EAST AFRICAN RIFT SYSTEM (EARS) – FRONTIER PETROLEUM EXPLORATION

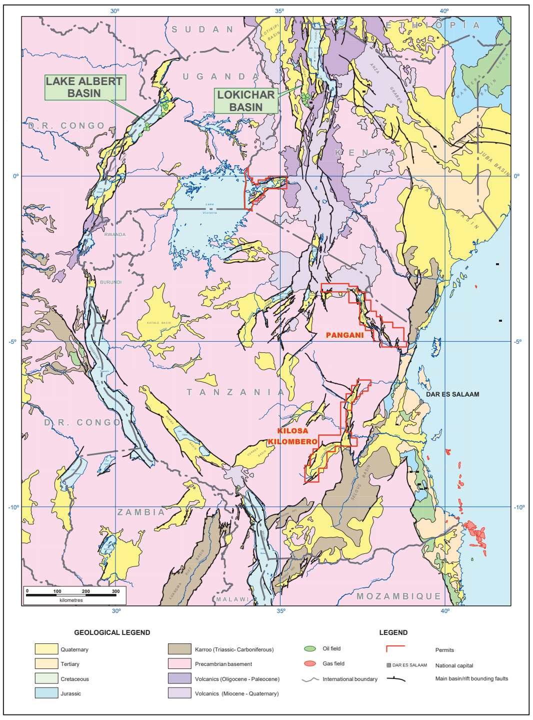


Fig 1.1

EXPLORATION & DISCOVERY IN THE EARS

- An exploration methodology developed for two Tanzanian East African Rift System (EARS) permits offers a cost-effective means of systematically re-focusing exploration from regional to permit and finally project scale.
- The East African Rift System (EARS), with its Western and Eastern branches separated by the Tanzanian Craton, extends from Ethiopia and Uganda through Tanzania into Mozambique and the DRC (Figure 1.1). Recent major discoveries (>4 billion barrels) in the Lokichar Basin, Kenya and Lake Albert Basin, Uganda highlight the potential for additional major discoveries within the EARS.
- The EARS is mostly underexplored and locally virtually unexplored and is a challenging play because there is little available relevant geological, exploration or background data, and no subsurface drilling control.
- As an example, there has been no effective previous exploration in southern Kenya and Tanzania (southern section of the Eastern Branch).
- Initial appraisals mostly rely on geological mapping and the interpretation of topographic and satellite imagery.
- No reliable physical property data is available for rift or basement lithologies.
- Difficult terrain and logistics and the possible presence of intra-rift volcanics makes first-pass seismic surveying high risk, very expensive and of uncertain effectiveness.

THE NEXT FRONTIER: KILOSA-KILOMBERO & PANGANI

- Swala Oil & Gas (Tanzania) PLC's Pangani & Kilosa-Kilombero permits cover ~ 34,500 km^2 of the eastern EARS in eastern Tanzania (Figure 1.1).
- Exploration methodology used on their Kilosa-Kilombero permit is presented on this poster.
- Le Gall (2004) suggested sediment accumulations of up to 6 – 8 km within the Kidatu rift segment.
- No legacy seismic data or well control information was available within the permit areas.
- Ground gravity coverage is sparse, unevenly distributed and not focussed on the rifts.
- Low resolution satellite gravity is of limited use at permit-scale.
- Satellite topography shows rifts as flat, low-lying areas, with rift margins clearly delineated (Figure 1.2).
- Interpretation of SRTM & Landsat TM data provided initial 'at surface' definition of rift margin faults and guidance to older Karoo and Neogene rift fill sedimentation (Figure 1.3).
- This SRTM-Landsat TM interpretation does not adequately show subsurface geometries and thickness variations within the rift basins.
- The use of vintage (1970s) aeromagnetics provided efficient, inexpensive definition of sub-surface rift geometries and sediment thicknesses.

