The Importance of Silali Basin (Kenya) as an Extra Terrestrial Impact Crater

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ABSTRACT

Impact cratering by extra-terrestrial bodies including; asteroids, comets and meteorites; is an important geologic process, not only for the minerals that it forms, but also because of the knowledge that it is dangerous to mankind and life on earth. There is also the fact that extra-terrestrial impact cratering is a continuous process that may be going on even this very minute, somewhere in the universe. Consequently, the earth, just like other members of the solar system, is targeted by extra-terrestrial falling objects. Silali basin is a depression that is found to the north of Lake Baringo; around Kapedo town. It is suspected to be an Extra – Terrestrial Impact Crater (ETIC). The objective of the study is to assess the importance of Silali basin as an extra-terrestrial impact crater (ETIC) besides describing the basin's ETIC characteristics. Data was collected using various research methods and has been presented in the form of analyzed satellite images, ground pictures, tables, a Digital Elevation Model, an aerial photograph, a cross section, maps and discussions. The socio-economic significance of the crater has been cited and include tourism, paragliding, quarrying of breccias and geothermal power harvesting. Notably, this is the first study on extra-terrestrial impact cratering and ETICs in Kenya. Consequently, Silali basin, as an ETIC, is a virgin field hence more scientific studies are recommended; for the basin and the surrounding area.

Key Words: Extra, Terrestrial, Crater, Impact, Importance

INTRODUCTION

Before the study that bore this paper; *Identification of an Extra-Terrestrial Impact Crater (ETIC): A Case Study of Silali Crater, Kenya*, by Kipkiror (2016), Silali basin was known as a volcano that was formed by ordinary volcanicity. The above study, thus, was born to explain an alternative origin of Silali crater/basin, as an ETIC and to demonstrate the use of remote sensing in the identification of an ETIC. ETICs (*Extra-terrestrial Impact Craters*) are morphological craters that result from the impact of an asteroid, a comet or a meteorite on the earth's surface. They look like *volcanic craters*, but *Volcanic Craters* are produced by volcanic activity and most of them are found at the top of conical volcanic edifices or on the flanks of volcanoes. Volcanic craters that are devoid of an edifice are called *maars***.** They form when magma rises through water saturated rocks and causes a phreatic eruption. More specifically, a *maar*(from Latin word *mare*, which means sea) is a broad, low-relief volcanic crater that is formed by phreatomagnetic eruption; when ground water meets hot lava or magma. Characteristically, a maar is filled with water, which transforms it into a shallow crater lake, above a diatreme.

Background to the Study

Extra-terrestrial impact craters, on the earth's surface, are formed by the impact of an asteroid, comet or a meteor on the earth's surface. The mechanisms associated with impact cratering are diverse but generally, when a sizable solid body strikes the ground at high speed, shock waves propagate into the target rocks. At collision speeds of tens of kilometers per second, the initial pressure on the material engulfed by the expanding shockwaves is millions of times the earth's normal atmospheric pressure, which is 101,300 Newtons per square meter. This can squeeze dense rocks into 1/3 of their normal volume. Stress can then overwhelm target rocks to an extent that they initially begin to flow almost like a fluid.A decompression wave follows the advancing front wave into the compressed rock, allowing the material to move sideways. As more and more of the target rock becomes engulfed in the shock wave, which expands radially from the point of impact, the flow of the target material behind the shock front, is diverted out along the wall of a rapidly expanding cavity created by the decompression wave. The compacted body, now vaporized or melted, moves outward with the divergent flow and lines the cavity, forming a conical sheet. Rocky material continues to flow outward until stresses in the shockwave drop below the strength of the target rocks. In large impact craters, the rock walls slump inwards, soon after excavation of the initial or transient cavity. On the earth's surface, many of the extra-terrestrial impact craters have been flattened and or filled by erosion, deposition, volcanic resurfacing and tectonic activity. Consequently, only about200 ETICs have been recognized and documented worldwide, the majority being in the geologically stable cratons of North America, Europe and Australia. On Saturday, 16^{th} of July 2011, the people of Thika, Kangundo and Yatta were gripped by fear, following the explosion of an object in the skies over the area. A black stone from outer space, weighing 5kg and 6 cm in diameter, was recovered from a farm. It is said that the stone fell on the farm at 1.017 hours and was accompanied by a thunderous sound and a tremor, after it had impacted on the land. In addition, the object (now known asKimwiri meteorite) blasted a small crater on the maize field, where it fell and displaced some dust that was visible from a distance.Plate 1.1 is a photograph showing the Kimwiri meteorite as it is today.

Plate 1.1: A picture of the Kimwiri meteorite, taken where it sits at the commissioner's office, Department of Mines and Geology –Kenya (Kipkiror, 2016).

From Plate 1.1, the meteorite is about 6cm wide. It is dark in color, probably because it burned up as it fell. The freshly broken portions display a speckled appearance, like a granite rock. Another recent impact event on Kenyan soil is the Kuresoi- Nakuru County, fireball event that took place around 7:30pm local time, on Thursday, 27^{th} February 2014. This entailed a space object that cruised through the Kenyan space, sighted by many and landed on

Kipara village- Kuresoi (approximately, 0^o3'S, 35^o5'E) burning down a mud-walled-grass-thatched house and injuring a woman.

Statement of the Problem

Extra-terrestrial impacts and their effects have not been researched much in Kenya yet extra-terrestrial impacts have occurred and can occur again in Kenya, just like in other parts of the world. In addition, Silali crater, also known as Silali basin in this study, is a major geological feature in the northern part of Kenya yet its importance, as an ETIC, has not been studied.

Objective of the Study

This study is aimed at highlighting Silali basin's ETIC characteristics and annotating the importance of the basin to Silali area and to Kenya, as a country.

Rationale of the Study

Very little information is available about ETICs in Kenya and the rest of Africa, yet extra-terrestrial impacts and craters on the earth's surface, have lots of environmental and socio-economic significance. ETICs, for example, may be associated with valuable minerals and in some cases, they are tourist attraction sites that are useful for income generation (Winchester, 2006). Again, there is no previous study that characterizes Silali basin as an ETIC except the study that bore this paper. Consequently, the ETIC characteristics of Silali basin should be profiled for a better understanding of the basin's importance.

Area of Study

The study reported in this paper covers the Silali basin, also known as Silale and its environs. Silali basin is found in East Pokot/Turkana East, within the mid Graben of the Great Rift Valley, 50km north of L.Baringo and near Kapedo Town. It is located on Latitude $1^0 10$' N and Longitude $36^0 12$' E. Turkana people call it Silali while the Pokot call it Silale. The basin covers an area of about 850km^2 and has a NNE diameter of about 5km and an ESE diameter of 8 km. It can be estimated that the impactor's size, could be 0.25-0.4km in diameter or 42.5km^2 in area, on the basis of the rule that an impactor's size is 1/20 the crater's size (Beatty *et al.*, 1999). Consequently, the Silali impact event may have been a huge event.

Figure 1.1 is a map of Kenya showing the location of Silali basin. Geographically, the area is in southern Turkana but administratively, it is at the border of Turkana East and East Pokot districts. It is an area whose ownership is disputed between the Pokot and the Turkana communities, hence frequent fights over pasture. In addition, the Silali area is very rich culturally, being endowed with special archeological sites.

