Morphological Characteristics of Silali Basin

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Abstract

The paper focuses on the formation of Silali basin as an Extra-terrestrial Impact Crater (ETIC) and its ETIC related morphological 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. The Silali crater has a near circular shape as shown by the satellite images of the area, the area's topographical maps (not in the paper), the DEM of the basin and the LIDAR image of the study area. Apparently, Silali's near circular shape is a product of remodelling of the original crater shape by various geological processes. These processes 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 4 km (it is 5-8 km). The crater floor contains small craters, volcanic cones and ridges besides slumped rock materials. Silali basin does not display a clear peak ring but there is an outline of a peak ring.

Keywords: *Extra-Terrestrial Impact Crater, Geological Processes, Ridges, Silali Basin, Volcanicity, Volcanic Cones.*

1. Introduction

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 utter destruction and death. This research paper brings to light the fact that Kenya, like the rest of the earth, is in the inherent potential danger of being hit by heavenly bodies. In addition, it provides, to a large extent, morphological evidence implicating Silali basin to be a possible ETIC and the possibility of the presence of other ETICs in Kenya.

The principal criteria for determining if a geological feature is an impact structure formed by the hypervelocity impact of a meteorite or comet are outlined below. These are classified as either megascopic (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).

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 a sufficient 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 center 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 evidence 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, Grieve, & Pillington, 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, Gudlaugsson, & Faleide, 1998).

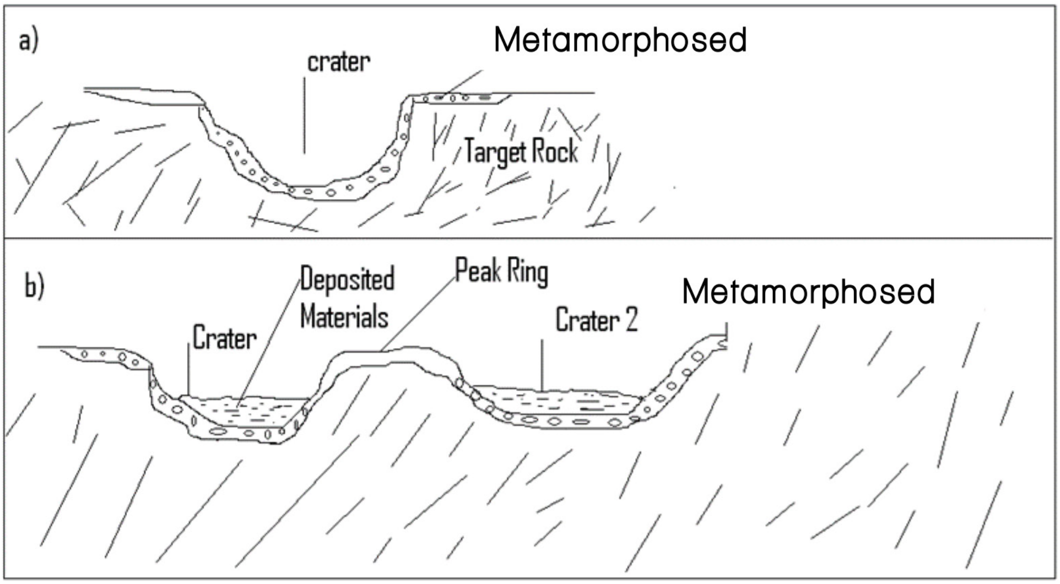


Figure 1: Diagram showing a simple crater (a) and a complex crater (b) with associated features (Author, 2013).

2. 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 850 km^2 and has a NNE diameter of about 5 km and an ESE diameter of 8 km. It can be estimated that the impactor’s size, could be 0.25-0.4 km in diameter or 42.5 km^2 in area, on the basis of the rule that an impactor’s size is 1/20 the crater’s size (Beatty, Petersen, & Chaikin, 1999). Consequently, the Silali impact event may have been a great event. According to Dunkley, Smith, Allen, and Darling (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 hot water falls, cross bedding slumps, sink holes, the shatter cones of Chemolingot and several breccias occur. Different volcanic rocks, prehistoric caves, some of the mentioned smaller craters, several 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 there existed a volcanic shield where the Silali basin is. The shield seems to have been stretching in a north-south direction. According to Smith, Dunkley, Deino, Williams, and McCall (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 (Dunkley et al., 1993; Smith et al., 1995). The existence of a volcanic shield in Silali before the ETIC formed is favoured by the following incidences:

i) The fact that Silali basin’s wall is made up of volcanic materials placed in layers;

ii) The non-contemporaneous nature of the wall materials in terms of age and physical characteristics; and

iii) 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, Macdonald, and Chapman (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 ring structure unless there was an outline of a ring structure in existence.

Caldera subsidence occurs in various ways, such as through plate / piston subsidence, trap door subsidence, chaotic subsidence and downsag 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 (Geyer 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, downsag 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 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.

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 Silali volcanic 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;

i) 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 300 m for the top most layer).
ii) 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 basins 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 the 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.