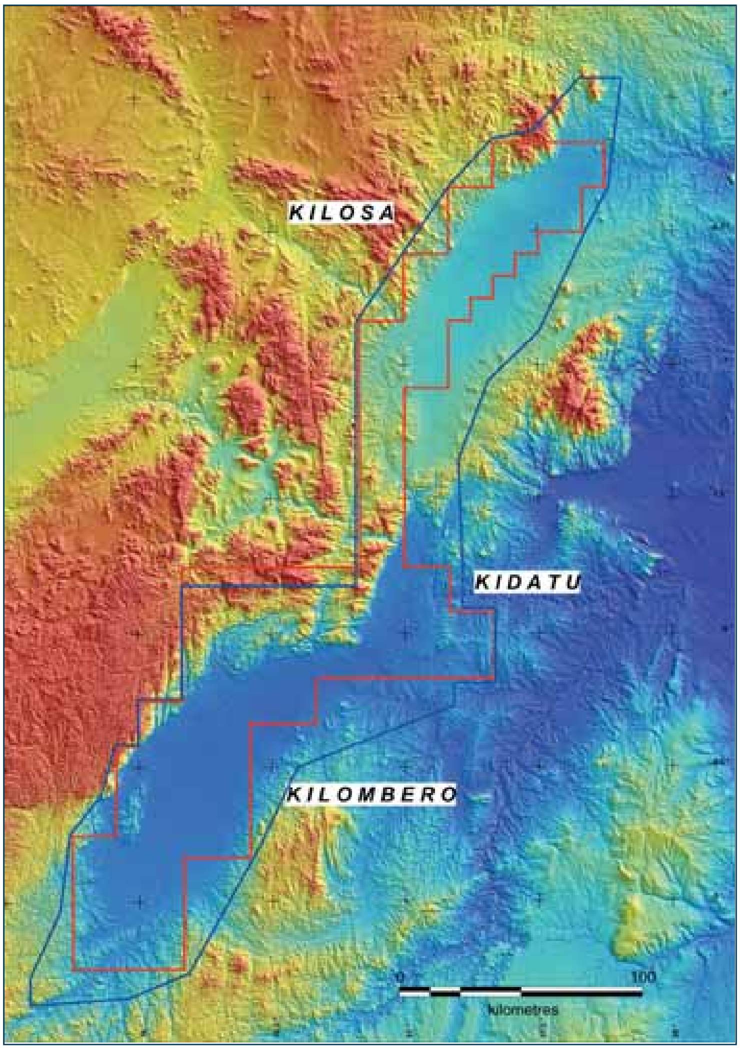


Fig 1.2

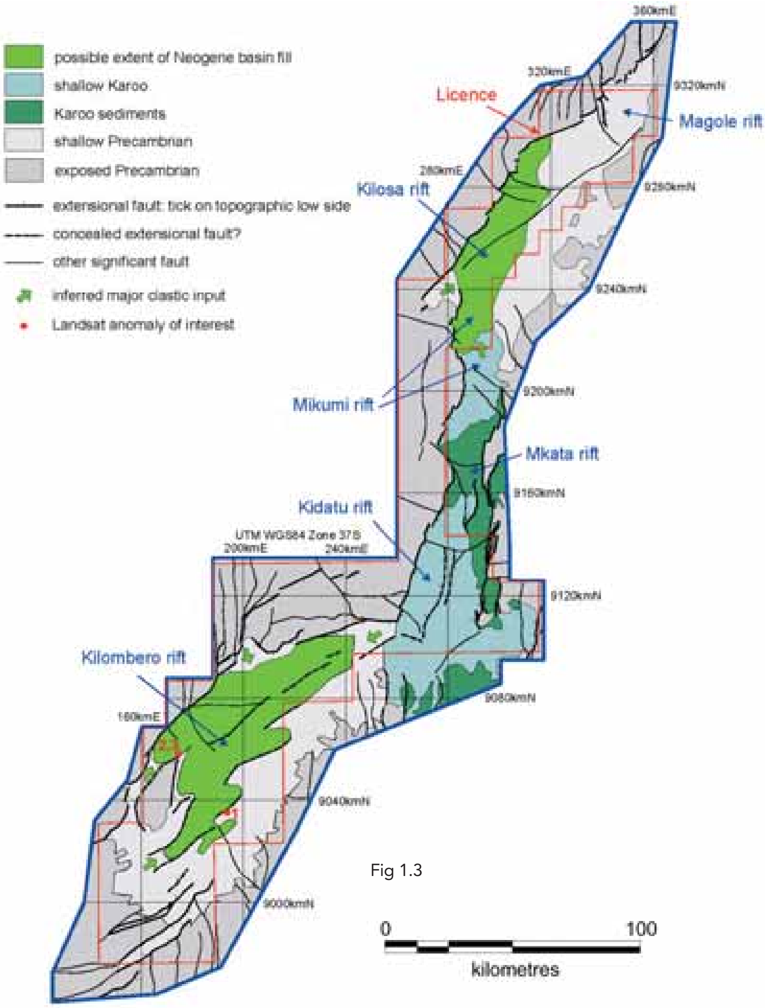


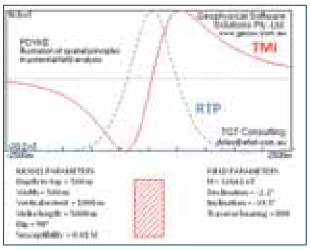
Fig 1.3

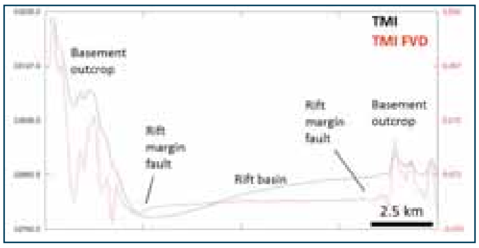
GeTech AEROMAGNETIC DATA COMPILATION

- 1970s vintage aeromagnetics was purchased over Swala's Pangani & Kilosa-Kilombero permits.
- The survey was flown at 1 km line spacing & 500m average drape, with visual flight path recovery (positional uncertainties).
- By modern standards, a low quality, low resolution dataset, but capable of yielding significant depth-to-basement and structural information.
- Identified prospective sections of the Pangani and Kilosa-Kilombero rifts for new detailed magnetics-gravity surveys.

DATA PROCESSING & ENHANCEMENTS

- Customised processing-filtering enabled identification of areas of deeper basement, faults, rift margins etc.
- Primarily reduction-to-pole (RTP) & first vertical derivative (FVD) FFT filtering.
- RTP filtering essentially located the magnetic anomalies directly over the causative magnetic source.
- FVD (vertical gradient) filtering is particularly useful for highlighting structure (e.g. rift margin faults).
- Images generated using customised sun-shading and colour palettes / colour stretches (Figure 2.1, 2.2).