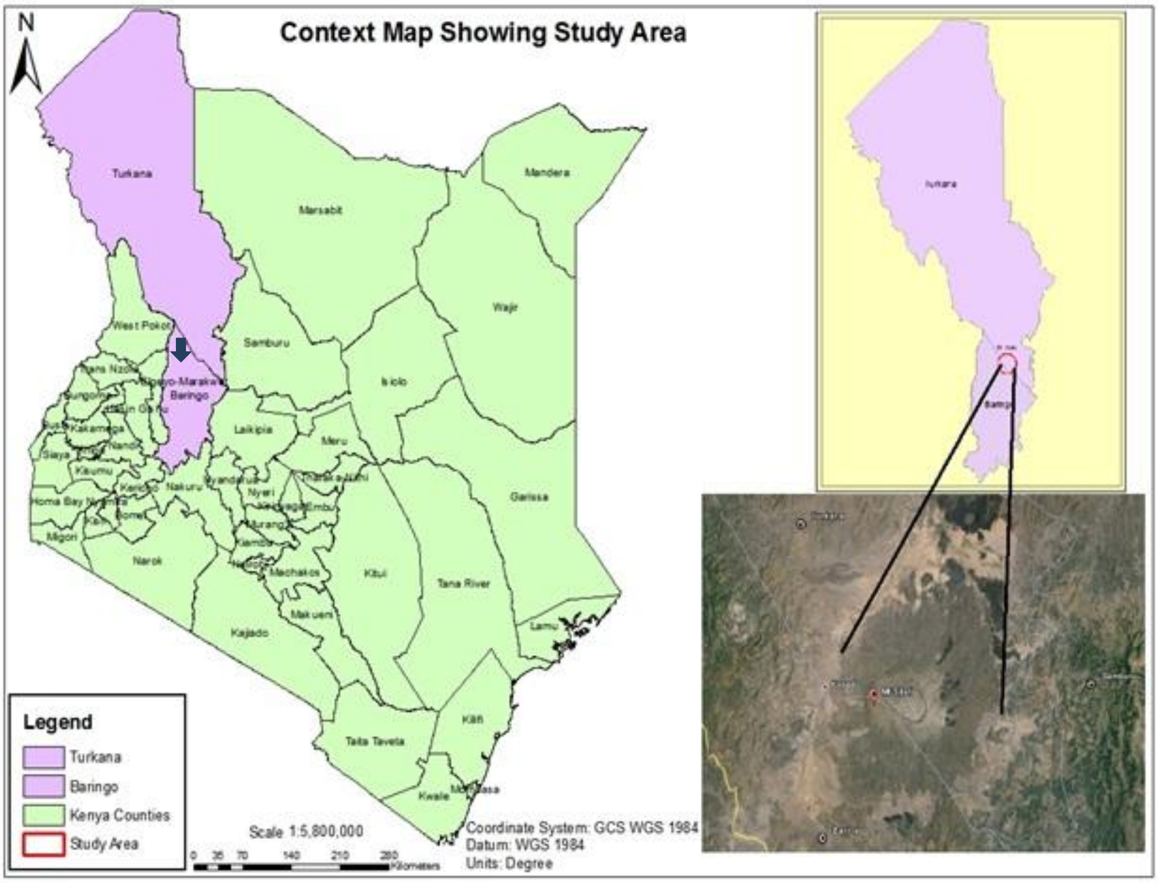


Figure 1.1: A map of Kenya, drawn to scale, showing the study area, pointed by a blue arrow and circled in red (Courtesy of Regional Centre for Mapping of Resources for Development-RCMRD).

From Figure 1.1, Silali basin, circled in red, is to the south of L. Turkana, to the northeast of Eldoret Town, to the north of Nakuru Town and 50 km north of L. Baringo, near the small semi-rural town of Kapedo. It is in a very remote area that can only be adequately accessed by heavyfour-wheel vehicles or a helicopter.

THEORETICAL FRAMEWORK

Silali basin is an environmental resource whose existence is of enormous socio-economic value. Unfortunately, the basin's importance, as an ETIC and a resource, has not been fully realized."The Tragedy of the Anti-commons" theory can aptly explain this scenario. The 'Tragedy of the Anti-commons' is a theory that describes a situation whereby, rational individuals, acting separately, collectively waste a given common resource by underutilizing it. It is the opposite of the 'Tragedy of the Commons' theory that was advanced by Garret Hardins (1968), which describes a situation where, individuals, acting separately, collectively over-utilize a certain common resource. A common resource in this case, is that which is owned by all and no one at the same time (communal resource). The term 'Tragedy of the Anti-commons' was originally coined in a 1998 Harvard Law review article by Michael Heller. In a 1998 article in 'Science', Heller, alongside Rebecca Eisenberg, pointed to biomedicine as one of the key areas where competing patent rights could prevent useful and affordable products from reaching the marketplace. This is because, too many property rights can lead to too little innovation (www.sciencemag.org, 1st May 1998).

The freely existing resources in Kenya include in this case, the unknown ETICs, which Silali could be one. These common resources are untapped for their economic worth. Kenyans may be acting individually in their 'non-utilization' of these resources but overall, the loss that accrues from their not using the resources is borne by all. For example, national poverty may partially proliferate due to lack of interest in untapped tourist resources, including the ETICs. Some countries have discovered the tourism potential of ETICs. In the USA, a meteor crater located 69 km East of Flagsruff, near Winslow in northern Arizona desert (the Barringer crater) is a popular tourist attraction in the region. There is $15 entrance fee to see the crater, for adults (Winchester, 2006). The crater is owned privately by the Barringer family (http://en.wikipedia.org/wiki/meteor-crater).

METHODS

The data presented in this study was collected through field observation, remote sensing, analysis of past geographical and geological studies, interviewing and laboratory analysis. The researcher employed Mixed Methods Design of research where qualitative (observation and interviews) together with quantitative (remote sensing, sampling and laboratory testing) research approaches were used to collect data. Data collection materials included a camera (working with a checklist), polythene bags, a small hammer, pens, labelling papers, tapes, a ruler and a notebook. Data collection tools entailed a checklist, laboratory testing, visual interpretation of satellite images, analysis of photographs and pictures, analysis of geophysical data and terrain analysis, using GIS software (Global Mapper). Remote sensing (Satellite Imagery, Aerial Photography and Ground Photography) was variously used to:

i) Reveal details about the Silali basin, for instance its size, shape and associated features.
ii) Identify the general topography of the area where Silali crater is found and the alignment of rock formations in the area and
iii) Provide images and pictures of the basin, its related features and the surroundings.

Satellite images were important and useful in this study because of their clarity in the appearance of the features on the earth's surface. Hand camera ground pictures of the terrain around and within the Silali basin were also acquired. First, these were a means of data collection but were used to record and store whatever information was collected. An aerial photograph was used to confirm features found in some of the satellite images. It provided an important means of data comparison. Qualitative research interview was used to obtain the understanding of the people, living in the proximity, about Silali basin's existence and any folklore that has been passed on through generations with regard to its formation. Exploratory interviews were also tactfully conducted, during the study, to seek the local people's understanding of the basin's importance. The interviewees were sampled through a 'by chance' kind of sampling; wherever and whenever they were found, which was by chance because of the insecurity that prevails in the area. The researcher visited the Silali area, to observe the nature of the basin, its environs and associated features. The observation that was done in this study was mostly non- participatory. It involved taking into consideration the observations made by field guides on the observable features of the basin. In addition, rock and soil samples were collected for chemical analysis. Pictures of the rock samples, rock formations in the study area and associated features were taken. Probability sampling was done to give each area of the field a chance (greater than zero) to be sampled, or to be selected as a site for collecting a sample. Noting that probability sampling can apply systematic and stratified sampling, simple random sampling (SRS) was used for the collection of all samples and in the 'by chance' sampling of interviewees. Laboratory testing was essentially carried out to establish the chemical composition of rock samples collected from within and around the basin, with the aim of finding out whether the rocks from the area of study bore mineral elements and mineral formations that are associated with ETICs. The mineral elements of interest included; Silicon Oxide (SiO_2), Aluminum Oxide (Al_2O_3), Sulphur Oxide (SO_3) and Iron Oxide (Fe_2O_3) - among others. The mineral formations that were of interest included; high pressure mineral polymorphs, Planar Deformed Features (PDFs), silica and siderophile elements. Laboratory tests were not carried out to determine Silali basin's age because this had previously been reported to be about 62-64ka (Smith *et al*., 1995 and Dunkley *et al*., 1993). Ages of most of the ETICs on the earth's surface are known thus, it is necessary to also document the age of Silali basin, because there is a coincidence between the ages of Hypervelocity Impacts (HVIs) crater formation and major events on the earth's surface. Impact cratering is closely associated with instantaneous drastic environmental change(http://jgs.geoscienceworld.org/cgi/content/abstract/164/5/923/).

Identification of the chemical components of the rocks around or within the basin, provided useful information on the mineral potential of the basin, for economic purposes. Geophysical data was used to determine the Gravity, Magnetic, Seismic and Electric signatures of the Silali basin. By its nature, geophysical data is very expensive to acquire. Consequently, secondary data sources were relied on and Silali basin's geophysical characteristics were deduced from a geophysical study, of the area, that was carried out by Lichoro (2013). Terrain analysis of the area of study was done through the drawing of topographic sections of the area and the drawing of a Digital Elevation Model (DEM). The topographical sections, such as figure 4.1,were all drawn from the topographical maps of the area; the map of Kapedo (77/3) and the map of Nakali (77/4)- maps of Kenya.Global mapper GIS software was used to create theDigital Elevation Model (DEM) of the Silali basin.

Results and Discussion

The study findings were as follows:

Silali's ETIC Characteristics

Silali basin may qualify to be an ETIC because of the following ETIC characteristics or evidences: -

Morphological Evidence/ Characteristics

The basic shape of an impact structure is a circular or near circular depression with an upraised rim, though other crater details may vary with the crater's diameter. With an increased diameter, impact structures become shallower and develop complex rims and floors (Therriault *et al*., 2002). The Silali crater has a near circular shape as shown by the satellite image, the topographical section, the DEM, the aerial photograph and the ground picture presented in this paper.

