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Geothermal Mineral Deposits in the Kenyan Geothermal System; Implications For Economic Viability.

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ABSTRACT

Geothermal systems in Kenya have long been acknowledged for their potential in the great production of renewable energy in the East Africa rift and worldwide. This is made possible by the vast and rich geological province- within the volcanic East African Continental rift setting. This paper delves into the assessment of the geothermal deposits in the Kenyan geothermal system with a focus on their distribution, their implications in geothermal exploration and their importance in the context of economic sustainability. This paper offers a compilation of preexisting geological and geochemical information by looking into the mineralogical compositions, depositions and amounts discovered in the geothermal regions of Kenya. The economic feasibility of geothermal energy is directly influenced by the presence of mineral deposits. Some minerals play a big role in enhancing the success of geothermal power generation, while others may present challenges and contribute to escalated operational expenses. Hence this paper is aimed at identification, characterization and distribution of mineral deposits in geothermal systems in Kenya with regard to their influence in exploration and exploitation of geothermal energy. This will help shed more light on the complex geological features of the Kenyan geothermal regions and give a better understanding of the underlying mineralogical conditions within these systems.

1. INTRODUCTION

Geothermal energy is one of the most promising renewable sources in the quest for sustainable energy sources, particularly in areas that have high geothermal potential such as Kenya in the East African Rift (EAR). Its location within the volcanic East African Continental Rift boasts significant potential for geothermal energy production as its potential is estimated at 10000MW along the Kenyan Rift Valley (Omenda, 2014). Geothermal energy in the EAR and Kenya to be particular has leaned majorly towards electricity production by playing a big role in the generation of power and contributing upto 50% of the energy mix (Berggren & Österberg, 2017; Muriithi et al., 2018).Geothermal energy exploration and exploitation also plays a significant role in understanding the relationship between the minerals in the subsurface and heated geothermal fluids.

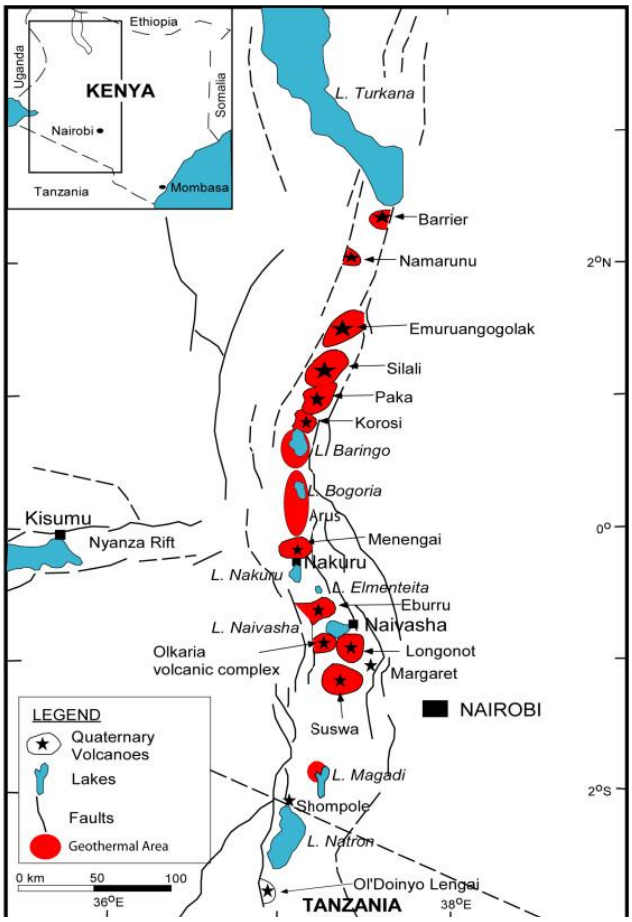

Figure 1: Volcanic centers of geothermal potential along the Kenyan Rift valley (Omenda, 2014).

