Review of Geothermal Resources as Manifestations of Volcanism in Eastern Africa

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Abstract—Igneous rocks are naturally occurring materials which continue to evolve from a molten state (magma) through cooling processes. The solid materials that evolve are often crystalline compounds known as minerals. Magmatic chambers that are located at shallow depths often form high temperature geothermal systems. The systems derive their heat from magmatic processes that culminate into volcanic activities in localities at which the magma gets extruded onto the ground surface. The magma gets extruded, in form of lava or volcanic ash, as a result of violent volcanic activities. Often volcanic activities are related to geothermal processes in favourable hydrogeological conditions. Geothermal reservoirs develop as a result and can be encountered on exploration. Such reservoirs are distributed all over the globe. They are prevalent along plate boundaries and continental rift systems as witnessed in Eastern Africa. Volcanic activities are usually related to plate tectonics and continental drifting. For instance, the Great Rift Valley, which traverses African Continent from the North to East and Central Africa, hosts numerous volcanoes. The volcanoes are both active and dormant and are located on the floor of the valley as well as on its flanks.

This paper examines geothermal activities that are manifested at the ground surface in different forms with emphasis on geothermal features of Eastern Africa, particularly on the features that are conspicuous in the Kenya Rift System. The features include hot springs, warm springs or geysers, steam jets, fumaroles, hot grounds and surface deposits of sulphur. Major global distribution of volcanic centers are also captured and related to plate tectonic setting. Subsequently, main operational geothermal investments in those volcanic centers are mentioned accordingly. For instance, Kenya government continues to invest heavily in exploration of geothermal resources as preferred form of green energy to spur development in all sectors of the economy. Indeed, major reserves are being exploited to add the generated energy to the national grid.

Keywords Rocks, magma upwelling, Geothermal activities, high temperature geothermal systems, geothermal manifestations, Geysers, Great Rift Valley, continental rifting and drifting, plate tectonics and volcanism.

I. Introduction

Rocks are naturally occurring solid materials which are classified into igneous, sedimentary and metamorphic rock types based on their mode of formation. Of these three rock types, igneous rocks evolve from a molten state (magma) through cooling processes that result into development of various crystal constituents known as minerals [1, 2]. Magmatic chambers that are located at shallow depths and often form high temperature geothermal systems. The systems consist of hydrological components that include a natural heating sub-system, recharge zone, all subsurface parts and the outflow components [5]. Geothermal activities that are related to volcanism are widely distributed all over the globe, particularly along plate boundaries and continental rift systems. Volcanic activities are usually related to plate tectonics and continental drifting. Indeed, most active volcanoes are located along the Circum-Pacific System also known as 'Ring of Fire' which continues to power geothermal manifestations. Presently, harnessing of geothermal energy targets the geothermal manifestations that are economically viable.

In Kenya, volcanism is widely distributed along regional rift systems from which separation of continental crust continues at a slow rate [4]. Geothermal activities are manifested at the ground surface in different forms which include hot springs, warm springs or geysers, steam jets, fumaroles, hot grounds and surface deposits of Sulphur [4, 5]. For instance, the Great Rift Valley, which traverses African Continent from the North to East and Central Africa, hosts numerous volcanoes that are both active and dormant [2]; the volcanoes are located on the floor of the valley as well as on its flanks. Those volcanoes that are active are a threat to infrastructure, human life and the environment altogether, despite powering the geothermal gradient. Manifestations of geothermal activities are widespread on the floor of the Rift Valley; directly above the center of an upwelling magmatic body such as the Kenya dome. The dome continues to experience magmatic activities of increased magnitude which bolster potential geothermal exploration, development and harnessing rationale.

II. INTRUSIVE AND EXTRUSIVE IGNEOUS ROCKS

Igneous rocks are categorized into two groups i.e. volcanic and intrusive [6].

- *Volcanic* or *extrusive* igneous rocks form when lava (magma that is extrude onto the surface) cools and crystallizes while;
- *Intrusive* or *plutonic* igneous rocks develop when the magma is not extruded on the earth surface but crystallizes at depth in the Earth.

Normally, *Magma* is a mixture of liquid rock, crystals, and volcanic gasses. It is characterized by a wide range of chemical compositions, with high temperature, and properties of a liquid. Magmas are less dense than surrounding rocks, and therefore move upward trough openings.

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A. Intrusive Igneous Rocks

(a) Types of Magma

Chemical composition of magma is controlled by the abundance of elements in the Earth particularly, Si, Al, Fe, Ca, Mg, K, Na, H, and O which make up 99.9%. Silicon and Oxygen are the most abundant. The two elements resulted into formation of silica (SiO_2) as the most abundant of the oxides unlike carbonates, sulphates etc. Chemical analysis of minerals that constitute major igneous rocks can be carried out in terms of the silica thereby giving three major categories [4] i.e.

1. *Mafic or Basaltic*-- SiO_2 45-55 wt%, high in Fe, Mg, Ca, low in K, Na
2. *Intermediate or Andesitic*-- SiO_2 55-65 wt%, intermediate. in Fe, Mg, Ca, Na, K
3. *Felsic or Rhyolitic*-- SiO_2 65-75%, low in Fe, Mg, Ca, high in K, Na.

(b) Magmatic Gases:

Nearly all magmas at depth in the Earth contain natural gases. The magmas have an explosive character since they expand as pressure gets reduced. Typical gases present are;

- Mostly H_2O with some CO_2 and;
- Minor amounts of Sulfur, Cl, and F while;
- Felsic magmas usually have higher gas contents than mafic magmas.

