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Extra-Terrestrial Impact Craters (Etics) and Related Geomorphology-A Case Study of Silali Basin, Kenya

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EXTRATERRESTRIALIMPACTCRATERSETICSANDRELATEDGEOMORPHOLOGYACASESTUDYOFSILALIBASINKENYA

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Keywords: ETICs, crater, silali basin, geomorphology.

I. Introduction

For a long time, Silali crater/basin has been described as a volcanic crater that formed through volcanicity. This would ordinarily entail the release of magma from inside the earth, through a volcanic pipe or vent, onto the earth's surface. A violent volcanic eruption can blast the earth to form a crater. The eruption can also pile up magma all around the blasted area, forming walls of lava (cooled magma).A recent study that was carried out in Silali basin: *Identification of an Extra-Terrestrial Impact Crater (ETIC): A Case Study of Silali Crater, Kenya*, by Kipkiror (2016), however, has unearthed facts that give an indication that Silali basin may be an Extra-terrestrial Impact Crater (ETIC); formed through an extra-terrestrial impact event. This involves the impact of an asteroid, comet or a meteor on the earth's surface, leading to the formation of a crater or a meteorite. When a heavenly body impacts on the earth's surface and excavates it, a crater is formed. If the heavenly body fails to completely burn up while transiting the earth's atmosphere, it will land on the earth's surface and if it does not get pulverized, it will form a shallow crater and rest on the crater as a meteorite.

The objective of this paper is to describe Silali basin as an ETIC and to enumerate the geomorphological features that form around ETICs and are directly related to the formation of the ETICs; Silali basin being the case study. Information for the paper was derived from the mother study: *Identification of an Extra-terrestrial Impact Crater (ETIC): A case Study of Silali Crater, Kenya* (Kipkiror, 2016). Data has been presented in the form of analysed satellite images, a chart (morphological section), pictures, a LIDAR image, a DEM and discussions.

II. Background Information

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; that can fall on any place on the earth's surface and can cause crustal deformation, mayhem and even desolation. This research paper provides geological and morphological evidence implicating Silali basin to be a possible ETIC and describes morphological features found around Silali basin, that enhance its ETIC nature.

The principal criteria for determining if a geological feature is an impact structure; formed by the hypervelocity impact of a meteorite or a comet, are outlined below. These are classified as either mega scopic (overview – bird's eye/satellite scale) or macroscopic (visible to the naked eye) or microscopic (those that require observation under a microscope).

i) Presence of shatter cones that are on site (macroscopic evidence).
ii) Presence of multiple planner deformation features (PDFs) in minerals within the site lithologies (microscopic evidence).
iii) Presence of high-pressure mineral polymorphs within in situ lithologies (microscopic evidence and requiring proof via X-ray diffraction).

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iv) The morphometry of the crater: -On other heavenly bodies such as the Moon and Mars, the shape of an impact crater is relied upon to determine its presence and type (simple or complex). This is a megascopic characteristic that can be seen, unaided, by the human eye, though requiring remote sensing and aerial photography for detailed mapping. On the earth, recognizing impact structures, solely by their morphology, is hampered by denudation and tectonic forces which deform the craters. The situation is worsened by certain terrestrial features having a circular shape and appearing like impact craters, for instance volcanic craters, such as Maars, salt diapirs, some glacial features, like cirques and kettle lakes and solution aided craters. This disqualifies the circular form, alone, as enough claim for a structure to be accorded the status of an impact crater. Buried craters that are revealed by geophysical techniques, also require a drill core to reveal macro and microscopic evidence to prove an impact origin.

v) Presence of an impact melt sheet and breccias: - These are generated by hypervelocity impact and are macroscopic. Impact melt has a crustal composition derived from the fusion of target rocks and meteoritic/ impactor's components. The rock may also have some suevite, especially around the centre of the crater. Impact melt can be determined by sampling, followed by microscopic observation and geochemical analysis.

vi) Pseudotachylites and breccias: - Pseudotachylite is a rock type generated by faulting at either microscopic or macroscopic scales. Unfortunately, pseudotachylites are also associated with tectonic faulting and are not therefore, exclusively impact generated. However, association of pseudotachylites with the above factors can make them one of the evidences of ETICs.

vii) Presence of unshocked or preserved fragments of the impactor around or within a crater.

As for the reasons why heavenly bodies fall onto the earth, three hypotheses have been advanced by scientists(www.csienceclarified.com/Ge-He/Gravity-and-Gravitation.html), as follows:

i) The sun has a faint undiscovered companion star that revolves on a highly eccentric orbit with a period of 26 million years. When this star passes close to the sun, it draws a stream of materials from the sun and sets them in motion around the sun. Some of these materials cool down to form new planets and some are attracted by the forces of gravity of other heavenly bodies, causing impacts, as these materials slam into these heavenly bodies.

ii) There is a massive undiscovered planet that orbits beyond Pluto and periodically disturbs an unseen disk of comets in the neighbourhood. These comets, once disturbed, are scattered and some fall onto heavenly bodies, including the earth.

iii) The up and down oscillations of the sun through the massive central plane of the Milky Way, may cause gravity differences between heavenly bodies of the galaxy. Consequently, some of the heavenly bodies may become unstable and vulnerable to the earth's gravitational pull, which attracts them, leading to extra-terrestrial impacts on the earth (Allen, 2014).

Extra-terrestrial impact Craters are divided into three categories according to their morphology, namely:

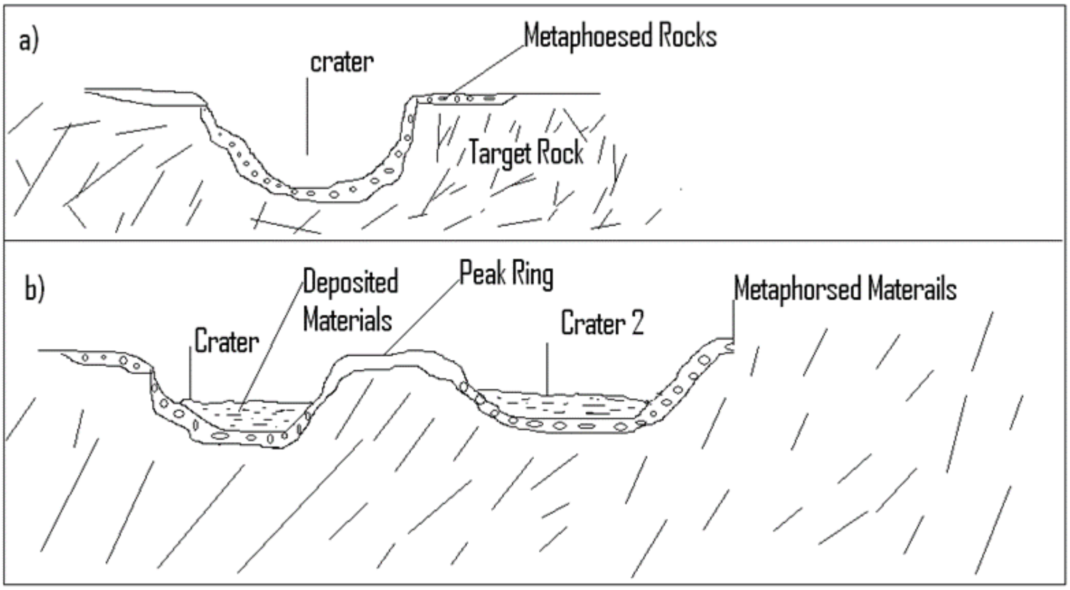
i) Simple Craters
ii) Complex Craters
iii) Basins

Simple craters are relatively small with a smooth bowl shape. In larger craters, though, gravity causes initially steep crater walls to collapse downward and inward, forming a complex structure with a central peak or peak ring and a shallower depth (Figure 1). The diameter at which craters become complex depends on the surface gravity and the planet. The greater the gravity, the smaller the diameter that will produce a complex crater. On the earth, the transition diameter of a complex crater is 2 to 4 km, depending on the target rock properties (www.solarviews.com). On the moon, where gravity is low, the transition diameter is 15-50 kilometres (www.solarviews.com).

The peak ring or the central peak of a complex crater is formed as the initial (transient) deep crater floor rebounds from the compressional shock of impact. Slumping of the rim further modifies and enlarges the final crater. Complex structures on crystalline target rocks will also contain sheets of impact melt rock, atop the shocked and fragmented rocks of the crater floor. On the earth's surface, weathering and erosion of the target rocks, as mentioned earlier, quickly alter the surface appearance of the structure, though in some cases, the resistant rocks will stand out as concentric rings/peak rings within the crater. On the surface of the moon, complex craters are said to be intact till they are destroyed by subsequent impact events (www.solarviews.com).

A basin, on the other hand, is an ETIC whose diameter is large and with the increasing diameter, a ring of peaks appears within it, transiting the complex crater into a basin. A single interior ring can qualify an ETIC into a basin (Therriault *et al.*, 2002).

