Hydrocarbon Prospectivity in Mesozoic and Early Cenozoic Rift Basins in Central/Northern Kenya*

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Abstract

Because they offer the oldest and longest-lived sedimentary basins of the Cenozoic East African Rift System (EARS) and because they are a crossover area between rifts of Cretaceous and Cenozoic age, the Northern and Central Kenya rifts, (NKR) and (CKR), respectively, or NCKR collectively, are among the most important areas for hydrocarbon prospecting in the EARS (Figure 1).

The NKR, or Turkana Depression, consists of strings of N-S oriented half-grabens, the oldest known basins being of Paleogene-middle Miocene age. Crossing at the north end of the NKR are the NW-oriented Anza-Sudanese rifts that both are Cretaceous to Paleogene. The CKR shows two N-S half-grabens, the Baringo Basin (Paleogene-Present) and the Kerio Basin (Paleogene-upper Miocene). All basins are filled by up to 8-km thick sediments/volcanics of Cretaceous-Neogene age.

New studies have focused on reservoir/source rock quality and structural link between reservoir/source rock/seal. Both questions relate to the sequence of deformation events between the Anza-Sudanese (Cretaceous-Paleogene deformation) and Kenya (Neogene-Recent) rifts. Geophysical/field geology results confirm continuity in terms of deformation events between the Anza-Sudanese and NK rifts. In terms of hydrocarbon prospect, arkosic sandstones in CKR/NKR (or NCKR) demonstrate a good reservoir quality, with porosity up to 25 %. Strong changes in terms of diagenetic alteration relate to deformation events (burial/uplift) or change in sediment source. High quality source rocks relate to freshwater lake environments under tropical climate. Such environments have been identified during Paleogene in the NKR and lower Neogene in the CKR and are suspected in basins of the same age that have not yet been prospected. Relations between reservoir/source rock/seal are connected to Neogene deformation and have been investigated by magnetotelluric methods and high-resolution seismic stratigraphy.

Introduction

In this article, we review the evidence of oil potential in a suite of Cretaceous (?) to middle Miocene-aged basins, in terms of source rock and reservoir properties. This study provides a necessary basic set of data for potential oil explorers in the Northern Kenya (NKR) and Central Kenya (CKR) rifts (or NCKR collectively).

Major exploration efforts have been carried out since the 1970s in the NKR following an extensive seismic survey offshore Lake Turkana by Project PROBE (Dunkleman et al., 1989). Three strings of deeply buried, N-S oriented half-graben basins have been identified by the Amoco Kenya Petroleum Company (AKPC) to the west of Lake Turkana. These basins are among the oldest known in the East African Rift System, being of Cretaceous to Paleogene-middle Miocene age. Basins to the immediate west of Lake Turkana are Lokichar and North Kerio (to the immediate east of the former); up to 7 km of fill have been identified by reflection seismic and tested by two exploration wells (the Loperot-1 and Eliye Springs-1 wells, drilled by Shell Exploration and Production Kenya B.V.) (Morley et al., 1999b) (Figure 1).

To the west-northwest of Lake Turkana, gravity and reflection seismic data acquired by AKPC indicate the presence of two elongated sedimentary basins, the Lotikipi Basin to the west, and the smaller Gatome Basin to the east, separated by a structural high (Lokwanamoru Range). The maximum depth to basement was interpreted to be 4 km for the Lotikipi Basin, and up to 6 km in the Gatome Basin (Wescott et al., 1999). Crossing at the northeast end of the NKR is the NW-SE-oriented Anza Rift that is Cretaceous to Paleogene in age (Figure 1). This large multi-phase rift contains more than 6 km of syn-rift sediments of marine and continental origin and Mesozoic to Early Tertiary in age. To the south, the Central Kenya Rift shows today a set of two parallel, N-S-trending half-grabens, the Baringo Basin to the east, and the Kerio Basin to the west (Figure 1). This segment of the EARS has not really been studied in terms of oil potential.