(c) Temperature of Magmas:

Heat distribution in magmas depends on the type of magma in consideration. The temperatures for three major categories of magma shown in table 1 range from 650oC to 1200 oC.as follows:

- Mafic/Basaltic - 1000-1200^{o}C
- Intermediate/Andesitic - 800-1000^{o}C
- Felsic/Rhyolitic - 650-800^{o}C.

Table 1: Typical characteristics for magmas [15]

Magma Type	Solidified Volcanic Rock	Solidified Plutonic Rock	Chemical Composition	Temperature	Viscosity	Gas Content
Mafic or Basaltic	Basalt	Gabbro	SiO2 % 45-55, High in Fe, Mg, Ca, low in K, Na	1000 - 1200 ^{o}C	Low	Low
Intermediate or Andesitic	Andesite	Diorite	SiO2 % 55-65, Intermediate in Fe, Mg, Ca, Na, K	800 - 1000 ^{o}C	Intermediate	Intermediate
Felsic or Rhyolitic	Rhyolite	Granite	SiO2 %65-75, Low in Fe, Mg, Ca, high in K, Na	650 - 800 ^{o}C	High	High

Rocks that are basaltic in composition are most widespread and constitute highest percentage of oceanic crustal rocks which happen to be overlain by thick sedimentary deposits that are derived from continental crustal rocks. The three rock types are widespread in continental rift systems such as the Eastern Africa Great Rift System.

(d) Viscosity of Magmas

Viscosity being the opposite of fluidity refers to 'the resistance to flow'. It depends mainly on silica on composition, temperature, & gas content of the magmatic melt. Usually;

- Higher SiO_2 content magmas have higher viscosity than lower SiO_2 content magmas while;
- Lower Temperature magmas have higher viscosity than higher temperature magmas.

(e) Magma generation

In order to generate magma in the solid part of the earth either the geothermal gradient must be raised in some way or the melting temperature of the rocks must be lowered. The geothermal gradient can be raised by upwelling of hot material from below either by uprising of solid material (decompression melting) or by intrusion of magma (heat transfer). Lowering the melting temperature can be achieved by adding water or Carbon Dioxide (flux melting).

(i) Decompression Melting: Under normal conditions the temperature in the Earth, shown by the geothermal gradient, is lower than the melting temperature for mantle rock material. Thus, in order for the mantle rocks to melt there has to be a mechanism to raise the geothermal gradient. One such mechanism is convection by which hot mantle material rises to regions of lower rock pressure and in the process it carries its heat with it (Fig.1).

If the raised geothermal gradient becomes higher than the initial melting temperature at any pressure, then a partial melt will form. Liquid from this partial melt can be separated from the remaining crystals because, in general, liquids have a lower density than solids. Basaltic magmas appear to originate in this way.

Upwelling mantle appears to occur beneath oceanic ridges, at hot spots, and beneath continental rift valleys. Thus, generation of magma in these three geological environments is likely to be caused by decompression melting process.

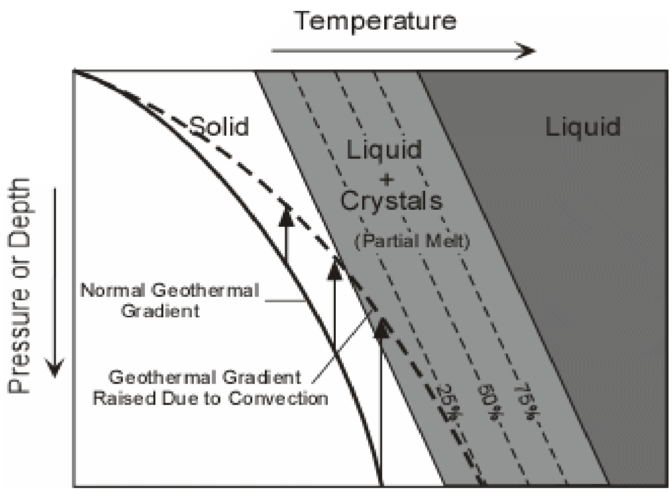

Fig.1 Pressure-Temperature relationship for Decompression melting

(ii) Transfer of Heat: When magmas that were generated by some other mechanism intrude into cold crust, they bring with them heat [5]. Upon solidification they lose this heat and transfer it to the surrounding crust. Repeated intrusions can transfer enough heat to increase the local geothermal gradient and cause melting of the surrounding rock to generate new magmas (Fig.2).

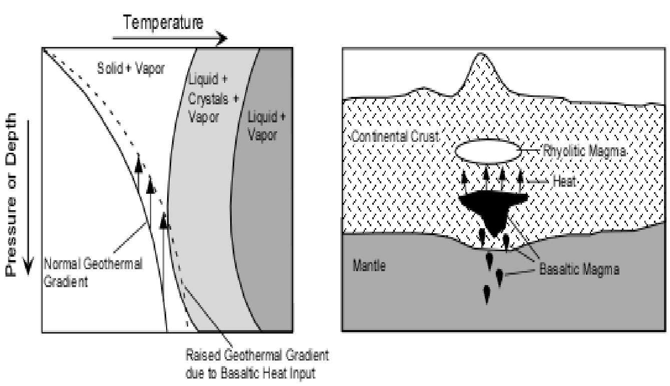

Fig.2: Magma generation through Heat Transfer

(iii) Flux Melting: If fluids such as water or carbon dioxide are added to a rock mass, then melting temperature gets lowered. If the addition of water or carbon dioxide takes place deep in the earth where the temperature is already high, then lowering of melting temperature could occur and cause the rock to partially melt and generate magma. Regions where water gets introduced accompanied by melting of rock mass are subduction zones (Fig.3). Here, water present in the pore spaces of the subducting oceanic crust or water present in minerals like hornblende, biotite, or clay minerals would be released by the rising temperature and then move in to the overlying mantle. Thus, introduction of the water in the mantle then lowers the melting temperature of the mantle to generate partial melts, which separates from the solid mantle and rises upwards toward the surface as geothermal fluids.