It must be noted that ETICs can also form in marine environments and the morphology of a marine ETIC is quite distinct. Marine impact structures are characterized by a broad shallow brim, extensive sedimentary infilling and prominent fault blocks on the floor (Tsikalas *et al*., 1999).



Source: Kipkiror, 2016.

Figure 1: Diagram showing a simple crater (a) and a complex crater (b) with associated features.

III. Formation of Silali Basin

Silali basin, also known as Silale,is found in East Pokot/Turkana East, within the mid Graben of the Great Rift Valley, 50 km north of L. Baringo and near Kapedo Town. It is located on Latitude 1^{0}10' N and Longitude 36^{0}12' E. The basin or crater is named *Kotong*, by the Pokot community living around it, which means a depression. The 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 5 km and an ESE diameter of 8 km. Spectacularly, Silali basin has a distinctive ring fracture structure all around it; which the study attributes to the impact origin of the basin. It can be estimated that the impactor's size, could be 0.25-0.4 km in diameter or 42.5km^{2}in area, based on 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 great event.

According to Dunkley *et al.* (1993), Silali volcano was formed around 225ka and the caldera (crater or basin) collapsed around 66-62ka.

Silali basin is a basin within a larger basin (the outer basin) with smaller basins within it. In addition, there seems to have been impacts at different times in the area, the oldest being the one that formed the huge 'outer basin' and probably triggered the formation of a section of the Great Rift Valley, example the mid graben and the many spectacular geological features within and around it. The 'outer basin' covers the area around the crater walls and it is as near circular as the Silali basin itself, going all around Silali. It is covered by alluvial material and volcanic flows in many places and thus, on Plate 1, it appears as the dark and bright circular area around the Silali basin. This is the basin in which the Suguta gorge, Suguta River and the Kapedo hot water falls are situated, alongside the Chemolingot shatter cones, cross bedding slumps, sink holes and several breccias. Different volcanic rocks, prehistoric caves, smaller craters, swamps, hot springs, fumaroles and alluvial deposits are also found in this basin.

Previous studies, by some scholars who carried out research in Silali basin, indicated that a volcanic shield existed where the Silali basin is. The shield seems to have been stretching in a north-south direction. According to Smith *et al.,* (1995), Silali's volcano started forming 400-220ka. This included the formation of a low relief lava shield. Volcanic eruptions in Silali occurred during different times and some of the later ones, according to the authors, resulted in an inward collapse of the shield summit, owing to the lateral drainage of magma from beneath the volcanic shield. According to the scholars, these are the eruptions that led to the formation of the caldera around 66-62ka (Smith *et al.*, 1995 and Dunkley *et al*., 1993). The existence of a volcanic shield in Silali before the ETIC formed is favoured by the following incidences:

- The fact that Silali basin's wall is made up of volcanic materials placed in layers;
- The non-contemporaneous nature of the wall materials in terms of age and physical characteristics; and
- The 'break off' or stepped walls of Silali basin, which may be layers of different volcanic materials, bearing different strengths against denudation.

Other scholars, however, came up with a proposition that there existed an earlier caldera before the present 'volcanic caldera'. According to Dunkley *et al.,* (1993) the 'break off walls' (stepped walls) of Silali basin, mark the traces of an earlier caldera. Not all scholars agree with this and according to Williams *et* *al.,*(1984), were these features indicative of a bonding within an early caldera, then some mechanism of topographic inversion is required (Williams *et al,*.1984). This mechanism of topographic inversion can be provided for by an extra-terrestrial impact.

As a volcanic shield, caldera formation by subsidence involving a volcanic pipe is not plausible for Silali basin. This is because subsidence would not be a quiet event and an explosion would most likely occur, pouring out magma onto Silali walls. One would then expect Silali to exhibit magma outpourings from its ring structure onto its flanks. This is not the case. Again, the collapse would not produce a perfectly circular structure unless there was an outline of a ring structure in existence, before the collapse, which again is not the case, as indicated by earlier studies.

Caldera subsidence occurs in various ways, such as through plate/piston subsidence, trap door subsidence, chaotic subsidence and down-sag subsidence, among others. Plate or piston subsidence involves the subsidence of a coherent block of rock into a magma chamber that evacuates magma along a ring fault. The caldera floor may be variably faulted, but the faults are less active than the ring faults (Traver, 2007). Trap door subsidence on the other hand, is subsidence that involves multiple collapse centres. It is a piecemeal subsidence. As for chaotic subsidence, wholesale disruption and brecciation of caldera floor rocks is involved. This generates low density materials which cause a caldera to register a low gravity signature. Finally, down-sag subsidence occurs when ring faults either do not form or do not penetrate the ground surface so that summit material subsides by bending downwards.

Silali's subsidence may be said to be a plate or piston type of subsidence because the rock layers forming the basin's walls show continuous uniformity in material type and height. This is supported by observations made by Dunkley and team, that; the caldera has a regular outline and vertical walls suggesting that it was formed by a piston like collapse (Dunkley *et al*., 1993). Unlike in the case of volcanic calderas, Silali's ring fracture was less active compared to the floor fractures, in magma emission. It is thus the crater floor fractures that evacuated most of the magma that may have been beneath the volcanic shield on which Silali basin was built. The lava flow to the northeast of Silali basin can be evidence of such an event. This is because it appears that the magma jetted off the base of the basin's wall. Notably the floor fractures of the basin extend outwards from the basin and not otherwise. The subsidence can also be termed chaotic because of the presence of brecciated rock on Silali's floor and walls. 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 10m 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.

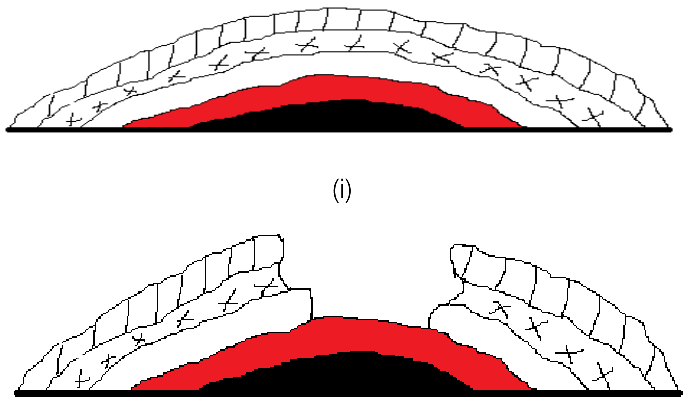
A more apt subsidence theory for Silali basin is any theory that involves withdrawal of magmatic support hence collapse. Silali's formation, as a volcanic shield or an ETIC, lacks a volcanic cone and a volcanic vent/conduit. According to McCall and Hornung (1972), Silali volcano was built by clustered vents (not a central single vent or a volcanic pipe). For the study on which this paper is based, Silali volcanic shield was built by a single fissure with limited branches, which build the shield's parasitic cones. Again, an extra-terrestrial impact, provides a viable explanation on how Silali developed a crater, via impact and consequent subsidence. The extra-terrestrial impact appears to have blasted a crater at the centre or near centre of the Silalivolcanic shield, creating the first crater which later subsided to form the present crater.

Silali's subsidence can be said to be the factor behind the basin's stepped or 'break off' walls, because as subsidence occurred, the more resistant rocks of the basin's wall remained 'standing' while the softer parts collapsed more and later got washed away by denudation. Denudation removed the softer rocks that made up the initial walls of the volcanic shield, forming scalloped areas, while resistant rocks, such as the young volcanic rocks making up the top most layer of Silali basin's wall, remained intact, forming the wall's protruding parts. There is a lot of evidence along the basin's wall, supporting subsidence and especially block/piston/plate subsidence. These include;

- The layers that make up Silali basin's wall are almost uniform and continuous around the basin and at the same height from the basin's floor (about 300m for the top most layer).
- The walls appear to have collapsed inwards, towards the basin. There is an appearance of 'turning inwards' on Silali basin's inner walls, which is different from the 'turning outwards' appearance of the basin's outer walls. Slumping has modified the appearance of the basin's inner walls, giving the walls a concave appearance.

Subsidence was possible for Silali basin because, after a probable extra-terrestrial impact, fractures formed around the basin, encouraged by pre-existing rock weaknesses, some of which built the Silali volcanic shield (400-200ka). The impact must have also widened the existing rock cracks, triggering the exit of magma from within the shield's magma chamber onto the areas around the basin. This should have formed some amount of emptiness beneath the impact basin, bringing about a collapse that left high stepped walls. There is evidence (in the form of brecciated and metamorphosed rocks on the crater walls) that hot gases and liquids hissed out of the crater chamber through the many fractures surrounding the crater. From pictures and satellite images of the basin, one can clearly see volcanic cones around the basin. These were built by magma that outpoured from the impact area, forming part of the evidence of subsidence in Silali. The volcanic cones sitting on the basin's walls would be as old as the Silali volcanic shield, being the products of the shield's parasitic fissures.

The following simplified schematic diagrams can explain the formation of Silali basin, especially the volcanic shield and impact stages.

