Proceedings 5th African Rift Geothermal Conference
Arusha, Tanzania, 29-31 October 2014

Geothermal Resource Prospects of Permian Karoo Rifts on the Western Flank of the Western Rift: A Review of Thermal Spring Records and the Regional Geology.

Getahun Demissie, Addis Abeba, Ethiopia

Mobile: +251 (91) 173 6725, (92) 720 9778

P. O. Box 7355 Addis Abeba, Ethiopia

E-mail: getahun.demissie.gemeda@gmail.com

Keywords: Luama Rift, Luangwa Rift.

ABSTRACT

The geologic make-up of the East DRC and Zambia region is the outcome of Archean cratonic development, three successive Proterozoic depositional and orogenic cycles and Phnanerozoic continental rifting and sedimentation. The interplay between cratonic masses emplaced and structured the orogenic belts. The successive orogenic and post-orogenic cycles installed and/or activated structures that behaved as long-lived zones of crustal weakness that participated in later tectonic events. During the Late Paleozoic and Mesozoic, these structures became the favored locii along which rifts developed and became receptacles for sedimentation. Some of these basins host anomalous concentrations of thermal spring activity. Thermal spring records dating from 1933, 1969 and 1974 are reviewed in the regional geologic framework in which the sprins occur. A number of deep reaching structures are seen to serve as pathways for the transfer, to the upper crust, of the heat of the tumescent mantle that underlies the region. Deep circulating meteoric waters relay that heat to the surface. Permeable layers in the Karoo succession, fractured underlying basement rocks, and/ or fault planes that may lie between the two may host the circulation and storage of geothermal waters. These thoughts led to the proposition that the areas of the higher temperature thermal spring activity in the Karoo sedimentary basins of Eastern DRC and Zambia may probably be associated with economically accessible and commercially usable geothermal resources. Detailed geologic mapping and thermal water sampling and analyses at selected high temperature spring areas, and follow-up by geophysical surveys of areas that yield the most promising results are recommended. Complementarily to this, high temperature thermal springs situated in Precambrian metamorphic and igneous terranes are described briefly.

1. INTRODUCTION

The Eastern part of Africa is the least electrified region in the World. In addition to the large unserved commercial energy market, there is also a rapidly growing demand for electricity for powering economic growth and essential social services. Not all countries in the region have adequate domestic renewable energy resources that can be developed to meet long-term demand.

Due to the progress achieved to-date, especially that in Kenya, there is growing political will in the region to develop geothermal energy. The limited resources that could be periodically allocated to geothermal surveys are, since recently, being augmented by a comparatively large scale intervention by multi- and bi-lateral technical assistance and funding. These aim at reducing the risks associated with geothermal resource exploration and development. They would also assure sustainability. Geothermal projects can now be progressed to the resource proving stages. Proven resources would attract investment in their commercialization. This opportunity warrants the broadening of the geothermal resource development horizon beyond the high-volcanicity Eastern and Northern sectors of the EARS, into the regions of Central and Southern Africa that do not have active magmatism but exhibit high temperature thermal spring activities. Some of these hydrothermal features may be associated with the possible existence of economically accessible geothermal resources, for electric power generation using appropriate energy conversion technologies or for direct use in industry, agriculture, and in the growing health and recreation, and tourism industries.

A compilation of old information on the worldwide distribution of thermal springs by the USGS (Waring, 1966), although incomplete for much of Africa, showed that an anomalously large numbers of thermal springs occurred in Eastern DRC and in the middle Zambezi River basin of Zambia and Zimbabwe. The thermal spring areas in the later have since been probably inundated by the lake impounded behind Kariba Dam. A cursory review of the information on DRC was contributed to the proceedings of the ARGeo-3 Conference in 2010. There is some interest in the possibility that commercially developable resources may exist in DRC. In addition, some old source publications were acquired more recently. This situation encouraged a new review of the available information in light of the current understanding of geologic processes and the geologic development of Eastern DRC. .