Reservoir/Source Rock Features of the Basins

All these basins in the Central and Northern Kenya rifts are filled by 5- to 8-km thick Cretaceous (?)-Neogene sediments and volcanics of Paleogene-Neogene age. Sediments of Paleogene-Neogene age crop out widely west of Lake Turkana, while Cretaceous sediments are only known from subsurface data, with the exception of the Lapur Sandstone Formation (LSF) that crops out toward the northwest end of NKR.

Reservoir/source rock quality has been studied within several basins and specific sedimentary formations in the NK and CK rifts—from north to south:

- 1) The Lotikipi and Gatome basins, and the Lapur Sandstone Formation.
- 2) The Lokichar Basin.
- 3) The Kerio and Baringo basins, and the Tambach and Ngorora formations in the CKR.

Lotikipi and Gatome Basins and Lapur Sandstone Formation

The Lotikipi and Gatome basins have been shown from gravity and seismic data to lie below the 120-km-wide Lotikipi Plain, which is located 80 km west of the present-day Lake Turkana. Due to the poor quality of the seismic data occasioned by the presence of thick piles of volcanics, the deep geometry of the Lotikipi and Gatome basins, as well as the basement contacts, are not clearly defined. The Lotikipi Basin was interpreted as a thermal sag basin or a rift basin by Wescott et al. (1999). The deep stratigraphy of the basin has been interpreted from seismic data and outcrop geology. The upper part of the basin fill is formed by Neogene sediments, overlying a thick pile of volcanics formed by more than 3.5 km of rhyolitic and basaltic rocks, known as the Turkana Formation. New radiometric ages obtained at the Lokitaung Gorge type-section to the immediate west of Lake Turkana indicate a late Eocene age at the base of the basaltic series and a late Oligocene age for the rhyolitic series (Clément, Bellon, Guillou, et al., unpublished data). Sub-volcanic strata seen on seismic (line TVK-4) are estimated to be fluvial sandstones and lacustrine deposits, forming one single sedimentary unit up to 700 m thick. The Gatome Basin shows a similar stratigraphic succession with a greater infill thickness at its northern end. Interpretation of seismic line TVK-7 suggests the presence of 3 distinct sedimentary units with a total thickness of 4 km (Desprès, 2008). According to the age of the lower basalts located to the east of the Lotikipi and Gatome basins, these sediments are older than late Eocene (possibly Cretaceous to Eocene ?).

To the east of the Gatome basin, a thick pile of siltstones, sandstones, minor conglomerates, and mudstones crop out along the main border fault escarpment (Lapur Range) that bounds the Lake Turkana rift basin to the west (Figures 1 and 2). The Lapur Sandstone Formation shows a maximum thickness of ~500 m at the Lokitaung Gorge type section (Thuo, Ph.D. thesis). The LSF unconformably overlies the Precambrian basement. The lower units contain poorly preserved dinosaur bones, dated Cenomanian (Arambourg and Wolff, 1969). Its uppermost section appears interbedded within the first lava flows of the Turkana Formation, dated late Eocene. Potential source rock occurrence is a major question within the Lapur Sandstone Formation. Lenses of dark grey or black silty mudstones, few metres thick, are locally present in the LSF, and they may represent floodplain or shallow lake deposits. Nevertheless, these deposits do not demonstrate a high organic content.

Considering its stratigraphic position between the base of the basalts of the Turkana Formation and the Precambrian basement, the Lapur Sandstone Formation is tentatively correlated to the sedimentary units identified in a similar stratigraphic position on the TVK-4 and –7 seismic lines within the Lotikipi and Gatome basins. However, major changes in thickness along a S-N trend identified for the LSF may suggest the presence in the Gatome and Lotikipi basins of other (older or younger) sedimentary packages in a similar stratigraphic position.

The Lapur Sandstone Formation has an original detrital composition made predominantly of polycrystalline quartz grains and K-feldspars sourced from metamorphic basement. This formation may offer an interesting reservoir potential that is mainly controlled by the different types of cementation, largely calcite in the lowest 150 m of the formation, hematite in the middle 100 m, and kaolin with subordinate hematite in the top zone of the formation (Thuo, Ph.D. thesis). The initial depositional porosity of the LSF may have been as high as 41%, which has since been reduced to values ranging from 3 to 25 %. Overall, the top half of the LSF constitutes a more prospective reservoir zone than the lower half.