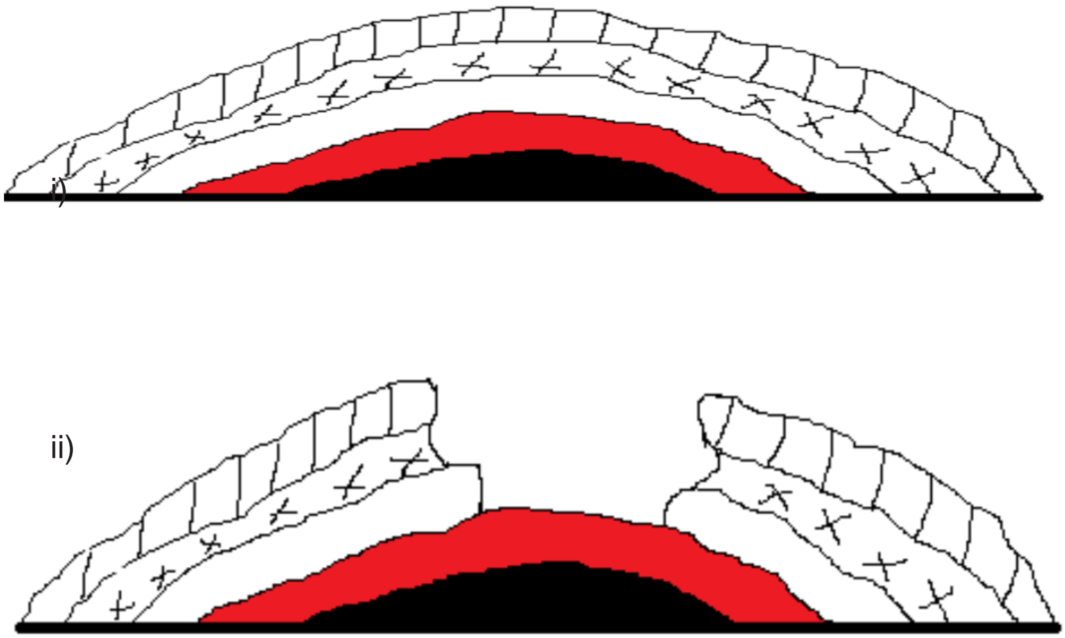


Figure 2: Schematic diagrams showing the formation of the Silali basin. (i) Represents the pre-impact volcanic shield. The shield is made up of different layers of volcanic rock. (ii) Represents the post impact volcanic shield.

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 can be seen as white patches extending from the base of the basin's wall towards the river, westwards of the basin. Plate 1 was adapted from Google maps.

3. 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 4 km (it is 5-8 km). 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 main crater. Also evident are cones that look like volcanoes, within the basin. Ground truthing has 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 main 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).

Plate 2: A natural color SPOT satellite image showing the Silali crater. The image was adapted from Google maps.

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 DEM of the basin.

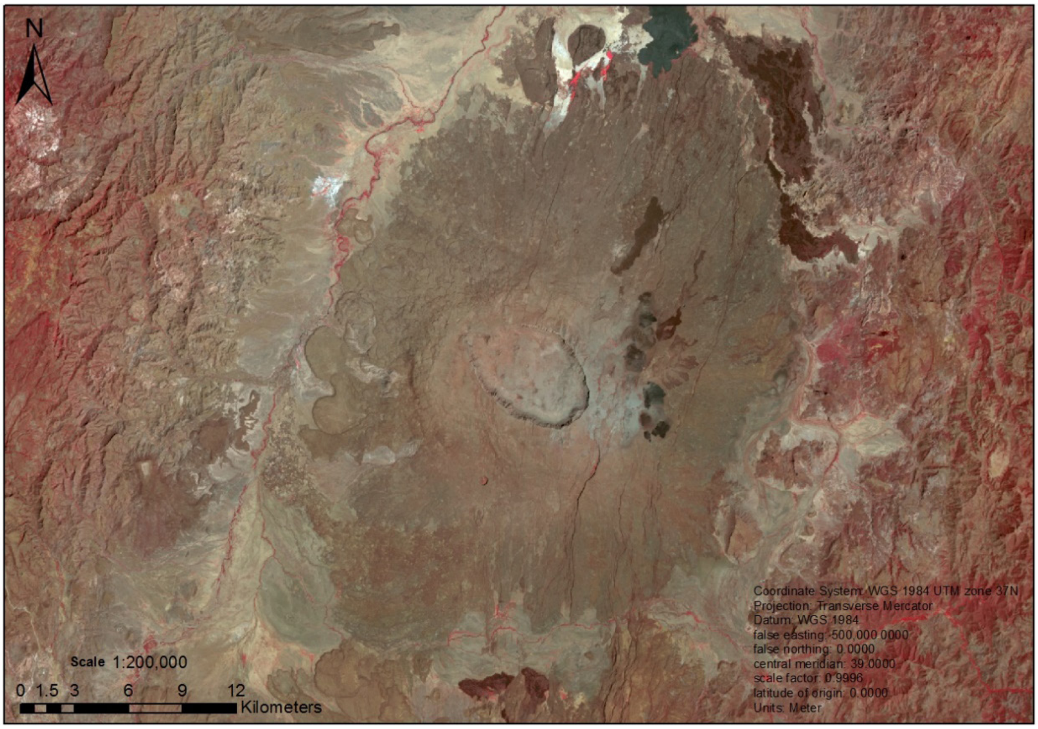


Plate 3: A false colour image of Landsat 8, bands 5 (Red), 4 (Green) and 2 (Blue), showing the Silali basin (courtesy of RCMRD).