High temperature springs were selected for the present exercise; as their temperatures indicate them to probably occur in close proximity to their subsurface sources. Their distribution and gross geologic settings were examined and a bias toward higher thermal spring densities and temperatures in the E. Kivu Karoo basin was recognized. This helped in focusing the study on this geologic environment. In addition, numerous thermal springs also occur in association with the Zambian Karoo basins. Pending the acquisition of more geologic and precise location information, a preliminary review of a reconnaissance survey report from 1974 was also made. The key Karoo basins in the two countries also happened to be located in regions that are remote from the national electricity grids. This allows the potential socio-economic impact of, and the return on investment in the development of any existing geothermal resources attractive. Brief notes are also added concerning high temperature thermal springs that characterize some Paleozoic terranes. This hoped to allow an overall view of the general situations in the two countries

This contribution presents the outcome of the review work. It is hoped to contribute to the cultivation of public and private interest in the development of the probable subsurface resources from which the thermal spring waters derive.

2. THE DISTRIBUTION OF HIGH TEMPERATURE THERMAL SPRINGS IN THE REGION

The thermal spring record comprises a list of 159 features for DRC (Passau, 1933, Le Bail et al, 1969) and 131 for Zambia (Legg, 1974). They are reported as single or groups of springs. Many of these, belonging to the same mode of occurrence and proximity to each other, are likely to issue thermal waters separated from the same columns of upwelling subsurface thermal waters. At least most springs are reported to occur along or close to rivers and streams, on lakeshores and around wetlands. These surface hydrologic features would be their obvious discharge areas. Thermal waters tend to buoyantly rise from their subsurface source regions to higher elevations than adjacent cold shallow or surface water bodies and outflow down the hydrologic gradient to the discharge zones. Thus, the thermal springs may not be necessarily situated directly above their subsurface sources. This would be even more true for the DRC thermal springs as they are distributed in a well-drained terrain that slopes westward toward Lualaba River, the eastern regional hydrologic sink. The threshold temperatures that were determined for consideration here are $80^{O}C$ for DRC and $70^{O}C$ for Zambia. These were somewhat arbitrarily determined, but done by taking into consideration the size of the thermal spring populations, the representation of key thermal spring/ geologic settings, the ranges of spring temperatures, and the necessary brevity of this contribution.

The list of thermal springs and maps that show their locations and broad geologic settings are appended at the back.

3. THE GEOLOGIC SETTINGS OF HIGH TEMPERATURE THERMAL SPRING ACTIVITY.

3.1 The Regional Geologic Background

The geologic make-up of the region is the outcome of Archean cratonic development, three successive Proterozoic orogenic and their precedent depositional cycles, and Phanerozoic continental rifting and sedimentation. The interplay between cratonic masses emplaced and structured the orogenic belts. The successive depositional and orogenic cycles created new terranes and installed structures that behaved as long-lived zones of crustal weakness. These structures participated in later tectonic events that resulted in the present tectonic fabric, geodynamic state, and resources of the region.

Four cratons surround the region: clockwise from the west, the Congo, North Ugandan, Tanzanian and Zimbabwean cratons. A fifth cratonic mass is believed to remain buried in the middle (Rainaud et al 2003). The Paleoproterozoic Ubendian belt occupies the northern border of Zambia and extends northwestward from the northern part of L. Malawi along the L. Rukwa-SE L. Tanganyika rift zone into Kivu and Maniema provinces of DRC. The Grenvillian orogenic cycle of the Mesoproterozoic raised the Irumide and Tete-Chipata (a.k.a. South Irumide) belts in the Southeast (SE and E. Zambia) and the Kibaran belt in the northwest (E. DRC). Two components of the global Panafrican belt occupy the southwestern and interior parts of the region: the essentially juvenile Lufillian-Zambezi belt in the south, and the northern flat-lying intracratonic Kundelungu belt of Katanga. The two are separated by the arcuate, deformed Lufillian Arc. The Bangwewulu Block of Northern Zambia is a discrete Paleoproterozoic intracratonic granitic and metavolcanic block overlain by Kundelungu age sediments. It borders on the Ubendian belt in the Northeast. Supposedly, it overlies an un-exhumed cratonic mass (Likasi craton) which extends under the Lufillian Arc and the Kundelungu Trough. This cratonic root and the block riding on its back have acted as an indenter on the Tanzanian craton resulting in the structural development of Central Africa as far north as in SW Uganda. Karoo rifts developed during the middle of the Paleozoic on surfaces made up of Ubendian metamorphics and Kibaran granites in the North of the region (DRC) and in the mainly metasedimentary Irumide terrane and the Panafrican Belt of the Zambezi River Basin in its Southeast (Zambia). Smaller exposures of Karoo sediments lie in rifted Panafrican terrane in Southern Zambia.