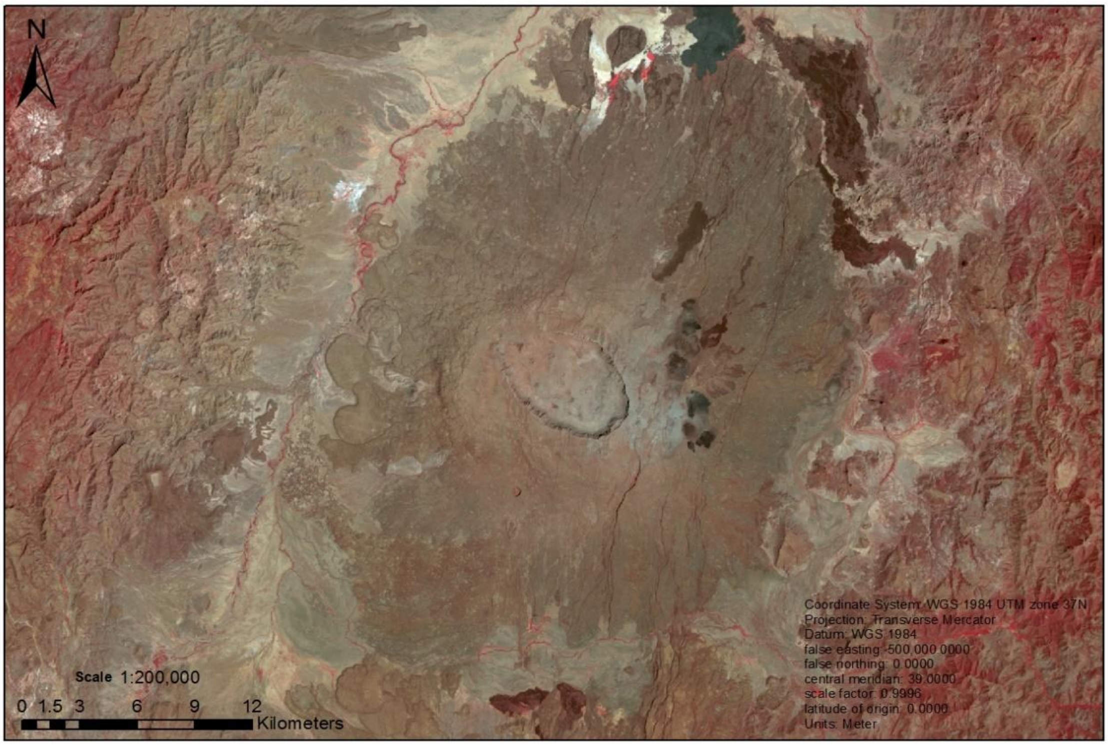
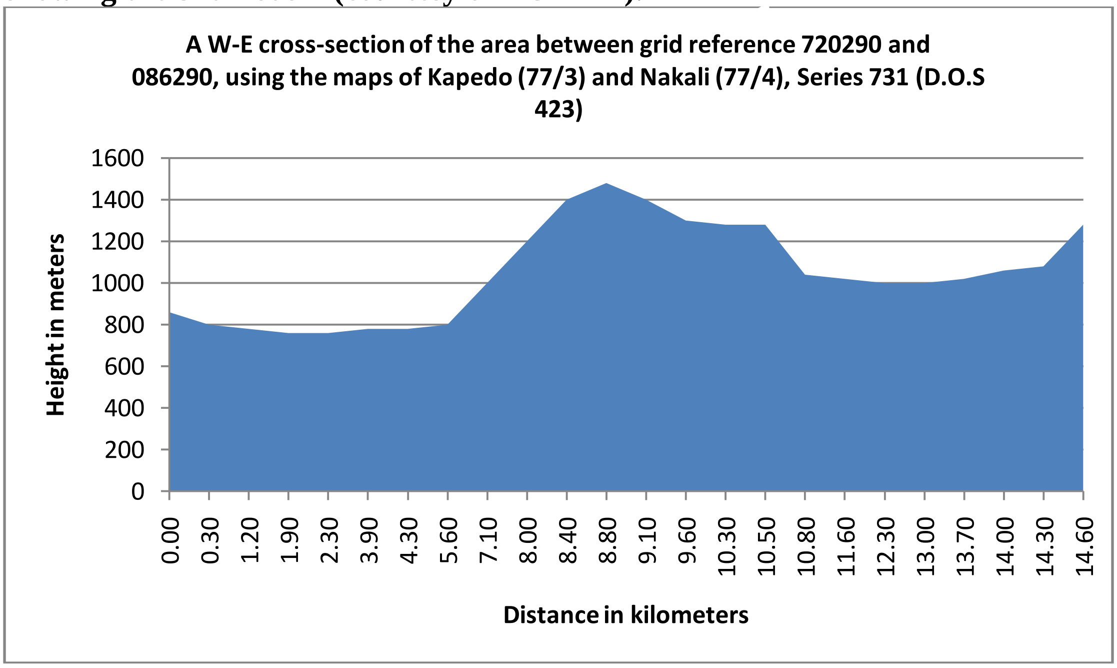


Plate 4.1: A false colour image of Landsat 8, bands 5 (Red), 4 (Green) and 2 (Blue), showing the Silali basin (courtesy of RCMRD).



A B

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Vertical scale = 1 cm represents 200 m

Horizontal scale = 1 cm represents 2.5 km

Figure 4.1: A morphological section of the outer basin and Silali basin (Kipkiror, 2016).

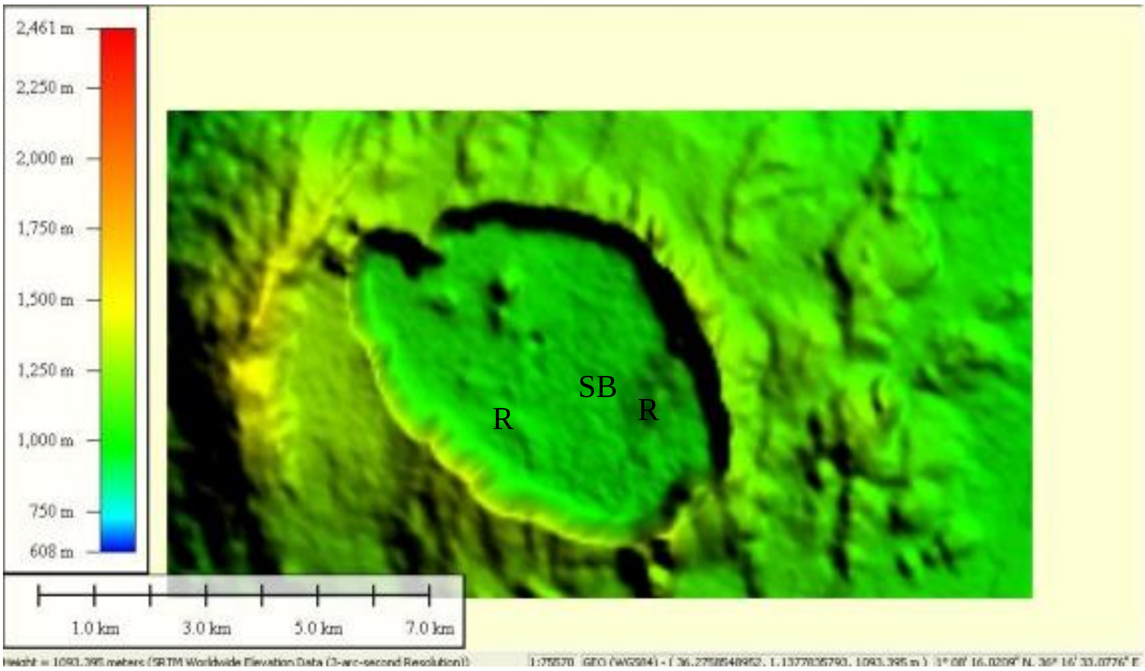

Plate 4.2: A DEM (with elevations) showing Silali basin's (SB) hummocky terrain and morphology. The DEM also shows the outline of Silali's probable peak ring (R) (Kipkiror, 2016).