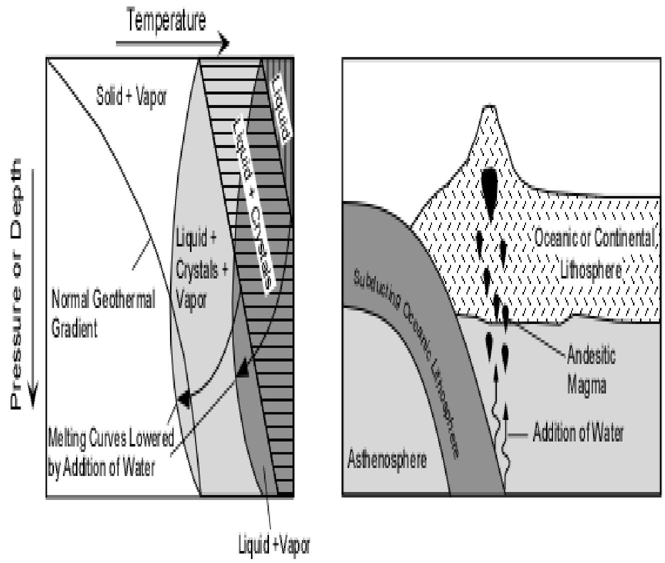

Fig.3: Flux Melting Process

(e) Initial Composition of Magma

The initial composition of the magma is dictated by the composition of the source rock and the degree of partial melting. For instance, melting of a mantle source that is normally garnetiferous and peridotitic results in mafic/basaltic magmas. However, melting of crustal sources yields siliceous magmas since continental crustal rocks are silica rich. In general, more siliceous magmas form by low degrees of partial melting. As the degree of partial melting increases, less siliceous compositions can be generated.

B. Extrusive Igneous Rocks

Magmas reach the surface of the Earth by erupting through a vent called at volcanic centers. The magma may erupt explosively or non-explosively. Non-explosive eruptions are favored by low gas content and low viscosity magmas and are typical for basaltic to andesitic magmas and sometimes rhyolitic magma. Such eruptions;

- Usually begin with fire fountains due to release of dissolved gases
- Produce lava flows on surface
- Produce Pillow lavas if erupted beneath water

Explosive eruptions are favored by high gas content and high viscosity and are typical for andesitic to rhyolitic magmas. In such eruptions;

- Expansion of gas bubbles is resisted by high viscosity of magma - results in building of pressure
- High pressure in gas bubbles causes the bubbles to burst when reaching the low pressure environment on the Earth's surface.
- Bursting of bubbles fragments the magma into ***pyroclasts*** and ***tephra (ash).***

- Cloud of gas and tephra rises above volcano to produce an ***eruption column*** that can rise up to 45 km into the atmosphere.

Tephra that falls from the eruption column produces a ***tephra fall deposit Fig.4.*** If eruption column collapses a ***pyroclastic flow*** may occur, wherein gas and tephra rush down the flanks of the volcano at high speed. This is the most dangerous type of volcanic eruption. The deposits that are produced are called ***ignimbrites***.

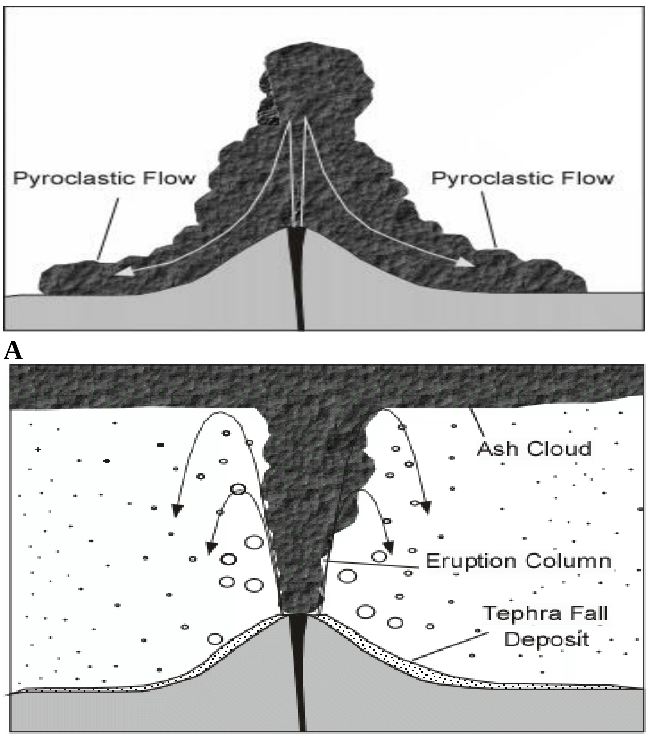

Fig.4: Schematic illustration for volcanic eruption: Lava flow (a) and Pyroclastic (b)

(a)Typical Extrusive/ Volcanic Rocks and Natural Glass

Basalts, Andesites, and Rhyolites are all types of volcanic rock that are distinguished on the basis of their mineral assemblage and chemical composition. These rocks tend to be fine grained to glassy or porphyritic. Depending on conditions present during eruption and cooling, any of these rock types may form one of the following types of volcanic rocks.