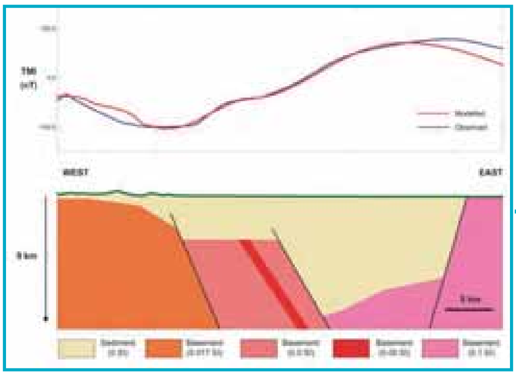


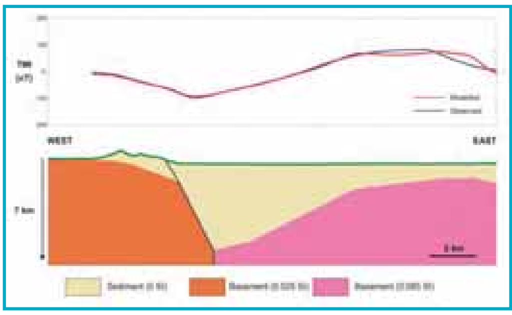
STRUCTURAL INTERPRETATION: DELINEATING RIFT PHASES AND BASEMENT INFLUENCE

- A plan-based structural interpretation (Figure 2.1) of the aeromagnetics clearly defined the geological framework of the rift system, and provided a context for the quantitative interpretation of basement depths.
- Main outcomes:
  1. Dominant N-S rift trend at Kilosa and Kidatu (mainly Karoo events?).
  2. NNE to NE dominant rift trend at Kilombero (Tertiary rift event?).
  3. Thicker rift fill sediments mapped as diminished, longer wavelength (smoother) magnetic basement response.
  4. Shallower basement or volcanics produce short wavelength (rougher) magnetic texture.
  5. The Precambrian basement magnetic signature indicates significant structural and lithological complexity (i.e. heterogeneity).
  6. Dominant NE-NNE and NW brittle structures control offsetting of the N-S and NNE rifts, no evidence of young transverse movement.
  7. Rift shoulders are clearly delineated in the aeromagnetic data.
  8. Rift margins defined by magnetic and topography are similar but not always coincident. This demonstrates that the main faults at surface are a recent (Quaternary) rifting event, not necessarily spatially coincident with the main Karoo or Tertiary structures.

2.5D MODELLING – HOW DEEP ARE THESE RIFTS?

- Hands-on' magnetic modelling on profiles across key areas identified from the aeromagnetics.
- Rift basins generally modelled as basic half-grabens.
- Magnetic susceptibility data non-existent. Basin sediments assumed to be non-magnetic, overlying homogenous or variably magnetic basement.
- Parts of the Karoo Group could be magnetic, as could intra-rift volcanic sequences.
- Qualitative interpretation and depth to basement modelling (Figure 2.2) highlighted three areas of deep basement and provided a focus for further evaluation.
- Modelling indicate basin depths of 7-8 km at Kilosa (Figure 2.3), 7 km at Kidatu (Figure 2.4), and ≤4km in the Kilombero rift.
- Models are unconstrained, but acceptable first-pass, low cost guides to rift basin depths.
- Detailed airborne magnetic and gravity surveys were designed to further evaluate these areas.