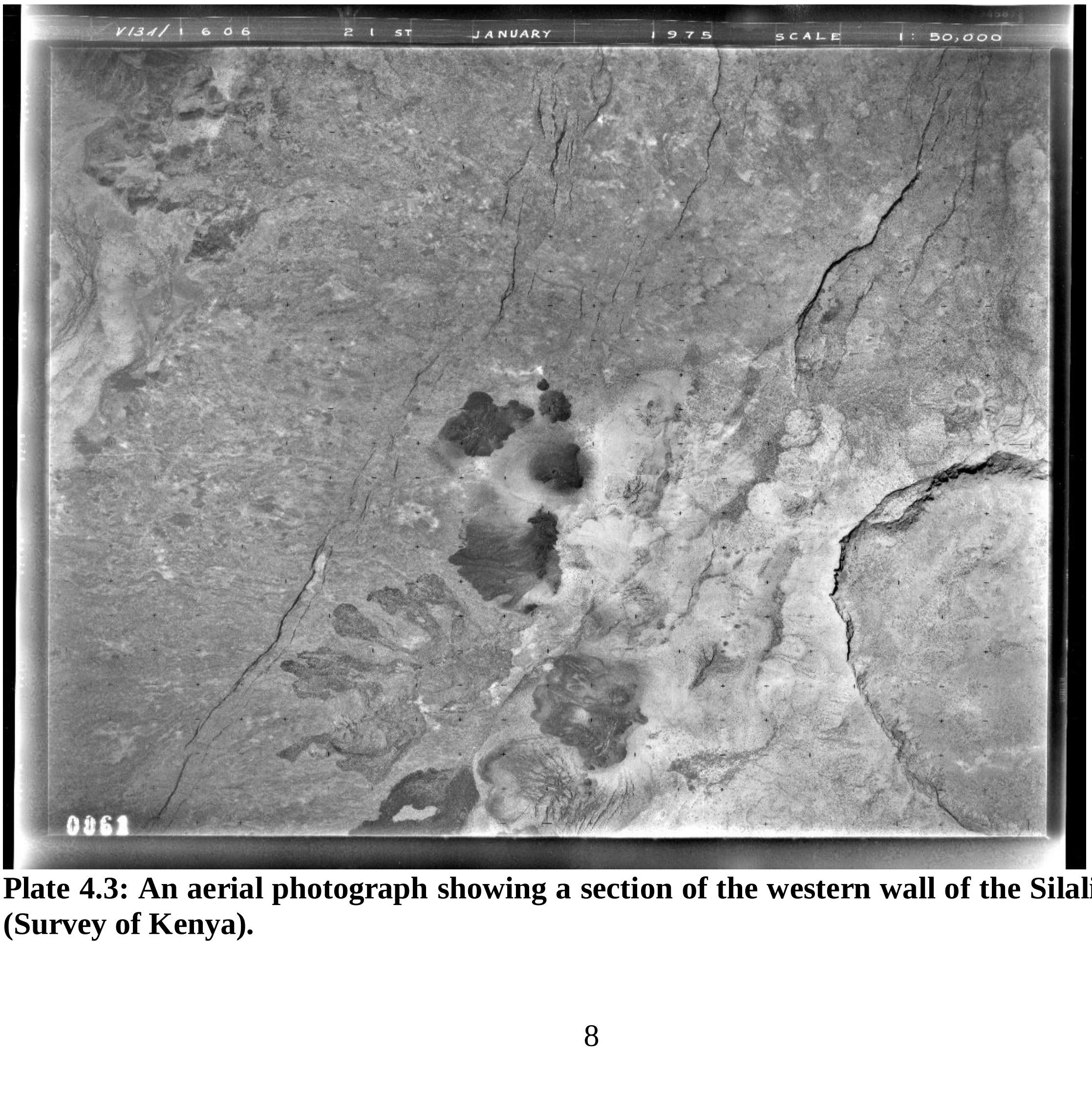

Plate 4.3: An aerial photograph showing a section of the western wall of the Silali basin (Survey of Kenya).

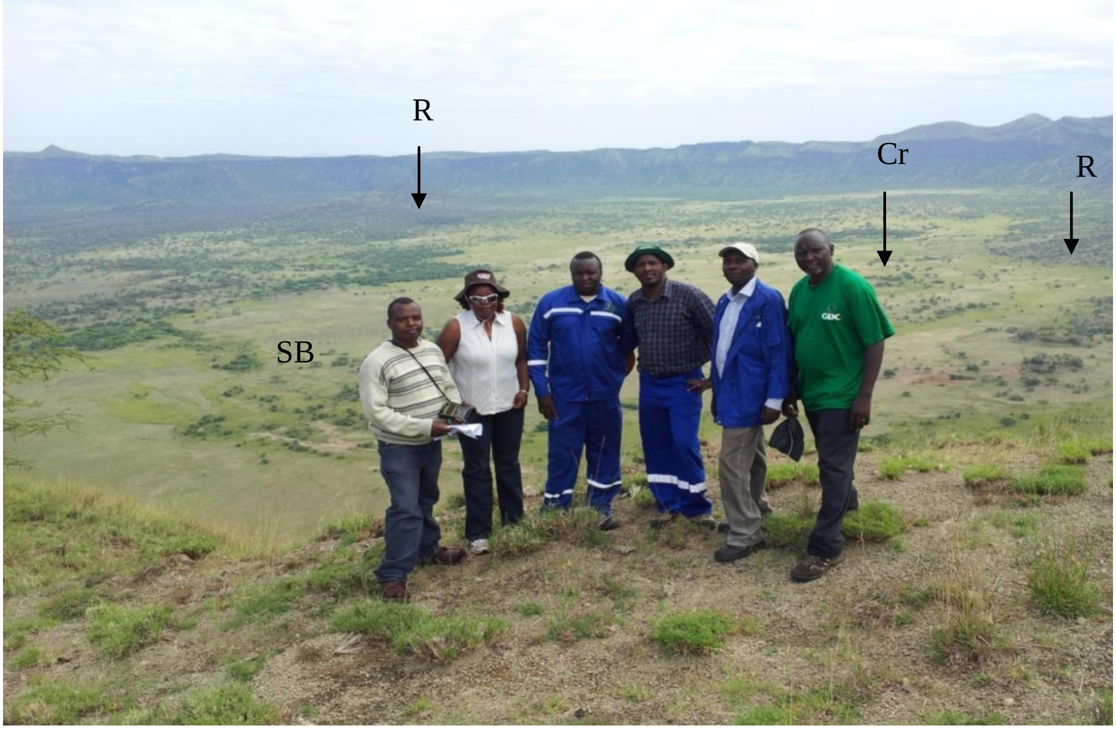

Plate 4.4: A picture showing Silali basin's circular shape and hummocky floor: Craters (Cr) and ridges (R) as viewed from the southeastern rim of the crater (Kipkiror, 2016).

Evidence of Associated Geomorphological Features

With all the geomorphological features within and around the Silali basin, the argument by Thompson and Turk (1992) that extra-terrestrial impact cratering is responsible for many geologic processes is highly plausible.

In their book on earth science, Thompson and Turk (1992), support a recent suggestion that lithospheric plate motion is caused by mantle plume. Mantle plume is a vertical column of plastic rock rising through the mantle like hot smoke through an industrial stack. Mantle plumes originate from deep within the mantle, probably, from the mantle-core boundary, according to the two scholars and when a plume reaches the base of the lithosphere, it spreads outward, dragging the lithosphere apart and initiating a spreading center or a divergent boundary. As for the origin of the plumes, the authors above point at large meteoritic impacts on the earth, that can blast a huge crater. These impacts cause magma in the mantle to flow upwards, as an attempt to fill up the crater and enhance isostatic adjustment. This begins a mantle plume. The Suguta gorge, Kapedohot waterfalls and hot water springs, Silali sinkholes and caves are all features that may have formed through the Silali's extra-terrestrial impact.

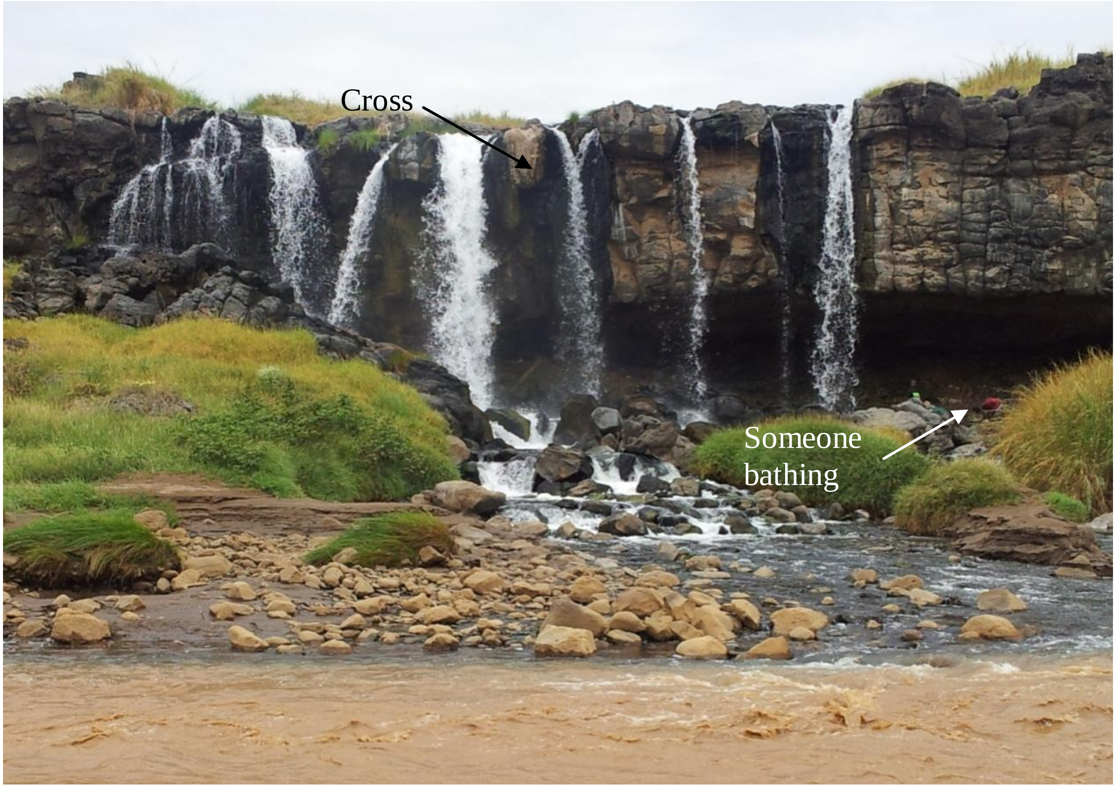

Plate 4.5: A picture showing the hot water falls of the Suguta River, near Kapedo (Kipkiror, 2016).