- ***Obsidian:*** Dark colored volcanic glass (amorphous material) showing concoidal fracture and few to no crystals, usually rhyolitic in composition.
- ***Pumice:*** Light colored and light weight rock consisting of mostly empty spaces (***vesicles***) that were once occupied by gas, usually rhyolitic or andesitic in composition.
- ***Vesicular*** rock: Dark coloured rock filled with holes (like Swiss cheese) or vesicles that were once occupied by gas. It is usually basaltic and andesitic in composition. If vesicles in vesicular basalt are later filled by precipitation of calcite or quartz, then the fillings are termed amygdales and the basalt is termed an amygdaloidal basalt.
- ***Pyroclasts:*** These are broken fragments which result from explosively ripping apart of magma. Loose assemblages of pyroclasts are referred to as ***tephra***. Depending on size, tephra material can be classified as bombs. lapilli, or ash.
- Rock formed by accumulation and cementation of tephra called a ***pyroclastic rock*** or tuff. Welding (compaction) causes tephra (loose material) to be converted into pyroclastic rock.

(b) Distribution of Volcanic Activities

Igneous activities continue to occur at various geotectonic settings since past geologic time. The geotectonic settings include diverging and converging plate boundaries, hot spots, and rift valleys.

(i) Divergent Plate Boundaries: At oceanic ridges, igneous activities involve eruption of basaltic lava flows that form pillow lavas at the oceanic ridges and intrusion of dikes and plutons beneath the ridges. The dikes formed are basaltic while plutons are mainly gabbroic in composition. These processes form the bulk of the oceanic crust result into sea floor spreading. Magmas are generated by decompression melting as hot solid asthenosphere rises and partially melts.

(ii) Convergent Plate Boundaries: Subduction that occurs at convergent plate boundaries introduces water into the mantle above the subduction and causes flux melting of the mantle to produce basaltic magmas. The magma rises towards the surface while differentiating by assimilation and crystal fractionation to produce andesitic and rhyolitic magmas. The magmas that reach the surface build island arcs and continental margins. Volcanic arcs are built up of basalt, andesite, and rhyolite lava flows and pyroclastic material. The magmas that intrude beneath these arcs can cause crustal melting and form plutons and batholiths of diorites and granites. Part of the heated water from flux melting process escapes through discontinuities and can reach the ground surface as geothermal manifestation.

(iii) Hot Spots: Hot spots are localities at which hot mantle ascends toward the surface as plumes of hot rock. Decompression melting in these rising plumes results in the production of magmas which erupt to form a volcano on the surface or sea floor, eventually building a volcanic island. As the overriding plate moves over the hot spot, the volcano moves off the hot spot and a new volcano forms over the hot spot. The Hawaii volcanic islands as shown in figure 5 were developed in that way.

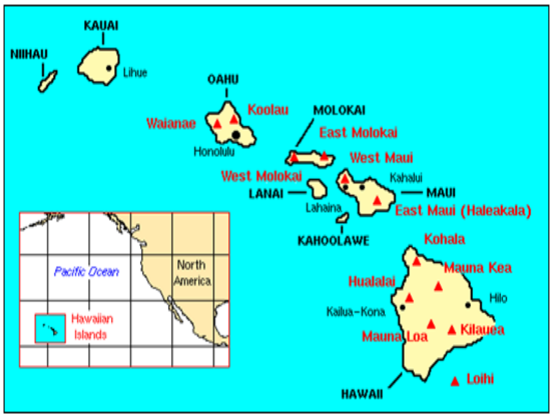

Fig 5: Hawaii islands

This produces a hot spot track consisting of lines of extinct volcanoes leading to the active volcano at the hot spot. A hot spot located beneath a continent can result in heat transfer melting of the continental crust to produce large rhyolitic volcanic centers and plutonic granitic plutons below. A good example of a continental hot spot is at Yellowstone in the western U.S. Occasionally a hot spot is coincident with an oceanic ridge. In such a case, the hot spot produces larger volumes of magma than normally occur at ridge and thus build a volcanic island on the ridge. Such is the case for Iceland which sits on top the Mid-Atlantic Ridge (Fig. 6).

Fig. 6: Plate tectonic setting of Iceland

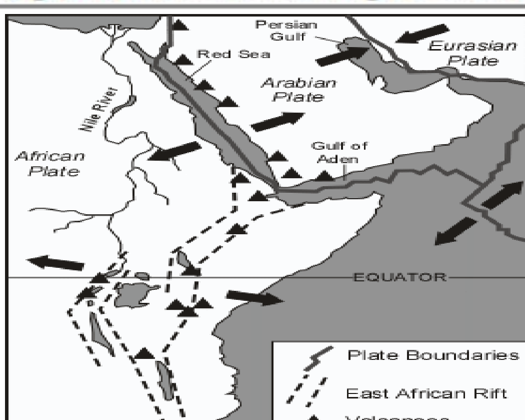

Fig.7:Eastern Africa Rift System

(iv) Rift Valleys: Rising mantle beneath a continent can result in extensional fractures in the continental crust to form a rift valley [4]. As the mantle rises it undergoes partial melting by decompression, resulting in the production of basaltic magmas which may erupt as flood basalts on the surface. Melts that get trapped in the crust can release heat resulting in melting of the crust to form rhyolitic magmas that can also erupt at the surface in the rift valley. An excellent example of a continental rift valley is the East African Rift. Rifting continues at different rates as eastern part of Africa drift to the east way from the rest of Africa continent. Indeed, the East African Rift Valley stretches over 3,000km from the Gulf of Aden in the north towards Zimbabwe in the south, splitting the African plate into two unequal parts.