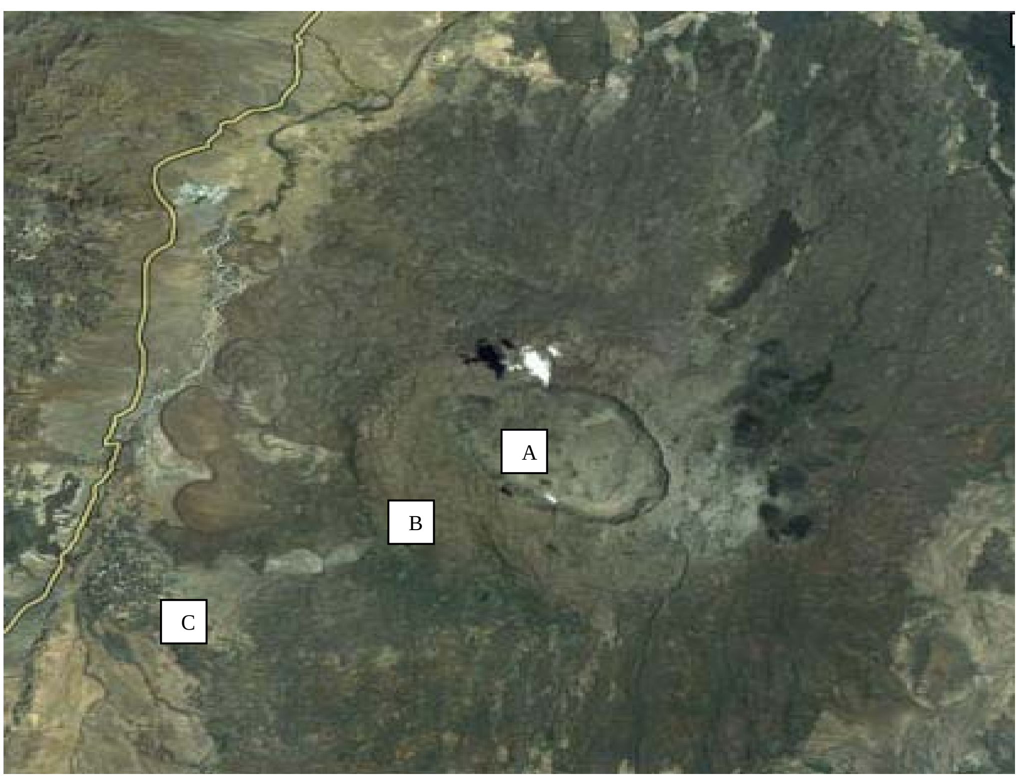


(i)

(ii)

Source: Kipkiror, 2016.

Figure 2: Schematic diagrams showing the formation of the Silali basin. (i) Represents the pre-impact volcanic shield. The shield is made up of different layers of volcanic rock. (ii) Represents the post impact volcanic shield.



Source: Google maps.

Plate 1: A natural colour SPOT satellite image showing the Silali crater, Marigat- Kapedo road (yellow), Suguta River (characterized by whitish sediments) and the outer basin around Silali. (A) is the Silali crater, (B) are the almost circular walls that surround the crater and (C) is the outer basin surrounding the crater. The hot springs feeding the Suguta River are the white patches extending from the base of the basin's wall towards the river, westwards of the basin.

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IV. Morphological etic Characteristics of Silali Crater

a) The Circular Shape of Silali Basin

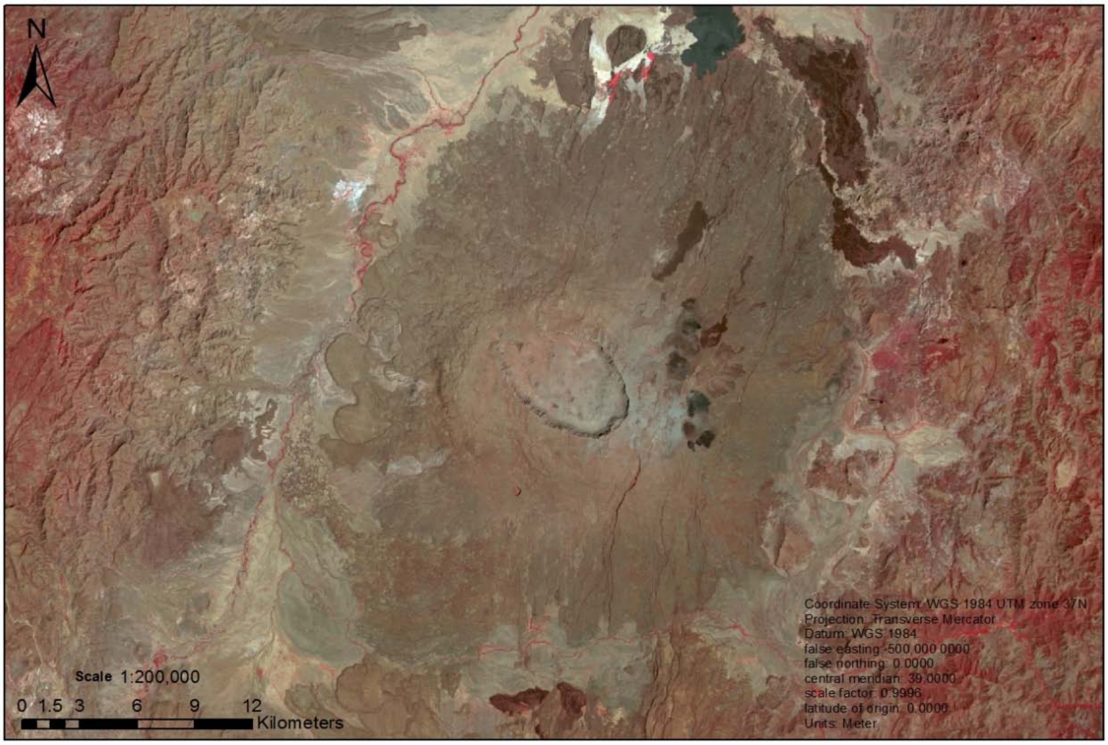
As stated earlier, Silali's near circular shape is a product of remodelling of the original crater shape by various geological processes; which include subsidence, plate tectonic movements, erosion and sedimentation. Further, the Silali crater can be classified as a complex crater, because of its hummocky floor, or a basin, because its diameter is above 4km (it is 5-8km). Silali's floor is hummocky/ lumpy, as shown by the satellite images of the area. The basin does not also display a clear peak ring but there is an outline of a peak ring as shown by Plate 1. The original peak ring may have been distorted by the basin's collapse, faulting, erosion and volcanicity. Faulting and volcanicity are not uncommon to impact cratering. These processes though, have not only re-shaped the basin but have made its origin quite complex.

Plate 2 also shows the circular shape of the Silali basin. However, in the image, the basin's walls appear to be very steep and five mini craters are clearly visible within the crater. Also evident are cones that look like volcanoes, on the basin's floor. Ground truthing placed the number of the mini craters at 5 and 2 cones with summit craters on them. There is a possibility that the cratering that led to the formation of the Silali basin may have triggered a spate of volcanicity within the crater and around it. There is also another possibility that the area may have been hit more than once by extra-terrestrial bodies, as it happened to Arounga crater in Chad. Multiple impact cratering, in Silali, is favoured by the presence of minor craters within the basin and around it, together with the fact that the Silali basin appears to be a basin formation within another basin (Plate 1).

Source: Google maps.

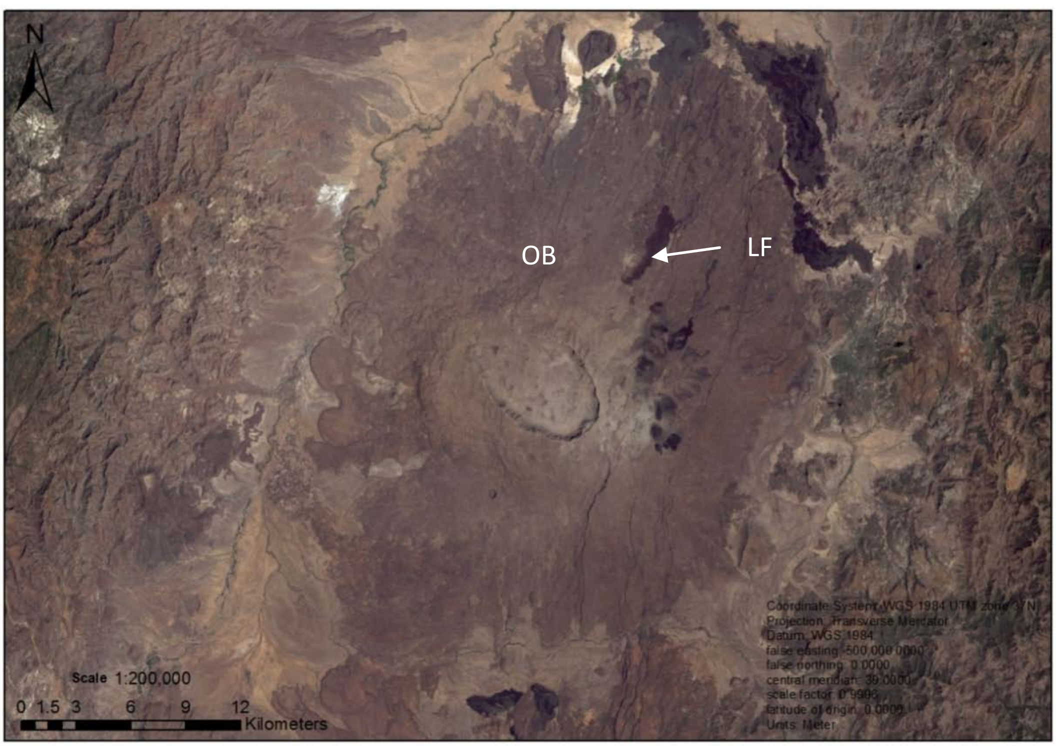
Plate 2: A natural color SPOT satellite image showing the Silali crater.