Plate 4.6: A picture showing the plain land above the hot waterfalls, where hot springs are found, on the outer basin (Kipkiror, 2016).

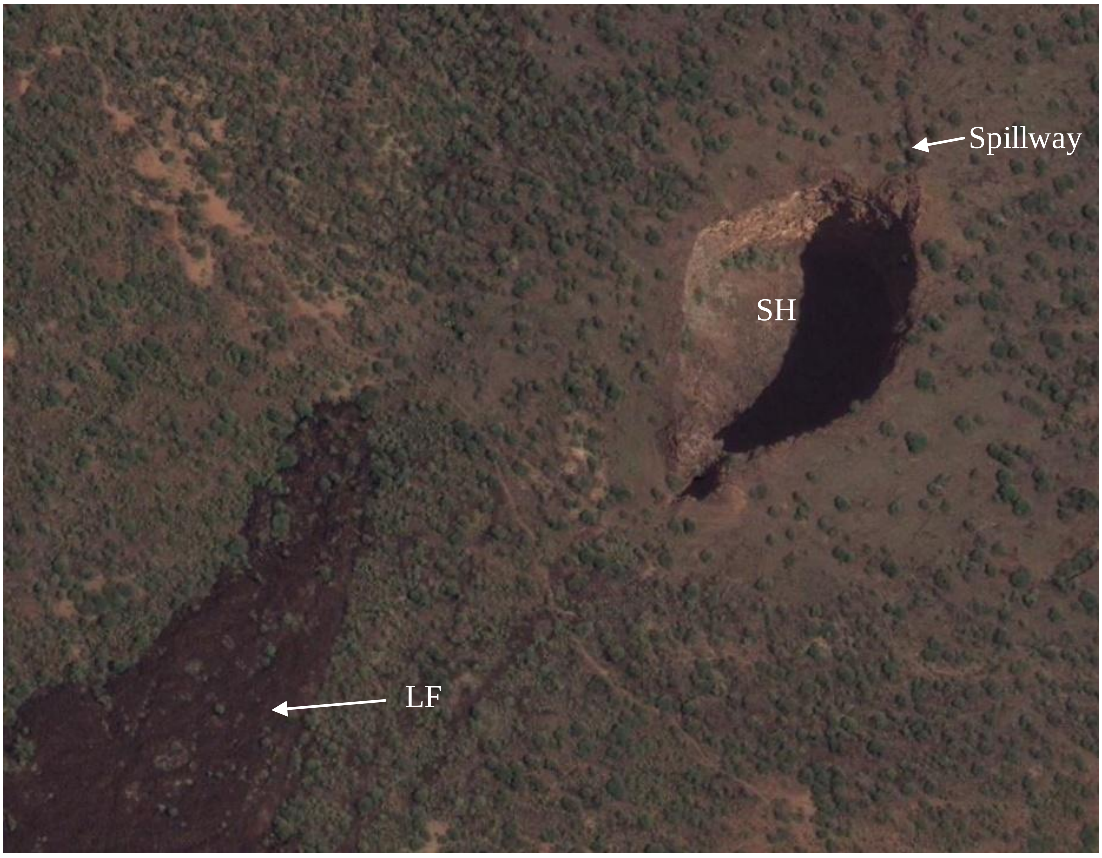

Plate 4.7: A SPOT image showing the lava flow (LF), the sinkhole (SH) and the sinkhole's spillway more clearly (modified from www.Google.com).

Plate 4.8: The entrance (E) of one of the large caves found near Natan market, on the plains south of the Silali basin (Kipkiror, 2016).

Geophysical Evidence/ Characteristics

a) Gravity Signature

ETICs that have been studied before, register a negative gravity anomaly or a gravity low. The gravity low is circular and extends slightly beyond the crater rim. Figure 4.2 is a Bouguer gravity data image, showing the gravity mapping of Silali basin and surrounding areas. Probably because of its complex formation, Silali basin, unlike all ETICs, registers a high gravity reading ofup to 100mCal, as shown by Figure 4.2. However, the data is too sparse to give a detailed picture of localized anomalies (Mariita and Keller, 2007).

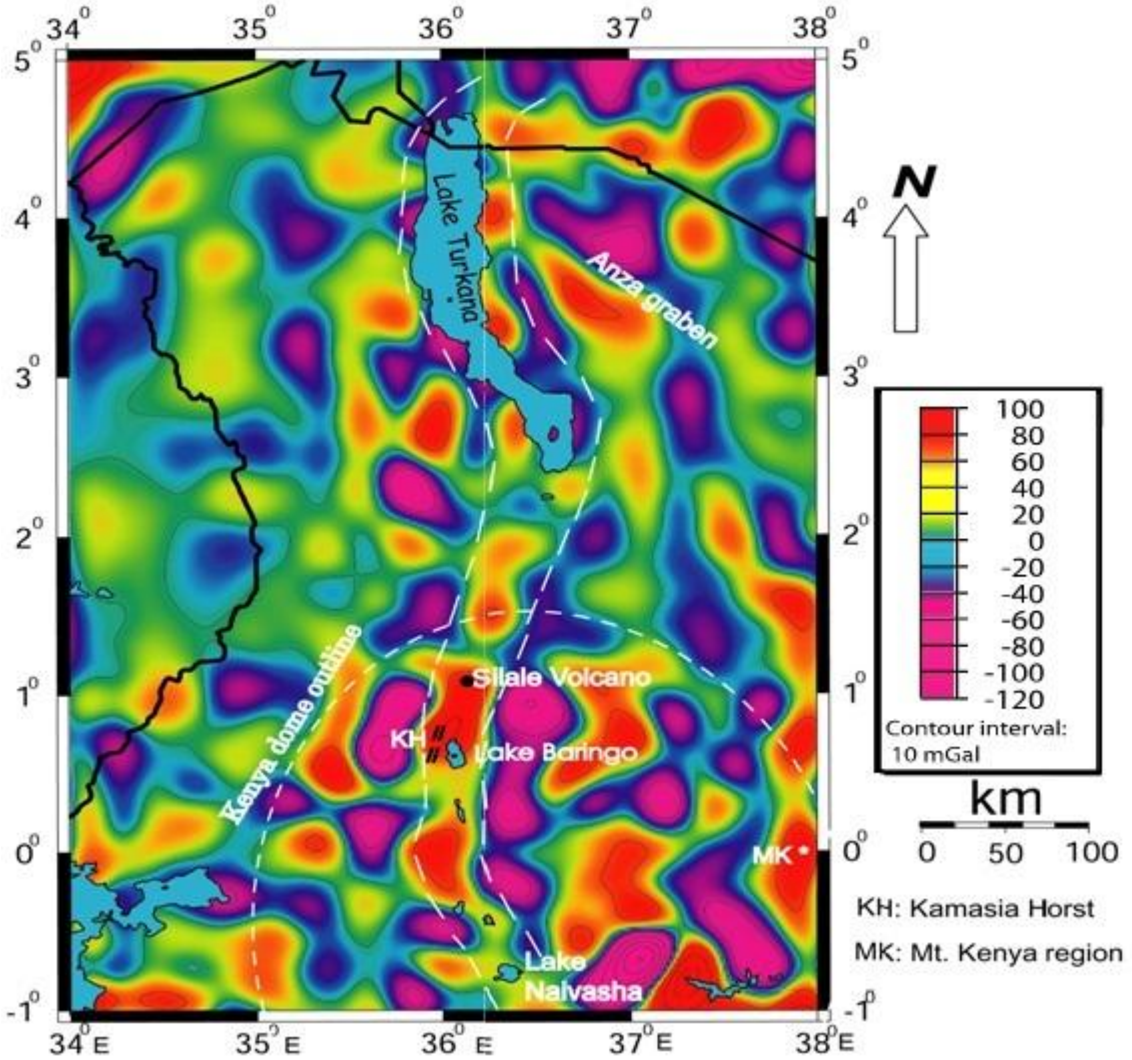

Figure 4.2: Band-pass filtered gravity map of the northern part of the Kenya rift. Wavelengths passed 30-150 km (Mariita and Keller, 2007).

b) Magnetic Signature

The magnetic anomalies associated with ETICs are usually more complex than gravity anomalies because of the complexities of rocks and their magnetism.Silali's case is even more complex because of the thermal characteristics of the crater and their effects on the rocks within and around the crater.