(v) Large Igneous Provinces: In the past, large volumes of mostly basaltic magma have erupted on the sea floor to form large volcanic plateaus, such as the Ontong Java Plateau in the eastern Pacific. The Ontong Java Plateau is a huge oceanic lava plateau in the Pacific Ocean north of the Solomon Islands.[13]. Most of the plateau was formed under water and is submerged, but tectonic collision with the Solomon Island Block has caused parts of the Ontong Java Plateau to be uplifted above sea level [14]. Such large volume eruptions can have effects on the oceans because they change the shape of ocean floor and cause a rise in sea level. The basalts for plateaus which in turn create obstructions that can drastically change flow pattern for ocean currents. These changes in the ocean environment along with massive amounts of gas released by the magmas can alter climate and have drastic effects on life on the planet.

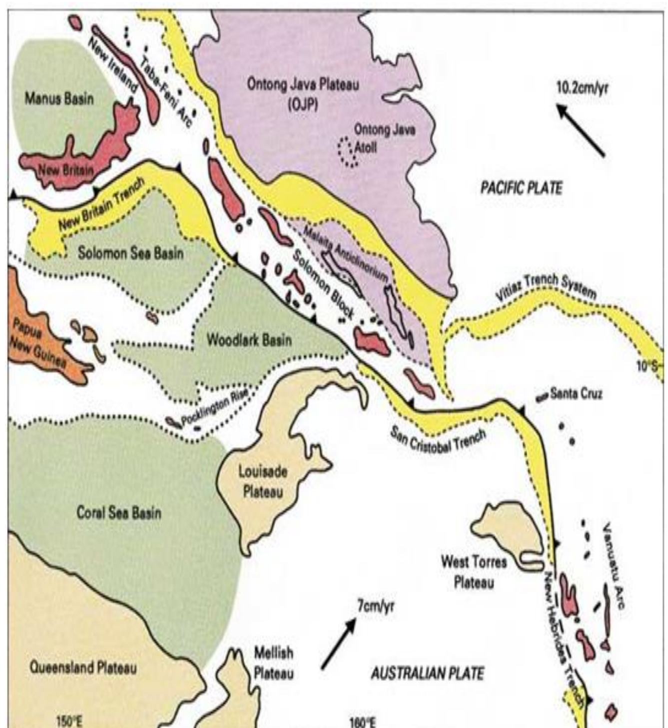

Fig.8: Tectonic Elements of South West Pacific showing Ontong Java Plateau

III GEOTHERMAL MANIFESTATIONS

Geothermal energy refers to the energy that is harnessed from high enthalpy waters, in form of warm or hot waters. It may also be in form of natural steam having been heated by heat that emanates from the earth's interior. Magma being natural material at high temperatures has adequate heat that heats up ground water which comes into contact with it. Presence of pores and week zones in rock masses facilitates easy seepage of the ground water.

Magma may form a magmatic chamber and be located at shallow depth from the ground surface or may be erupting at volcanic centers onto the surface such as is the case for Hawaii volcanic chains. The magma may also have upwelled onto the surface through regional faults such as the ones associated with evolution of rift valleys. Figure 9 shows the Hawaii volcanic Islands with scenarios of eruptions for Mauna Loa which occurred in 1984 and Kilauea in 2010. Hawaii's geothermal resources are potentially vast, yet they are largely uncharacterized [11]. One study completed by GeothermEx Inc. in 2000 estimated that the state of Hawaiʻi could have more than 1500 MW of geothermal energy potential, enough to meet nearly three-quarters of the state's electricity demand [12]

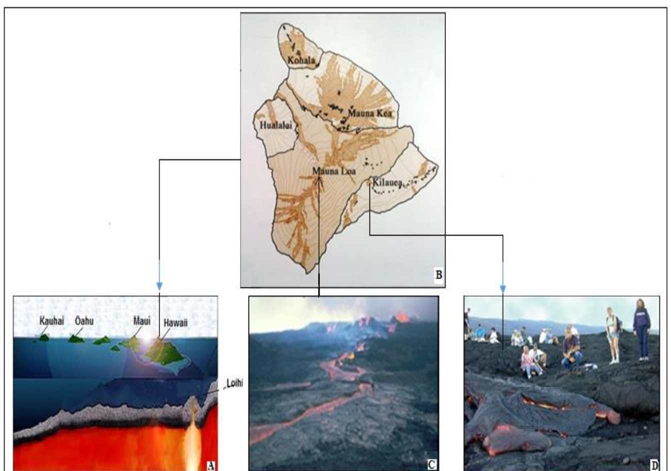

Fig.9:Illustration for Hawaii Islands(A), The 'Big' Island of Hawaii(B) and Lava flows from Mauna Loa(C) and Kelauea(D)

Magmatic chambers that are located at shallow depths often form high temperature geothermal systems [5]. The systems as illustrated in figure 10, refer to all parts of the hydrological components that are involved in a natural heating process. The components include the recharge zone, all subsurface parts and the outflow of the system. Usually, a geothermal system is geotechnically classified into three main categories i.e.

