



Effect of Silali Basin's impact cratering on the Environment of the Area

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ABSTRACT

This paper investigates the effects of extra-terrestrial impact cratering of Silali Basin on the environment of the area. The Silali Basin is located in Turkana East /Pokot East regions of Kenya. The basin is a depression suspected to be an extra-terrestrial impact crater (ETIC). The objective of the study was to document the effect that the cratering of Silali had on the environment of the area. To answer the study research question, remote sensing was utilized to map the Silali basin. Satellite images were used to identify the nature of the crater and characterize it, since most large terrestrial impact craters are not identifiable from the surface of the earth. The study established that the effects of Silali's impact cratering on the environment of the area include formation of physical features and minerals. The crater's potential economic and social significance has also been cited and include tourism, paragliding, quarrying of breccias and geothermal power harvesting. Being a pioneer study in the investigation of ETICs in Kenya, the study may form a basis for further research on ETICs in the country, besides enhancing knowledge on Extra-terrestrial impact cratering in Kenya and its environmental significance. It is also hoped that the study will enhance the economic utilization of Silali basin.

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Introduction

Impact cratering research has gained attention throughout the world following the suggestion that a large impact event caused the extinction of about 50% of all living species, including the dinosaurs, approximately 65 million years ago (Koeberl & Sharpton, 2001). Researchers believe that a large asteroid or comet struck the earth at that time and caused massive extinctions of mega-fauna. Evidence came from detailed studies of a thin clay layer that globally marks the stratigraphic boundary between the Cretaceous Tertiary (K-T) geological periods. The layer is enriched with iridium (siderophile element) indicating that the clay represents a mixture of normal crustal rocks, which typically have low siderophile element abundances and a small percentage of extra-terrestrial material. According to Koeberl and Sharpton (2001), the worldwide integrated volume of the extra-terrestrial material in the K-T boundary layer is equivalent to an asteroid approximately 10 kilometres in diameter; large enough to have produced a 200-kilometers-diameter crater.

In the early 1990s, the subsurface Chicxulub structure in Mexico was confirmed as the long-sought cretaceous tertiary boundary impact crater. An environmental crisis, triggered by the gigantic collision, contributed to the extinctions of most mega-fauna that existed on the earth's surface 65 million years ago. Based on apparent correspondences between periodicities observed in the marine extinction record and in the terrestrial impact record, some scientists have suggested that large meteorite impacts might be the metronome that sets the cadence of biological evolution on Earth - an unproved but intriguing hypothesis (Koeberl & Sharpton, 2001). Nevertheless, the study of the K-T extinction and its association with one of the largest impact structures known on Earth, led to renewed and widespread interest in impacts of

cratering on the environment. Extra-terrestrial impact craters, on the earth's surface, are formed by the impact of an asteroid, comet or a meteorite 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. Research shows that impact craters are not immediately obvious on the surface of the Earth because our planet is geologically active; the surface is in a constant state of change from erosion, infilling, volcanism, and tectonic activity. These processes have led to the rapid removal or burial of Earth's impact structures. Thus, only about 200 terrestrial impact craters have been recognized to date. The majority of them are located within the geologically stable cratons of North America, Europe, Africa, and Australia (Plate 2). This is also the region where most research on ETICs has taken place. The current paper looks at the effect of extra-terrestrial impact cratering (ETIC) on the environment, with focus on the Silali Basin- Kenya.

Statement of the Problem

The study's main problem is that the effect of extra-terrestrial impact cratering and creation of extra-terrestrial impact craters (ETICs), on environment, has not been adequately researched in Kenya. Moreover, the extra-terrestrial impact process is a continuous process that is never totally predetermined at any one time. It is important to note that; impacting of the earth's surface by extra-terrestrial objects is an on-going process over which no one has control and can happen anywhere; anytime. Kenyan landscape is equally vulnerable to these impacts of varying magnitudes as anywhere else worldwide.