Generally, though, ETICs register a magnetic low or subdued zone ranging in amplitude from tens to a few hundred nanoteslas, looking at it regionally. Shock effects in an ETIC, though, can increase or decrease magnetism in an area (Dabizha and Fedynsky, 1975).

Figure 4.3 shows the magnetic mapping of Silali basin and the surrounding area. Regionally, the area is marked by a series of high amplitude magnetic anomalies. The wavelengths of these anomalies are less than 2.5 km, their amplitudes showing broad peaks reaching several hundred gammas and their shapes are either isometric or oval. These high magnetic markers would suggest massive basalts in the subsurface (Dabizha and Fedynsky, 1975). Silali basin has basalts around it and within its bed sediments, owing to its volcanic roots. However, it must be noted that the basin does not have an infilling of lava (G.o.K, 1975). Consequently, there may be impact melt buried beneath the basin's floor, which may be posting a high magnetic anomaly.

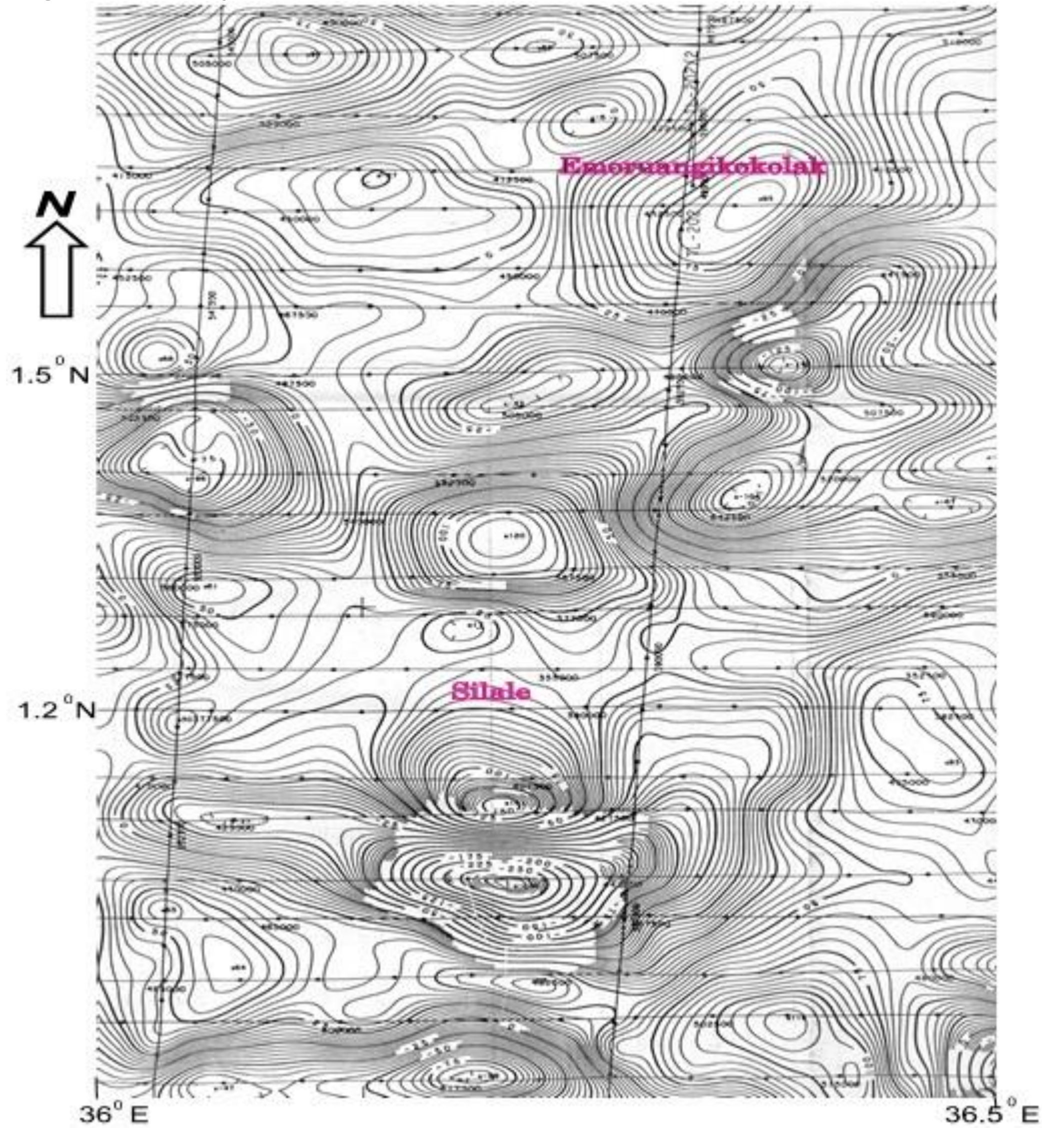

Figure 4.3: Aeromagnetic residual field intensity contour map for areas around Korosi-Chepchuk, Silali and Emoruangikokolak volcanic centres. Regional field correction used IGRF 1985 and updated to 1987 (Modified from NOCK, 1987).

c) Seismic Signature

Refraction seismic surveys allow for the imaging of an ETIC's seismic signature, though the presence of rock fractures and breccias can make seismic readings complex. Past studies have shown that the eastern Rift Valley has moderate seismic activity, except for its southern tip in Tanzania (Nyblade and Langton, 1995).

A regional seismic refraction study was carried out on a traverse covering 750km along the Rift Valley, in a N-S direction. Figure 4.4, below, shows the results.

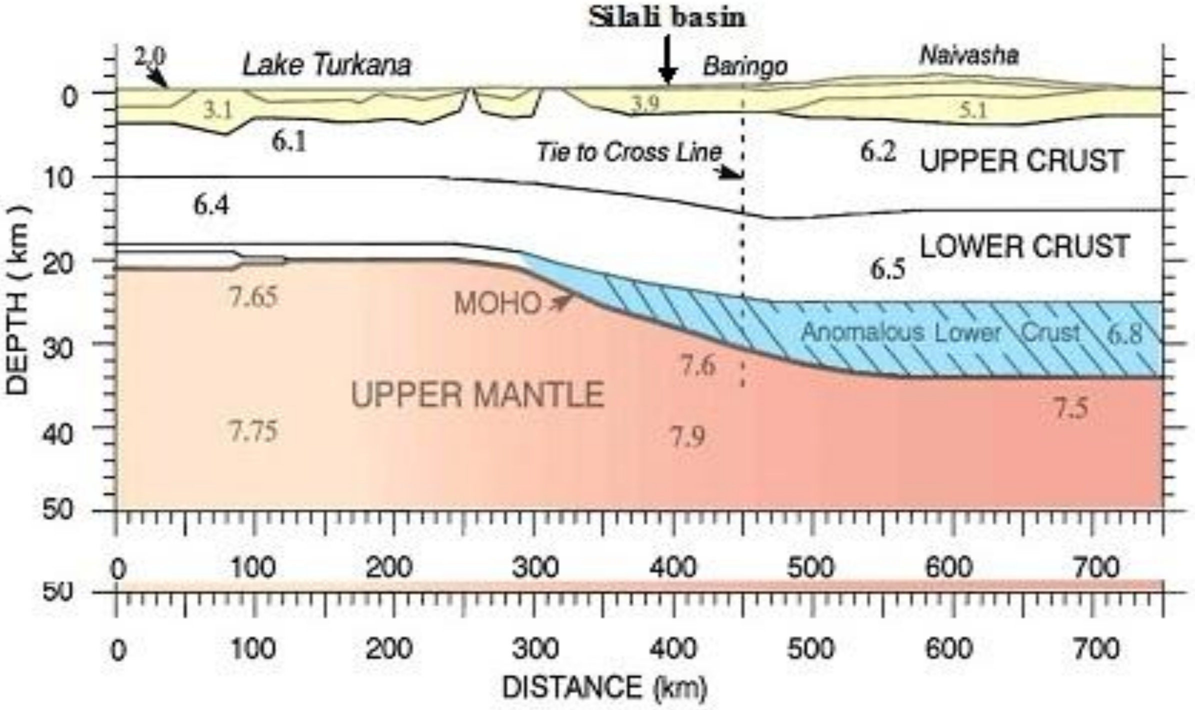

Figure 4.4: Axial crustal model showing P-wave velocities in km/s(adapted from Simiyu and Keller, 1997). Silali basin is 50 km to the North of L. Baringo, towards L. Turkana.

Silali basin and its environs are seismically active, though the waves are not equally distributed. This may be the reason behind Silali basin's present day sinking as evidenced by massive slumping of the basin's walls. The reservoir of magma in the mid-graben could be a part of a mantle plume that is believed to be beneath the Silalibasin.

d) Electrical Signature

The conductivity of rocks is heavily dependent on their water content. The presence of fluids in impact induced structures, due to the presence of fractures and increased soil and rock pores, leads to a decreased resistivity and an enhanced conductivity. Use of resistivity sounding can help map the electrical characteristics of an ETIC, as was done in Silali.