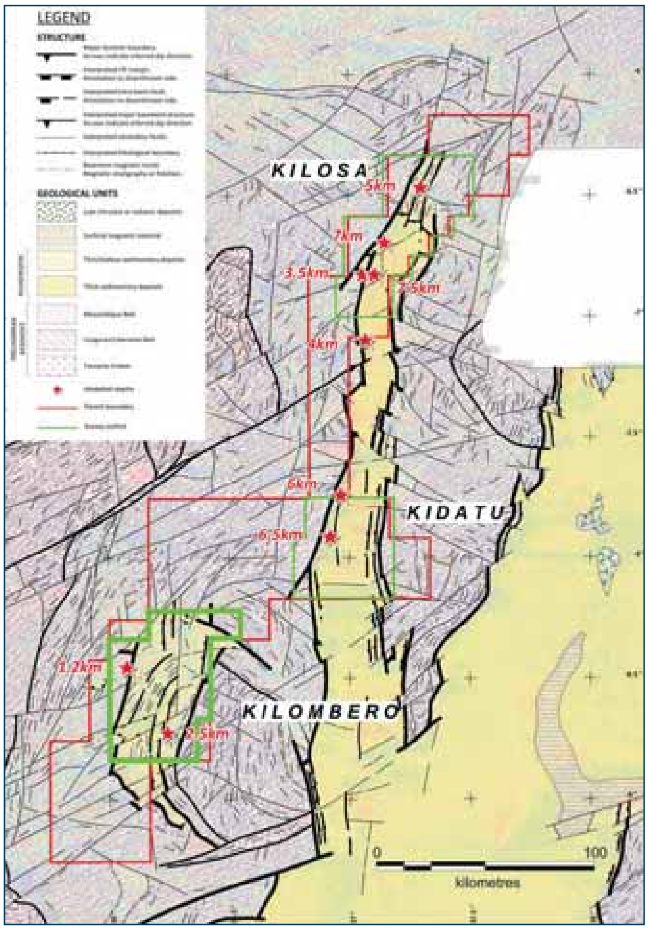


Fig 2.1 Structural interpretation over TMI FVD image

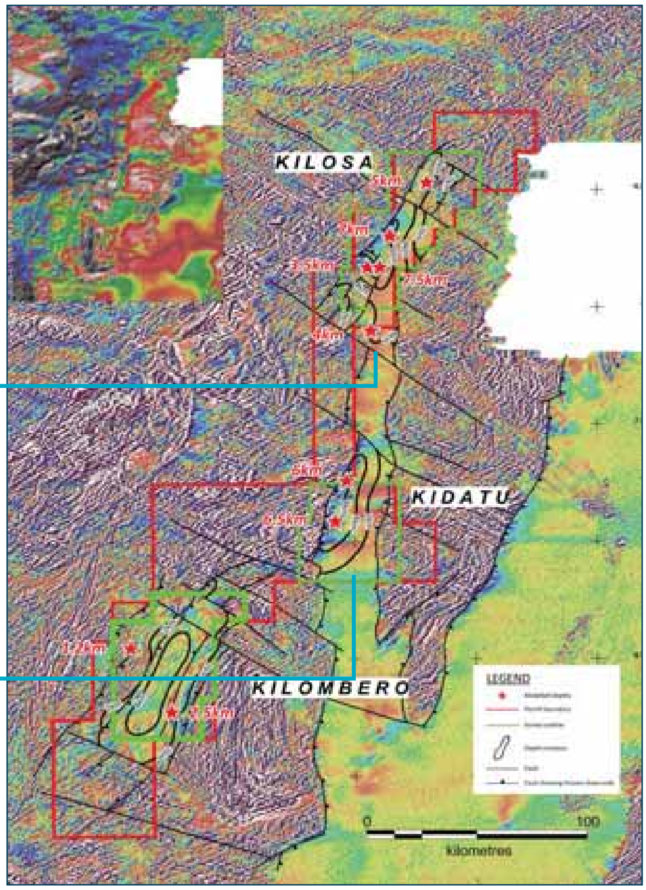


Fig 2.2 Hand-contoured depths derived from modelling results & simplified structure over TMI FVD image; Inset – TMI image.

PHASE 2: PROPRIETARY AIRBORNE MAGNETIC & GRAVITY SURVEYS – FROM PERMIT TO PROJECT SCALE

PROPRIETARY AIRBORNE MAGNETIC AND GRAVITY SURVEYS

- Magnetic and gravity surveys flown by NRG over 3 areas within the Kilosa- Kilombero permit (Figure 3.3, 3.4).
- Poster focus is on the Kilombero area. Same methodology applied to other survey areas.
- Gravity & magnetic surveys flown separately to optimize resolution and quality. Parallel acquisition compromises the quality and resolution of the magnetics because of the higher ground clearance required for good quality gravity data.
- Aeromagnetics collected on 1km spaced lines & 50-100m drape (helicopter).
- Gravity collected on 2km spaced lines & 500-700m drape (fixed-wing aircraft).
- Total coverage (3 survey blocks) of approximately 13,000km^2.

Pilatus Porter PC-6 fixed-wing carrying GT-1A gravimeter. Killimanjaro looming on the horizon.

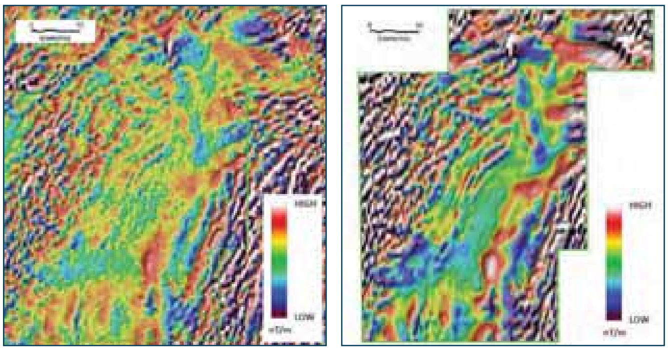


Fig 3.1a TMI FVD images from the vintage aeromagnetic data (left) and proprietary aeromagnetic survey (right).

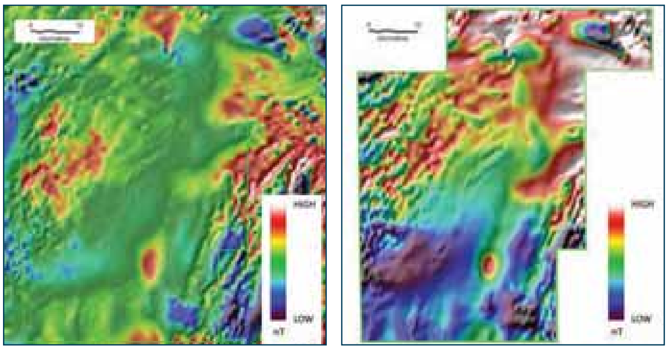


Fig 3.1b TMI images from the vintage aeromagnetic data (left) and proprietary aeromagnetic survey (right).

COMPARISON AGAINST THE LEGACY AEROMAGNETIC DATA

- The new magnetics compared well with the 1970s GeTech data, and gave increased confidence in the Phase 1 outcomes (Figure 3.1a, 3.1b).
- The along-line resolution, quality and reliability of the new magnetics is far superior to the 1970s data, providing much better control on important input parameters for modelling.

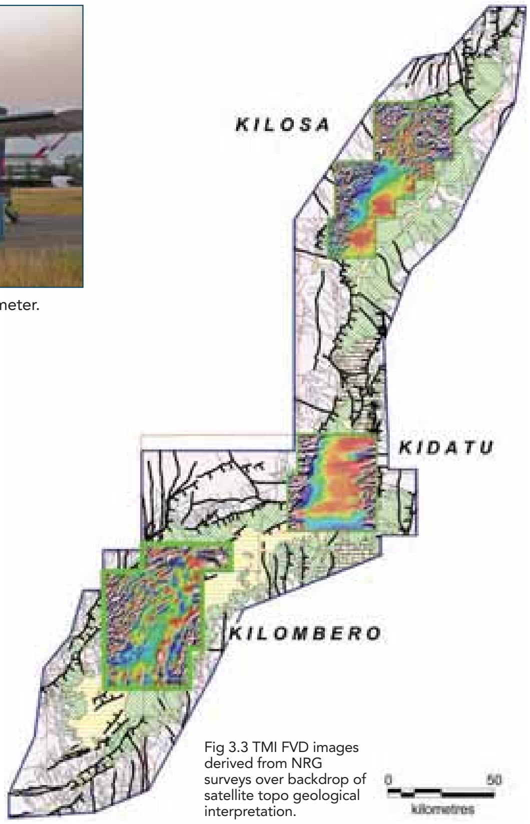


Fig 3.3 TMI FVD images derived from NRG surveys over backdrop of satellite topo geological interpretation.