Extra-terrestrial impact craters may be present in Kenya but their existence is not known and their social and economic values cannot be fully ascertained.

These natural structures may have immense socio-economic values. Therefore, the main research question for this research paper was: In what ways did Silali basin's formation affect the environment of the surrounding area?

Silali Basin

Silali Basin is located in Sub Saharan Africa, in the northern region of Kenya. It is one of the many extra-terrestrial impact craters that have not been adequately researched. It is also called Silale and is located on Latitude 1°10' N and Longitude 36°12' E. Geographically, the area lies on the mid-section of the East African rift valley but administratively, the basin is found at the boundary of former Turkana East and East Pokot districts. The Pokot and the Turkana communities are the inhabitants of the area; to the south and north respectively. The basin covers an area of about 850km² 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 km² in area, on the basis of the rule that an impactor's size is 1/20 the crater's size (Beatty *et al.*, 1999).

The following is a map of Kenya showing the study area; pointed by a black arrow and circled in red.

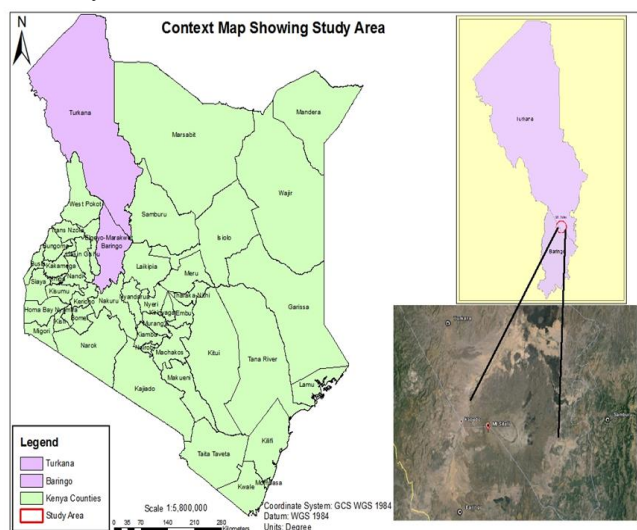


Plate 1. A map of Kenya, drawn to scale, showing the study area (circled in red)

Literature Review

From the status of a 'minor curiosity' 50 years ago, impact cratering has now been elevated to one of the most important geologic processes that affect the earth's surface. Impact cratering is not unique to the earth. It occurs on other bodies of the solar system such as the natural satellites (moons) and the planets. The earth's moon, for example, has conspicuous craters which are generally circular depressions, ranging in size from less than one inch to more than 1,200 km in diameter. Many of the larger ones are visible at full moon, viewed through a pair of binoculars. The most visible lunar structure is Tycho, which is located on the moon's southern hemisphere. This crater has the classic hallmarks of an impact crater, namely; concentric nest of slumped walls inside the rim, central (uplift) peak, rough irregular crater floor and ejecta in hummocky deposits. The craters on the moon are intact because craters on heavenly bodies are safe from erosion and tectonic deformation that plague impact craters on the earth's surface. Consequently, on the earth's surface, truly circular structures are rare but mapping of parts of the continents since the early 19th Century has led to discoveries of many ETICs that are nearly circular. About 200 impact craters have been studied and recorded as shown by plate 2.

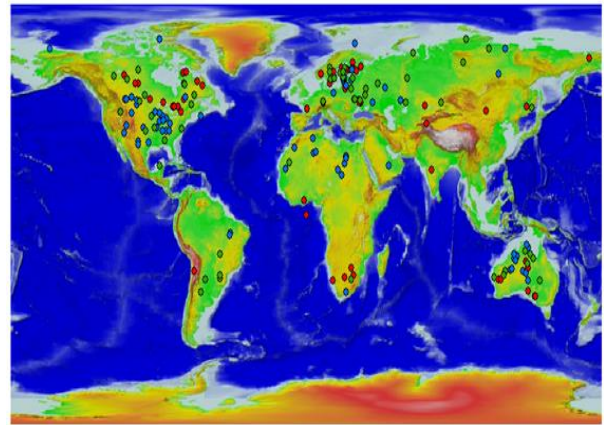


Plate 2. Global distribution of some of the recognized terrestrial impact structures superimposed on a digital elevation map (DEM) of the Earth. The red dots represent structures formed entirely in crystalline target rocks; blue dots represent structures formed entirely in sedimentary target rocks; and green dots represent mixed crystalline-sedimentary targets. Data was adapted from the Earth Impact Database (www.google.com).