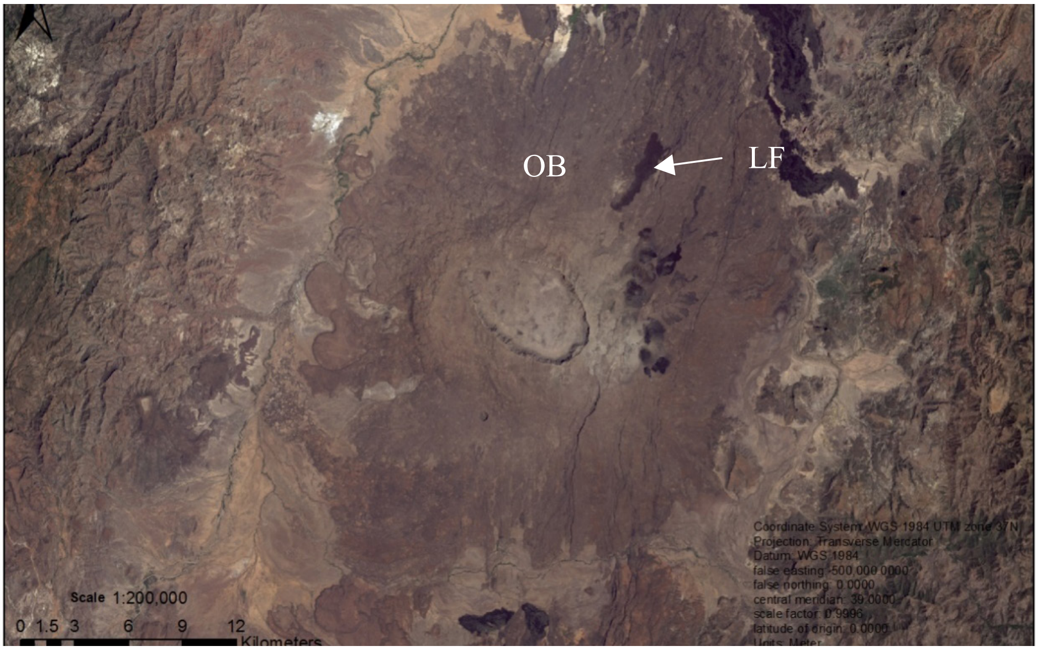
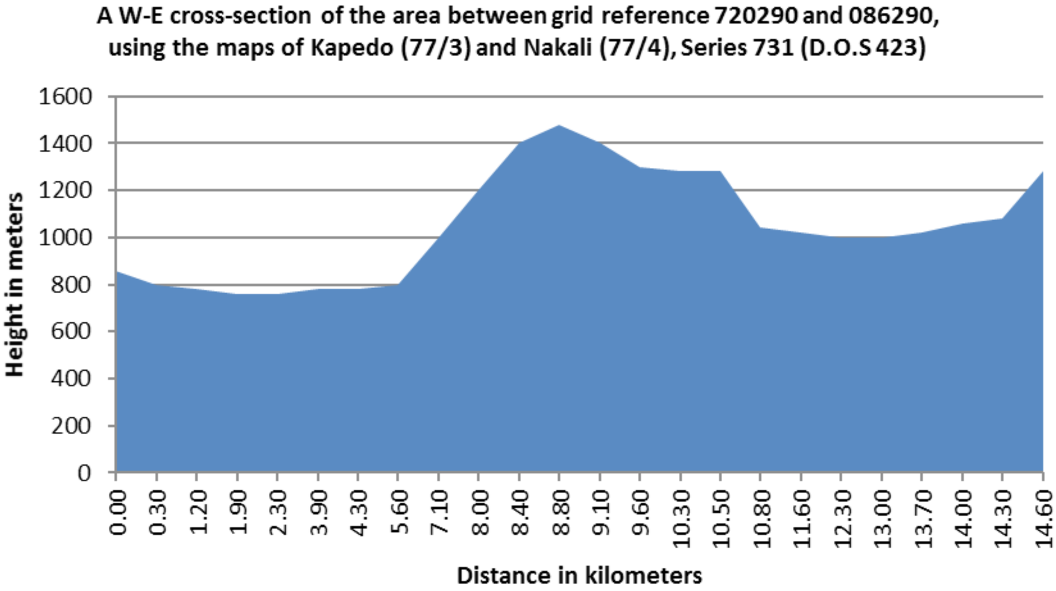


Plate 4: A natural colour image of Landsat 8, bands 4 (Red), 3 (Green) and 2 (Blue), showing the Silali basin (courtesy of RCMRD)

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. The lava 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.



