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Airborne gravity gradiometer surveying of petroleum systems under Lake Tanganyika, Tanzania

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SUMMARY

Beach Energy has been the sole interest holder and operator of the 7,200 km^2 Lake Tanganyika South block since 2010. The block is located within the western arm of the East African Rift System. The prospectivity of the lake sequence was enhanced by large oil discoveries in the similar geological environment of Lake Albert in Uganda and in the eastern part of the rift in Kenya. The lack of wells drilled in the lake to date make predicting sedimentary sections difficult. In 2010 Beach Energy commissioned CGG to fly a FALCON® Airborne Gravity Gradiometer (AGG) and a high-resolution airborne magnetic (HRAM) survey over the Lake Tanganyika South block in order to map the basin structural framework and the depth to magnetic basement. The AGG survey facilitated the imaging of the architecture of the rift zone and the interpreted sediment thickness provided an indication of prospective petroleum target areas. This information was used to plan a subsequent 2D marine seismic survey, which was shot in 2012. The preliminary results from the 2D marine seismic survey has confirmed a rifting structure similar to that encountered further north at Lake Albert in Uganda. A number of targets over tilted fault blocks, low-side rollovers and mounded features, have been identified for follow-up from the seismic sections. Natural oil seeps evident on the surface of Lake Tanganyika, which have been sampled and analyzed by Beach Energy, also indicate that a working petroleum system is present in the sedimentary section of the rift beneath the lake.

Key words: East African Rift, Lake Tanganyika, Petroleum, Airborne Gravity Gradiometry, FALCON

GEOLOGY

Lake Tanganyika is over 600 kilometres long and 40 to 80 kilometres wide. The Lake Tanganyika South block is approximately 7,200 km^2 and covers the southern portion of the Tanzanian side of Lake Tanganyika (Figure 1). The Lake Tanganyika South block is within the western arm of the East African Rift System, formed during the Miocene to present-day rifting of central Africa. This rifting event created all the major lakes within eastern Africa.

Interpretation of the evolution of the Tanganyika rift basin has been based upon two different models. One model assumes pure east-west rifting and the other model assumes northwest-southeast rifting with a strong wrenching component (Fairhead and Stuart, 1982). If present-day seismicity is an accurate indicator of the long-term regional extension direction, then focal mechanism solutions support dominant east-west extension for the Lake Tanganyika area. Previous age estimates suggest that the Tanganyika rift basin began to form before 12 Ma in its central region, at about 7–8 Ma for the northern region, and at about 2 Ma for the southern region (Lezzar et al., 1996).

Even though the development of the Tanganyika rifts occurred exclusively during the Neogene, the position and orientation of the Tanganyika rift basin has originated from movement of a series of major fault zones associated with much older tectonic and metamorphic events. These include structures within cratonic areas and orogenic belts that range from early Precambrian to late Precambrian in age.

The rifting process has formed large rotated fault blocks which provide numerous play types in the basin. These include horst structures and down-thrown closures against the major basin bounding faults.