Economic mineral mining of metals in Kenya generally as of 2017-2018, indicated minerals such as ilmenite, rutile and zircon accounted for 2.6% of the mineral exports with a revenue of $5.1 billion and metals such as iron and steel exportation at 2.2% (Yager, 2022). These minerals were mainly of great occurrences and exploitation in areas off the Kenyan rift system-geothermal areas and majorly in Archean cratons; the greenstone belt and the metamorphic belt of Kenya (Pulfrey et al., 1969). Geothermal systems form in relation to volcanic settings where there is a form of heat source transfer from the subsurface through heated fluids. The heat transfer from heated fluids is manifested on the surface via fumaroles, hot springs, hot grounds and solfatara deposits. Minerals are deposited in a geothermal and hydrothermal system from the interaction of the heated fluids with rocks in the subsurface that are enriched with metal from magmatic activity and are deposited along the fluid conduits; vein faults and fractures (Pirajno, 2012). The geothermal systems in the EAR have been mainly utilized for heated fluids conversion to electrical energy.

To increase the economic value of the underexplored geothermal systems in the East African Rift, evidence from other active and ancient geothermal systems in the world (Izawa et al., 1990) suggest the potential of coupling the East African Rift system (EARs) as both a source of geothermal energy(Omenda, 2014) and epithermal mineral deposits. The potential of economic metals such as copper, gold, zinc, tin, lead, iron, and cobalt in the EARs geothermal areas will not only increase the availability of industrial raw materials but also increase the foreign exchange in addition to improving exploitation of clean energy that is in line with the UN SDGs; SDG 7 –affordable and clean energy, SDG 13- Climate Action, and ultimately SDG 1-No poverty and SDG 2 Zero hunger (United Nations: Department of Economic and Social Affairs, 2022). This review highlights epithermal mineral deposits and their potential with a greater comparison in the EAR-Kenyan geothermal systems to other geothermal systems of economical deposits.

2. EPITHERMAL MINERAL DEPOSITS

Epithermal minerals are termed as minerals that form in the lower subsurface in depths of 1 to 2 km based on the observed elements, mineralization styles, and texture of deposits (Lindgren, 1933). Later works on epithermal deposit characterizations enabled the identification of the temperatures of formation to be between 250 °C -300 °C hydrothermal fluids at low pressure near the surface (White & Hedenquist, 1995). Epithermal mineral deposits are mostly found in association with volcanic igneous rocks and also in porphyry environments near intrusion and also in sedimentary environments of secondary deposition. Ore deposition of hydrothermal fluids in the subsurface is dependent on the host rock, the fluid chemistry, and the rock-water interaction in the subsurface. The source of the heated fluids in these geothermal systems are either of magmatic origin, meteoric water, and /or oceanic water (Ellis & Mahon, 1977).

The chemistry of the fluid plays a major role in the dissolution of metals in these heated geothermal fluids and the deposition of these metals where the mixing of the geothermal fluids and boiling leads to deposition (Henley, 1985; Simmons & Browne, 2000). As mentioned earlier, epithermal deposits are characterized based on the different fluids that lead to the dissolution and deposition of these metals. They can either be classified as an Acid-sulfate type of deposits or Adularia-sericite deposits with Adularia-sericite being formed from reduced fluids and the latter from Oxidized fluids. These deposits can also be classified based on the sulfidation assemblage due to the sulfide fugacity at pressure–temperature conditions (Dilles & John, 2020). They are classified as High sulfidation, intermediate, or low-sulfidation deposits (Hedenquist et al., 2000; Dilles & John, 2020).

The characteristic mineralization of epithermal depositions is typically vein fillings, dissemination, calcite deposits chalcedonic quartz, and bladed calcite, colloform –crustiform amorphous silica deposits that indicate boiling within the system that led to deposition (André-Mayer et al., 2002). Geothermal systems may have precipitated from the heated fluids containing economically viable metals. The economically important metals that are commonly reported in geothermal systems are precious metals (Gold and silver), base metals (Iron, Copper, tin, Lead, cobalt, manganese, magnesium, titanium cobalt, chromium, and more), and Alkali metals (Lithium). These deposits have been found in high concentrations in various geothermal systems in geothermal pipes as scales in Ohaaki, precipitates with gold and silver concentrations of 180ppm and 8000ppm respectively (Raymond et al., 2005) and in down-hole geothermal waters (Simmons & Browne, 2000). Epithermal gold and silver deposits have been recovered in the Hauraki goldfield with a production of 32,000 kg gold and 1.5 Million Silver between the year 1862-2006 (Christie et al., 2007) and Honko ore zone production (Izawa et al., 1990).