Some of the ETICs that have been mapped on the earth's surface include: Barringer meteor crater (Arizona, USA), Chicxulub (Yucatan Peninsula, Mexico), Wolfe creek (Australia), Aorounga (Chad, Africa), Roter Kamm (South West Africa/Namibia) and Bosomturi (Ghana, Africa).

Less than 100 years ago, near circular craters were products of volcanic processes. This is because, some volcanic craters, such as maars, have a circular shape. Maars are formed when lava encounters near surface water, which flashes into steam, causing overhead rocks to be pushed out explosively to form a depression that is somewhat backfilled by volcanic fragments and land sediments from surface runoff. Despite this similarity, impact craters differ from volcanic craters in various attributes as depicted in Table 1.

There are also circular craters on the earth's surface that are not impact related in their origin, besides the maars. These are craters that are produced by other geologic processes, other than volcanicity. They include sinkholes and depressions caused by the solution of sodium chloride (natural salt) in salt domes that reach the surface after diapiric piercing of sedimentary rocks by plastically flowing salt. This plastic flowing salt can invade rocks, causing them to collapse. This phenomenon occurred in Melville Island, near Baffin Island in the Canadian Arctic, leaving a crater on the earth's surface (Spencer *et al.*, 2008).

Until the space programme in the 1960's, debate over the nature of lunar craters raged as a controversy for more than a century. But with close exploration of the moon and other planets, like Mercury, opinion has shifted in favour of impact as a dominant process creating the myriads of circular depressions spread widely over the surfaces of heavenly bodies.

Impact, as a lunar and terrestrial process, was first suggested by European geoscientists in the early 1900's. The proposal that the Meteor crater in Arizona had a meteorite impact origin opened the possibility of extra-terrestrial impact as the cause of other similar circular features. Gulbert (1898) conceived the idea and supported it by finding iron meteorites around the crater (<http://rst.gsfc.nasa.gov/sect18>). Though there were skeptics, all skepticism changed in 1960 with the study of cratering mechanics at meteor craters and several nuclear explosions of craters by Shoemaker, who came up

with discoveries of shock metamorphism on target rocks in impact craters, alongside its various effects (Shoemaker *et al.*, 1994).

Table 1. Some pertinent differences between volcanic and impact craters

	Volcanic craters	Impact craters
1	Except for maars, they occur at the top of built up mountain-like edifices (volcanic cones)	They occur anywhere, even on plains and flat lands
2	They have steep interior walls that sometimes become gentler due to slumping	They have gentle, slumped interior walls
3	The layered units are at low angles (are sub-horizontal)	Layered units are overturned or rippled away.
4	The crater rim is slightly raised	The crater rim is low
5	Do not have distinct ejecta beyond the rim, only lava flow	Have distinct ejecta (fragments with broad size range, from small to massive blocks) beyond the rim
6	Occur solely due to volcanic activity in the earth's crust and on the earth's surface	They can occur anywhere and can induce volcanism, leading to formation of volcanic rocks on the crater floor and around it.

Source: (<http://rst.gsfc.nasa.gov/sect18>)

The earth today, despite many recycling of the oceanic and continental crust, retains signs of huge impacts that have taken place over many years, including smaller ones. Nevertheless, more craters remain to be discovered and satellite imagery, without doubt, is the most effective means for conducting systematic research on ETICs, with the support of other research methods.