Lichoro (2013) did a total of 154 TEM (Transient Electrical Magnetic) soundings in Silali basin since 2010 and the results are summarized by 4.5.

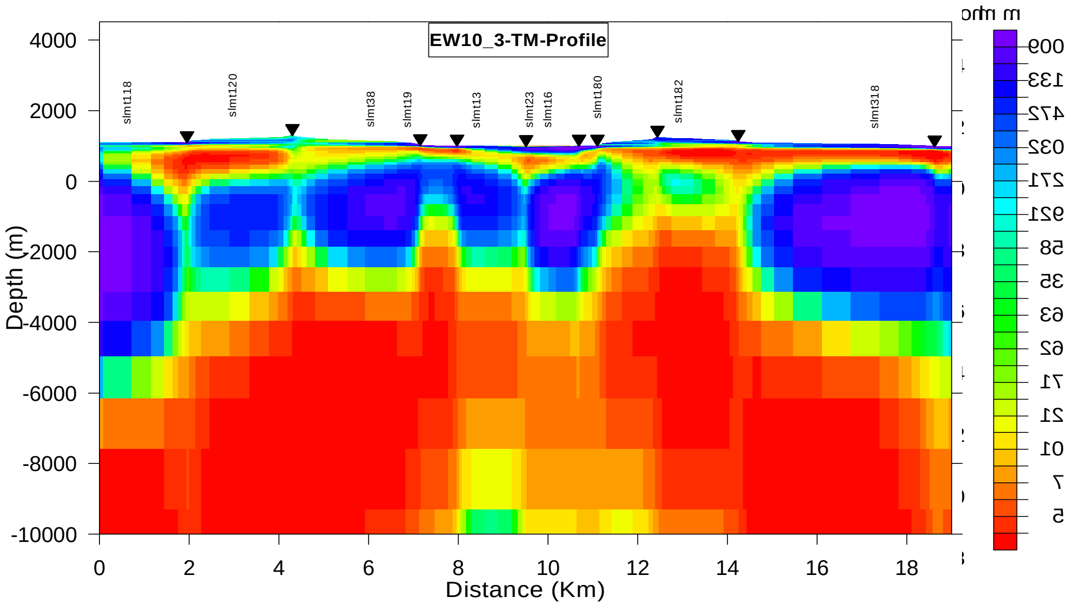

Figure 4.5: A WinGlink image showing Silali basin's resistivity (adapted from Lichoro, 2013).

Figure 4.5 shows an E-W cross section. The upper panels represent resistivity in the basin's shallower layers and the lower ones represent resistivity in the deeper structures. The top layer of about 300 m thick exhibits a high resistivity across the entire profile reflecting an un-altered rock formation, which may be a block of earth built by thick sediments or impact melt. After the crater formation, for instance, the crater surface would have been porous and fractured but following several years of deposition of sediments, however, the rock fractures would have been silted up, leading to the formation of a surface that behaves like a compact rock. This 'compact rock' would then post a high resistivity reading. Alternatively, a tough layer of melted rock could be buried inside the crater, from one end to the other, as it is in Brent crater, in Ontario, Canada. This impact melt would, therefore, be responsible for the high resistivity anomaly recorded for Silali basin's about 300 m thick floor surface layer. This is the same layer that Dabizha and Fedynsky believe to be massive basalts beneath Silali basin that post a high magnetic anomaly (Dabizha and Fedynsky, 1975).

Geological Evidence/ Silali's Geologic ETIC characteristics

The ETIC related geology of the Silali basin comprises of allochthonous, impact ejecta, shatter cones, breccias, tektites, pseudotachylites, Planar Deformed Features (PDFs) and ETIC related minerals and mineral elements.

Plate 4.9: A picture showing Silali basin's shatter cones (Kipkiror, 2016).

PDFs and siderophile elements were not netted satisfactorily by the study that yielded this paper. This is due to the limited number of rock and soil samples that were collected from the study area, courtesy of the insecurity that prevailed at the time of study and the inaccessibilityof the northern and western sections of the basin. Despite these challenges, the few rock samples collected were tested for the presence of PDFs and indeed, there appears to be PDFs in the Silali basin, as shown below:

Table 4.1: A table showing the results of a petri-graphic study of a rock sample from Silali basin, courtesy of the Department of Mines and Geology, 2015.

Petrographic study in thin section	
Major constituents (%)	Cryptocrystalline pyroxenes -50% Quartz 35% Opaque -10% Others - 5%
Accessory (% or trace)	-
Secondary (% or trace)	-
Lithology	The rock is interpreted as volcanic trachyte
Petrographic descriptions	
Quartz (35%), Cryptocrystalline pyroxenes -50% and other minerals. Individual grains of quartz are fractured.	

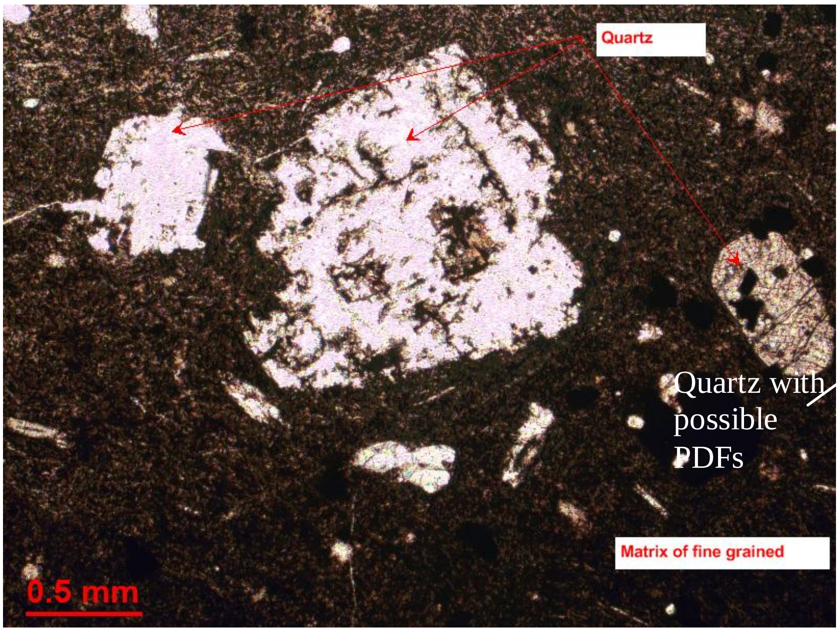

Figure 4.6: PDFs in a thin section of one of Silali basin's sampled rocks, courtesy of the Department of Mines and Geology, 2015.

A unique rock was collected from the outer basin (Chemolingot) and it is suspected to be a chondrite meteorite because it has what appears to be chondrules. Plate 4.8 shows the unique rock (Chemolingot rock).

Plate 4.10: A picture showing a unique rock (Chemolingot rock) collected from Chemolingot area, in East Pokot. A brown coated probable chondrule is pointed by the black arrow (Kipkiror, 2016).

Laboratory tests were carried out on the Kimwiri meteorite, Chemolingot rock and solid rock samples from Silali basin. The tests were done by the department of Mines and Geology, Nairobi, Kenya and the results were as shown by Figure 4.7.