2.1 Classification of epithermal mineral deposits

Epithermal deposits have been classified in different but relative techniques such as based on the fluid chemistry of the depositing heated fluids, the sulfide assemblages, and the relative alteration type. It is however good to note that the best criteria to classify epithermal deposits is through the observations made on the mineralogy, mineral texture, mineral assemblages, and alteration mineralogy which concurs with the sulfidation styles of deposition. The temperatures of formation, depth, and fluid chemistry characterize further the environment and conditions which favoured the deposition of bi-sulfide complexed metals.

Based on the sulfur reactions and sulfide assemblages, epithermal deposits can be classified as high sulfidation deposits and low epithermal deposits. As suggested by the name, these deposits are distinguished by the sulfides assemblages with high sulfidation deposits typically having an assemblage of; enargite, covellite, luzonite, famatinite, pyrite, and possible assemblages of ±chalcopyrite, ±tennantite, ±sphalerite, and ±galena, as summarized by Einaudi et al (2003). A comparative volcanic zone of Volcán Popocatépetl, Mexico, with HS deposits, has indicated an assemblage of pyrite, chalcopyrite, sphalerite, galena, tennantite, galena, magnetite, chromite, barite, stannite, Au Cu telluride, related Ag sulfide, and calaverite. The intermediate deposits were characterized and compared from different systems to have similar sulfide mineral assemblages as the high sulfide deposits, but it however lacks enargite. The intermediate deposits have been characterized to have halos in the veins with illite ±adularia grading downwards to sericite and outwards to a propylitic zone (Einaudi et al., 2003).

Numerous low sulfidation deposits such as in Guanajuato, Batopilas, Fresnillo, Peru, New Zealand and in the united states such as Nevada have been summarized to have sulfide assemblages typically sulfide poor; dominated by pyrite (Kissin & Mango, 2014). The sulfides present in this deposit type tend to be minor or trace amounts of sphalerite, arsenopyrite, galena, pyrrhotite, and iron-rich sphalerite. The geochemical halos that are commonly distinctive from this system are majorly of illite or chlorite with major chloritization in mafic hosts (Einaudi et al., 2003). In comparative studies, the fluid chemistry of these HS, IS, and LS deposits have indicated a correlation between their formation fluids with LS deposits being formed from near-neutral pH fluids of gas-rich reduced-hydrothermal fluids (Kissin & Mango, 2014). Relative high sulfidation deposits are formed from acidic-sulfate, oxidized hydrothermal fluids as of the analysis of the hydrothermal fluids in this system such as those noted in the Okuaizu geothermal system. Geothermal systems have been particularly characterized to mostly entail the sub-alkalic low sulfidation deposits such as those in the extensional boundaries; of Hishikari Japan (Einaudi et al., 2003).

3. SUBDUCTION ZONES

Subduction zones are mostly dwelled by numerous volcanic activity with major examples such as Japan, Indonesia, lying in the infamous "Ring of Fire". The subduction zones encounter tectonic activities from the movement of the plates; slab pulling causing stress state, compression and magma movement that generates pressure for rock fracturing and other permeable features. These are the ideal condition for mineral deposition sites due to the movement and time it takes for the heated fluids, given adequate water-rock interaction that favours the dissolution of metals from magma and country rocks. The changes in the condition of the heated fluids during conduit causes disequilibrium that leads to the deposition of the heavier solutes as metal complexes. The chemistry of the fluids in the subduction range depends on the magmatism; silica under saturated or saturated.