Plates 3 and 4, are Landsat satellite images that further show the circular shape of the Silali basin and some of the associated topography and physical features. The same circular shape is seen on the LIDAR image of the area, the area's topographical section and the Digital Elevation Model (DEM) of the basin.



Source: Remote Sensing of Resources for Regional Development (RCMRD).

Plate 3: A false colour image of Landsat 8, bands 5 (Red), 4 (Green) and 2 (Blue), showing the Silali basin.

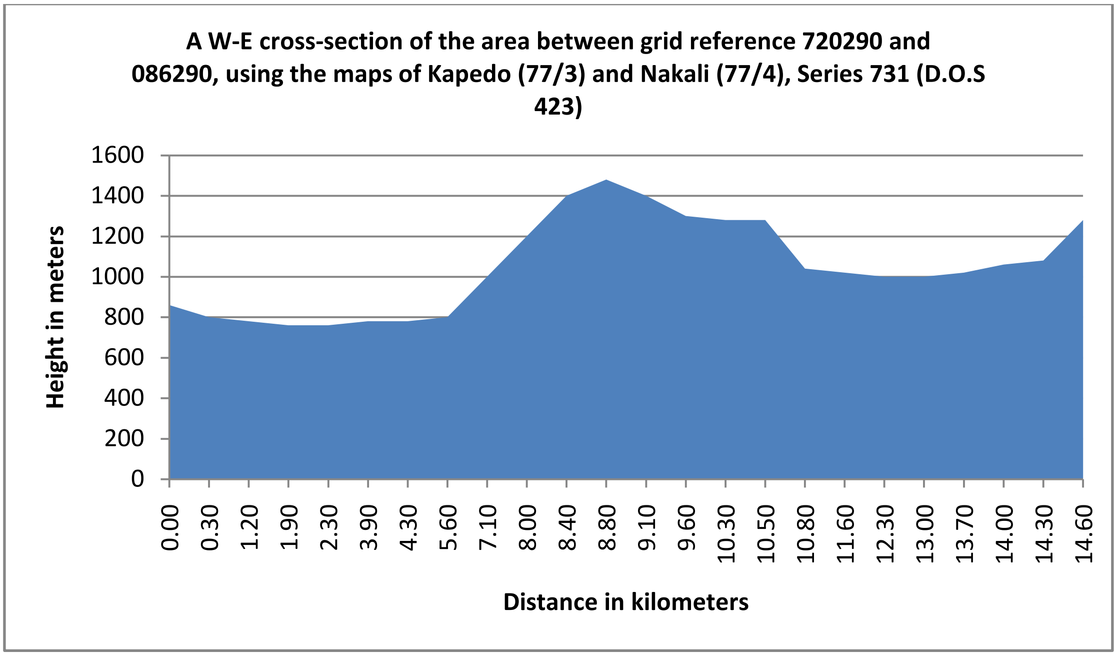


Source: RCMRD.

Plate 4: A natural colour image of Landsat 8, bands 4 (Red), 3 (Green) and 2 (Blue), showing the Silali basin.

The dark volcanic rock surface of sections of the outer basin (OB), can be seen on Plate 4, as labelled. The young lava flows (LF) to the east of the basin can also be seen from the plate and they appear to start right at the base of the Silali basin's wall. Thelava flows within and around Silali basin are rooted in the formation of the basin.

Figure 3 shows a morphological section of Silali basin and the outer basin. The section was drawn using the topographical maps of Kapedo and Nakali, which were acquired from the Survey of Kenya office.



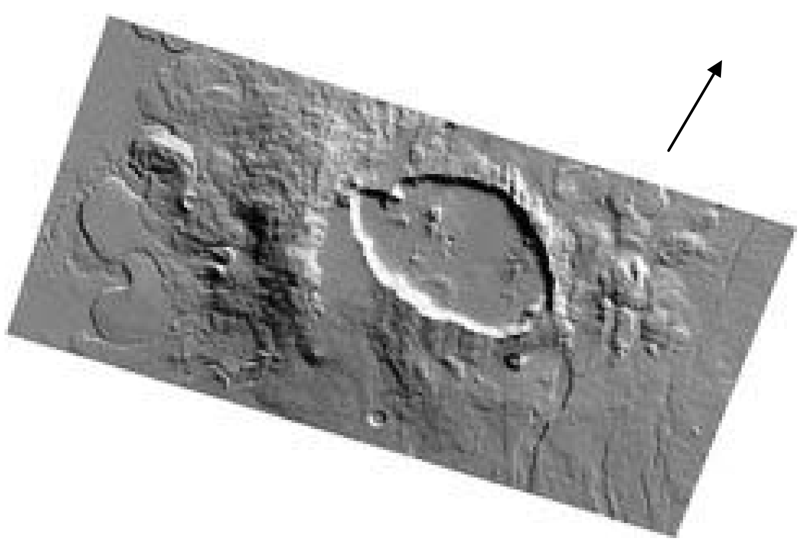
Source: Kipkiror, 2016.

A (720290) B (086290)

Vertical scale = 1 cm represents 200 m
Horizontal scale = 1 cm represents 2.5 km

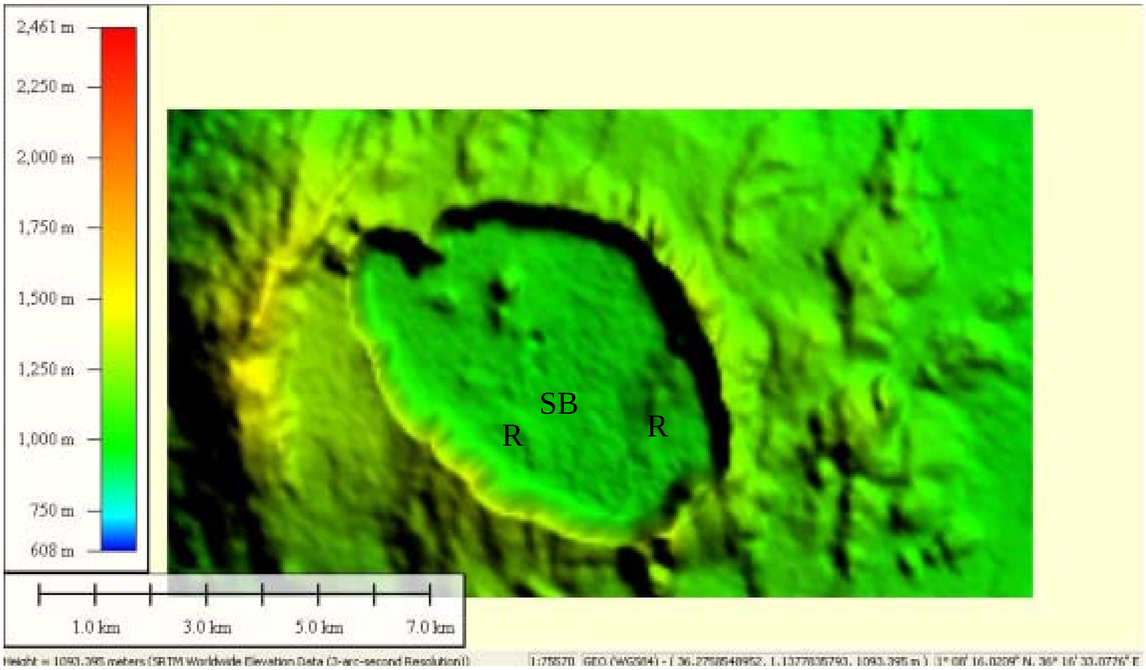
Figure 3: A morphological section of theSilali basinand the outer basin.

From the morphological section, it appears that the outer basin's floor to the east of Silali is higher than the floor to the west of the basin. This is possible because of the recent lava flows covering the area. Much of the magma that exited Silali basin, before subsidence, appears to have poured out more to the east of the basin than to the west. The lava flows are very evident from the satellite images presented in this paper.



Source: Geothermal Development Corporation- GDC-Kenya library.