Various satellite images were studied and analyzed to provide information pertaining to the mapping of the Silali basin. They include Landsat, SPOT, GeoEye and ASTER images-among other remote sensing data that provided critical information about the basin.

Materials and methods

Many ETICs are not recognizable from the earth's surface perspective. In addition, a large proportion of them are quite old so that there may be no remaining human beings alive today to recount their formation in comparison to recent events. In addition, their deformation by physical processes such as erosion and other geological events can interfere with evidence on their formation and the formation of related features, making them hard to recognize on the earth's surface. For the current work, remote sensing, which includes satellite imagery, aerial photographs and ground pictures, were variously used to:

- i) Explain how impact craters are located and recognized on the earth's surface, using morphological characteristics.
- ii) Reveal details about the Silali basin, for instance its size, shape and associated features.
- iii) Identify the general topography of the area where Silali crater is found and the alignment of rock formations in the area and
- iv) Provide images and photographs of the basin, its related features and the surroundings

Hand taken ground pictures of features around and within the Silali basin were also acquired, first, as a means of data collection and later as a means of data recording and presentation. A substantial number of ground pictures form a crucial part of this study and are sources of evidence regarding the formation of the Silali basin and the basin's ETIC

characteristics. Aerial photographs were used to confirm features found in the satellite images. They also provided an important means of comparing data. 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. In addition, rock and soil samples were collected for chemical analysis.

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 minerals and mineral formations that are associated with ETICs. The minerals of interest included Silicon Oxide (SiO₂), Aluminium Oxide (Al₂O₃), Sulphur Oxide (SO₃) and Iron Oxide (Fe₂O₃) - among others while the mineral formations that were of interest included; high pressure mineral polymorphs, PDFs, silica and siderophile elements.

Results

Silali basin may qualify to be an ETIC because of its circular morphology and other geomorphological ETIC characteristics associated with it. It's more than 4km wide diameter, makes it a complex impact crater.



Plate 3. A natural colour SPOT satellite image showing the Silali crater. The image was adapted from Google maps.

The diagram shows the basin's raised walls, the small craters, the ridge and the volcanic cones found inside Silali basin. A crude outline of Silali's peak ring feature can also be seen from the image, at a close look. Plate 4 and 5 show the peak ring feature more clearly. The ring feature is characterized by the ridges that are broken in places.



Plate 4. A picture showing Silali basin's stepped eastern wall and a section of the basin's peak ring.

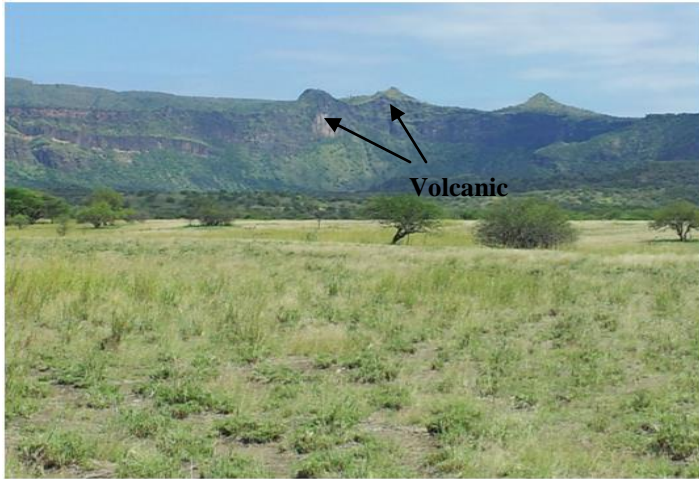


Plate 5. A picture showing the western walls of Silali basin, the basin's peak ring and breccia rich walls.

From ground truthing, Silali basin's wall is stepped all around, almost regularly and this is ingrained in the basin's formation. 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 because it follows the basin's ring fault structure.

Minerals found in Silali Basin

A study that was carried out by the Department of Mines and Geology, following a government funded project on mineral exploration and assessment of geological materials and geotourism sites in ALRMP project area of Baringo and East Pokot districts in 2009, revealed that Silali area has minerals that are impact related. These include iron, gold, copper and nickel.