3.1 Epithermal deposits in subduction zones

With regards to epithermal deposits, most of the deposits that have been are mostly related to andesitic volcanoes; andesitic-dacitic volcanoes in volcanic–island arcs. These include subduction zones of Volcán Popocatépetl, Japan, Nevada district/basin and Oatman District (Izawa et al., 1990; DeWitt et al., 1991; John, 2001; Larocque et al., 2008; Oyman, 2019). The deposition of epithermal minerals in this setting has indicated that the majority of the epithermal mineral deposits type are majorly of the High sulfidation type(Western assemblage of northern basin, Popocatépetl, Mexico, negroes Philippines, Hishikari, Japan, Osorezan, Okuaizu, and Oatman District). The ore deposits in these localities are emplaced particularly as stock works, breccia, localized fault systems and veins. The majority of the fluids in the subduction zones of epithermal deposits have been found to contain highly acidic fluids that lead to high leaching, which are related to deposition of the high sulfidation type of deposits (Sillitoe & Hedenquist, 2003). Localities of epithermal deposits that have both subduction zones and post-collisional rifts (basin and range extension) such as the Northern basin of Nevada, Trans-Baikal region, and Hishikari are seen to represent low sulfidation deposits that are relatively of bimodal basalt- rhyolite magma assemblage (Izawa et al., 1990; John, 2001; Zorin et al., 2001).

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3.1.1.1 Epithermal deposits in geothermal systems of Subduction zones

A geothermal area can be defined as a designated region on the earth's surface with surface manifestations such as fumaroles, hot springs, geysers, hot grounds, and volcanoes that indicate the presence of an active geothermal point in the subsurface (Toth & Bobok, 2017). Geothermal systems entail the convectional flow of heated fluids from the subsurface particularly in the presence of permeable features such as faults and fractures. The source of the heated fluids within a geothermal system is attributed to meteoric, connate, or magmatic and ocean water sources (Ellis & Mahon, 1977). Upon movements in the subsurface with the continuous water-rock interaction, there are changes in temperature and pressure which leads to fluids boiling conditions that favour the precipitation of minerals in the near-surface depths (Dilles & John, 2020). Geothermal systems in subduction zones have been related to appreciable concentrations of metal deposition in precipitates (Izawa & Aoki, 1991). These precipitates have been collected in geothermal components such as control valves, pipelines, and wellheads and also in hot springs, for instance in Okuaizu geothermal area showing a very high and appreciable concentration and percentages of metal deposits. This is noted in Table 1 below indicating the concentration of precious metals and trace metals in these components;

Table1: The chemical composition from some geothermal waters; hydrothermal gold-bearing precipitates. (Abbreviations ppm, parts per million, % per cent, - not determined.) **(Izawa & Aoki, 1991).**

Elements	**Onuma (pipeline)**	**Okuaizu (Control Valve)**	**Fushime (Pipeline)**	**Osorezan (hot spring)**
Au (ppm)	0.86	116	1.4	6510
Ag (ppm)	23	34900	2225	0.4
Hg (ppm)	-	-	0.03	5520
As (%)	-	2.75	-	0.37
Sb (%)	0.005	11.1	1.23	0.10
Pb (%)	0.001	13.1	40.16	0.14
Zn (%)	0.004	13.4	17.15	0.26
Cu (%)	-	16.0	7.79	0.007
Fe (%)	0.35	1.56	2.92	3.34
Te (%)	-	-	-	1.05

The chemistry of geothermal fluids in geothermal areas ranges in composition from; chloride waters, acid-sulfate waters, bicarbonate, and a mix of both acid-sulfate waters. For instance, the Okuaizu geothermal field had high chloride waters that led to epithermal gold deposition (Izawa & Aoki, 1991).

3.2 Intraplate rift settings

The Continental rifting is triggered by active mantle plumes that cause stretching of the crust as magma moves towards the earths subsurface, or by post-collisional compression and stress. Comparatively with the subduction zones, extensional and intraplate rifts have been seen to exhibit bimodal types of magmatism; basalt-rhyolite, trachyte and generally alkaline magma. These tectonic activities increase the permeability of the zones creating perfect conditions for the movement of fluids in the subsurface. The rift zones of Menderes massif, the East African Rift and the Patagonian massif have similar magmatism to the characterized Nevada basin; calc-alkaline magmatism-peralkaline magmatism; rhyolitic–trachyte–andesite magmas (Omenda, 1998; John, 2001; Özgür, 2019; Pugliese et al., 2021).