(720290) (086290)

Vertical scale = 1 cm represents 200 m, Horizontal scale = 1 cm represents 2.5 km
Figure 3: A morphological section of the Silali basin and the outer basin (Author, 2015).

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 Silali. 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.

It must be noted that a circular shape, alone, cannot qualify a crater to be an ETIC.

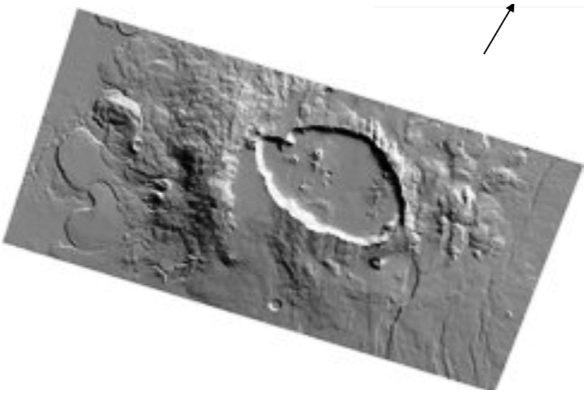


Plate 5: A LIDAR image showing the crater and the fault lines within and around it. (Source: GDC library).

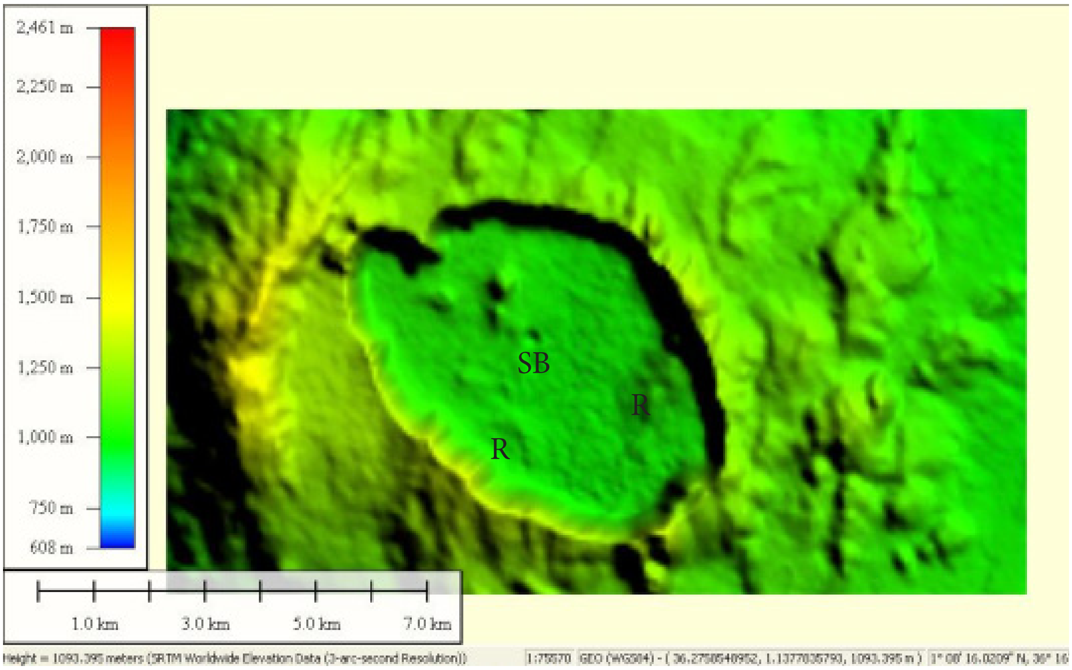


Plate 6 A DEM (with elevations) showing Silali basin’s (SB) hummocky terrain and morphology. The DEM also shows the outline of Silali’s probable peak ring (R) (Author, 2015).

4. 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 shows one 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.

