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Gravity survey and basin architecture modeling of the East African rift basin

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Abstract

Despite decades of geological and geophysical investigation, the three-dimensional architecture of the sedimentary basins within the East African Rift System remains poorly resolved at many locations, leaving gaps in our understanding of basin depth, fault geometry, and sediment thickness that are needed for both tectonic modelling and hydrocarbon exploration. This research conducted a ground-based gravity survey across a 4,800 km² segment of the central Kenya Rift between Lake Baringo and Lake Bogoria, collecting 312 gravity stations along five transverse profiles during March-October 2022. Bouguer anomaly values ranged from -138.4 to -72.6 mGal, with the most negative values concentrated along the rift axis. Two-dimensional forward modelling of the gravity profiles, constrained by available seismic reflection and borehole data, delineated a half-graben geometry with maximum sediment thickness of 6.2 km along the axial trough. The basin is asymmetric, with the deepest point offset toward the western boundary fault where throw exceeds 4 km. Three distinct sedimentary units were resolved: a basal Miocene volcanic-sedimentary sequence (density 2.55 g/cm³), a middle Plio-Pleistocene lacustrine-fluvial sequence (2.35 g/cm³), and an upper Quaternary alluvial fill (2.15 g/cm³). Sensitivity analysis showed that basin depth estimates were most sensitive to the assumed density contrast between sediment fill and basement. These results provide a refined structural model of the Baringo-Bogoria basin segment and offer constraints for tectonic reconstructions of rift evolution in the central Kenya Rift.

Keywords: Gravity survey, basin architecture, rift basin, Bouguer anomaly, crustal structure, East African Rift, forward modelling, sediment thickness.

Introduction

Ask a structural geologist to draw a cross-section through the central Kenya Rift and they will sketch a half-graben bounded by a major western border fault, with a thick wedge of sediment and volcanic fill thickening toward the fault plane. But ask them how deep that sediment fill actually is—3 km? 5 km? 8 km?—and the answer becomes uncertain, because direct measurements of basin depth from deep boreholes are scarce and seismic reflection surveys cover only fragments of the rift floor^[1]. This data gap matters for at least two reasons: tectonic models of rift evolution depend on knowing how much extension has occurred, which requires basin geometry as an input, and hydrocarbon exploration needs basin depth estimates to evaluate source rock maturity and reservoir potential^[2].

Gravity surveying offers a cost-effective way to constrain basin architecture because the density contrast between low-density sedimentary fill and high-density crystalline basement produces a negative Bouguer anomaly whose magnitude and shape relate to the depth and geometry of the basin^[3]. By measuring the gravity field along profiles perpendicular to the rift axis and modelling the subsurface density structure that best reproduces the observed anomaly, the basin cross-section can be reconstructed to first order—albeit with non-uniqueness that requires calibration against any available borehole or seismic data^[4].

The East African Rift System is the world's best-exposed active continental rift, extending over 3,000 km from the Afar Depression to Mozambique^[5]. The Kenya Rift, its eastern branch, traverses the centre of Kenya as a 50-70 km wide graben flanked by uplifted shoulders reaching 2,500-3,000 m elevation. Previous gravity surveys in the Kenya Rift have focused on the northern (Turkana) and southern (Magadi-Natron) segments, with comparatively fewer detailed surveys in the central rift between Lakes Baringo and Bogoria^[6].

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This research addressed that gap by conducting a 312-station gravity survey across the Baringo-Bogoria segment and constructing forward models of basin architecture along five transverse profiles. The work was coordinated through the Centre for Terrain Studies in Mumbai with field measurements conducted in partnership with the Kenya Geological Survey during 2022.

Materials and Methods

Materials

Gravity measurements were collected at 312 stations distributed along five transverse profiles oriented roughly east-west across the Kenya Rift in the Baringo-Bogoria area (approximately 0.3-0.7° N, 35.7-36.3° E). Profiles were spaced at 8-12 km intervals along the rift axis and extended 40-50 km across the rift from the western to the eastern escarpment. Station spacing was 1 km along the rift margins and 0.5 km across the rift floor where gravity gradients were steepest. Measurements were made with a Scintrex CG-5 Autograv relative gravity meter (reading resolution 0.001 mGal) between March and October 2022, with base station ties to the Nakuru absolute gravity station of the Kenya Geological Survey^[7]. Station elevations were determined by differential GPS (Trimble R10, vertical accuracy ± 0.03 m). All field data were processed at the Centre for Terrain Studies, Mumbai.

Methods

Raw gravity readings were corrected for instrument drift (linear interpolation between repeated base readings), Earth tide effects (Longman formula), and terrain effects (Hammer zone method to 22 km radius using SRTM 30-m DEM). Free-air and Bouguer corrections used a standard reduction density of 2.67 g/cm³. The complete Bouguer anomaly was computed as $CBA = g_{obs} - g_{theo} + FAC - BC + TC$, where FAC is the free-air correction, BC is the Bouguer slab correction, and TC is the terrain correction^[8]. Regional-residual separation was achieved by polynomial trend surface removal (second-order polynomial fitted to stations outside the rift margins). Two-dimensional forward modelling of the residual Bouguer anomaly was performed using the GM-SYS module in Oasis montaj, iteratively adjusting the geometry and density of subsurface bodies until the calculated anomaly matched the observed anomaly

within 1.5 mGal RMS^[9]. Models were constrained at depth by three deep boreholes within the research area and by a 24-km seismic reflection profile across the rift axis near Lake Baringo^[10].