1. Volcanic geothermal systems with the heat source being hot intrusions or magma chambers in the crust,
2. Convective systems with deep water circulation in tectonically active areas preferably of high geothermal gradient,
3. Sedimentary systems with permeable layers at great depth (2-5 km), including geo-pressured systems often found in conjunction with oil resources.

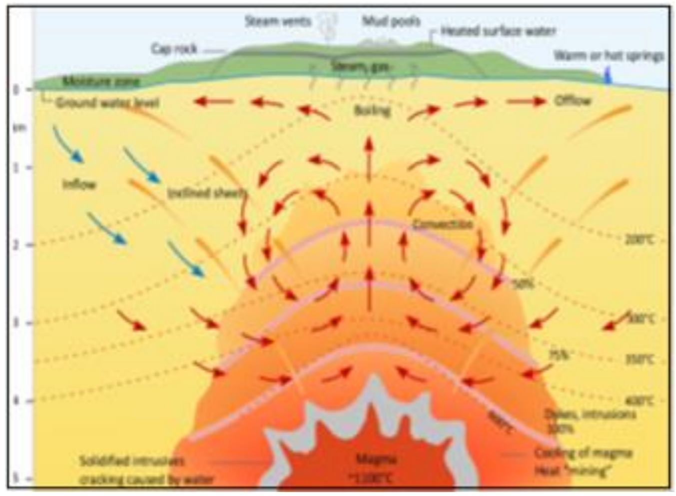

Fig.10: Simplified Model of a high temperature geothermal system [5]

Geothermal activities are manifested at the ground surface in different forms which include hot springs, worm springs or geysers, steam jets, fumaroles, hot grounds and surface deposits of Sulphur [4, 5. Geothermal activities that are related to volcanism are widely distributed all over the globe, particularly along plate boundaries and continental rift systems.

A. Volcanic at Plate Boundaries

Volcanic activities are usually related to plate tectonics and continental drifting [7]. Indeed, most active volcanoes are located along the Circum-Pacific System also known as 'Ring of Fire' (Fig11). Volcanic activities in those volcanoes continue powering geothermal manifestations leading to harnessing of geothermal energy.

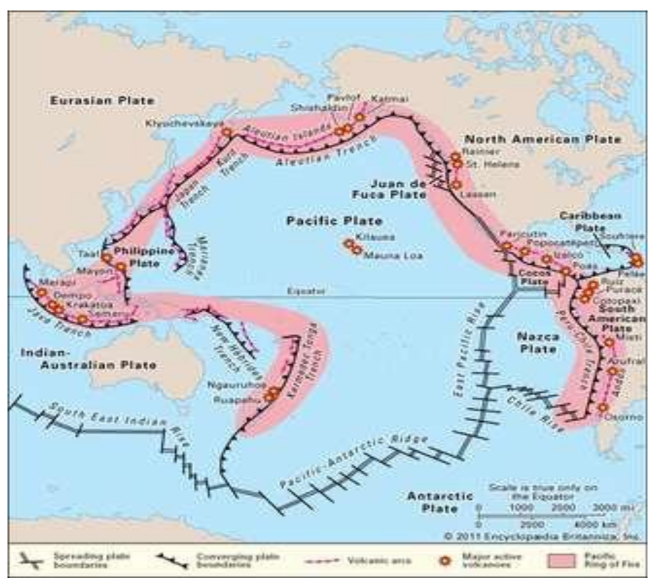

Fig.11: Volcanic centers for Circum-Pacific System and plate tectonic boundaries [7]

For instance, Indonesian active volcanoes extend from Sumatra, Jawa, Bali, Lombok, Flores, North Sulawesi, and Halmahera. The volcanic arc hosts 276 volcanoes with 29 GWe of Geothermal Resources thereby indicating a promising geothermal potential for the region [6, 7, 8]. The subduction of Indian-Australian oceanic plate to the Eurasian continental plate, which started since Late Miocene until presently with some paucity, produces magmatic activities along the Sunda-Banda arc. In the Sunda-Banda subduction margin, some quaternary volcanic-magmatic rocks host geothermal systems. The high cluster of geothermal localities that is located in West Java (Fig.12) currently supply about 80 % of geothermal energy which is derived from high temperature geothermal fields underneath.

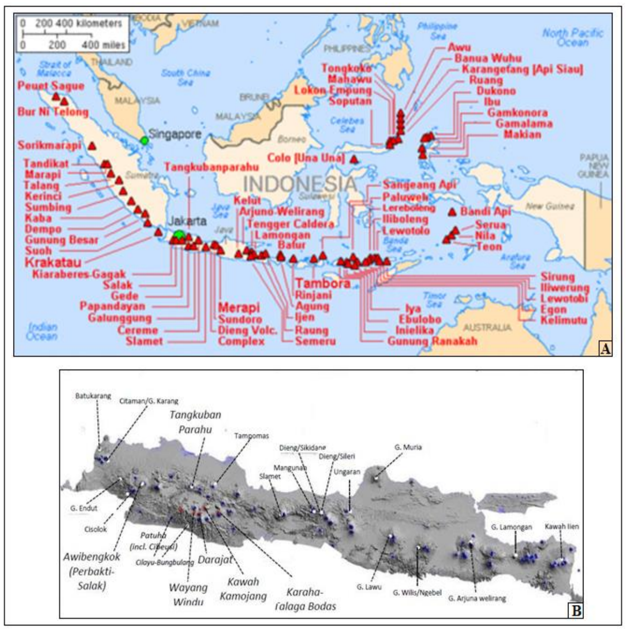

Fig.12: The active volcano-magmatic arc in Indonesia (A) and Volcanics that are associated with geothermal activities in Java alone(B)