Lokichar Basin

Located to the south-southwest of the N-S- trending part of Lake Turkana, the Lokichar Basin is a N-S-trending, east-facing half-graben, 60 km long and 30 km wide and floored by Precambrian crystalline basement. This basin is bounded to the west by a prominent east-dipping listric fault, the Lokichar Fault, with no present-day topographic expression. As shown by reflection seismic data, the fill of the basin is 7 km thick (Figure 3). It consists of interbedded Paleogene to middle Miocene lacustrine and fluvio-deltaic sediments. Capping the basin fill is a 300-m-thick basaltic sequence, the Auwerwer Basalts and dated from 12.5 to 10.7 Ma (Morley et al., 1999b). The 3-km-deep Loperot-1 exploration well (Figures 1, 3) was drilled close to the Lokhone Horst, a basement high that separates the Lokichar Basin from the North Kerio Basin to the east. Alternating packages of coarse to fine sandstones tens to hundreds of meters thick were encountered in the well. These packages are divided into two main sedimentary units, from bottom to top: the Lokhone Sandstone Formation and the Auwerwer Sandstone Formation (Morley et al., 1999b). The Lokhone Sandstone Formation includes two major lacustrine shale intervals that are several hundreds of meters thick in the well but may be as thick as 1.3 km to the west, approaching the boundary fault. Exposures of the Lokhone and Auwerwer formations are poor. Pebbly sandstones and conglomerates onlap the gneissic basement of the Lokhone Horst. Quartz, K-feldspar, biotite, and muscovite are the dominant minerals. The upper part of the Lokhone Formation and the Auwerwer Formation show minerals, such as quartz, feldspars, biotite, muscovite, with significant amounts of fresh volcaniclastic material, amphibole, pyroxene, and plagioclase. Volcanic components can reach more than 50 % of the detrital material, indicating a major change in the sediment source, from basement outcrops to an alkaline volcanic source, possibly the basaltic flows occurring to the south of the Lokichar Basin, linked to the lower Miocene Samburu Basalts. Diagenetic changes in the Lokhone/Auwerwer Formations are marked by analcite and calcite cement, resulting in a rather low porosity (values of 1-15 %; Tiercelin et al., 2004).

Possible equivalents of the lower parts of the Lokhone Formation crop out to the east of the Lokichar Basin, at Lariu, and on the eastern side of Lake Turkana, at Mount Porr (Tiercelin et al., 2004) (Figure 1). The Mount Porr sandstones are composed mainly of quartz and feldspars, indicating a regional metamorphic source. Diagenetic events are recorded by calcite, quartz, or kaolin cements. A high porosity (up to 33 %) was nevertheless preserved, probably associated with late diagenetic dolomitization.

The upper shale interval in the Loperot-1 well is dated late Oligocene-early Miocene, while the lower shale interval is of possible Eocene to early Oligocene age (Morley et al., 1999b). Organic matter studies demonstrate a good source rock potential with high TOC values (up to 17 %) and prove an algal lacustrine origin for this organic matter (Talbot et al., 2004). Pollen analyses conducted on the upper shale interval from the Loperot-1 well demonstrate the presence in the Lokichar region of a mosaic environment of semi-deciduous forest and humid woodland presenting strong affinities with vegetation occurring today in the Guinea-Congolia/Zambezia phytogeographical zone (Vincens et al., 2006). Rainfall more than 1000 mm/year characterized the Lokichar region during late Oligocene-Early Miocene. The Lokichar Lake was interpreted as similar to some of the modern large lakes of the western branch of the EARS, such as Lake Albert or Lake Edward.