Plate 5: A LIDAR image showing the crater and the fault lines within and around it.



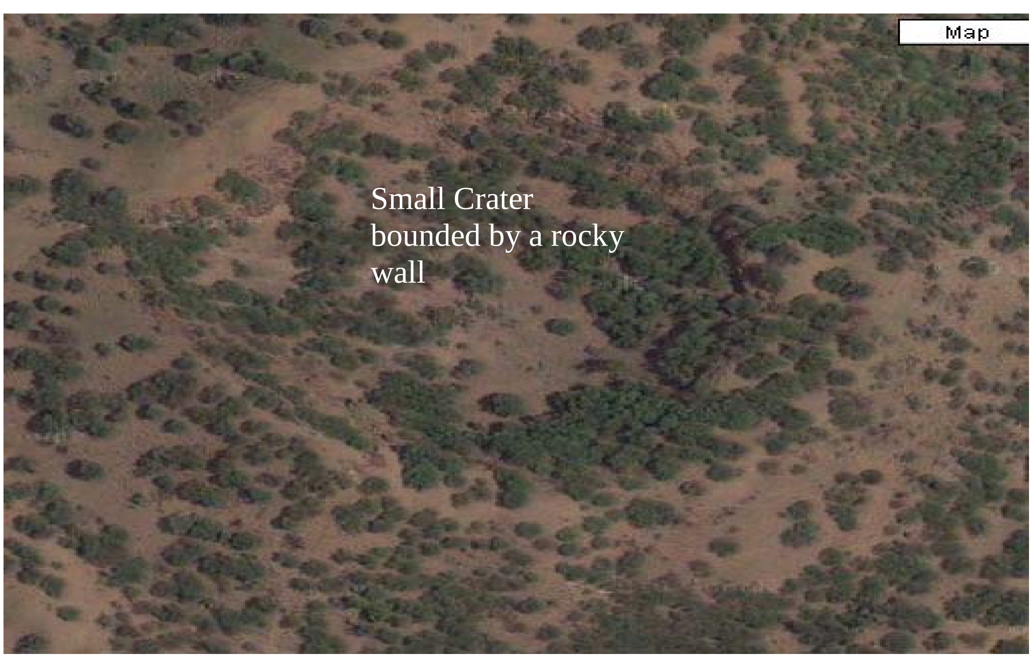
Source: Kipkiror, 2016.

Plate 6: 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).

b) The basin's flat and hummocky floor

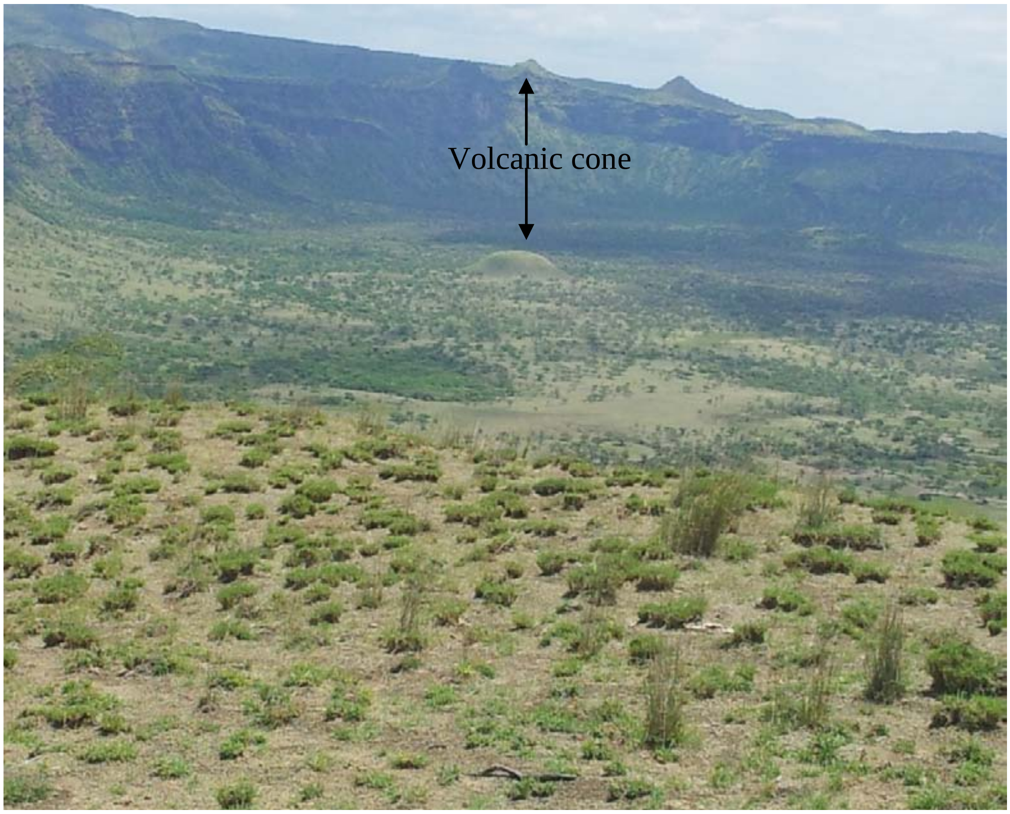
Silali basin's floor, like the floor of other Extra-Terrestrial Impact Craters (ETICs), is uniformly flat and hummocky. It is characterised by smaller circular craters, volcanic cones, pseudotachylites, ridges that are remnants of a possible peak ring and heaps of slumped soil and rock material.

Plate 7 showsone of the small craters within the Silali basin and like the Silali basin itself, the small crater has very steep walls and its floor is flat and hummocky. Plate 8 shows one of the most prominent volcanic cones within the basin.



Source: Google Earth maps.

Plate 7: A SPOT satellite image showing one of the smaller craters (mini craters) found within the Silali basin.

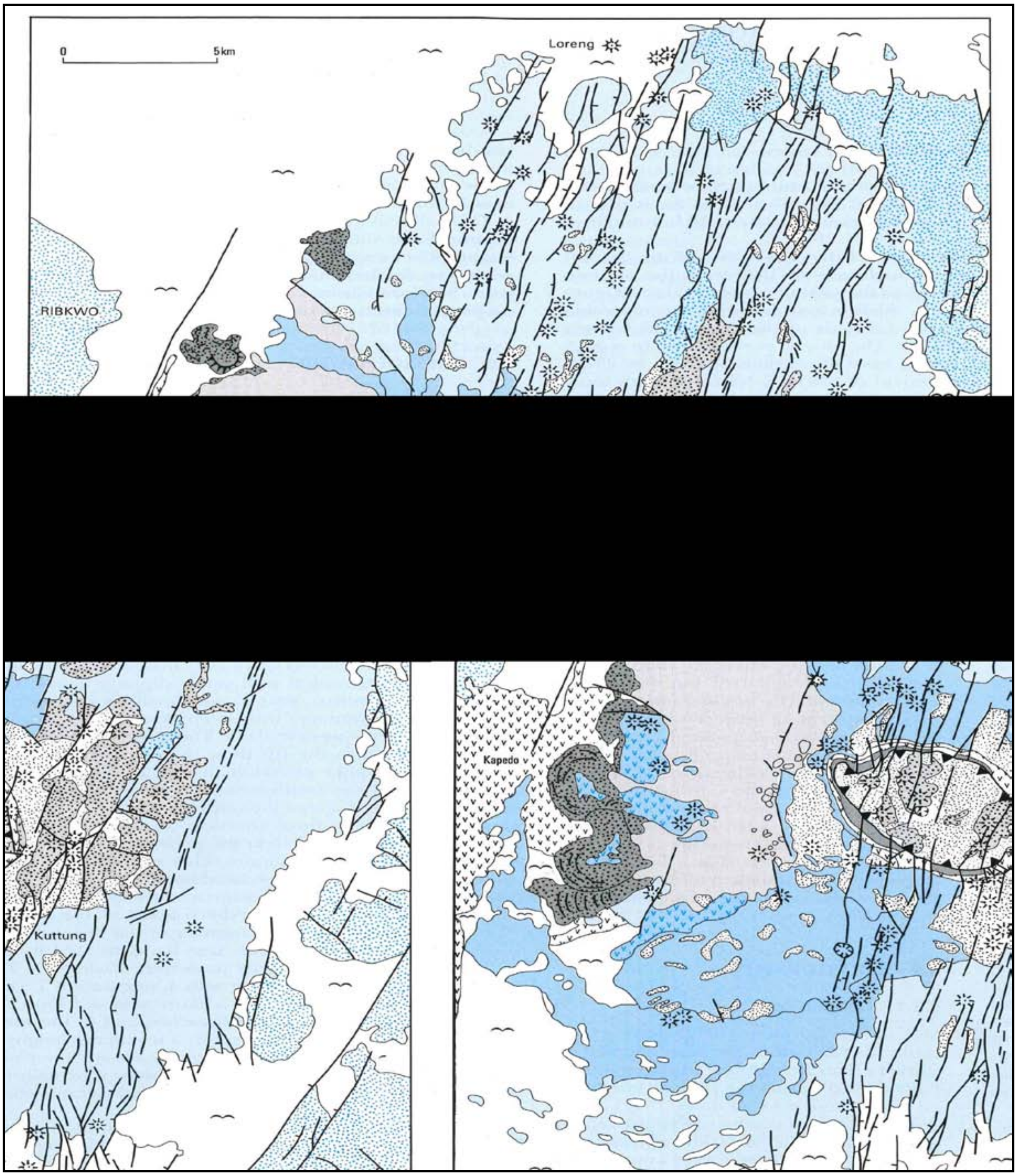


Source: Kipkiror, 2016.