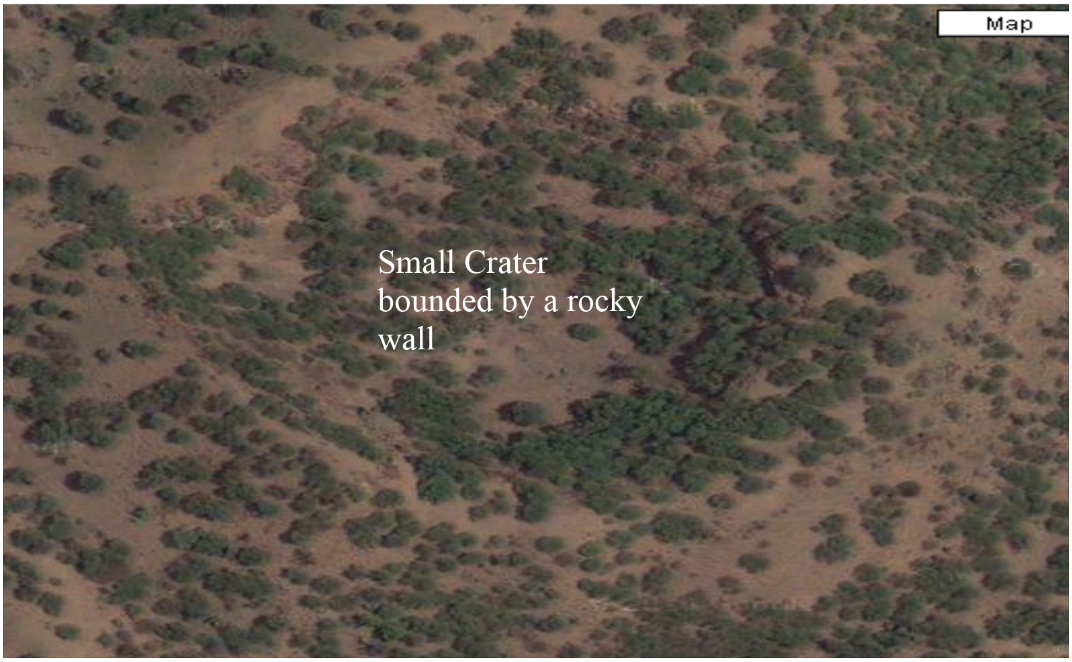


Plate 7: A SPOT satellite image showing one of the smaller craters (mini craters) found within the Silali basin, adapted from Google Earth maps.

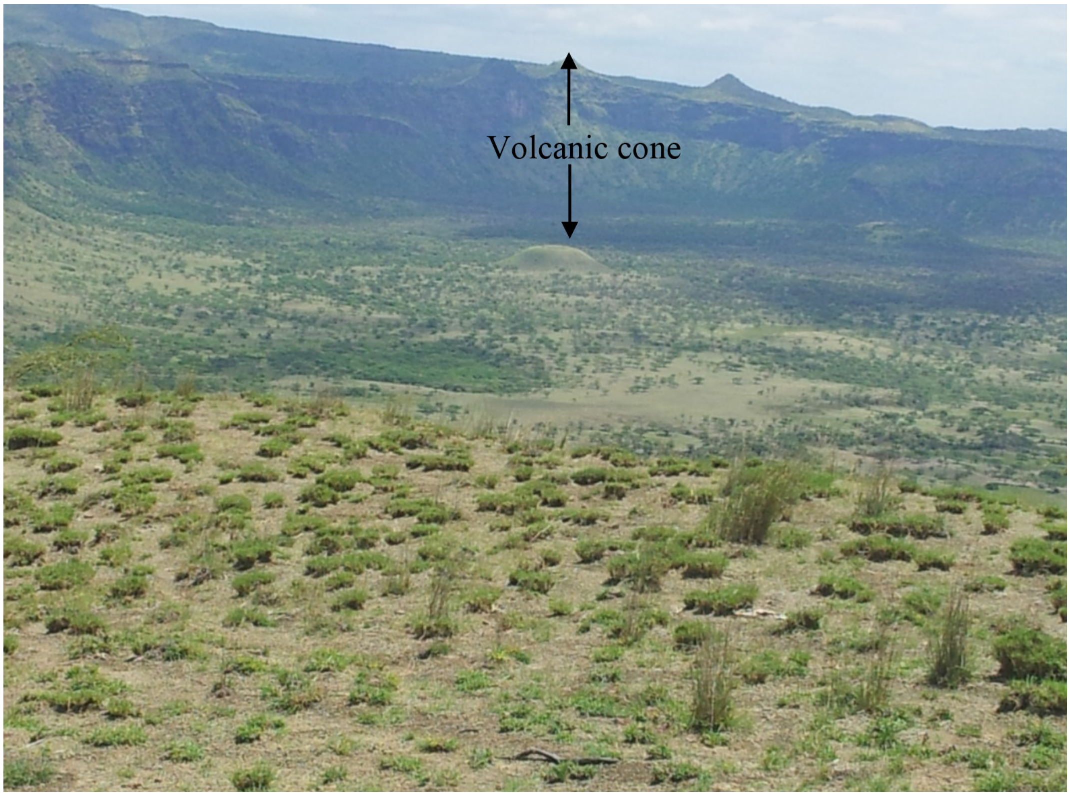


Plate 8: A picture showing one of the cones found on the Silali basin's floor (Author, 2015).

5. 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 5-8 km wide 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.