B. Rift Valley Volcanism and Geothermal Association

Volcanics are also widely distributed along regional rift systems along which separation of continental crust continues at a slow rate. For instance, the Great Rift Valley, which traverses African Continent from the North to East and central Africa, hosts numerous volcanoes. The volcanoes, both active and dormant, are located on the floor of the valley as well as on the flanks. Active volcanoes are a threat to infrastructure, live and the environment altogether, despite powering the geothermal gradient. A typical example is Mt. Nyiragongo (Fig.13). It is located 20 km from Goma town in Democratic Republic of Congo and is one of the 10 most dangerous volcanoes in the world at the moment. Its caldera has boiling magma and last erupted in January 2002 resulting into displacement of over 200,000 people as well as destruction of infrastructure.

Fig. 13: Mount Nyiragongo when active (A) and its Bubbling hot lava lake in the crater (B)

The Eastern Africa rift Valley has several volcanic centers located in Kenya as shown in figure 14. The volcanic centers are associated with numerous geysers such the ones that can be encountered in Olkaria Area of Nakuru county, Lake Bogoria and Lake Baringo in Baringo county (Figs.15, 16, 17, 18, 19, 20).

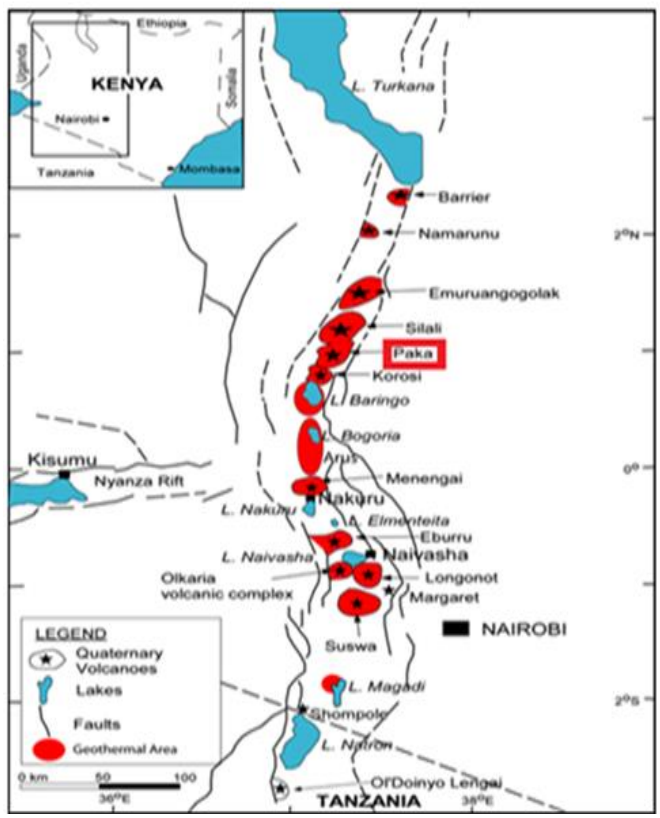

Fig. 14: Typical Geothermal fields on the flow of Kenya Rift System (After [5])

Fig. 15: Steam discharge from geothermal reservoir testing phase: Volcanic profile in the background Olkaria field, Nakuru County

Fig. 16: Above Olkaria Geothermal Plant System and geysers

C. Geothermal Manifestations in Lake Bogoria

The Eastern Africa Rift Valley has several volcanic centers located in Kenya. The manifestations of geothermal activities are widespread on the floor of the rift system (Figs. 17A and 18). However, areas that are directly above the center of an upwelling magmatic body such as the Kenya dome experience magmatic activities of increased magnitude. Such areas include water bodies on the floor of the rift valley [2, 3]. They are blessed with hot springs, warm springs or geysers as manifestations of the geothermal activities. For instance, Lake Bogoria alone has about 200 hot springs that discharge Na-HCO-CO waters into the lake from three main spring groups located along the shoreline at Loburu, Chemurkeu, and Ng'wasis-Koibobei-Losaramat, respectively (Fig. 17B). Figure 17C shows the enhanced situation for Loburu delta.

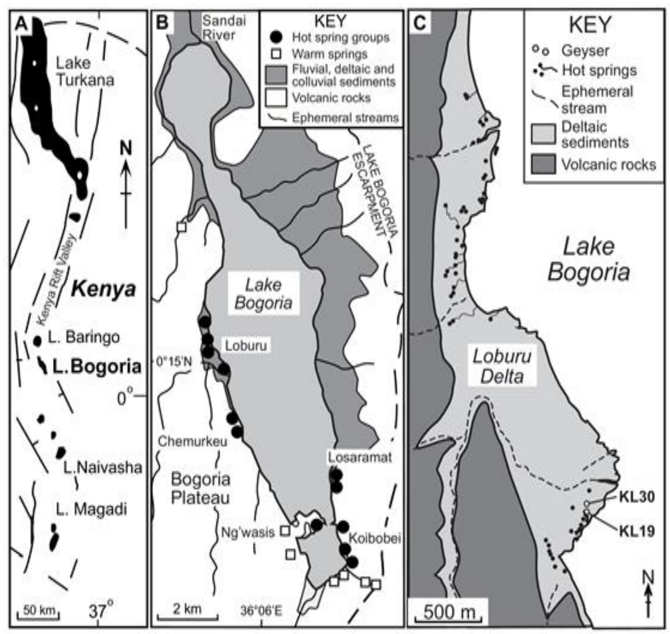

Figure 17: A part of geothermal features of Lake Bogoria [4])

Lake Bogoria, with a salinity approximately twice that of seawater, lies north of the equator in a narrow half-graben basin in the central Kenya Rift Valley. Typical active geysers and fumaroles of the lake are as shown in figures 17 and 18.