3.2.1 Epithermal deposits in intraplate rift system

The mineral deposits of these settings indicate mineral metals being deposited with low sulfidation deposits with very low chances of high sulfidation state deposits in intraplate settings. This is because the chemistry fluids in these systems are reduced neutral pH fluids which do not favor intense leaching that is noted in high sulfidation zones (Sillitoe & Hedenquist, 2003). The studies of the extensional basin such as Nevada have been characterized to be of bimodal-basalt rhyolite assemblage that influences the chemical deposition of low sulfidation deposits in the locality. Mineral assemblages range from Pyrite, sphalerite, galena, sphalerite and chalcopyrite mostly in veins and as disseminated deposits with economic grade Au at depths of between 0.5 to 1 km (Pugliese et al., 2021). Deposits of Hg at Halıköy in Menderes massif indicate formation temperatures of between 128°C – 200°C (Özgür, 2019). This corresponded closely with the geothermal reservoir temperature of fluids which ranged from 220°C- 260°C (Özgür, 2019). Generally from the review of the relationship of epithermal deposits and tectonic-volcanic settings, the geothermal systems studied in these localities have been able to indicate a correlation of high Sulfidation deposits with subduction zones, neutral stress state areas, and LS being associated majorly with extensional settings such as intra-arc, near and back-arc and post-collisional rifts (Sillitoe & Hedenquist, 2003). More could be done on the intraplate rift of the East African rift.

3.2.1.1 Epithermal deposits in geothermal systems of intraplate rift settings

The geothermal areas in intraplate rift settings that have reported deposition of epithermal mineral deposits are such as the Nevada northern rift basin, Continental rift of Menderes Massif, Western Taupo Volcanic Zone, Afar rift, Tendaho in the Main Ethiopian rift and many more crustal extensions. With relations to active and or extinct geothermal systems; the aforementioned localities have had epithermal deposits at low temperatures of between 180 –-250- 300. The low temperature of mineralization at low depths of the earth crust from the circulation of geothermal fluids has enable deposition of minerals such as Au, Hg,Sb,,Cu, Zn and Fe in traces. These are from the studies such as EPMA analyses in Western Taupo volcanic zone that is reported to have Au deposits of hydrothermal origin, related to geothermal fluids, in conglomerates in pyrite veins and in fumaroles (Zhang et al., 2016). The Kucuk menderes with epithermal precious metals has also been considered a fossil geothermal system (Özgür, 2019).

The Au deposits of the western Taupo Volcanic zone are low with values of between 20-120ppm and an average of 60ppm. The epithermal deposits of the Afar depression were found with Au deposits in search for geothermal energy exploitation which raised heads on the values of the deposits. The geothermal areas in Tendaho rift of Ethiopia and the Afar rift of Djibouti indicated values of gold of upto 400ppm in a bimodal volcanism rift.

4.0 POTENTIAL IN INTRAPLATE RIFT SETTINGS; THE EAST AFRICAN RIFT.

4.1 The East African Rift Systems- Regional Geology

The East African rift system is characterized as one of the widely known continental rift systems that are quite extensive in length. It runs from the Afar region in the Ethiopian rift, triple joint to southern sections of Tanzania. The extension from the Afar region in the Ethiopian rift splits into two branches; the Eastern branch and the Western branch. The Eastern branch is more volcanically active as compared to the Western branch and it runs from the Ethiopian rift, Kenyan rift, and the North Divergence Tanzania (Chorowicz, 2005). The East African rift is attributed to mantle pluming which characterized the region to be overwhelmingly alkaline, covered by mafic magmatism; bimodal-basalt rhyolite magmatism with flood phonolites, trachytes and ignimbrites (Baker et al., 1972; Furman, 2007). The Ethiopian rift is covered predominantly by tholeiitic basalts and transitional–evolved prevalent rhyolites and trachytes. The Kenyan rift is predominantly covered by mafic lavas of transitional tholeiitic basalts and felsic lavas of trachytic composition in the northern Kenya rift and the southern Kenya rift is majorly dominated by trachytic and pantelleritic composition with little basalt exposures (Furman, 2007).

The EARs were formed from the process of lithospheric extension bringing the mantle plume to the near-surface with large volumes of magma. Omenda shows in Figure 2 a visual representation of the continental rifting and the mantle upwelling that led to the numerous volcanic centres in the EARs.