Kerio and Baringo Basins and Tambach and Ngorora Formations

The Kerio and Baringo basins are located in the central segment of the Kenya Rift between 0° 15’ and 0° 45’ N. The present-day Kerio Basin is occupied by the Kerio River valley and is considered today as tectonically inactive, while the Baringo Basin is occupied by the Baringo and Bogoria lakes and is tectonically active. Gravity and seismic investigations conducted by the National Oil Corporation of Kenya in the Kerio Valley in 1989 and a magnetotelluric survey conducted in 1996 in the Baringo Basin demonstrated that the modern Kerio and Baringo basins are superimposed on two sedimentary basins, several km deep, that possibly initiated during Paleogene (Hautot et al., 2000). The Kerio Basin is a typical half-graben, >8 km deep, while the Baringo Basin is 7 km deep. Both basins are filled by alternating fluvial and lacustrine sediments and thick piles of volcanics. The lowest part of the Kerio Basin infill is of sedimentary origin and possibly of Paleogene age. Sandstones known as the Kimwarer Formation crop out along the western faulted margin of the Kerio Basin (the Elgeyo fault escarpment) and may represent the earliest section of the Kerio Basin infill. More than 2 km of volcanic rocks fill the Kerio Basin and formed between 23 and 15 Ma, then between 14 and 7 Ma (Figure 4).

Thick sedimentary deposits are found interbedded between these volcanic units and relate to the existence of two large lakes known as the Tambach and Ngorora lakes, both dated middle Miocene. Sediments crop out along the western faulted margins of the Kerio (the Elgeyo fault escarpment) and Baringo (the Saimo fault escarpment) basins (Figure 4). They represent a succession of lake environments from shallow, freshwater lakes resembling the present-day Lake Baringo to small saline, alkaline lakes such as Lake Bogoria, that evolve as a consequence to combined tectonic, volcanic and climatic events to a large freshwater lake. Potential source rocks are represented in the Ngorora Formation by the Poi shales that contain up to 20 % TOC. These shales are similar to the Oligo-Miocene shales found in the Lokichar Basin, or to the organic-rich muds found in the modern Lake Tanganyika Basin.

Although these basins have not attracted much interest from oil exploration companies in the past, recent oil discoveries in the Albertine Graben in Uganda has shifted the focus of many oil companies to such rift basins. With the increased oil exploration activity within Kenya rift basins, it will only be a matter of time before deep exploration wells are drilled in these basins, providing a better understanding of the evolution of basin architecture and sedimentary fill.

