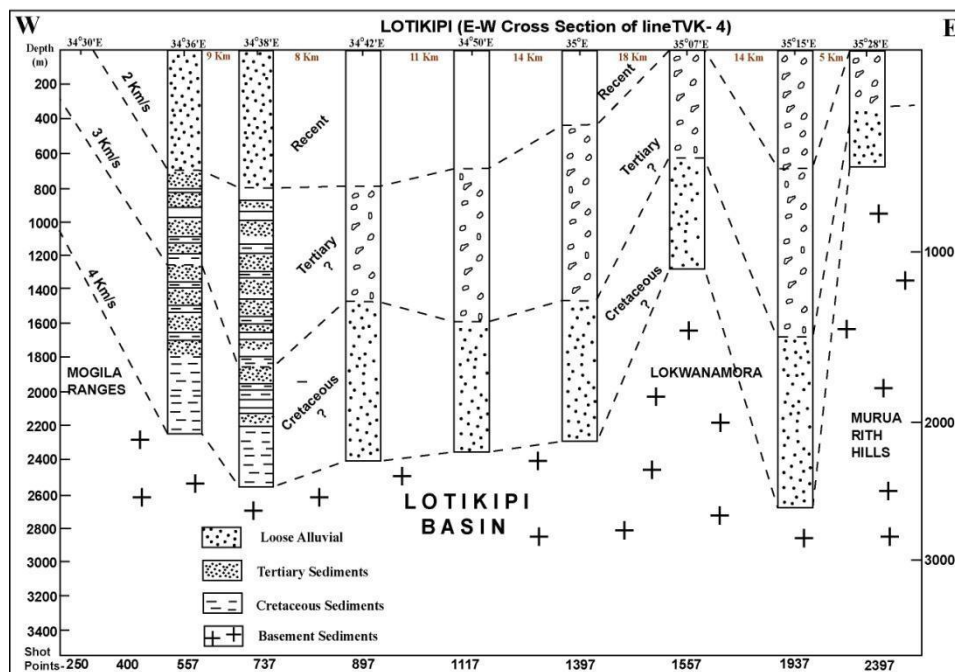


Figure 9. Probable E-W subsurface stratigraphic columns of seismic line TVK-4

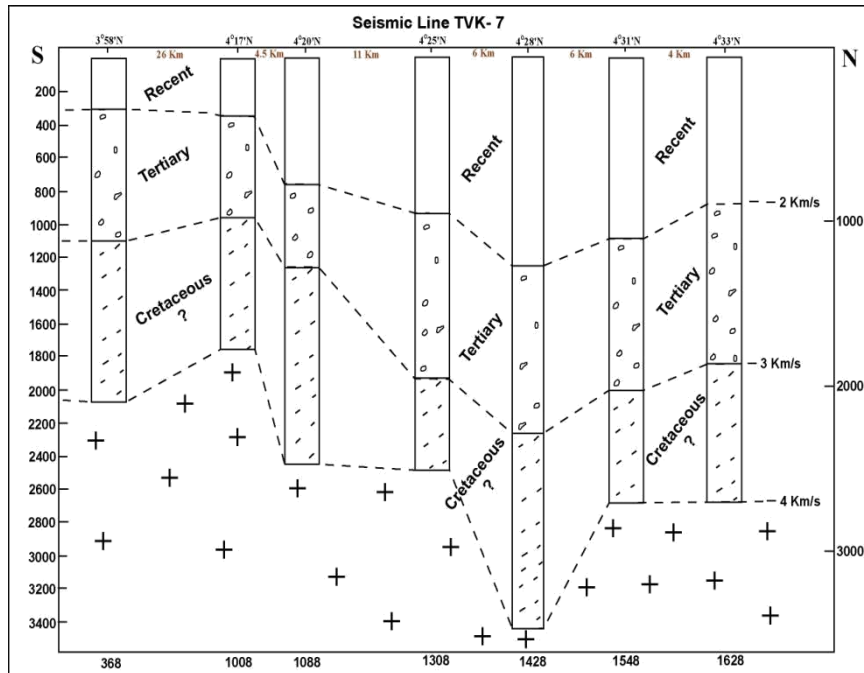


Figure 10. Probable S-N sub-surface stratigraphic columns of seismic line TVK-7

b) Tarach-Nakalale Formation

The best-developed (Tertiary) section (1420 m thick) located beneath the Tarach and Nakalale river systems (Figures 9, 10 and 11), characterized by V_p between 2.0 and 3.0 km/s, has been named as the Tarach-Nakalale Formation. Deduced along TVK-6 the area covered under Longs. $34^{\circ}45'E$ and $35^{\circ}03'E$ and Lats. $4^{\circ}24'N$ and $4^{\circ}42'N$ shows a better development of this formation, which seems to be constituted of less consolidated sands, gravels, silts and clays which increasingly become more compact towards the basal part of the section (1560-2060m depth). The sub-basin on the TVK-6 line bounded by lats. $4^{\circ}24'N$ and $4^{\circ}42'N$ and longs. $34^{\circ}45'E$ and $35^{\circ}03'E$ can be considered as representing the 'type' section of the Tarach-Nakalale Formation. The 'type' Tarach-Nakalale Formation sequence shows well-developed representation of both the members, which range to about 800 m thick each.