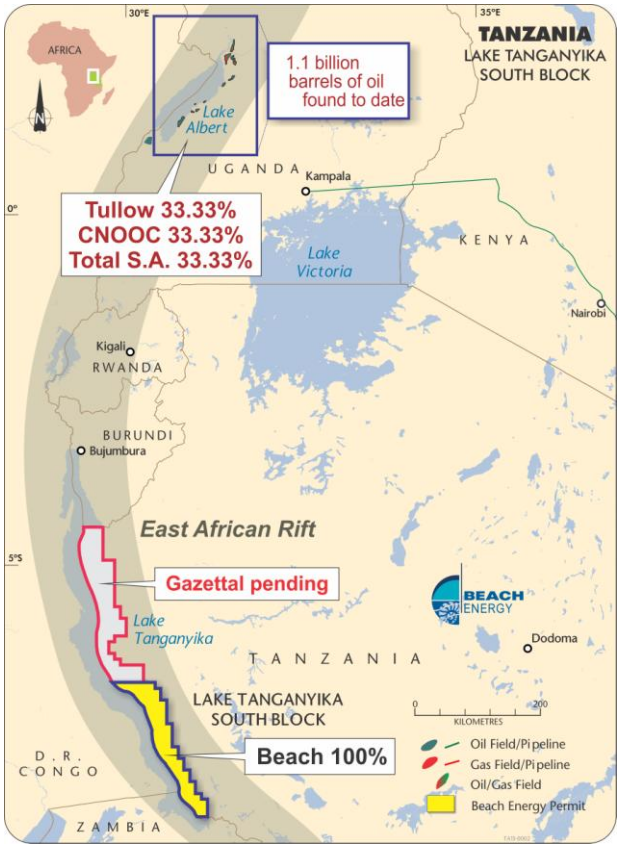

Figure 1. Map of the East African Rift System with the Lake Tanganyika South block.

EXPLORATION HISTORY

Beach Energy has been the (100%) interest holder and operator of the Lake Tanganyika South block since 2010. The lack of wells drilled in the lake to date make predicting sedimentary sections difficult. Vintage 2D seismic data from the mid-1980's suggested that sufficient sediment thickness is present for hydrocarbon generation. In addition significant changes in reflectivity on the 2D seismic data indicated an inter-layered sequence of sands and shales, which have the potential to provide source, reservoir and seal for oil and gas. Finally the occurrences of natural oil seeps indicated a working petroleum system underneath the lake. The prospectivity of the lake sequence was further enhanced by large oil discoveries in the similar geological environment of Lake Albert in Uganda (Van 'Dort et al., 2010), and more recently in the eastern part of the rift in Kenya and Ethiopia (Doherty et al., 2013).

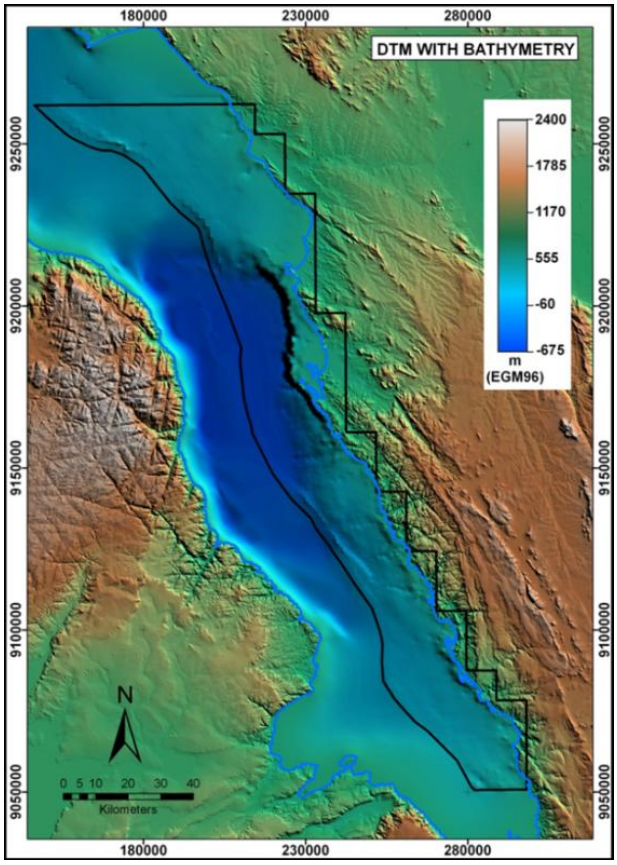

Figure 2. Map of the digital elevation model of the Lake Tanganyika South block.

AIRBORNE GRAVITY GRADIOMETRY SURVEY ACQUISITION, PROCESSING, AND RESULTS

In the past decade AGG surveys have proven to be a cost-effective method to rapidly delineate the structural framework of sedimentary basins (Moore et al, 2012), transition zone basement faulting (Rose et al., 2006), and onshore basement horsts (Fernandez et al., 2010). AGG surveying has also successfully mapped the similar geological environment of Lake Albert in Uganda (Price et al., 2013).

In 2010 Beach Energy commissioned CGG to fly an AGG and a high-resolution airborne magnetic (HRAM) survey over the Lake Tanganyika South block in order to map the basin structural framework and the depth to magnetic basement.