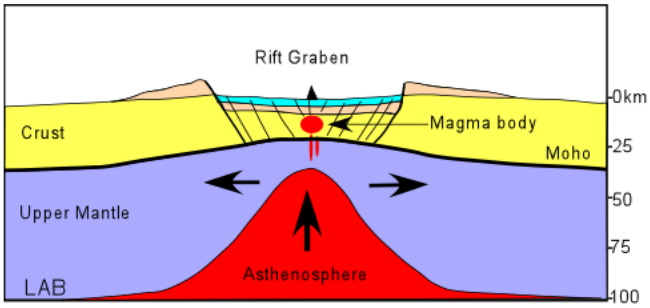

***Figure 1; A standard model showing a generalized E-W cross-section of the continental rift formation; last stages*(Omenda, 2014)**

The geothermal activity in the EARs is mainly manifested by the presence of volcanic centres such as domes, Kenyan domes, Ethiopian domes, and Tanzanian domes, hot grounds, fumaroles, hot springs, altered-red ground, and geothermal grass (Omenda, 2014). Geothermal activity in the EAR is vast with high chances of hydrothermal deposition of precipitates in the subsurface by the heated fluids that circulate the igneous rocks of alkaline magmatism.

4.1.1 The Kenyan Rift

The Kenyan rift is a vast intra-continental extension structure that runs from the northern Kenya-Lake Turkana to the northern Tanzania divergence. The extension and evolution of the Kenyan rift have been revealed from radiometric dating to have begun in northern Kenya during the late Oligocene- early Miocene times (Morley C. K. et al., 1992). The Kenyan rift valley becomes younger as it extends to the southern rift with major rifting in the central rift and further propagation southwards about the middle to the late Miocene. This was preceded by volcanic activity towards the southern rift in mid-Miocene 15 Ma- 20 (Morley C. K. et al., 1992). There was numerous formation of shield volcanoes along the axis of the rift in the Quaternary with a vast number of quaternary volcanoes in the Kenyan rift of silicic composition. The most developed segment of the rift for geothermal resources is the central rift-particularly the Olkaria area, Menengai, and ongoing exploration drilling in some sections of the northern rift; Paka, silali, and Korosi volcanoes. Olkaria geothermal has the highest generation of electricity from geothermal with 790MW as of the year 2022 (Cariaga, 2022).

4.2 Comparative characteristics of the East African Rift setting-Kenyan rift system and other settings for epithermal mineral deposits.

From the attempts to study the possible mineralization along the East African rift, deposits are seen in Afar rift and the main Ethiopian rift where epithermal gold deposit occurrences were found in relation to quaternary volcanism. Epithermal mineralization in the EAR was found in relation to bimodal magmatism particularly in abundant peralkaline silicic volcanic of the Main Ethiopian Rift (MER);pyroclastic, ignimbrites, trachytes and basalts (Tadesse, 2001;Moussa et al., 2010).The mineralization is related to the lithology of other rift basins such as Trans Baikal region of Russia and Northern Nevada rift which have low epithermal deposits of gold being related to bimodal magmatism of basalt-rhyolite assemblages (John, 2001; Zorin et al., 2001).The depositional area in the Ethiopian rift and those of the northern Nevada-western bimodal assemblage, coincides with the Kenyan rift which has similar geology as that of the Ethiopian rift and the Afar rift.

The mineralization of gold deposits in the hydro-geothermal areas of a Tendaho district in Ethiopia and the South East Afar rift in Djibouti occur as similarly as that of trans Baikal region and the northern Nevada assemblage; low sulphidation types with concentrations ranging from 200 ppb to 300pbb normally in core samples at epithermal depths (Tadesse, 2001; Moussa et al., 2010). The alteration sequence in four (4) localities of the MER, related to the epithermal deposits ranged from propylitic-potassic –argillic and advanced argillic alteration with abundant metal minerals of oxides and Sulphide; Magnetite, ilmenite, Ti-oxides, pyrite, chalcopyrite and sulphosalts (Tadesse, 2001).similar alterations are noted in the Kenyan rift particularly Olkaria geothermal area geothermal wells with alteration zones ranging from zeolite-chlorite, illite-chlorite, garnet biotite-actinolite to epidote-illite chlorite zones (Lagat et al., 2005).The low epithermal deposits of gold and related precious metals other rift localities outside the EAR with low epithermal deposits indicate mineralization with alteration deposits similar to those mentioned in the EAR (John, 2001; Özgür, 2019; Zorin et al., 2001).