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 event, but 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, Platinum Group of Minerals (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 gold that is either mesothermal or associated with impact breccias., 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. Silali basin and surrounding area has some iron, gold, copper and nickel. Petroleum deposits will not be expected in Silali basin because of the high temperatures.

The following figures, adapted from the report produced by the Department of Mines and Geology, following the government funded project on mineral exploration and assessment of geological materials and geotourism sites in ALRMP project area of Baringo and East Pokot districts in 2009 (G.o.K, 2009), show the distribution of some of the minerals mentioned, in Silali basin and its immediate surroundings. The minerals are in ppm (parts per million).

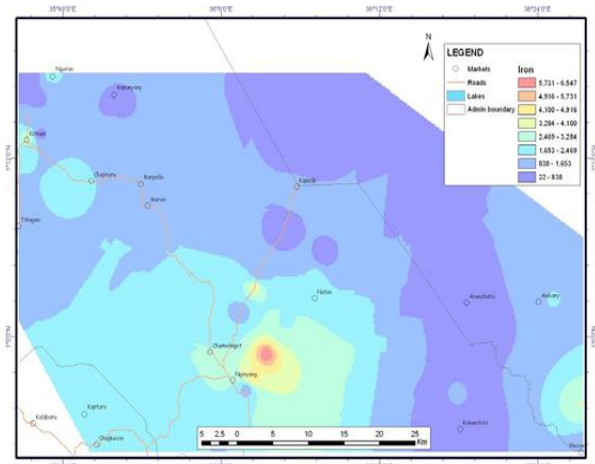


Figure 1. Map showing iron concentration distribution in Silali basin and surrounding area (G.o.K, 2009).

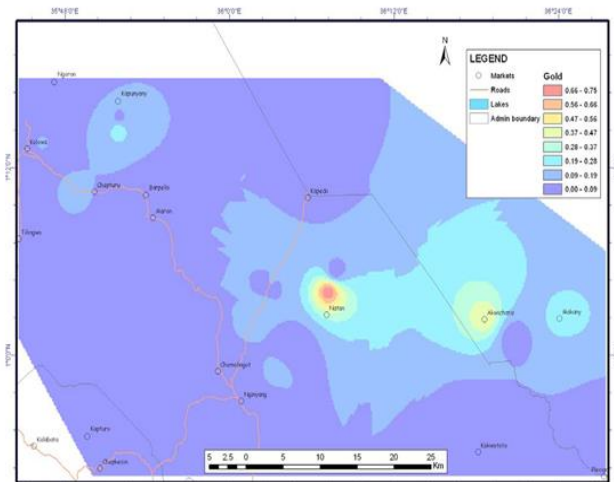


Figure 2. Map showing gold concentration distribution in Silali basin and surrounding area (G.o.K, 2009).

Though the minerals are in small portions, at least they prove the importance of ETICs as mineral resource areas, with all viability of encouraging mining. Located in the eastern Yilgarn, Australia, lies the Watchorn Impact Structure (WIS), which is 560km wide and about 2.6 billion years old (<http://m.phys.org/news/2013-11/meteorite-impact-reveals-mineral-deposit.html>). The crater has gold and nickel fields. Sudbury basin in Ontario, Canada, is home to some of the world's most productive metal ore mines (<http://www.galactic-stone.com/product/sudbury-crater-mine-ore-rich-in-rare-metals-iridium>). More studies should be carried out to investigate the existence of nanodiamonds and PGMs in Silali basin.