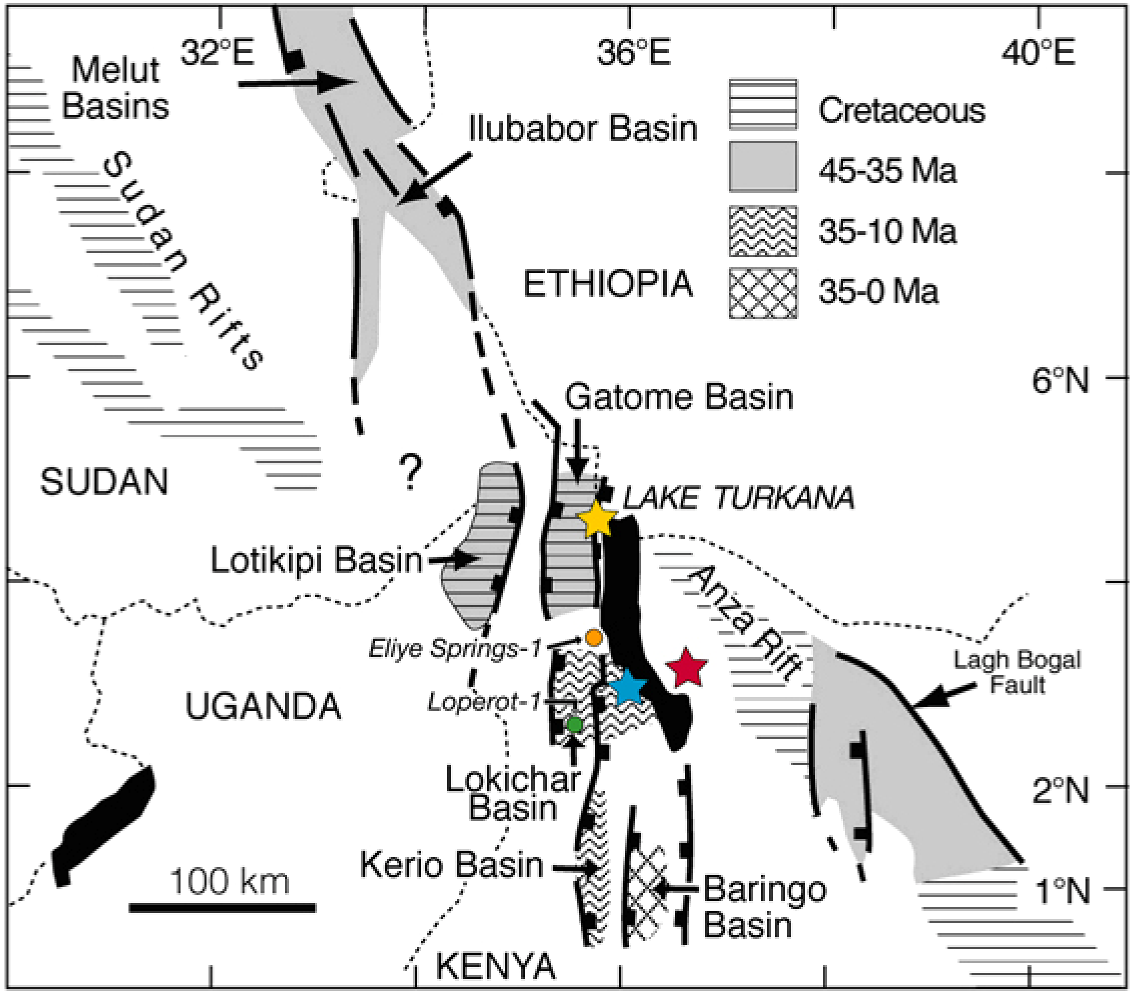

Figure 1. Map showing the distribution of Cretaceous to Paleogene-Neogene rift basins in Sudan and Northern-Central Kenya (modified from Morley et al., 1992; Tiercelin et al., 2004). Yellow star: Lapur Sandstone Formation; Blue star: Lariu sandstones; Red star: Mt Porr sandstones. The Loperot-1 and Eliye Springs-1 wells are also indicated.

Figure 2. Left: General view of the Lapur Sandstone Formation, Lapur Range, northwest Turkana Basin. Right: Close view of the upper units of the LSF overlying the Precambrian basement at Lapur Peak.