The sulfur content in these low sulphidation deposits of the EAR has indicated abundant sulphides of low fugacity ranging from pyrite, chalcopyrite, galena, sphalerite and bornite. The Hes Daba prospect of Afar rift in Djibouti has sulfur isotope of pyrite ranging from -9.20 – 1.45 ‰ ,with general high sulfide content in both localities of the Afar rift with epithermal assemblage (Moussa et al., 2010).From the studies prospects in EAR, most of the ideal epithermal depositions have occurred in the low end of sulfidation with low sulfur and oxygen fugacity as such in northern bimodal assemblage of Nevada with pyrite/marcasite, Arsenopyrite, stibnite, tetrahedrite, minor local sphalerite, local pyrrhotite and chalcopyrite (John, 2001).These deposits are mineralized massive breccia's and fracture fillings in Ali Adde and Hes daba respectively, in veins; acidic intrusions in Tendaho, and disseminations of pyrite which are abundant as also characterized in the Kenyan geothermal wells (Tadesse,2001;Lagat et al.,2005;Moussa et al., 2010).

The epithermal mineral deposits of the Tendaho prospect had the gold assemblage at lower depths of > 20m -< 305 m. This compares to characterized formation depths of these type of deposits, as in Trans Baikal region, Patagonian massif, Menderes massif and the bimodal assemblage of the northern basin of deposits at <1km at temperatures ≤200°C – 300°C as varied in the geothermal systems and deposition locations (John, 2001; Zorin et al., 2001; Özgür, 2019; Pugliese et al., 2021). The chemistry of the depositing fluids in both EAR and the corresponding epithermal deposit sites that are similar in the rifting setting are particularly of neutral-pH; reduced geothermal fluids. This has also proven to be similar to the chemistry of the geothermal fields in Kenya; Olkaria geothermal fluids with moderately alkaline, mostly mixed type of fluids but majorly chloride waters (Karingithi, 2000; Okoo et al., 2017). In as much as the characteristic of the epithermal deposit formation is similar to the areas that have been found, people haven't really done much core drill geochemistry in geothermal areas of Kenya; with relation to mineralogy. This need to be done in the Kenyan rift to clarify on the potential and possible outlook of the mineralogy for economical purposes.

5. CONCLUSION

From the comparison of the different geothermal settings and epithermal deposits in subduction-related zones, extensional settings and rifts, we see that the majority of epithermal deposits occur as an implication of the chemistry of the magma, reduced or oxidized, the chemistry of the hydrothermal fluids which correspond to the lithology alteration. The majority of the epithermal deposits zones in the subduction zones such as the north basin deposits, Hishikari deposits and Oatman district are andesitic-dacitic arcs which are high sulphidation type deposits. Comparatively, the epithermal deposit in the rifting zones majorly occurs in relation to low sulphidation zones. These areas are mostly of highly alkaline volcanic rocks. The EAR is characterized as a high alkaline–peralkaline volcanism area which is likely to have encountered low sulfidation deposits such as in the south-east afar rift, where vein deposits of Telluride related gold deposits were found (Moussa et al., 2010).

Similarly, the low sulphidation deposits in the Tendaho district of the main Ethiopian rift have discovered low sulphidation gold deposits related to acidic volcanic rocks. The discoveries have similar characteristics with the environment of formation of economic deposits in the Patagonia massif, extensional Nevada rift, Trans-Baikal rift and the Menderes rift. The under-explored EAR could have more localities of low sulphidation deposits since the rift has been mainly characterized to have low sulphidation deposits. The Kenyan rift in particular; the Olkaria geothermal system has been seen to have similar conditions as that in Tendaho and S.East Afar rift, which may have some potential in epithermal mineral deposits. The EAR has fewer documented economic deposits studies however making it limited in identifying areas of economical geothermal deposition.

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