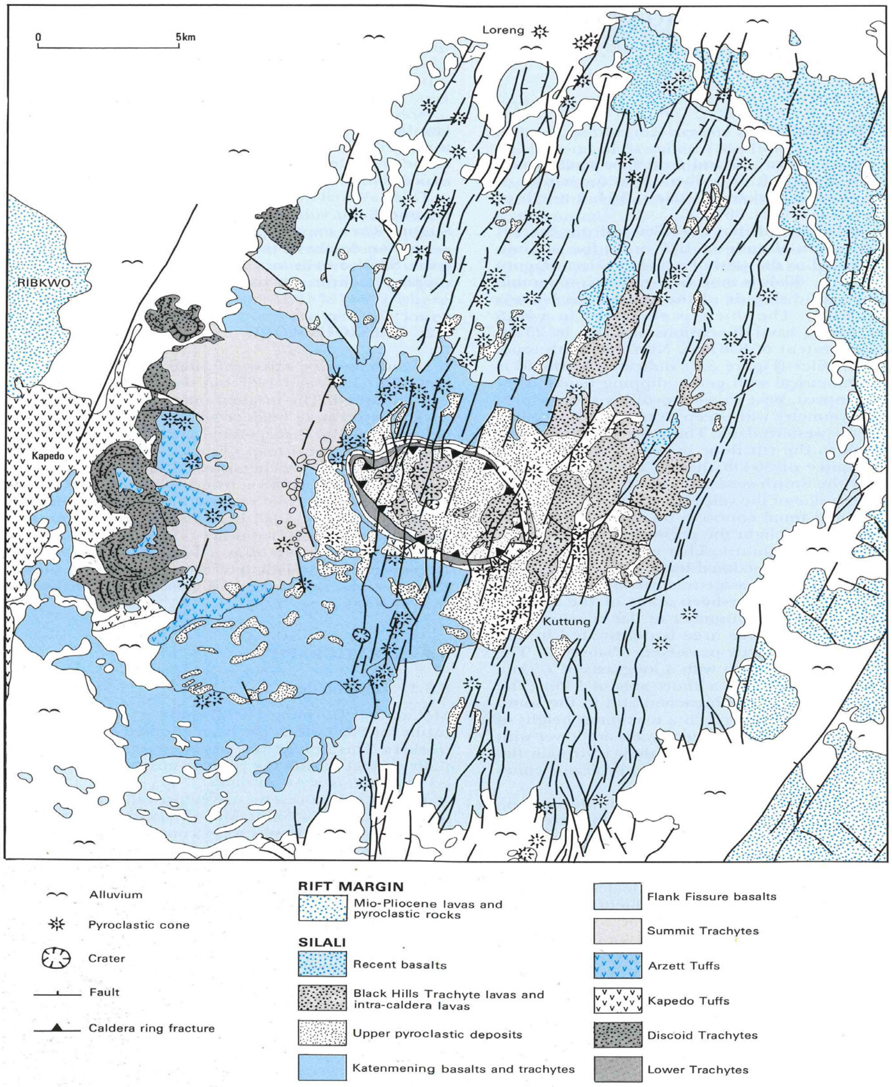


Figure 4: Simplified geological map of Silali basin, showing the basin's ring like structure and the fault lines cutting across the basin (adapted from Dunkley et al. (1993).

Although in some cases, caldera subsidence can cause ring structures similar to 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 10 km/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 5 illustrates how an extra-terrestrial impact results in concentric fracturing of rocks.

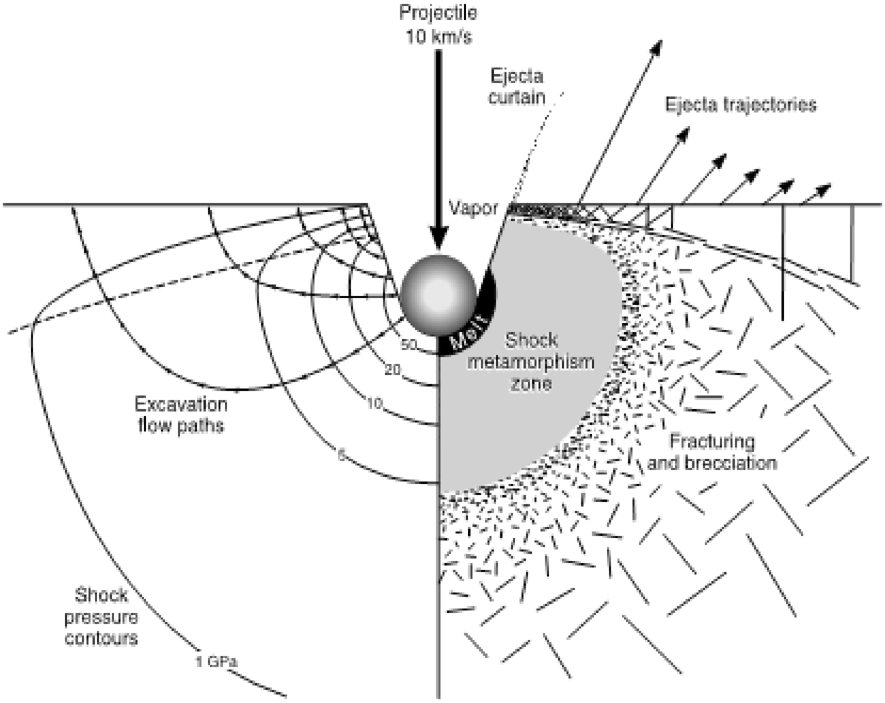


Figure 5: A cross section of an ETIC showing the effects of shockwaves on target rocks (shattering and fracturing). The figure was adopted from *www.lpi.usra.edu/publications.*

6. 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 the floor of the ETICs. Plate 9 shows Silali basin's raised walls, the small craters, the ridge and the volcanic cones found inside the basin. For Silali basin, however, subsidence and slumping has raised the crater's rim, creating a steep wall that is about 300 m below the crater rim. In some instances, as the slumping material converges inwards, a central peak or hill is produced, that rises above the general floor of the crater as in the case of Silali basin and Tenoumer crater, Mauritania (French, Hartung, Short, & Dietz, 1970). A crude outline of Silali's peak ring feature can also be seen from Plate 9, at a close look. Plate 11 shows the peak ring more clearly. It consists of a ridge ring that is broken in places.