The Tarach-Nakalale Formation could also be sub-divided into an upper member ($V_p > 2.0 < 2.5$ km/s) and a lower member ($V_p > 2.5 < 3.0$ km/s). The lower member is better developed on the horst-like features in the Lotikipi basin and extends only up to a depth of < 220 m (e.g. beneath the Lokwanamoru Range and Murua Rith Hills along TVK-4 line, shot point 737, at long. $35^{\circ}07'E$ and at shot point 2397, at long. $35^{\circ}28'E$, respectively). In other sections on the TVK-5 (shot point 782) and TVK-7 (shot point 1482) lines the older member sequence seems to reach up to a maximum depth of 750 m and 1460 m, respectively. The two seismically defined members of the Tarach-Nakalale Formation have variable thickness in different parts of the Lotikipi basin. The variations in thickness as well as the maximum depth reached by each of them show that the sedimentation was accompanied by subsidence. Of interest is the fact that areas with the thinner sections of sediments showing $V_p > 2.5 < 3.0$ km/s do not coincide with those showing thinner sequences of $V_p > 2.0 < 2.5$ km/s.

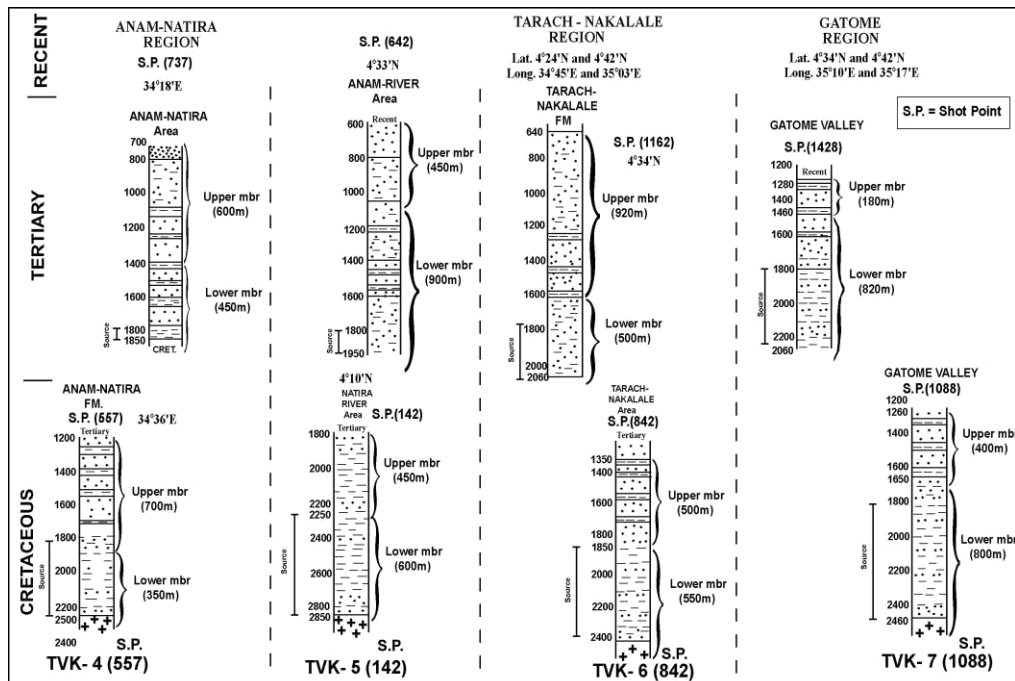


Fig.5.1: General stratigraphic columns variations (Cretaceous - Tertiary) of probable type sections of the Lotikipi formations

Figure 11: General stratigraphic columns variations of probable type sections of Lotikipi formations based on seismic profiles