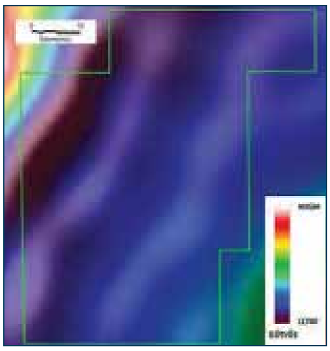


Fig 3.2c Residual bouguer gravity anomal

COMPARISON AGAINST THE LEGACY GRAVITY DATASETS

- The proprietary airborne gravity has much greater spatial coverage and more systematic sampling than the legacy ground gravity dataset.
- It has vastly improved spatial resolution than the satellite gravity dataset (Figures 3.2a, 3.2b, 3.2c).
- The rifts are generally characterised by gravity lows (as expected). Gravity lows are also present over areas of shallow or outcropping basement; i.e. low density lithological blocks are present within the basement.
- The narrow Kilombero gravity trough is significantly narrower than the rift indicated by the topography and the surface geology.
- Crucially, the gravity dataset enables direct modelling of basin depths whereas the magnetics is better suited to modelling the basement depth.

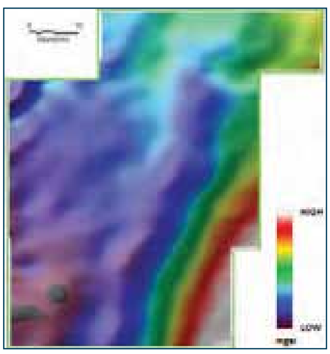


Fig 3.2b Bouguer gravity anomaly derived from NRG survey. y derived from NRG survey

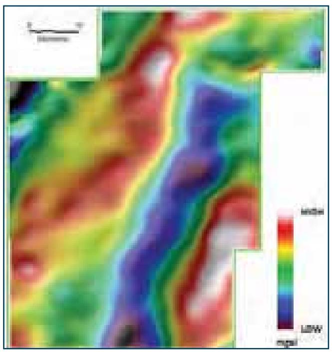


Fig 3.2b Bouguer gravity anomaly derived from NRG survey. y derived from NRG survey

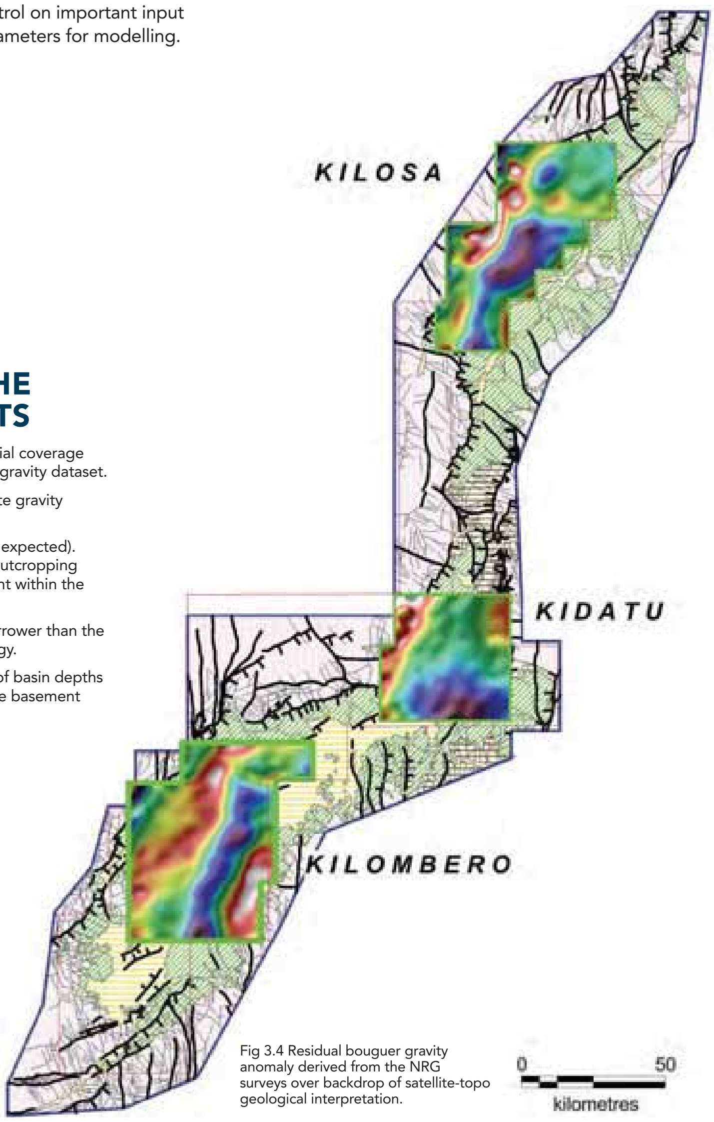


Fig 3.4 Residual bouguer gravity anomaly derived from the NRG surveys over backdrop of satellite-topo geological interpretation.