Plate 8: A picture showing one of the cones found on the Silali basin's floor.

c) Silali's ring fracture structure

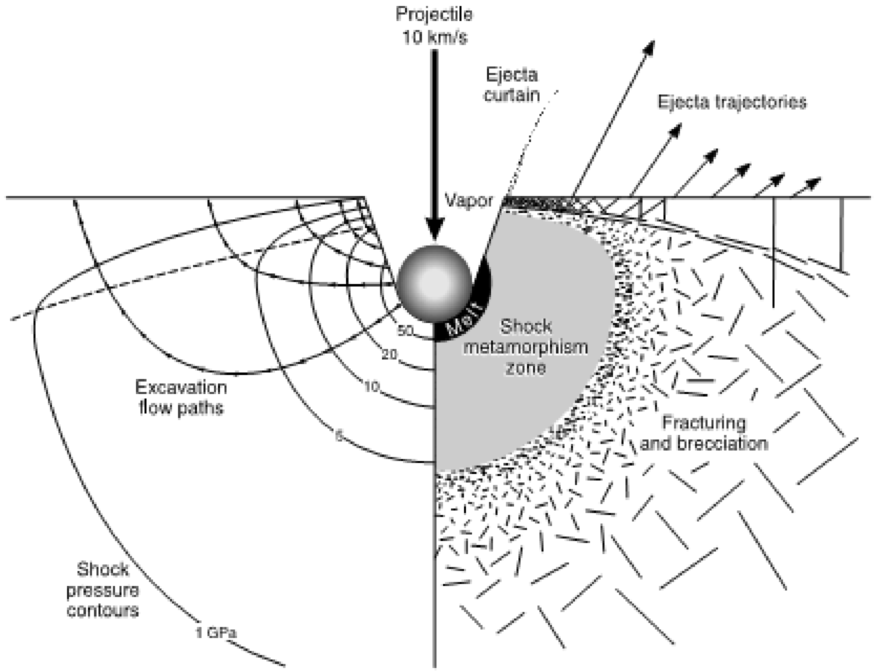
Subsidence does not completely explain the circular shape of Silali basin, especially if it is a product of a fissure eruption and not a vent type eruption. Fissures mainly build up volcanic shields and elongated domes, which in most cases do not have craters, let alone the 5-8kmwide crater formation of the Silali basin. The question that arises here is how the fissures that are responsible for the building of the Silali basin occurred in a concentric formation culminating into the formation of a near circular depression. Additionally, how these developed lithologically into a ring-like structure. The map below (Figure 4) of Silali area, provides evidence of fractures all around the basin that appear concentric in formation.



Source: Dunkley et al., 1993.

Figure 4: Simplified geological map of Silali basin, showing the basin's ring like structure and the fault lines cutting across the basin.

Although in some cases, caldera subsidence can cause ring structures like those found in Silali basin, due to doming effects, the caldera must be associated with a volcanic pipe/vent. Silali's ring fracture structure could be the product of an extra-terrestrial impact because; when a heavenly body falls on an area, it causes the area rock to fracture in a concentric manner. The fractures are the result of hypervelocity shock waves, which usually radiate outwards from the impact point at speeds of 10km/s or more (Therriault*et al.*, 2002). Further outward pressure can produce distinctive shock deformation effects (shattering and fracturing) in large volumes of unmelted target rock (Melosh, 1989).Figure 5illustrates how an extra-terrestrial impact results in concentric fracturing of rocks.

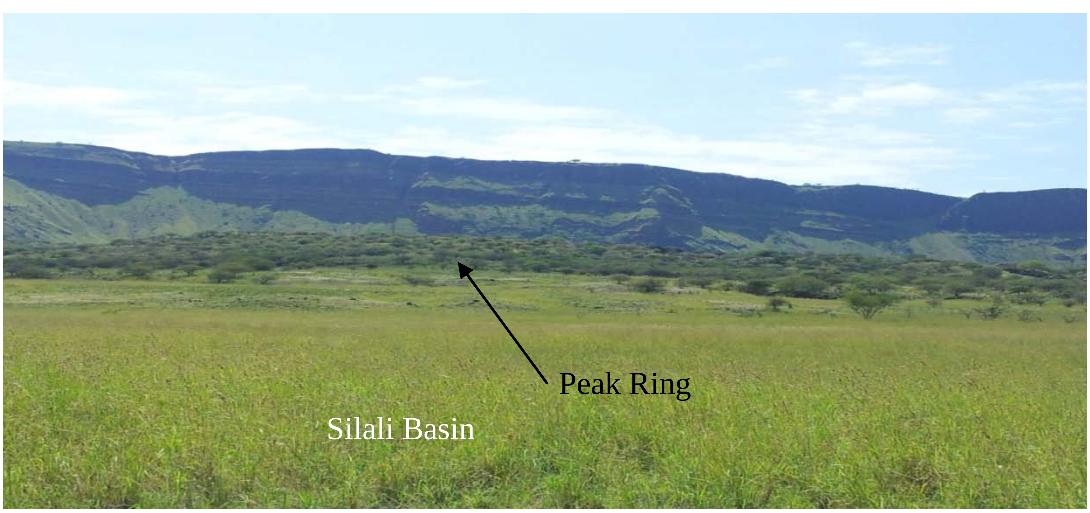


Source: www.lpi.usra.edu/publications.

Figure 5: A cross section of an ETIC showing the effects of shockwaves on target rocks (shattering and fracturing). GPa is Gigapascal that is measured in newtons/square millimetre (N/mm^2).

d) Silali Basin's upraised rim and Peak Ring

ETICs have upraised rims that mostly consist of proximal impact ejecta. The rim of an ETIC defines the circular shape of the ETIC and encloses the ETIC's wall. Notably, the walls of ETICs vary in height from their floors.A peak ring, on the other hand, is a concentric raised ridge that goes all around a complex crater. Notably, some complex craters/basins may have more than one peak ring and in other instances, a complex crater may develop a central pit (s)/depression(s) instead of a peak ring (s) (https://en.m.wikipedia.org and French, 1998). A peak ring forms when the initial (transient) deep crater floor rebounds from the compressional shock of impact, dragging impact eject a backwards into the basin. In some instances, though, a peak ring is formed when slumping material converges around an ETIC floor, as in the case of Silali basin and Tenoumer crater, Mauritania (French et al., 1970).Plate 9shows Silalibasin's raised walls and a ridge that may be a remnant of the crater's peak ring. Subsidence and slumping, in Silali basin, has raised the crater's rim, creating a steep wall that is about 300 m below the crater rim. Plate 10shows Silali basin's peak ring. It consists of a ridge ring that is broken in places.



Source: Kipkror, 2016.

Plate 9: A picture showing Silali basin's peak ring.

Source: Google maps.

Plate 10: A SPOT image showing Silali basin's crude peak ring (PR).

e) The basin's steep, slumped and stepped walls

ETICs are generally circular and their outer walls are rough with an overflow of proximal and distal ejecta. The immediate inner walls are steep, especially on the upper parts, due to slumping of materials and later denudation. The lower inner walls are gently sloping upwards (conically) due to melt material lining up the inner walls and the slumped or eroded materials that cover the melt.

Large ETIC walls collapse/slump more spectacularly giving rise to wall terraces (Melosh et al.,1999). According to Heiken and a team of other researchers, true complex craters contain terraces on their interior walls, a flat floor and a single peak or group of peaks in the centre of the crater floor (Heiken et al., 1991). For them, the interior wall terraces are products of landslides as evident in one of the craters on the moon called Copernicus (Heiken et al., 1991). Silali basin's walls could thus be products of subsidence, slumping and erosion. Plate 11 shows the basin's slumped walls while Plate 12 shows a slumped section of the basin's wall.

Source: Kipkiror, 2016.

Plate 11: A section of Silali basin's wall that is both stepped and slumped.

Plate 11shows the height of the basin's wall against an average human height. The slumping of the basin's walls may be an indication that the basin is still be in the process of subsiding, especially following the release of hot gases and steam from the basin's magma chamber.

From ground truthing, Silali basin's wall is stepped all around, though irregularly and this is ingrained in the basin's formation, as explained earlier. The basin's wall is also slumped all around, as can be seen in the ground pictures and satellite images presented in this paper.

Though slumped walls are associated with faulting, even in the rift valley where Silali basin is located, the slumping in Silali basin defines a circular basin and enhances the basin's circular morphology.