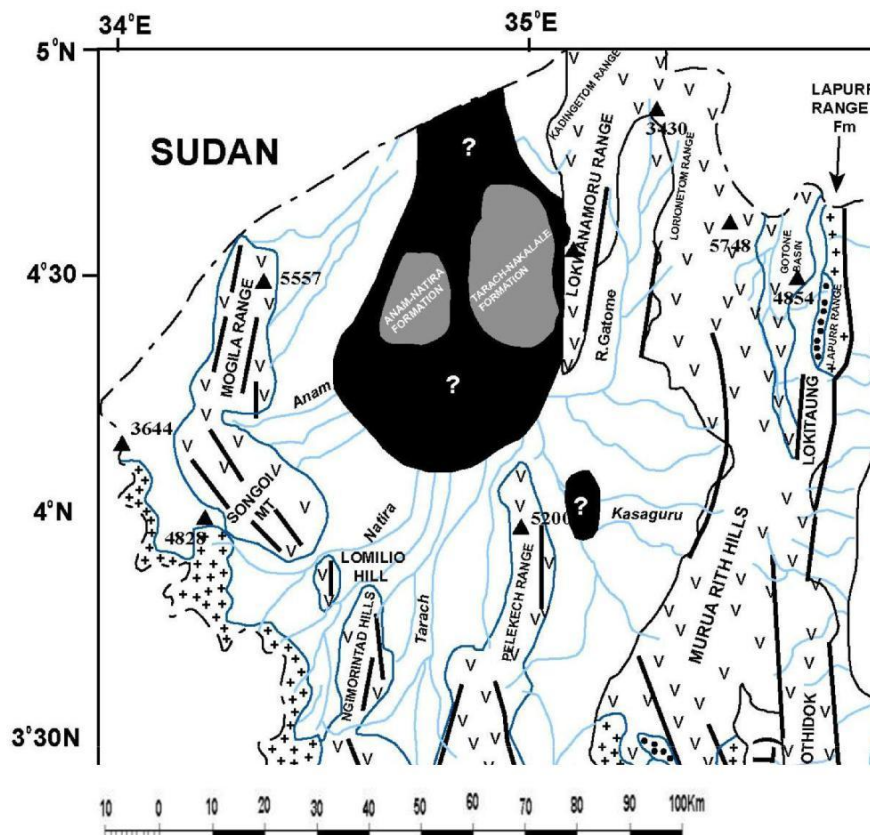


Figure 12. Map showing probable prospective hydrocarbon areas (shaded black and grey)

Conclusion

At this juncture the section cannot be assigned a definite stratigraphic age, but occurring in similar tectonic and stratigraphic set-up, it is suspected that the Anam-Natira Formation might be homotaxial to the Sharaf and Abu Gabra Formations (Neocomian or Albian-Aptian in age [Schull, 1988]) of southern Sudan. Although future drilling alone would enable assigning additional lithological attributes to these two subdivisions, in the absence of any other criteria to assign a stratigraphic age, it might help to consider Tarach-Nakalale Formation as coeval to the Kordofan Group of southern Sudan (early Tertiary in age [Schull, 1988]). Additionally, one might also point out that the sub-basins in which the thicker Anam-Natira Formation sequences (Upper Cretaceous) are suspected are different than the sub-basins in which a greater thickness of Tarach-Nakalale Formation (Lower Tertiary) is anticipated.

Recommendations and Prognostic Evaluation

Since there has been no exploratory wells drilled in the Lotikipi basin, most of the prognostic evaluation of the basin would depend upon the evaluation done on rocks of equivalent age belonging to the other basins (along the Anza and Abu Gabra Rifts). The two major Formations have been recognized on the basis of seismic attribute (Rop, 2003). The Anam-Natira Formation, which is the older of the two, has been considered equivalent to the Sharaf and Abu Gabra Formations in Sudan, both Cretaceous in age. Those formations are constituted of thick lacustrine and fluvial shales, claystones, sandstones and conglomerates which include source rocks for hydrocarbons. Their Cretaceous age has been established mostly on palynological evidence. Sediments deposited in graben structures of that age are known to have occurred in other rift-related basins prior to separation of the Gondwanaland. Conforming to the thought that the Lotikipi basin forms a part of the north-western extension of the Great Anza Rift, stratigraphically equivalent sequences (with $V_p > 3.0 < 4.0$ km/s) of the Anam-Natira Formation could also be visualized to contain some source rocks for hydrocarbon generation. Formations considered equivalent in age in the Chalbi and Kaisut basins (Winn *et al.*, 1993), much to the southeast of the Lotikipi and Lake Turkana basins, also contain potential source rocks for oil generation. This correlation, however, requires further confirmation by detailed seismic data.