Plate 9: A natural color SPOT satellite image showing the Silali crater. The image was adapted from Google maps.

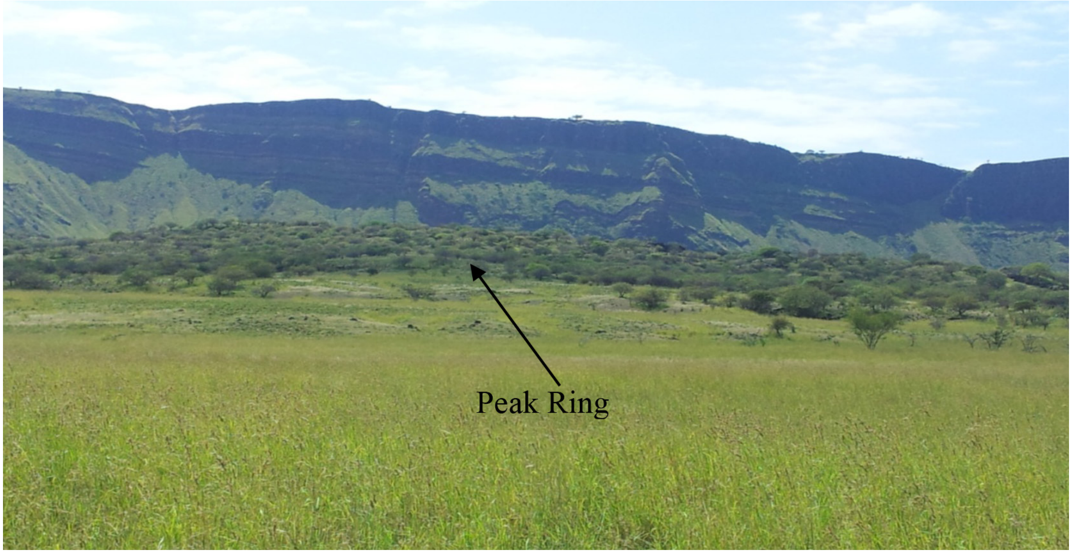


Plate 10: A picture showing Silali basin's peak ring (Author 2015).

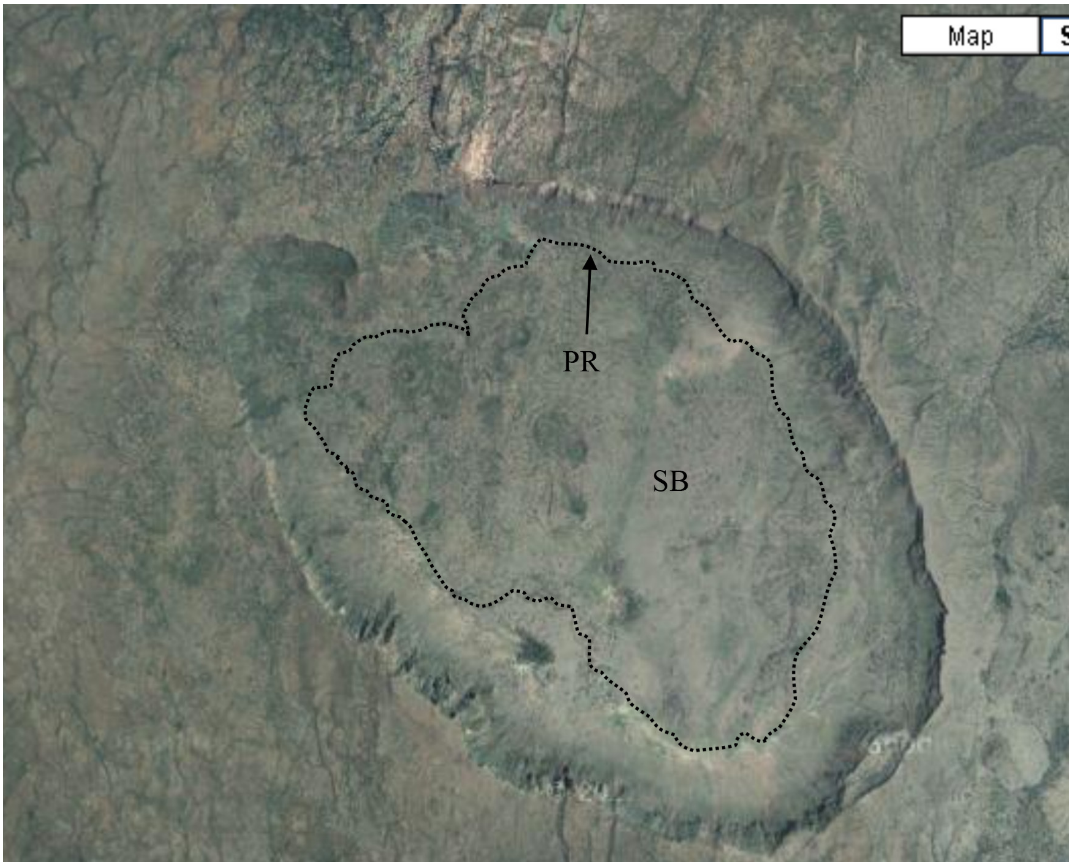


Plate 11: A SPOT image showing Silali basin's crude peak ring (PR) (image modified from Google maps).