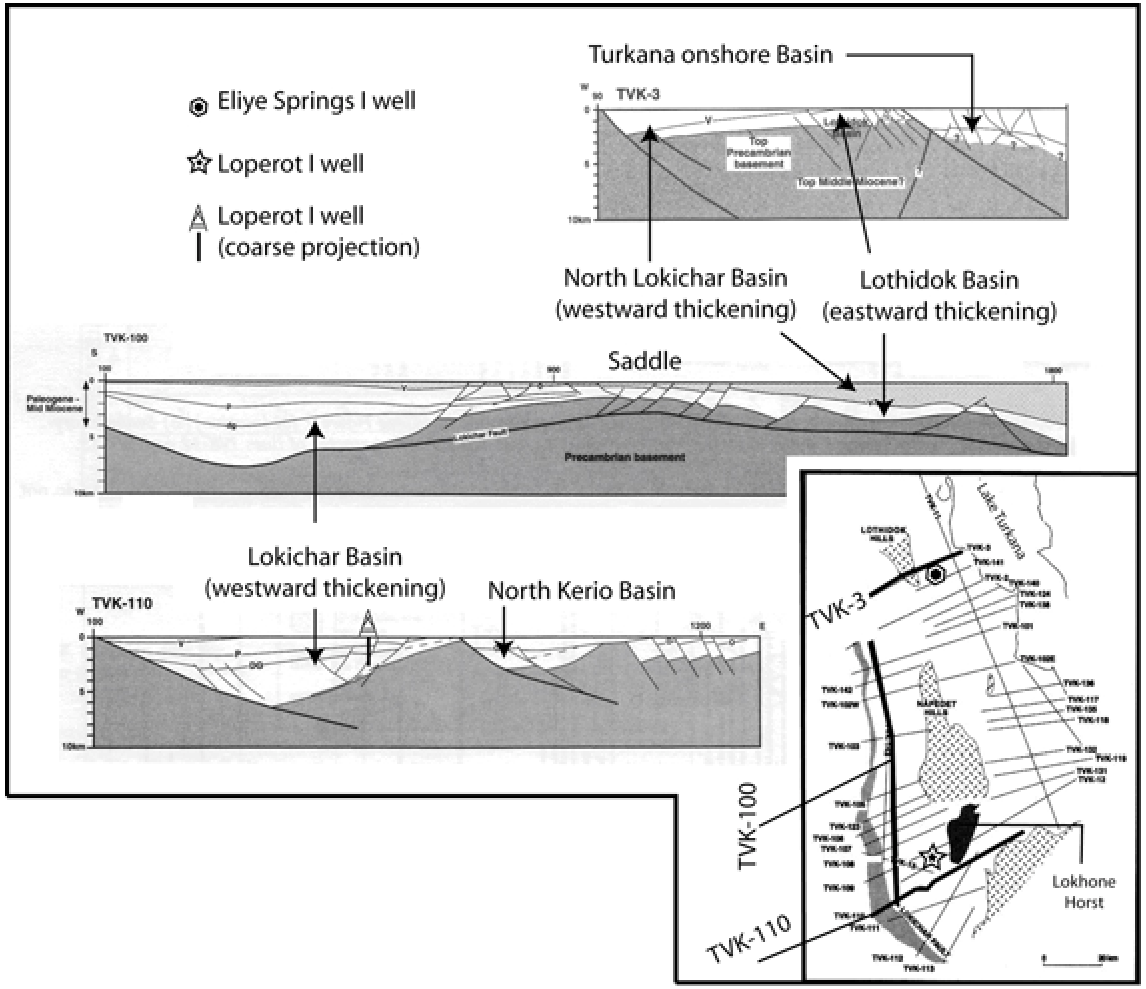

Figure 3. Cross-sections through the Lokichar, North Kerio, Lothidok and Turkana Basins (modified from Morley et al., 1999b).

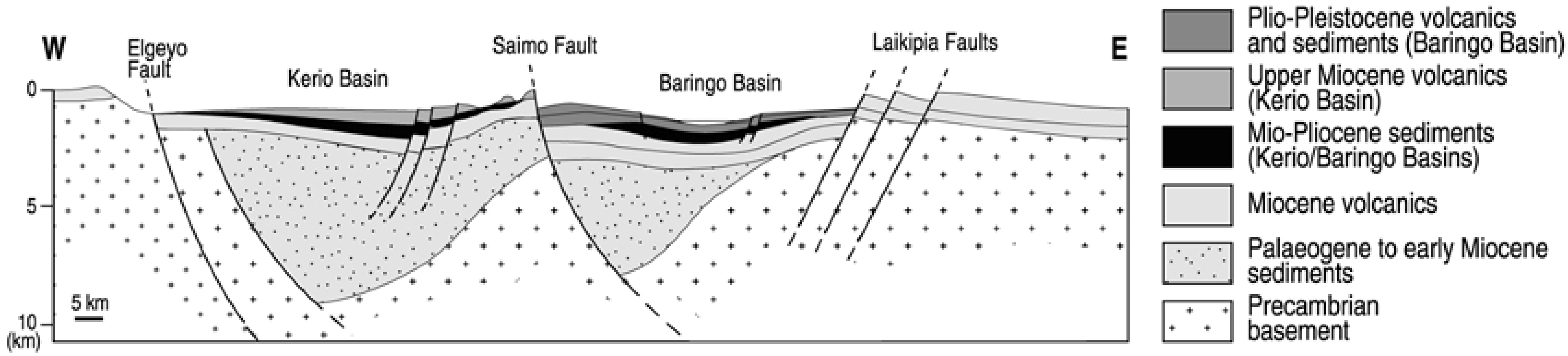

Figure 4. Geological cross-section through the Kerio and Baringo Basins, central Kenya Rift (modified from Hautot et al.,2000).

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