PHASE 2: PROPRIETARY AIRBORNE MAGNETIC & GRAVITY SURVEYS – FROM PERMIT TO PROJECT SCALE

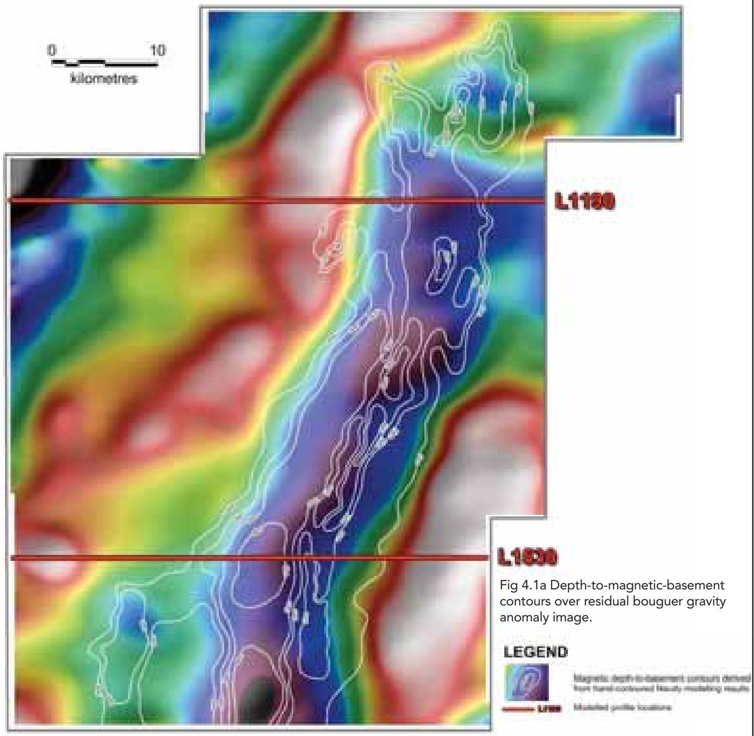


Fig 4.1a Depth-to-magnetic-basement contours over residual bouguer gravity anomaly image.

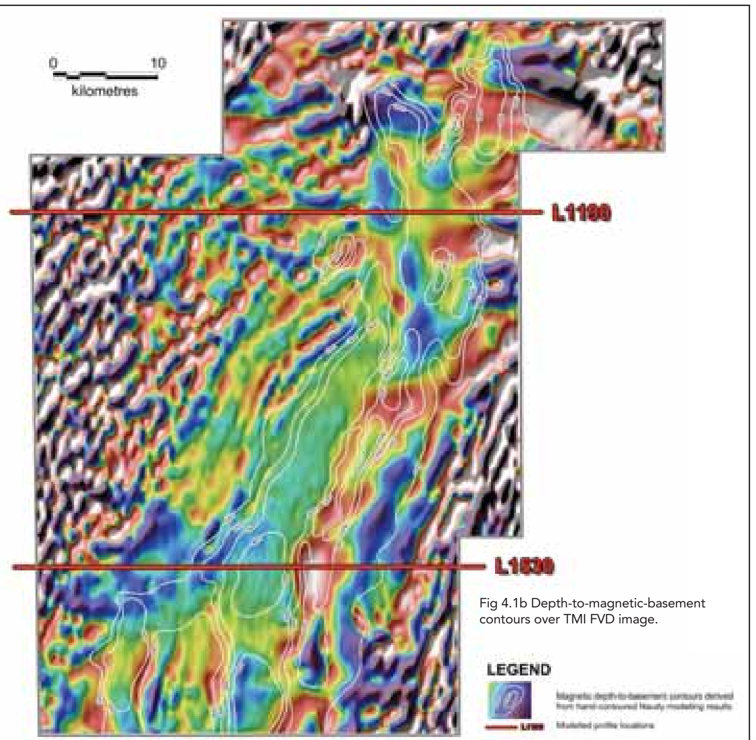


Fig 4.1b Depth-to-magnetic-basement contours over TMI FVD image.

AUTOMATED DEPTH-TO-BASEMENT MODELLING

- Automated depth-estimation (DTB) techniques applied to the gravity and magnetics included Naudy, Euler deconvolution, spectral depth analysis and 3D inversion modelling.
- Naudy depth estimates from the magnetics produced the most consistent results, but with statistically few valid solutions over the deeper parts of the basins.
- Hand-contouring of the sparse depth solutions produced a coherent, simple and geologically plausible interpretation of the automated depth analysis data (Figures 4.1a, 4.1b).
- Final DTB results indicate ≤4km of sediments within a narrow NNE corridor (Figure 4.2), consistent with the TMIFVD image enhancement; smooth, broader wavelength, low intensity responses indicative of deeper basement (Figure 4.1a).
- The Naudy DTB corridor also clearly correlates with a residual gravity low zone (Figure 4.1b), indicative of a thicker section of low density sediments.

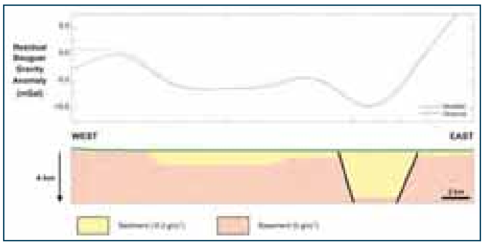


Fig 4.2c

2.5D INTEGRATED GRAVITY & MAGNETIC MODELS

- 'Hands-on' gravity & magnetics modelling completed on selected profiles in the Kilombero rift (Figures 4.1a, 4.1b).
- Models indicate possible sediment thicknesses of 2- 4km in the deepest part of the basin, using sedimentdensity contrasts of ~0.2 to 0.3 g/cm3 (Figures 4.2a, 4.2b).
- Consistent with automated DTB estimates from the magnetic data.
- Final models predominantly reliant on the gravity data, modified to fit the magnetic data where possible.
- Magnetic modelling was extremely difficult: low magnetic signal over the deeper basins and heterogeneous basement.

Fig 4.2a

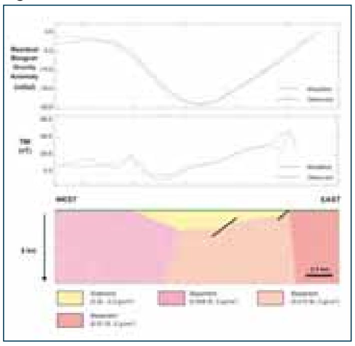


Fig 4.2b

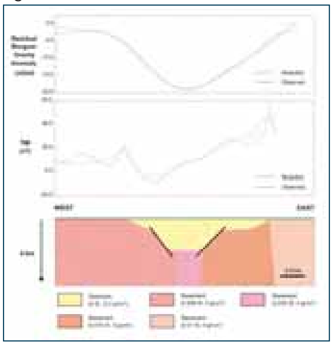


Figure 4.2a, 4.2b: Gravity models (top panel) indicated between 2 to 4 km of sediment deposition into a 5km wide trough in the northern section of the Kilombero rift (L1190 – Fig 4.1a, 4.1b). Magnetic model (bottom panel) indicated variable basement composition and/or intrarift volcanics /magnetic horizons (not modelled in this scenario).