The production flights took place during September and October 2010. To complete the survey area coverage a total of 42 production flights were flown, for a combined total of nearly 28,000 line kilometers of data acquired.

The survey was flown at a nominal terrain clearance of 140 meters (subject to safety considerations) above the terrain, with SSE-NNW oriented traverse lines at 330m line spacing and NNE-SSW oriented tie lines with 1,500m tie-line spacing. Generally moderate turbulence was encountered during surveying, with lower turbulence encounter over the offshore portion of the survey, resulting in moderate RMS difference noise levels of 3.4 eotvos in the measured G_{NE} and G_{UV} gravity gradiometer component data (1 eotvos equals 10^{-9} s^{-2} making 1 Eo equivalent to 0.1 mGal/km) (Dransfield and Christensen, 2013).

The measured G_{NE} and G_{UV} gravity gradient components were converted to vertical gravity, g_D, and vertical gravity gradient, G_{DD}, by standard potential field integration and derivative techniques operating in the spatial and wave-number domains (Dransfield and Lee, 2004).

The AGG system has on-board laser scanner and differential GPS capability to record and construct a Digital Elevation Model (DEM) for terrain correction of the AGG data. Figure 2 shows the DEM constructed by combining the high resolution laser-scanner DEM with lower resolution Shuttle Radar Topography Mission (SRTM) data and detailed bathymetry collected by Beach Energy. The AGG data have been fully terrain corrected with a terrain density of 2.67 g/cm^3, and a lake water density of 1.0 g/cm^3.

Figure 3 shows the first vertical derivative of the reduced-to-pole total magnetic intensity, and readily defines the magnetic textural characteristics of the high-intensity, high-frequency zones over outcropping or shallow buried basement. However, while textural features are evident, over Lake Tanganyika the response is very subdued.

Figure 4 shows the resulting fully terrain corrected vertical gravity gradient data, G_{DD}, over the Lake Tanganyika South block. The amplitude range of the data set is quite substantial from -105Eo to +125Eo, from the gravity gradient high over outcropping basement in the east to a low developed in the center of Lake Tanganyika in the west. Two separate low areas can be identified over the lake; one in the north and one in the west central part of the survey. These lows are separated by a subtle gravity gradient high.

DATA INTERPRETATION

A preliminary interpretation was undertaken by CGG with the aim to image the architecture of the rift zone and define the sediment thickness. The interpretation incorporated the newly acquired airborne magnetic data, gravity gradiometer data (g_D and G_{DD}), regional geology, four vintage 2D seismic lines, the digital terrain model (DTM) and detailed bathymetry and Landsat 321 data.

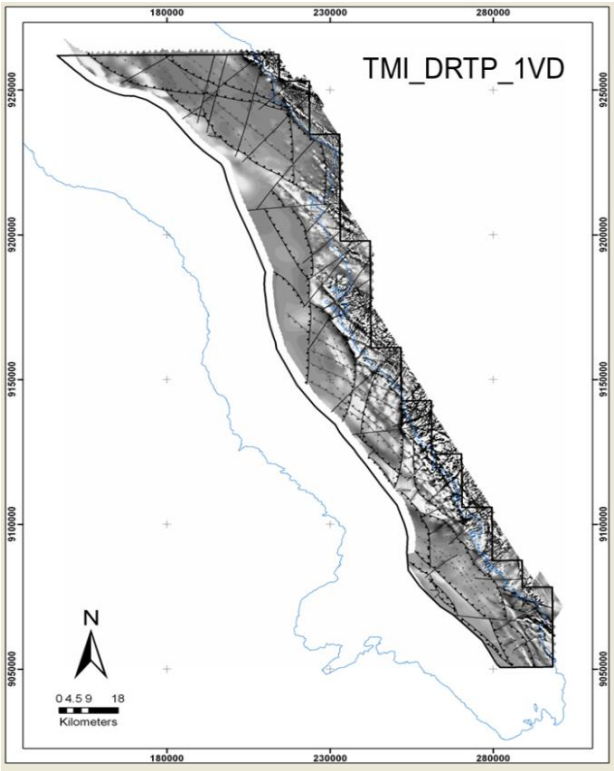

Figure 3. Basin structural interpretation superimposed on the first vertical derivative of the reduced-to-pole total magnetic intensity data.