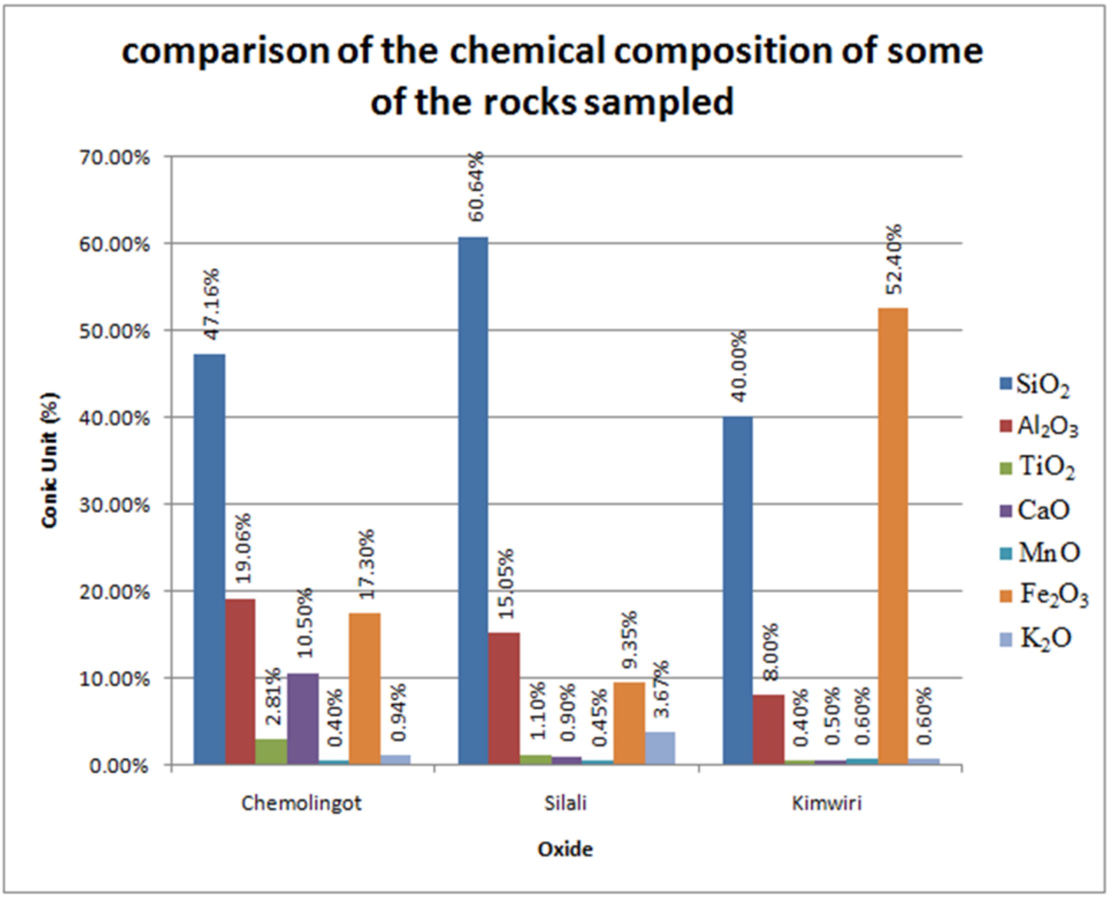

Figure 4.7: A comparative bar graph of the chemical composition of the rocks sampled (Kipkiror, 2016).

From Figure 4.7, Kimwiri meteorite, the Chemolingot rock and the rocks from the Silali basin share certain characteristics that include all the three rocks having similar chemical elements, among the sampled ETIC related oxides, though in varied percentages.

Evidence of the 'Outer Basin' and its Features

Silali basin can be said to be a basin within a basin because of a near circular basin that surrounds it (the 'Outer Basin'). The outer basin and some features which were observed in it, support an impact formation of the outer basin and the Silali basin as well. These features include the slumped walls of the outer basin, breccias and shatter cones

Plate 4.11: A picture showing shatter cones (SC) around Chemolingot area of East Pokot. (Kipkiror, 2016).

Importance of the Silali basin as an ETIC

Although Silali basin is already of use to the Turkana and Pokot communities sharing it, the basin's full potential has not been fully utilized for commercial purposes. Currently, the Turkana and the Pokot communities use the basin for grazing their livestock, reside in the basin, harvested ochre from it for decorating purposes and use the basin as a venue for religious functions.

Geothermal Development Company (GDC) has carried out studies to determine Silali basin's geothermal power potential and there is a possibility of the organization harvesting geothermal power from the basin soon. Besides harnessing of Silali basin's heat for geothermal power, Silali basin may be economically viable for socio-economic development in the following areas:

i) Tourism

Silali basin is a unique geomorphological feature that can be an important part of the mid-graben tourism sites. The basin is also surrounded by magnificent geological and landform features that include; volcanoes (example Mt, Pakka), caves (such as Natan caves), gorges (example Suguta gorge), the Kapedo hot water falls and hot water springs, the Chemolingot and Silali shatter cones, the beautiful breccia walls of Silali basin and the numerous smaller craters within and around Silali.

ii) Recreational Sports

Silali basin's rim is about 300m from itsexpansively flat floor and the basin's walls are extremely steep. Consequently, the basin is good for paragliding and parachuting as a recreational and economic activity. At Kerio View hotel, Iten; Elgeiyo-Marakwet county, paragliding and parachuting to the Kerio valley floor is done at a cost of 5000 Kenyan Shillings ($50) per trip. The paragliders and parachute flyers, however, use their own equipment. They are only charged for the launching pad. This can be replicated in Silali basin.

Hot air balloons can also be launched from Chemolingot as part of the Mid Graben tourism initiative. This can earn some money for Kenya's tourism sector, the local governments whose jurisdictionSilali falls (Baringo and Turkana counties)and individual investors. At the Masaai Mara, for instance, a hot air balloon ride can cost up to 40,000 Kenyan Shillings ($400) per person.

iii) Mining

McCall and Hornung (1972), mentioned that the 'black hills' to the northeast of Silali basin are made up of pure black glass. It was not possible to access these hills for sampling, because of insecurity. Knowing that ETICs are associated with diaplectic glass or impact glass and tektites, the black hills can be investigated to ascertain their glass mining potential. The 'outer basin' and beyond should also be prospected for glass because impact glasses are known to form thousands of kilometers away from their impact origin (http://www.unb.ca/passc/impactDatabase/Africa.html). Lake Bosomturi, in Ghana, is an ETIC that is believed to be the source of Ivory Coast's tektites and microtektites in the nearby ocean sediments(http://www.unb.ca/passc/impactDatabase/Africa.html).

Breccias are also found in the Silali basin. The lower layers of the north-eastern wall of the caldera, for instance, consist of massive trachyte lithic breccias while the northern wall has up to 10 m of polymict lava lithic rich breccias (Dunkley *et al.*, 1993). Lithic and Polymict breccias are breccias whose particles are cemented in a way that they form a matrix. In fact, lithic breccia is an impact breccia that contains shocked and unshocked clastic material in a clastic matrix.

The multicolored breccias of Silali basin, such as the one shown by plate 5.1, can be harvested for home decoration or construction purposes. The rocks also have ornamental uses and can be used for architectural as well as sculpturing purposes. In 1800 BC, for instance, breccia was used to create the columns of the famous Minoan palace of Knossos in Crete. The ancient Egyptians curved their goddess 'Tawaret', found in the British museum, from breccias and the Romans included breccias in their construction of high profile public buildings (www.thefreedictionary.com/brecciation).

Plate 5.1: A picture of a dark brown- purple-grey breccia (Kipkiror, 2016).

Many large ETICs host mineral resources that range from large deposits to localized occurrences. ETIC minerals can be **progenetic**, **syngenetic** or **epigenetic**. Progenetic minerals are pre-impact minerals. These are minerals that existed in target rocks before an impact eventbut may have become exposed or accessible after impact. They include iron ores, uranium and gold. Syngenetic minerals, on the other hand, are syn-impact minerals or minerals that owe their existence purely to an impact event. They include copper, nickel, PGMs and impact diamonds. Epigenetic minerals, as far as impact is concerned, are post impact minerals. These are minerals that result from impact induced thermal activity. Apart from a few metalliferous deposits and mesothermal gold, impact hydrocarbons form the bulk of many epigenetic impact deposits. This is because; impacts do not only encourage the burial of plants and animals under pressure and heat, to degrade them to hydrocarbons, but also because ETICs provide the necessary structural trap needed for localizing mineral rocks and holding mobile liquids, which may include oil. There are impact related minerals in Silali basin and the surrounding areas, except for petroleum. Petroleum deposits will not be expected in Silali basin because of the high volcanically driven ground temperatures and heat in the region; which can easily vaporize petroleum and natural gas.

A study by the Department of Mines and Geology; on mineral exploration and assessment of geological materials and geo-tourism sites in Arid Lands Resource Management Programme (ALRMP) project area of Baringo and East Pokot districts in 2009 (G.o.K, 2009), showed that Silali basin and its surrounding areas has gold, copper, nickel and iron.

Conclusion

As stated earlier, Silali basin is in a deep jungle and can only be accessed on foot or by a chopper. Thus, for tourism, recreational sports, mining and other socio-economic activities to progress in Silali region, the area should be opened for development. This can be done through infrastructural development including construction of good road networks, establishment of social amenities and provision of communication structures. Currently, there is only one weather road leading to Kapedo, from Chemolingot and no road to Silali basin. Mobile phone use is not also possible within and around the basin because of poor connectivity to mobile phone networks. A good transport and communication network in the area will certainly boost national unity and development in region. The environmental, social and economic beauty of Silali basin also seems to have instigated disharmony between the Pokot and the Turkana, who claim ownership of the basin; each stating their exclusive right to the environmental resource. It is the onus of the Government of Kenya to quell the cattle rustling related insecurity within and around Silali basin, for the region to get modernized. Finally, Silali basin as an ETIC and impact cratering in Kenya, are fertile research areas that need more studies. For Silali basin specifically, more studies are advised on Silali's paleoclimate and detailed geomorphology. It is important to investigate Silali's past climate from evidence provided by the prehistoric cave dwellings and paintings found to the southeast of the basin. This will yield information on Silali's past and more information on the basin's formation. Secondly, a detailed scientific research should be carried out in Silali basin with a succinct focus on establishing the presence or absence of PDFs and siderophile elements in the area. More gravity mapping of the area should also be conducted to establish Silali basin's localized gravity signature for a better understanding of the basin's origin. According to Mariita and Keller (2007), Silali basin's existing gravity data is too sparse to give a detailed picture of localized anomalies.

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