Within the Lotikipi basin (Figure 12), certain areas could be demarcated as potential target areas for future hydrocarbon and drilling operations:

- 1) Area immediately north of the Pelekech Range, between lats. $4^{\circ}15'N$ and $4^{\circ}30'$ and longs. $34^{\circ}45'E$ and $35^{\circ}15'E$, at the east of the Lotikipi basin.
- 2) The areas to the north of lat. $4^{\circ}30'N$ (possibly extending up to the Kenya-Sudan border) and longs. $34^{\circ}36'E$ and $35^{\circ}07'E$, in the central part of the Lotikipi basin.
- 3) The areas to the northwest of Pelekech Range (beneath Nakalale-Kasanguru and Gatome rivers system), between lats. $4^{\circ}00'N$ and $4^{\circ}30'N$ and longs. $35^{\circ}07'E$ and $35^{\circ}17'E$.

Future drilling activity must take into consideration that the subsurface geology is tectonically complex. The Cretaceous sequences were deposited within the graben structures formed under the E-W and NE-SW extensional stresses. The degree of subsidence in the graben along the strike of the rifting was not uniform as seen by the thickness variation of the individual two stratigraphic members defined seismically. It has also been inferred that in the Lotikipi basin, the maximum thickness of Cretaceous sequences was achieved in graben areas, with smaller thickness of sequences of that age visualized over the horst areas. Interestingly, the Cretaceous sequences on horst-like structures, with smaller thickness, also show V_p between 3.0 and 4.0 km/s, characteristics of good source rocks. However, among older member sequences, those that have reached depths beyond 1800 m could only be visualized as containing potential source rocks for hydrocarbon generation. As the Cretaceous basin was further affected by the Cenozoic rifting, it is possible that the hydrocarbons earlier generated, migrated even into the Tertiary sandstones, overlying the thin upper member sequence of the Cretaceous strata.

Acknowledgements

This paper is published with the permission of the Managing Director, National Oil Corporation of Kenya. The fieldwork, data analyses and interpretation formed part of the PhD research-related thesis work submitted to University of Pune, under the guidance of Prof. A.M. Patwardhan, formerly the Professor of Geology and Head, whom I thank for his invaluable comments and discussions during my research period.

References

- Barker, B. H., Morh, P. A., & Williams, L. A. J. (1972). Geology of the Eastern Rift systems of Africa. *Geological Society of American Special Paper* 136, p 67.
- BEICIP (1984). *Petroleum potential of Kenya 1984 follow-up*. Ministry of Energy and Regional Development, p. 100.
- Davidson, A., & Rex, D. C. (1980). Age of volcanism and rifting in south-western Ethiopia. *Nature*, 283, 657-658.
- Green, L. C., Richards, D. R., & Johnson, R. A. (1991). Crustal structure and tectonic evolution of the Anza rift, northern Kenya. *Tectonophysics*, 197, 203-211.
- Key, R. M., Rop, B. P., & Rundle, C. C. (1987). The development of the Late Cenozoic alkali basaltic Marsabit Shield Volcano, northern Kenya. *Journal of African Earth Sciences*, 6, 475-491.
- Key, R. M., Rop, B. K., & Rundle, C. C. (1987). *Geology of Marsabit area*. Republic of Kenya, Mines and Geological Department: Report No. 108, 42p.
- Morley, C. K., Wescott, W. A., Stone, D. M., Harper, R. M., Wigger, S. T., & Karanja, F. M. (1992). Tectonic evolution of the northern Kenya Rift. *Journal of the Geol. Soc., London*, 149, 33-348.
- Rop, B. K. (1990). *Stratigraphic and sedimentological study of Mesozoic-Tertiary strata in Loiyangalani area, Lake Turkana District, NW Kenya* (Unpublished M.Sc. thesis). University of Windsor, Canada, p. 128.
- Rop, B. K. (2002). Subsurface geology of Kenyan Rift Basins adjacent to Lake Turkana based on gravity anomalies. In *The abstracts of International seminar on Sedimentation and tectonics in space and time*, 16th-18th April; 2002, pp. 83-85.
- Rop, B. K. (2003). *Subsurface stratigraphical studies of Cretaceous-Tertiary basins of northwest Kenya* (unpublished Ph.D. thesis, University of Pune, India), 174p.
- Schull, T. T. (1988). Rift Basins of interior Sudan: Petroleum Exploration and Discovery. *The AAPG Bulletin*, 72, 128-1142.
- Walsh, J., & Dodson, R. G. (1969). Geology of Northern Turkana. Geological Survey of Kenya. In W. W. Bishop, (Eds.), (pp. 395-414). Scottish Academic Press, Edinburgh.
- Winn, R. D., Steinmetz, J. C., & Kerekgyarto, W. L. (1993). Stratigraphy and Rift History of Mesozoic-Cenozoic Anza Rift, Kenya. *The AAPG Bulletin*, 77, 1989-2005.