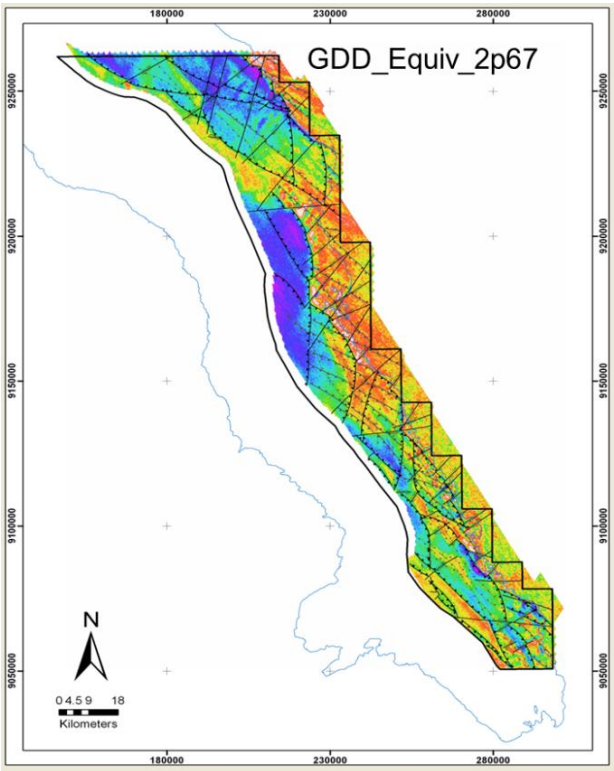

Figure 4. Basin structural interpretation superimposed on the terrain corrected vertical gravity gradient data, G_{DD}.

The rifts in the study area are believed to reflect a simple shear rifting model exhibiting stretching, thinning, and lithospheric detachment, exploiting pre-existing crustal weakness through fault reactivation. The Tanganyika rifts are a series of half grabens that are mostly arcuate or crescent shaped in plan view. When combined with differential subsidence of the half graben, this geometry creates horizontal movement which is expressed as shearing and rotation along the ends of the units.

The magnetic dataset (Figure 3) reflects the nature of the magnetic basement underlying the rift system. NW-SE trends dominate in most of the areas along with some NE-SW & E-W trends in some places. The relative basement elevation can be ascertained from the varying magnetic frequency. The basement appears to be very shallow in the central eastern part of the block area and steps down towards the west, whereas in the northern part of the block area the basement sees a sharp drop in elevation. The difference in basement composition is also reflected in the magnetic texture and intensity. The linear texture of the basement in the central eastern part of the block area suggests the basement fabric consists of a number of joints. The high intensity magnetic anomaly indicates that the basement is composed of highly magnetic material, probably shallow volcanic intrusions.

The gravity dataset (Figure 4) shows the various half graben and their associated intra-graben highs. It also indicates the general dip of the half-graben. The relative density contrast amongst the various half grabens is apparent and reflects the differential evolution of the rifts in space and time. The half graben which developed in the northern part of the block appears to be deeper and have thicker sedimentary infill than the half graben in the central and southern parts of the block area.

A preliminary depth to magnetic basement model was generated using grid-based Euler deconvolution depth estimation techniques. A basement elevation model was produced showing the elevation of the magnetic basement surface relative to datum. Basement elevations range from approximately -8,000 m to 1,400 m with elevations in the range of 700 to 1,400 m tending to be coincident with basement outcrop, which form topographic highs. In the shallow lake areas basement elevations are concentrated within a range of approximately -1000 to 700 m. Basement elevations less than -3000 m occur in the north and west central areas and are coincident with gravity lows.

A sediment thickness model (Figure 5) was generated by subtracting basement elevations from the bathymetry. This model exhibits good correlation with major features in the structural interpretation, with basement lows forming NW-SE orientated troughs. The sediment thickness model indicates a large, deep trough (with excess of 4,000m sediment thickness) in the north, and in the west central area a trough with excess of 3,000m sediment thickness. In addition smaller depocenters (<3000 m sediment thickness) occur in the southern part of the survey area.