As stated earlier, the peak ring or the central peak of a complex crater can also be formed as the initial (transient) deep crater floor rebounds from the compressional shock of impact.

7. 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, 1989). 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, Vaniman, & French, 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 12 shows the basin's slumped walls while Plate 13 shows a slumped section of the basin's wall.

Plate 12: A section of Silali basin's wall that is both stepped and slumped (Author, 2015).

Plate 12 shows 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 may 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.

Plate 13: A picture showing a section of Silali's steep and slumped walls (Author, 2015).

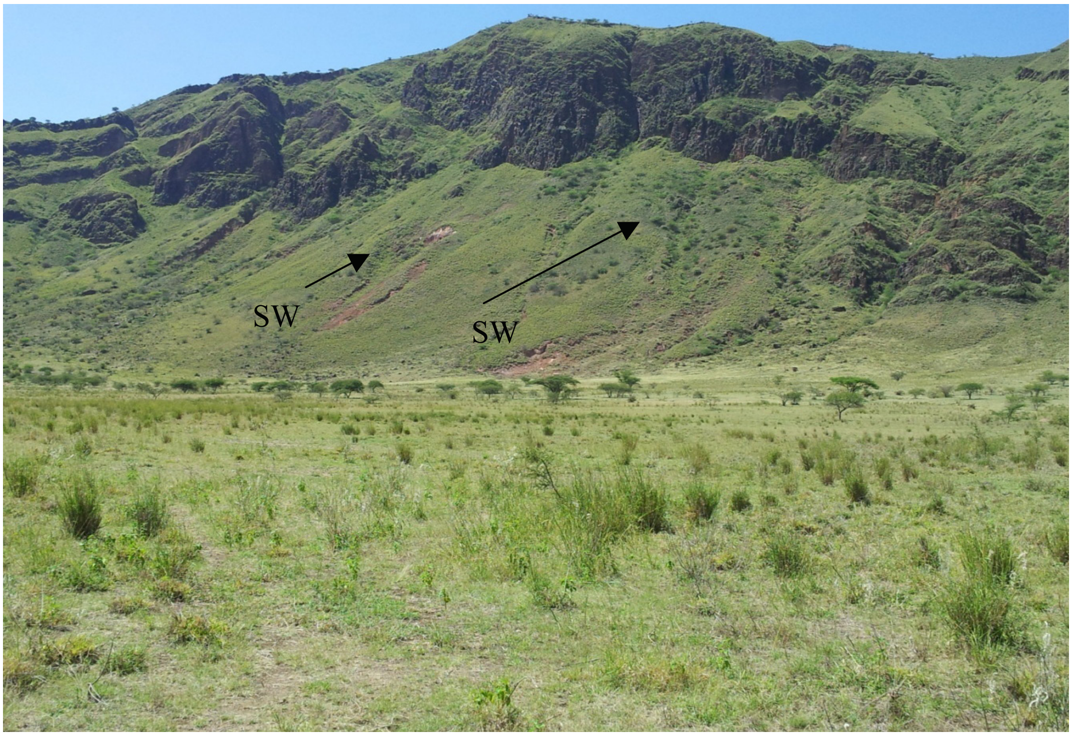


Plate 14: A picture showing more of Silali basin's slumped inner walls (SW) (Author 2015).

8. 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 300 m; they remain unbreached and the caldera is not infilled by a lava pool' (Government of Kenya, 1987). As it is, the basin is surrounded by an 'apron of alluvium' which is considered to be proximal ejecta or allochthonous materials in 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 similar to volcanic ash because they consist of pulverized rock 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 15, below, shows this butterfly pattern of ejecta spread.

Plate 15: A SPOT satellite image showing terrace like features (T) on a part of the Silali basin's eastern wall, a portion of the basin (SB), butterfly pattern (BP) of ejecta spread and slumped walls (SW). Image was adapted from Google maps.

9. Conclusion

Before the study: *Identification of an Extra-Terrestrial Impact Crater (ETIC); A Case Study of Silali Crater, Kenya*, Silali basin was considered a volcanic crater by all previous studies. This is not unique to Silali basin because Tenoumer crater, in Mauritania, was also known as a volcanic crater for twenty years until PDFs were found in its rocks in 1970 (Dunkley et al., 1993). Today, 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, such as the nearby Mt. Paka. 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 16.

Plate 16: A picture showing the outside western walls of the Silali basin, in the background, at a distance (Author, 2015).

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, a circular morphology and hummocky deposits (ejecta) outside the basin- among other features that have been mentioned in the paper.

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Further reading

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