Fig. 18: Typical active geysers and fumarole in Lake Bogoria

D. Geothermal Manifestations in Lake Baringo

Lake Baringo is the second largest lake in Kenya's Great Rift Valley, after Lake Turkana (Figs. 13 and 17A). The lake covers an area of 130km^2 at an elevation of 970m above the sea level. It is part of the spectacular section of the Baringo-Bogoria 'half-graben,' and lies between the Elgeyo/Tugen Escarpments to the west and the Laikipia Escarpment in the east. The lake has fresh water although it has no obvious outlets. However, water for the lake is assumed to be seeping through lake sediments into the underlain volcanic bedrock.

Fig. 19: General view of Lake Baringo from a view point west of the lake with Ol Kokwe Island at the background.

Lake Baringo has seven small islands. The largest, the Ol Kokwe Island (Figs. 19 and 20), is an extinct volcano composed of basalts and trachytes [2]. The island has several hot springs and steam jets at the north eastern shores some of which have precipitated sulfur deposits. The Ol Kokwe Island has three villages, one primary school and about 500 inhabitants. The locals rely on canoes and boats for transportation to the mainland.

Fig. 20: One of the bubbling water springs (fumaroles) at the northeastern shores of the Ol Kokwe

IV. DISCUSSION AND CONCLUSION

Volcanic rocks in Kenyan are widely distributed along the regional rift system from which splitting and subsequent separation of continental crust continues at a slow rate due to continental drifting and rifting. The rifting is an ongoing process within the Great East African Rift system, which traverses African Continent from the North to East and central Africa. The rift system hosts numerous volcanoes that are both active and dormant. Volcanoes are located on the floor of the Rift Valley as well as on its flanks. Geothermal activities, in the rift system are linked to the volcanic activities and are manifested at the ground surface in different features. The features include hot springs, warm springs or geysers, steam jets, fumaroles, hot grounds and surface deposits of sulphur.

Manifestations of geothermal activities are widespread on the floor of the Rift Valley; directly above the center of an upwelling magmatic body such as the Kenya dome, which experiences magmatic activities of increased magnitude, thereby bolstering potential geothermal exploration, development, and harnessing rationale. Indeed, geothermal resources have become a focus for harnessing of the natural green energy and will continue to rival the natural petroleum deposits which man has lied upon for time in memorial.

Unfortunately, active volcanoes particularly Nyiragongo of Zaire are a threat to environment, infrastructure, human live and the environment altogether, despite powering the geothermal gradient [4]. Another notable threat to the environment is Greenhouse Gases that are associated with geothermal activities such as Hydrogen sulphide and carbon dioxide. The gases continue to be emitted to the atmosphere and are of increasing concern. Such gasses are prevalent in New

Zealand's hydrothermal activity which is located in the active Taupō Volcanic Zone that extends from White Island to Mt. Ruapehu[7]. Furthermore, Traces of harmful base metals such as mercury are also being encountered in geothermal high enthalpy waters. This is a documented scenario for Larderello geothermal power plant which is located in Mt. Amiata Area of Italy. Thus, mitigation measures need to be put in place so as to safeguard mankind and other valuable lives [8].

Three categories of geothermal systems have been noted in this paper, the first two being anchored in igneous environments while the third one is linked to sedimentary environment. The geothermal systems have also been related to plate tectonic environments i.e. divergent and sub-duction zones as well as to continental rifting systems that continue to split continental crust at a slow rate. Volcanic centers in these rifting systems have been noted to be linear while magmatic activities for the volcanic centers have been rightfully mentioned as the source of heat that generates high enthalpy waters. Subsequently, exploration for the geothermal reservoirs continues to focus on rift valley regions. However, since presence of hot springs is an indication of magmatic processes that are ongoing at shallow depth, then the focus does not necessary have to be in rift valleys alone. Hot springs are also be located away from rift valleys and can as well be considered for geothermal exploration. Typical example is the Dzombo hot springs, also known as 'Maji-moto' springs that occur in coast region of Kenya. The springs are geologically located in Duruma Sedimentary Basin. Hot saline water of the springs escape to the surface through concealed faults that developed during down-warping of the Basin in Permo-Triassic times, far way back before the onset of Eastern Africa Rifting in Tertiary times [9]. Directional drilling, as an exploration tool, can be used to access the magmatic body which acted as a source of the carbonatite volcanism to form Dzombo hill that is located in the vicinity of the hot springs [4]. The magmatic body is the source of heat which worms up ground water of the hot springs. The Hot spring were found to have temperatures ranging between 55°C and 70°C, alongside mildly altered grounds, with secondary minerals such as chalcopyrite, pyrite and calcite[10].

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