The 'Outer Basin' and Features in the 'Outer Basin'

The 'outer basin' and some features which were observed in it may support an impact formation of the outer basin and most likely the Silali basin. These features include the slumped walls of the outer basin, breccias, shatter cones and a unique rock that looks like a magma pillow. A magma pillow is a pillow-shaped lava structure that is attributed to the extrusion of lava under water (subaqueous extrusion). It is commonly basaltic in nature and the more viscous the lava, the bigger the pillow. Magma pillows are common along marine volcanic hot spots and constructive plate boundaries (tensional boundaries) of fault areas. Due to the rapid cooling of the magma as it touches water, the magma's outer layer forms its outer coat or shell. Subsequent shells are formed as the magma

cools towards its core. Thus, magma pillows are layered. The outer layers are made up of finer particles, owing to fast cooling, while the core is made up of coarse grains. The outer layer of a magma pillow is mainly glassy. The unique rock, here known as the Chemolingot rock and the Chemolingot shatter cones, together with the slumped walls of the outer basin, can act as evidence that the 'outer basin' may also be an ETIC. Plate 6 and 7 show the Chemolingot rock and Chemolingot shatter cones respectively. Chemolingot area 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. More research on the outer basin can be carried out in the future.



Plate 6. Chemolingot rock, collected from Chemolingot area, in East Pokot. A brown coated probable chondrule is pointed by a black arrow

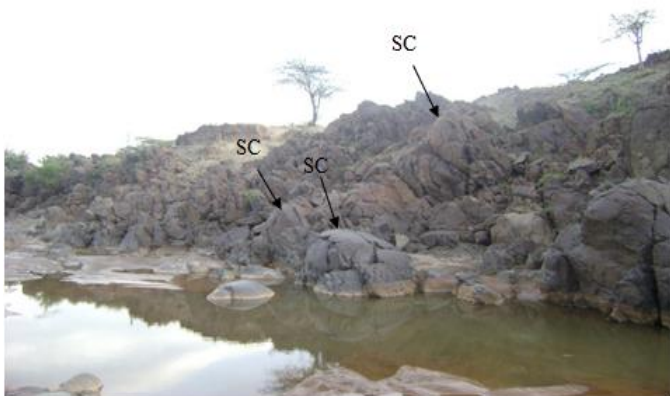


Plate 7. Chemolingot shatter cones (SC) around Chemolingot area of East Pokot. These can compare well with the shatter cones at Beaverhead impact structure, Montana

Associated Geological Features of Silali Basin

A huge extra-terrestrial impact has all the potential that is adequate to move crustal rocks apart and create faults. There are many faults around and within Silali basin, some of which may be responsible for the creation of volcanic mountains like mt. Pakka, to the south of Silali basin, while some could be the fissures through which hot water gushes onto the earth's surface, as occurs around Kapedo town. Suguta gorge, the caves, the lava flow and the sinkholes around Silali basin are all fault associated features. Hot waterfalls are found on the

eastern wall of the Suguta River (within Suguta gorge). Near the heavier water fall, 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.

According to Thompson and Turk (1992), extra-terrestrial impacts can trigger the formation of major geological features.

Volcanicity and existence of a magma chamber

Silali basin's volcanic features are many and splendid; ranging from the volcanic rocks found within and around the basin to the many volcanic cones. Volcanic activity within and around the basin, may have been simultaneous or intermittent and some of the features formed are old while others are young. From literature review, there appears to have been some pre-impact volcanicity and post-impact volcanicity in Silali basin. There was volcanicity before the crater formed, that build a volcanic shield around 400-200ka. This is the shield on which Silali basin sits. Post impact volcanicity is responsible for the volcanic cones inside and outside the basin, the ridges within and around, together with the numerous volcanic rocks, hot springs and fumaroles around and within Silali basin.

A serious extra-terrestrial impact, involving a large heavenly body that is able to excavate a crater, can be accompanied by volcanicity, especially if it hits a tectonically active area, such as the old rift valley floor, upon which the Silali shield rested.