Fig 4.2d

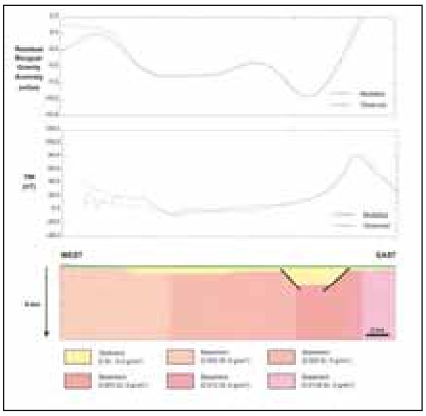


Figure 4.2c, 4.2d: Gravity model (top panel) indicated up to 4 km of sediment deposited into a 7 km wide trough within the Kilombero rift (L1530 – Fig 4.1a,4.1b). Broad platform to the west contains up to 1 km of sediment, possibly related to Quaternary rifting. Magnetic model indicated basement composition and/or intrarift volcanics/magnetic stratigraphy (not modelled in this scenario).

SUMMARY OF MODELLING WORK – FOCUS FOR SEISMIC PLANNING

- Automated Naudy depth analysis produced a plausible magnetic depth-to-basement map (Figure 4.2). Manual interpretation and hand-contouring was crucial.
- DTB map + 2.5D modelling and qualitative image interpretation generated a coherent, geologically plausible basin geometry.
- Higher density contrast modelling suggest Tertiary sediments are present in the Kilombero rift.
- The deepest basin occurs within a narrow, NNE trough in the central Kilombero rift. This is not obvious in the topography and surface geology which indicated a much wider basin, with little indication of the deep, inner rift.
- This key outcome efficiently focussed seismic follow-up planning, and indicated sediment thicknesses sufficient for hydrocarbon generation.

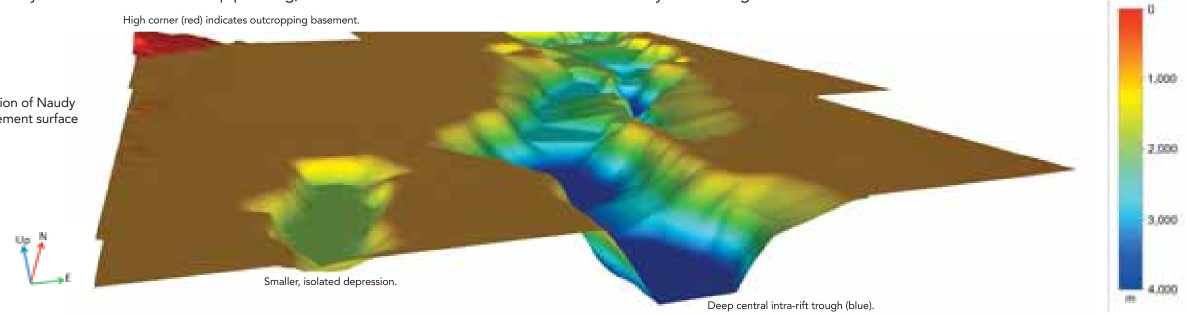


Figure 4.3 3D presentation of Naudy depth-to-magnetic basement surface

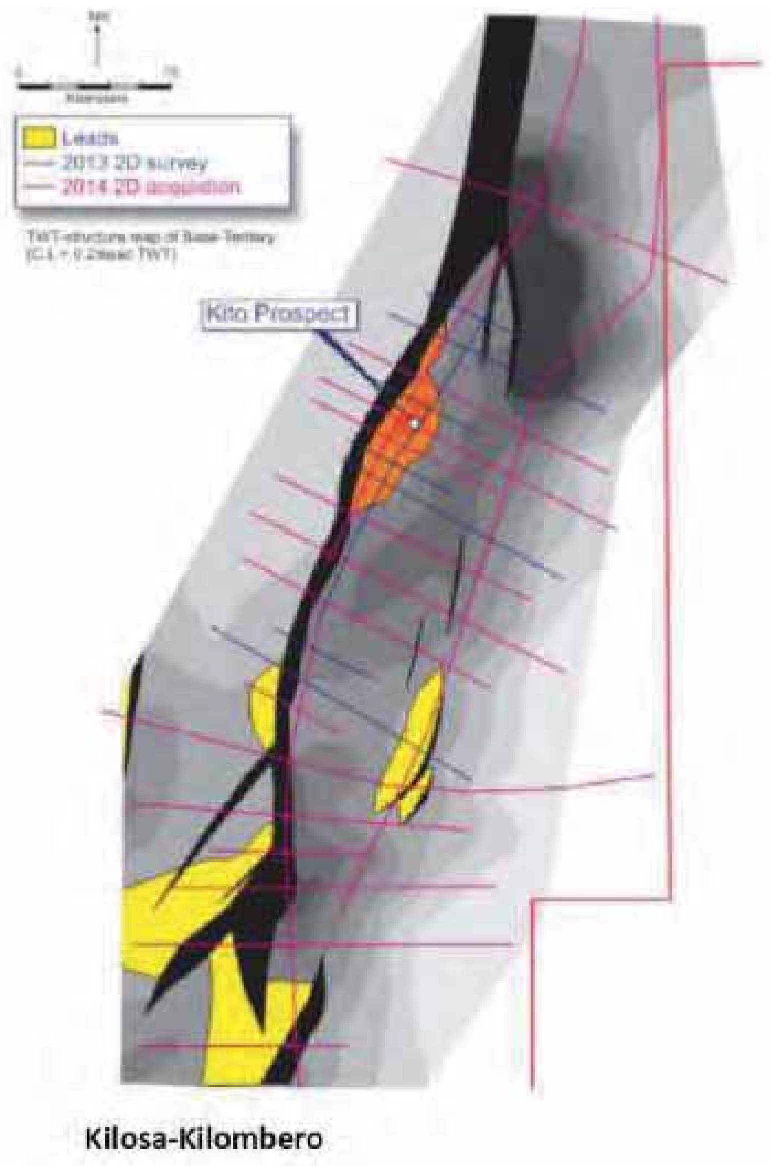
POTENTIAL FIELD ANALYSIS AS A FRONTIER EXPLORATION TOOL – WHAT HAS IT SHOWN US?