It is advisable that anyone desiring to climb down into and out of the Silali basin should do so with the help of a helicopter, especially if one has a heart or a breathing problem. This is because temperatures within the basin are high and the basin's walls are not only extremely steep but very rugged, making it possible for human exhaustion to easily turn fatal. Some of the rocks on the basin's wall are also loose and movable.

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Source: Kipkiror, 2016.

Plate 12: A picture showing more of Silalibasin's slumped inner walls (SW).

f) The basin's butterfly pattern of ejecta

Lichoro (2013) observed that there is absence of massive lava deposition on the flanks of Silali basin. There are no visible lava deposits on the basin's floor either and according to the book on the geology of the Maralal area 'the caldera walls have inner vertical drops of about 300m; they remain unbreached and the caldera is not infilled by a lava pool' (GOK, 1987).

As it is, the basin is surrounded by an 'apron of alluvium' which can be proximal ejecta or allochthonous materials, according to the study that bore this paper. Indeed, an explosive volcanic eruption is capable of depositing lots of dust around a crater and Silali basin's ejecta are like volcanic ash because they consist ofrock minerals and volcanic glass.This would suggest that the dust on the flanks of Silali basin is pyroclastic material erupted from the Silali shield. However, this is not the case because the dust does not have recent lava deposits on it.It is just loose dust, of non-specified shape, broken by huge rock blocks (hummocky ejecta and allochthonous material) in places. Volcanic ash also has vesicles and the ash particles display some distinctive shape in their looseness, such as being blocky, convoluted, vesicular and spherical or plate like (http://en.wikipedia.org/wiki/volcanic_ash).

Interestingly, the ejeta on Silali basin displays the butterfly pattern of spread that is common in some ETICs (https://en.m.wikipedia.org/wiki/ejecta). Plate 13, below, shows this butterfly pattern of ejecta spread.

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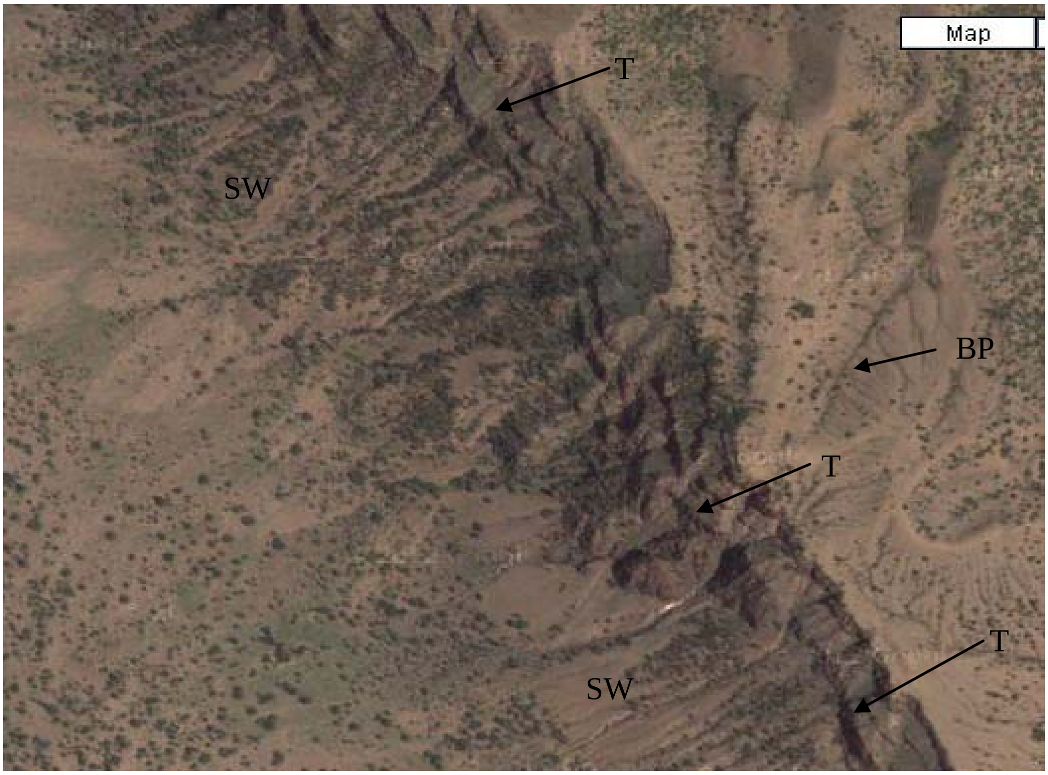


Source: Google maps.

Plate 13: A SPOT satellite image showing terrace like features (T) on a part of the Silalibasin's eastern wall, a portion of the basin (SB), butterfly pattern (BP) of ejecta spread and slumped walls (SW).

V. Etic Associated Geomorphological Features

Extra-terrestrial impacts and impact cratering are responsible for many geologic processes, that in turn are the forces behind the formation of different geomorphological features, as stated by Thompson and Turk (1992), in their book on earth science.

In the case of Silali basin, an extra- terrestrial impact would be the seed for volcanicity in and around the basin, besides faulting and other modes of land transformation.

Volacnicity, in Silali, has led to the formation of volcanic cones, such as those found on the floor and walls of the crater, as seen in the pictures and satellite images presented. Mt.Paka, a huge edified cone on the same plane as Silali basin and to the south of Silali, may also be a product of Silali's impact. The magma that exited Silale basin, after impact, may have constructed Mt. Paka and other neighbouring volcanic cones, such as the black hills to the east of Silale, which are believed to be made of pure black glass (McCall and Hornung, 1972). This black glass may be impact glass.

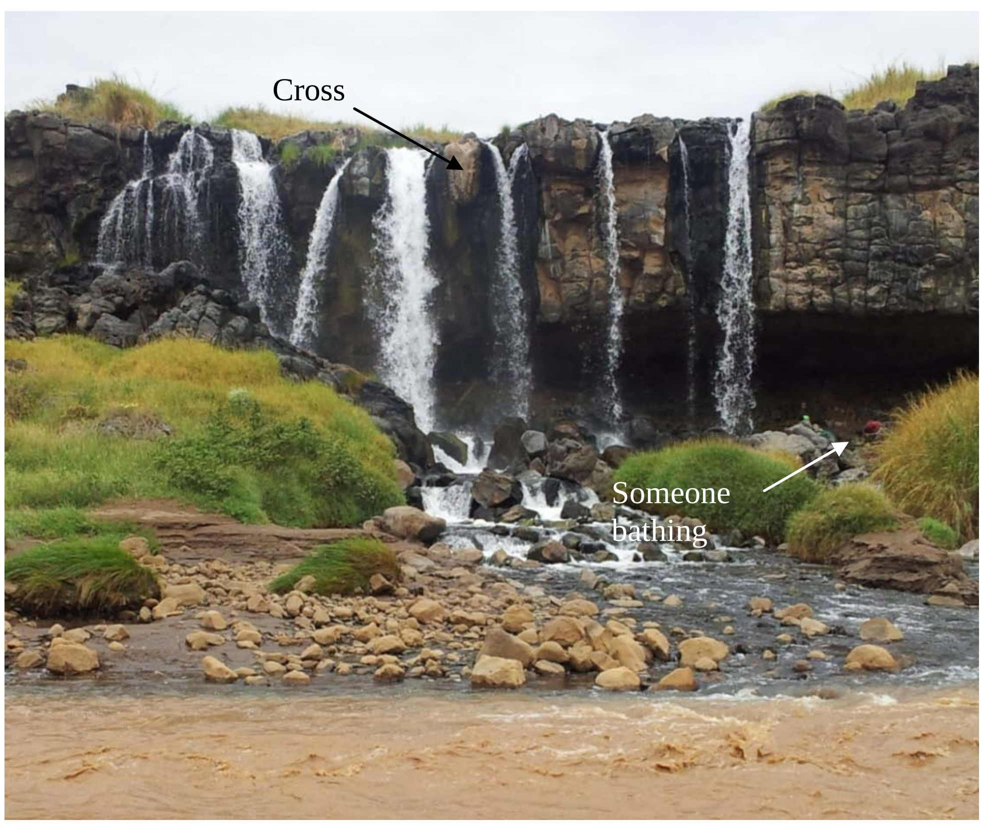
Faulting is prevalent within and around Silale crater and one of its main products is the Suguta gorge, in which River Suguta flows. A huge extra-terrestrial impact has all the potential that is adequate to move crustal rocks apart, leading to the creation of faults, some of which may criss-cross. While some of the major faults of Silali became conduits for the construction of huge volcanoes, the minor ones (fissures) provided avenues through which hot water and steam gushes onto the earth's surface, as occurs around the Silali basin. Suguta gorge, the caves, the lava flow and the sinkhole around Silali basin are fault associated features. Silali area is heavily faulted and it is a volcanic hot spot with unending volcanic capabilities.