Silali basin's magma chamber is also evidence that Silali basin may be an ETIC. According to McCall and Hornung (1972), there is a high and low magma reservoir beneath Silali basin. This magma chamber may be quite restless, being full of uprising and falling of currents, as is expected in any mantle plume. For this reason then, the faults within and around Silali basin exist because of ongoing faulting, encouraged by hydrothermal fracturing. The hot springs and fumaroles also survive because liquids beneath the basin are continually heated up by high temperatures therein and forced to move out of the earth's crust, fanned by the ever renewed heating from the base of the magma chamber. Beneath each impact crater, there is a mantle plume that is responsible for continued volcanicity in an impact area, as Thompson and Turk (1992) suggested. In the case of Silali basin, the mantle plume would be expected to cover areas outside the basin (regional dimensions) because the impact seems to have been an enormous event.

Volcanism in an area impacted by an extra-terrestrial object is expected and it is quite evident in Silali. In addition, the basin is on the floor of a section of the rift valley which is tectonically active.

Environmental effects of Silali basin's cratering

A major impact event releases the energy of several million nuclear weapons detonating simultaneously, when a heavenly body of a few kilometres collides with the earth (https://en.m.wikipedia.org/wiki/impact_event). The energy released by an impact event and the impact itself has different effects on the environment; both physical and human environment. These effects may be local, regional and global, in terms of scale. Notably, the effects decay with an increase in distance from the impact area.

As mentioned earlier, many impact events known today occurred millions of years ago so that there is no one alive to tell about their environmental effects. Consequently, the effects of impact cratering can be deduced from scientific studies and from recent impact events. This applies for Silali

basin. The possible effects of Silali basin's cratering on the area's physical environment would have included:

i) Dust displacement and climate change

The dust that is displaced by an impact event can blanket the earth's atmosphere, preventing terrestrial radiation from escaping the earth's surface. This causes global warming and its many problems. The same dust, in the long run, may reduce solar radiation reaching the earth's surface enhancing cold temperatures and glaciation, even globally. The impact ejecta sitting on Silali basin's wall is evidence of this dust.

ii) Volcanicity

Impact cratering can initiate or enhance volcanicity in an area. Volcanicity can occur in an impact area, if a hypervelocity object drills the earth's surface upon impact and creates a channel for magma to explode. Extra-terrestrial impact can also enhance volcanicity if it deepens or widens existing fault lines, causing volcanic eruption to occur. This appears to have happened in Silali basin, causing the crater to subside.

iii) Fire breakouts

Fire ball impact events, such as the Tunguska fire ball event in Siberia or the recent Kuresoi (Kenya) impact event, can cause massive fire break outs that can destroy life on earth. This may have happened in Silali basin, especially with the proposition that Silali basin and the craters around it may have been formed by a heavenly body that exploded above the area, causing multiple impacts.

iv) Earthquakes

Impact events are associated with tremors and earthquakes because of their ability to shift rocks. The Thika impact event (the source of the Kimwiri meteorite) was reported to have caused a tremor when a small heavenly rock fell on a dusty maize field near Thika town, Kenya. Silali's impact event, from the impactor's size (0.25-0.4km wide) may have caused a serious earthquake in the area.

v) Landscape re-modeling

Extra-terrestrial impact cratering can alter the face of the earth by constructing new geomorphological features or destroying existing landforms. In Silali, impact cratering may have led to the formation of Silali basin and the other craters, ejecta deposits, gorges and caves- as suggested by Thompson and Turk (1992) that extra-terrestrial impact cratering is responsible for many geological processes on the earth's surface.

vi) Disruption of life on earth

Huge impact events can have negative biospheric effects that include collapse of food chains and ecosystems with a single swipe. The formation of Chicxulub crater 65 million years ago, for instance, is associated with the extinction of dinosaurs and other megafauna (Kring, 2000). This is because mega impact events can cause coast to coast fires that can kill plants and animals or bring about glaciation. Both ways, plants will die and the food shortage that will ensue will kill animals. This may have happened following Silali basin's formation, noting that Silali basin appears to have formed about the same time as the Chicxulub crater (between 62-66ma).