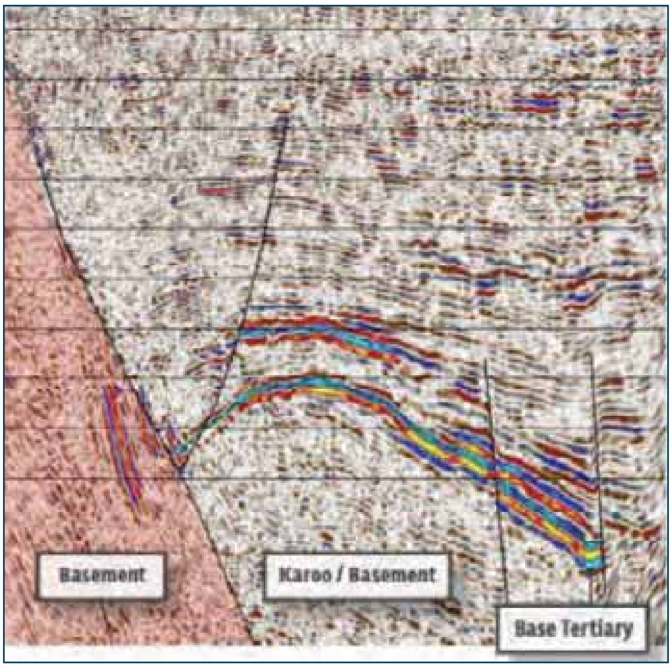
FRONTIER EXPLORATION STRATEGY USING POTENTIAL FIELD GEOPHYSICS

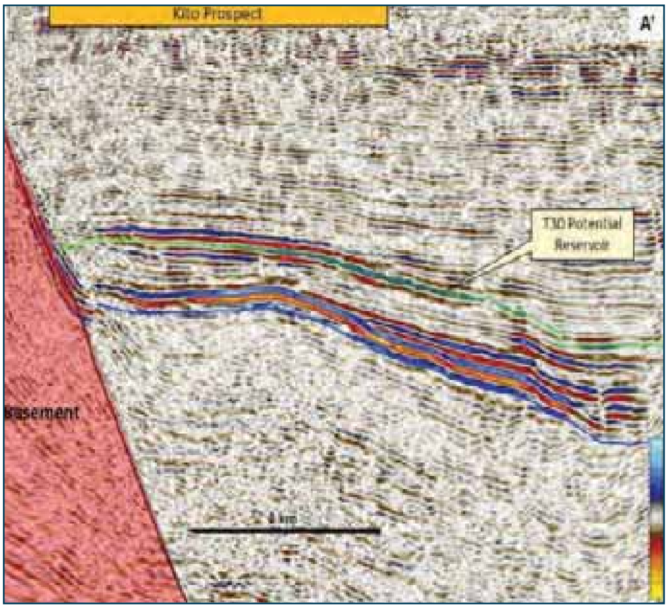
- Crucial first step: sourcing low-cost vintage aeromagnetic data (~\$0.10/km^2!!).
- This provided first-pass geological and structural context, and depths / sub-surface geometries of the rifts.
- Up to 4 km of sediment indicated in a deep trough within the Kilombero rift segment.
- Little indication of the trough in the satellite/topography ‘surface’ interpretation.
- Vintage data provided focus for follow-up aeromagnetic & airborne gravity surveying.
- Plan-based structural interpretation and hands-on modelling (± automated depth estimation methods) of new magnetic data further defined basin structure and geometry.
- Better definition of the narrow, deep trough within the Kilombero rift.
- Enabled downsizing of exploration permit by further delineating shallow areas / potential complications (e.g. volcanics).
- Airborne gravity data mapped sediment distribution and enabled direct modelling of basins.
- Together, magnetic and gravity methods are complimentary techniques – sensitive to basin and basement characteristics.
- De-risked the large permit areas and advanced knowledge of basin structure / geometry and basement architecture.
- Key ingredient for success: collaboration between geophysical specialists and geological advisors – sound geological input maintained through each phase of work.
- Reduced size of area for follow-up seismic, provided pertinent information for seismic planning (constrained geological strike, mapped potential problem areas – intra-rift volcanic s).
- Result – significant reduction in overall cost of exploration.

2D SEISMIC ACQUISITION

- Swala conducted 2D seismic reflection surveys in the Kilombero Rift in 2013 and 2014.
- The narrow, elongate rift basin interpreted from gravity and magnetics was confirmed.
- A large hanging-wall structure has been detailed as the Kito Prospect and is scheduled for drilling in 2016.
- More information on the seismic results and exploration plans are available on Swala’s website (www.swala-energy.com)







Note: Figures sourced from Swala website

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