On the outer basin, there are impact related rocks that have formed unique sceneries. Examples are the shatter cones near Chemolingot (Plate 19) and the slumped wall areas of the outer basin (Plate 20). Chemolingot is to the south of Silali basin, near Chemolingot town on the outer basin. Since shatter cones only form inside an impact crater, their presence in Chemolingot is a likely suggestion that the Chemolingot area is an extra-terrestrial impact area. Consequently, the outer basin could bea product of an extra-terrestrial impact cratering. However, more research on the outer basin is advised.

Plates 13 shows a part of the steep Suguta River gorge. Plate 14 shows the hot water falls on the eastern wall of the Suguta gorge and Plate 15 shows the area that is the source of the hot springs that feed the hot water falls.

Source: Kipkiror, 2016.

Plate 13: A picture showing a part of the steep walls of the Suguta River valley, which may pass for a gorge.



Source: Kipkiror, 2016.

Plate 14: A picture showing the hot water falls of the Suguta River, near Kapedo.

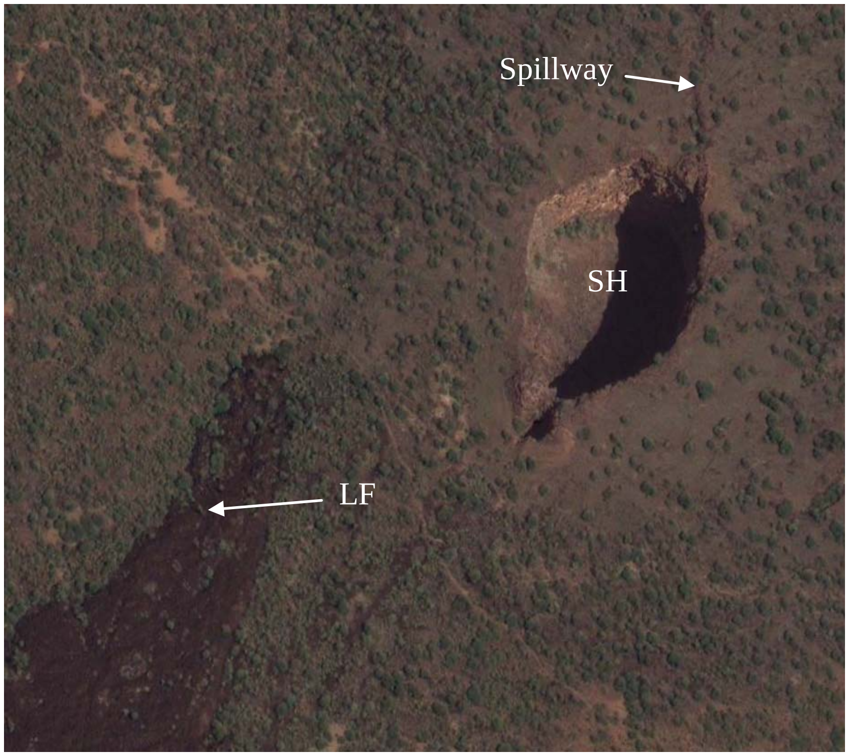
Near the heavier water fall, on the wall, there is an engraving of the cross as known to Christians. This may have been done by missionaries who had built a church at Kapedo. They are no longer in the area.

The picture also shows someone bathing at the water falls.

Source: Kipkiror, 2016.

Plate 15: A picture showing the plain land above the hot water falls, where hot springs are found, on the outer basin.

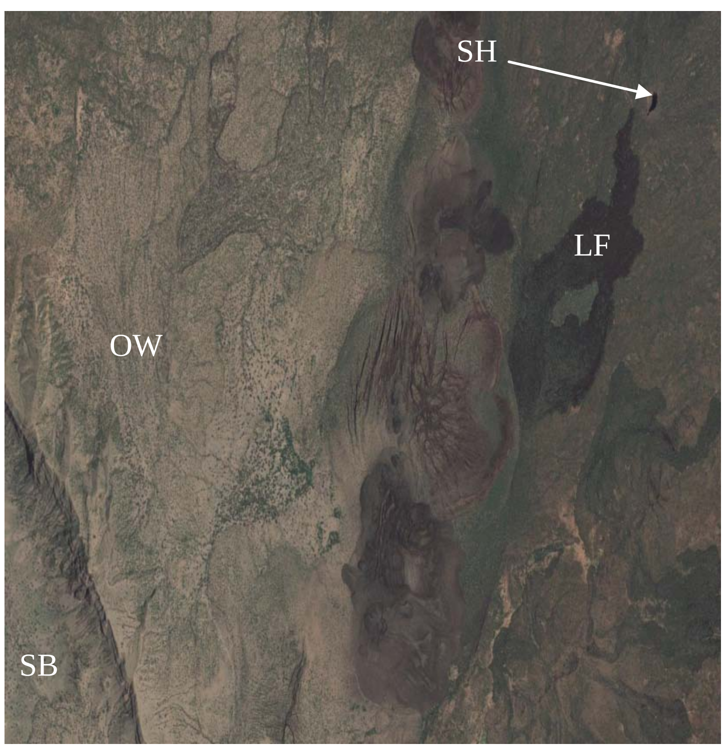
To the northeast of Silali basin, there are other spectacular geological features, most of which are visible from the satellite images presented in this paper. Examples of these features include a sinkhole and a mass of dark volcanic rock that seems to dip towards the NE of Silali. Evidence of this is the direction of water flow from the volcanic rock. When it rains, overland flow, from the bare volcanic rock, runs north-eastwards towards the sinkhole. When the sinkhole fills up, its spilled water runs further north-eastwards along a valley that appears dry. Notably, the sinkhole does not retain any water for it appears dry on the SPOT satellite image (Plate 16) and has vegetation. There could be more sinkholes around Silali basin.



Source: Modified from www.Google.com.

Plate 16: A SPOT image showing the lava flow (LF), the sinkhole (SH) and the sinkhole's spillway more clearly.

The sinkhole is found to the northeast of Silali basin and the Lava flow starts right at the base of the north-eastern wall, flowing outwards. This flow can be seen from the rim of the eastern wall.



Source: Modified from www.Google.com.

Plate 17: A SPOT image showing the sinkhole (SH) and lava flow (LF), Silali basin (SB) and Silali basin's outer wall (OW).

The features shown on Plate 17 are found to the east and northeast side of the Silali basin. It is the side of the basin where massive lava outpourings appear to have occurred, near the base of the basin's wall. Though the area was inaccessible for a close study, due to insecurity as a result of cattle rustling in the area, the image clearly shows the sinkhole and the lava flow, which are shown by Plate 16. Plate 17 also shows the Silali basin itself, its stepped inner walls and the basin's outer wall on the eastern side. It is important to note the rippling away appearance (butterfly pattern) of the rough dust covering the basin's outer wall (ejecta). This is a characteristic of the dust that could not be seen clearly while standing directly on it.

In ETICs, 'ejecta are layered thickly at the crater's rim and thin to discontinuous at the blanket's outer edge' (www.google.com). This may probably be because of the decompression wave that follows an impact event, which causes impact ejecta to shrink backwards into the crater.

Source: Kipkiror, 2016.

Plate 18: The entrance (E) of one of the large caves found near Natan market, on the plains south of the Silali basin.

The caves could have formed due to the widening up of existing faults around Silali basin, following Silali basin's possible impact.

Source: Kipkiror, 2016.

Plate 19: The cave on Plate 18 from the inside.

Source: Kipkiror, 2016.

Plate 20: A picture showing shatter cones (SC) around Chemolingot area of East Pokot. These compare well with the shatter cones at Beaverhead impact structure, Montana, shown by Plate 21.

Source: www.impact-structure.com/impact-rocks-impactites/the-shatter-cone.

Plate 21: Assemblage of massive shatter cones with sizes of up to one meter, at Beaverhead impact structure, Montana.

Source: Kipkiror, 2016.

Plate 22: A picture showing asection of the slumped walls of the outer basin; to the southwest of Silali basin.

VI. Conclusion

Silali basin can be said to be a probable ETIC that is rich in volcanic features. Old and recent volcanicity has created many volcanic features in the basin to an extent that the basin can easily pass for a volcano. However, Silali crater may not be considered a volcano because it is not found at the top of a volcanic edifice the way summit craters are found at the top of volcanic cones. The lack of a cone shape in the raised area surrounding the basin is clearly visible, even from the side of the basin captured by Plate 23.

Source: Kipkiror, 2016.

Plate 23: A picture showing the outside western walls of the Silali basin, in the background, at a distance.

Besides the basin's ETIC morphological characteristics, Silali basin has many other ETIC characteristics that include; the basin's ETIC related geology and rock chemistry, the basin's geophysics and the many geomorphological features that are associated with the basin. In Conclusion, Silali basin seems to have formed, as an ETIC, not only on an area of volcanic rock but on a volcanic shield; through an extra-terrestrial impact and later, subsidence. The basin also bears the morphological classic hallmarks of an impact crater, which include slumped walls inside the rim, rough irregular crater floor, stepped walls, shatter cones, polimict breccia, circular morphology and hummocky deposits (ejecta) outside the basin- among other features.

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