vii) Ozone depletion

Besides ordinary dust, impact ejecta are associated with chemically active gas components such as aerosols that produce SO₂, SO₃ and greenhouse gases, especially H₂O and CO₂. Impact events are also associated with ozone depleting gases such as Br and Cl (Kring 2000). Aerosols yield acid rain that can cause chlorosis in plants and poison water bodies. Br and Cl are produced from the projectile-target water or target

rocks interaction and post impact wild fires (Kring, 2000). Acid rains may have occurred in Silali basin but without eye witnesses, future studies in the area may be relied upon to unearth ancient chlorosis.

viii) Tsunamis

Impact events are known to cause tsunami waves which are destructive in their own way. Silali's impact may have caused an earthquake that would have affected the whole of what is Kenya's landscape today and possible tsunamis in the nearby Indian Ocean and lakes.

On human environment, Silali's impact cratering may have led to:

i) Destruction of property due to acid rains that destroy crops and kill animals through poisoning of water bodies, impact events that collapse buildings and infrastructure and wildfires that destroy the human environment.

ii) Death of people, which may result from some impact related episodes such as: Impact shock and trauma, burial by impact ejecta, propulsion by impact explosion, noxious gases and impact related accidents. On 15th September 2007, for instance, a chondrite meteor crashed near the village of Carancas in southeast Peru, near L. Thicaca, leaving a water filled hole and spewing gases across the surrounding areas. Many residents became ill from the poisonous gases (http://en.m.wikipedia.org/wiki/impact_event). Similarly, on 15th February 2013, an asteroid airburst occurred over the city of Chelyabinsk, Russia, at an altitude of 30-50km above the earth's surface. About 1500 people were injured by broken window glasses and the fireball cost \$30 in losses (http://en.m.wikipedia.org/wiki/impact_event). This shows that impact airbursts as well as earth surface collisions can cause death. Silali basin's impact may have killed some people, if the area was inhabited 65 million or so years ago.

Impact cratering also has positive effects on both the physical and the human environment. Some scholars believe that impact craters provide shelter for early life forms especially microbes (Charles, 2014). Impact events are also associated with rare minerals such as PGMs and important minerals like Gold, Nickel and diamonds. Petroleum can also be found in an impact crater, probably because an impact crater can trap migrating petroleum or because of impact ejecta burying massive vegetation and creating hydrocarbons. The spectacular landforms that are created by impact cratering, such as the gorges, craters and volcanic cones can be used for economic purposes, such as tourism.

Conclusion

Silali basin is a probable ETIC that is rich in volcanic features. Old and recent volcanicity has created many volcanic features in Silali basin to an extent that the basin can easily pass for a volcano and it would have been so if this study had not been conducted. The study, thus, has introduced a new perspective into the basin's formation through extra-terrestrial impact cratering. It has also revealed the ETIC characteristics of the basin, proving that the basin may indeed be an ETIC. The extra-terrestrial impact that may have occurred in Silali area did not only create the Silali basin and the other basins, but affected the environment of the area in many ways. Because of the age of the event, it is not possible to succinctly explain the effects of the impact on the human environment because there is no one alive today who witnessed the event 65 million years ago. Such effects may be speculated to entail the usual hazards and disasters that accompany an extra-terrestrial impact. These include; massive deaths of people, collapse of structures, loss of property, environmental

pollution, migration and its social problems. There is a cave to the southeast of Silali basin that may hold secrets about ancient human settlement in Silali area. The cave has an old homestead and paintings on its walls. Unfortunately, it was not possible to visit the cave because of the unfriendly terrain and insecurity.

Economically, Silali basin can be a wonderful tourist attraction feature, together with all its associated features and terrain. The various breccias can be harvested for home decoration or construction purposes, Breccias are associated with various mineral elements, such as the mesothermal gold ore and can form over large areas. The rocks also have ornamental uses and can be used for architectural as well as sculpturing purposes. The volcanicity that must have ensued following the formation of Silali basin has created a rich geothermal field in the area that GDC-Kenya, is considering for the generation of geothermal power.

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