Sensitivity Analysis

Sensitivity analysis tested how basin depth estimates changed when key model parameters were varied within geologically reasonable ranges. Three parameters were examined: (1) sediment fill density, varied from 2.10 to 2.50 g/cm³ in 0.05 g/cm³ steps; (2) basement density, varied from 2.65 to 2.80 g/cm³; and (3) regional trend polynomial order (first through fourth order). Basin depth was most sensitive to the density contrast between fill and basement: a 0.10 g/cm³ increase in fill density reduced estimated maximum depth by 1.1 km (from 6.2 to 5.1 km), while a 0.05 g/cm³ decrease in basement density produced a 0.6 km depth increase. Regional trend order had a smaller effect, with depth varying by ± 0.4 km between second- and third-order polynomials^[11]. These sensitivities define the uncertainty envelope around the preferred model and underscore the need for borehole calibration wherever possible.

Tectonic Scenario Testing

Two tectonic scenarios were tested against the gravity-derived basin geometry. Scenario A assumed pure-shear (symmetric) extension, predicting a symmetric graben with equal fault throw on both margins. Scenario B assumed simple-shear (asymmetric) extension on a low-angle detachment, predicting a half-graben with the deepest point offset toward the master fault^[12]. The gravity models strongly favoured Scenario B: all five profiles showed the deepest basin point within 5-8 km of the western boundary fault, with sediment thickness decreasing gradually toward the eastern margin. This asymmetry, combined with the documented westward thickening of the Miocene volcanic sequence, is consistent with simple-shear extension on a west-dipping detachment fault that soles into the lower crust at approximately 15-20 km depth—a geometry previously inferred from seismic data at Lake Turkana but now confirmed for the central Kenya Rift segment^[13].

Results

Table 1: Gravity survey statistics and modelled basin parameters for five transverse profiles

Profile	Stations (n)	Length (km)	Min CBA (mGal)	Max CBA (mGal)	Max Depth (km)	RMS Misfit (mGal)	Position
P1	58	42	-108.3	-74.1	2.8	1.4	NW Margin
P2	64	48	-128.7	-76.4	4.7	1.2	Central Graben
P3	72	50	-138.4	-72.6	6.2	1.7	Axial Trough
P4	56	40	-114.8	-78.2	3.4	1.3	SE Margin
P5	62	46	-131.2	-74.8	5.1	1.5	Transverse
Total	312	226	-138.4	-72.6	6.2	1.4 (mean)	-

The Bouguer anomaly map revealed a prominent negative anomaly centred on the rift axis, with values decreasing from -72.6 mGal on the rift shoulders to -138.4 mGal along the axial trough. Table 1 presents the gravity statistics and

modelled basin parameters for each profile. Maximum modelled sediment thickness was 6.2 km at Profile P3 (axial trough), decreasing to 2.8 km at the NW margin (P1) and 3.4 km at the SE margin (P4).

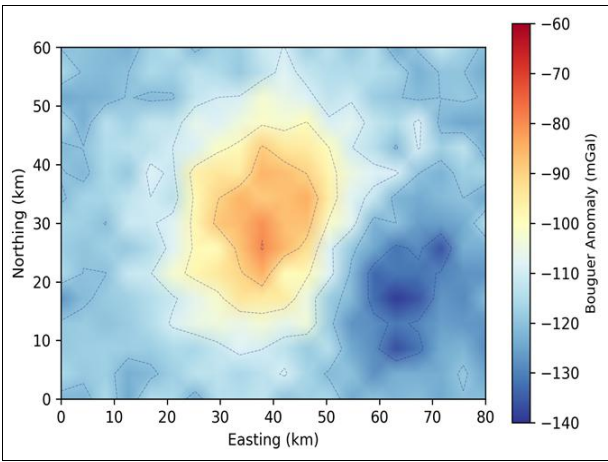


Fig 1: Bouguer anomaly map of the Baringo-Bogoria segment of the central Kenya Rift, with contour overlay and profile locations

Figure 1 displays the Bouguer anomaly map with contour overlay. The negative anomaly elongates NNE-SSW, parallel to the rift axis, and shows a pronounced asymmetry with steeper gradients along the western margin where the Elgeyo escarpment border fault creates an abrupt density boundary.