The 3D Euler depth to basement analysis provides a broad overview of basement architecture and forms a good starting point for a more detailed investigation along profile data. However, the grid-based depth to basement analysis lacks the spatial resolution of the structural interpretation and some minor graben structures are not detected.

DISCUSSION AND CONCLUSIONS

The AGG survey facilitated the imaging of the architecture of the rift zone and the interpreted sediment thickness provided an indication of prospective petroleum target areas. This information was used to plan a subsequent 2,100 kilometer 2D marine seismic survey, which was shot

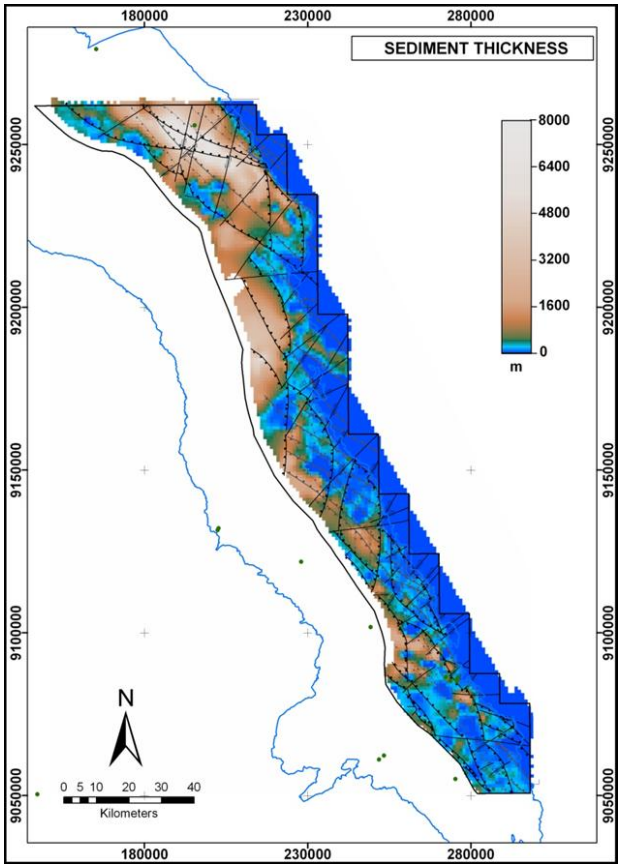

Figure 5. Sediment thickness model of the Lake Tanganyika South block.

between June and August 2012. The preliminary results from the 2D marine seismic survey has confirmed a rifting structure similar to that encountered further north at Lake Albert in Uganda. A number of targets over tilted fault blocks, low-side rollovers and mounded features, have been identified for follow-up from the seismic sections (Figure 6). Natural oil seeps evident on the surface of Lake Tanganyika, which have been sampled and analyzed by Beach Energy, also indicate that a working petroleum system is present in the sedimentary section of the rift beneath the lake.

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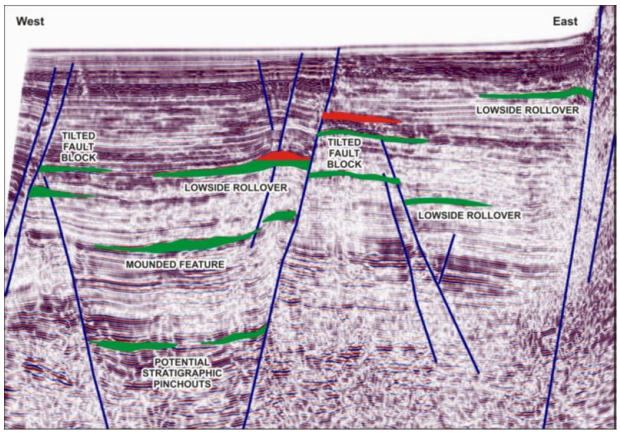

Figure 6. Lake Tanganyika South block potential play types from the 2012 2D marine seismic data, red = gas, green = oil.