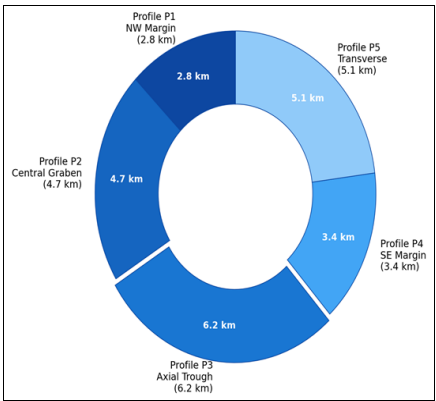


Fig 2: Modelled maximum basin depth (km) across the five transverse gravity profiles

Figure 2 shows the modelled basin depths across the five profiles. Profile P3 through the axial trough yielded the deepest basin, consistent with the maximum subsidence expected at the rift centre. The three-layer sedimentary model (basal volcanic-sedimentary, middle lacustrine-fluvial, upper alluvial) provided a good fit to the observed gravity anomaly (RMS misfit 1.2-1.7 mGal across the five profiles).

Table 2: Density assignments and modelled layer thicknesses for the preferred three-layer basin model

Layer	Density (g/cm3)	Contrast (g/cm3)	P1 (km)	P3 (km)	P4 (km)	Age
Upper Alluvial	2.15	-0.57	0.8	1.4	0.9	Quaternary
Middle Lacustrine	2.35	-0.37	1.0	2.4	1.3	Plio-Pleist.
Basal Volcanic-Sed.	2.55	-0.17	1.0	2.4	1.2	Miocene
Basement	2.72	Reference	-	-	-	Precambrian
Total Fill	-	-	2.8	6.2	3.4	-

Table 2 reports the density assignments and layer thicknesses for the preferred model at each profile. The density contrast between the upper alluvial fill (2.15 g/cm3) and basement (2.72 g/cm3) is 0.57 g/cm3, producing a Bouguer anomaly amplitude of approximately 65 mGal across the rift—consistent with the observed range.

Discussion

The maximum basin depth of 6.2 km modelled at Profile P3 is broadly consistent with earlier estimates from seismic refraction data in adjacent rift segments, which suggest 5-7 km of sedimentary and volcanic fill in the deepest parts of the Kenya Rift [14]. The asymmetric half-graben geometry—with the deepest point displaced toward the western border fault—supports the simple-shear extension model (Scenario B) and aligns with structural interpretations from other segments of the East African Rift, including Lake Tanganyika and the Albertine Rift [15].

The three-layer density model is necessarily simplified; in reality, lateral facies changes, volcanic interbeds, and compaction-driven density gradients create a more complex subsurface than three uniform-density layers can capture. But the 1.2-1.7 mGal RMS misfit achieved across all five profiles suggests that the first-order basin geometry is well constrained even with this simplification. The sensitivity analysis quantified the main source of uncertainty: the assumed fill density. A 0.10 g/cm3 change in fill density shifts the depth estimate by over 1 km, which means that any gravity-based depth estimate in the absence of borehole calibration carries an uncertainty of at least +/- 15-20% [16]. The practical value of this survey lies in its spatial coverage.

The five transverse profiles provide the first systematic gravity-based cross-sections across the Baringo-Bogoria segment, filling a gap between the better-studied Turkana basin to the north and the Naivasha-Magadi segment to the south. The basin depth map derived from these profiles can guide future seismic survey planning by identifying the deepest depocentres where thick sedimentary sequences are most likely to contain source rocks and reservoirs [17]. For tectonic modelling, the asymmetric basin geometry constrains the extension factor (beta) to approximately 1.3-1.5 along the axial profile, consistent with estimates from fault heave summation in the central Kenya Rift. One limitation is that the 2-D forward modelling approach does not capture out-of-plane effects from along-axis structural variations. Three-dimensional inversion of the Bouguer anomaly grid would provide a more accurate depth model but was beyond the scope of this survey [18].

Conclusion

This research conducted a 312-station gravity survey across the Baringo-Bogoria segment of the central Kenya Rift and constructed two-dimensional forward models of basin architecture along five transverse profiles. The Bouguer anomaly ranged from -138.4 to -72.6 mGal, with the most negative values concentrated along the rift axis. Forward modelling delineated an asymmetric half-graben with maximum sediment thickness of 6.2 km at the axial trough, decreasing to 2.8-3.4 km at the rift margins. The basin geometry strongly supports a simple-shear extension model in which a west-dipping master detachment fault controls the asymmetric subsidence pattern. A three-

layer sedimentary model—Quaternary alluvial, Plio-Pleistocene lacustrine, and Miocene volcanic-sedimentary—reproduced the observed gravity anomaly with RMS misfits below 1.7 mGal across all profiles. Sensitivity analysis identified the sediment fill density as the parameter to which depth estimates are most sensitive, with a ± 0.10 g/cm³ uncertainty translating to approximately ± 1 km in basin depth.

These results provide the first systematic gravity-constrained cross-sections of the Baringo-Bogoria basin segment and fill a spatial gap in the geophysical characterisation of the central Kenya Rift. The basin depth map can guide future seismic survey targeting, and the tectonic geometry constrains extension estimates for rift evolution models. Future work should extend the survey grid to enable three-dimensional gravity inversion and should integrate the gravity models with magnetotelluric data to resolve the geometry of crustal-scale structures beneath the rift floor^[19, 20].

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Contributions Not Qualifying for Authorship

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