The region has remained amagmatic since the Cretaceous. However, except for the Bangweulu Block, the other geologic terranes host varying numbers of thermal springs, sometimes issuing at the high temperatures that are not common in such regions. Furthermore, a bias toward larger thermal spring populations and higher temperatures prevailing in the region's Karoo basins and their geologic structures is noticeable, and warrants scrutiny.

3.2 Karoo Structures and Sediments

The Post-Gondwana extensional tectonic phase that eventually broke-up Gondwanaland progressed through successive crustal sag-rift-drift-dispersal stages. Crustal sag resulted from the relaxation of the compressive tectonics of the Panafrican orogeny that had assembled Gondwana Supercontinent during ~700-540 Ma. It lasted during the Late Cambian to the Late Carboniferous and the Gondwanide continental sediments that were derived from the denudation of Panafrican fold mountain ranges were deposited in the sag basins, as in the Barotse Basin. The continental rifting stage occurred during 290-180 Ma and the Luangwa, Luano, Zambezi, and Proto-Rukwa-Tanganyika rifts formed. Great thicknesses of sediments of the Karoo System were deposited in the rift basins. The sedimentary succession reflects that climatic conditions ranged from early glacial to late arid conditions throughout Gondwanaland. Rifting had exploited newly activated pre-existing zones of crustal weakness. Reactivation may have been far-field effect of the Hercynian orogeny that raised the Cape Fold Belt and /or the Varsican Orogeny which resulted in the short term assembly of Pangea Supercontinent (300-250 Ma). The reactivated structures were the Sanangoe, Mwembeshi, and Miose (a.k.a Mugesse) shear zones along which the Zambezi, Luangwa-Luano, and Proto-Rukwa-Tanganyika rifts opened, respectively. These structures had long histories of involvement in the structural development of the region and still are active, including in influencing the occurrence of the thermal springs of the region. They will be further discussed below.

The drifting stage lasted respectively during 180-169 Ma and 110-100 Ma for the opening of the Indian and Atlantic Ocean basins. This led to the drifting and dispersal of the newly individuated continental blocks, the present southern continents. Rifting occurred in the present lower Zambezi River basin and the Proto-Rukwa-Tanganyika rift was reactivated. Cretaceous-Triassic sediments were variously deposited in these two rifts. All of the above rifts remained within the region as failed rifts. Although they did not contribute to ocean basin development like the major Karoo basins of the Indian Ocean coast, they have continued to involve in later fault dislocation, sediment accumulation and terrestrial heat flow, including till the present.

Karoo rifting and sedimentation extended from the Cape Karoo Basin (CKB) of the Republic of South Africa to as far north as the Kenya-Ethiopia-Somalia border region. While it may vary in the detail from basin to basin and even within each basin, the overall stratigraphic succession in the Karoo System is widely shared as similar climatic conditions prevailed throughout Gondwanaland; thus the common use of rock-unit designations from type areas in the CKB. The earliest sediments consisted of fluvial and glaciogeneic deposits (Dwyka Formation). They are overlain by organic rich layers deposited under unoxic conditions. Coal seams are common in these layers in many countries of the region. Overlying this horizon are a sequence of claystones and siltstones with red colours that indicated deposition under oxidizing conditions, and may also contain minor coarser clastics and carbonates (Ecca Formation). The uppermost sediments are mainly aeolian sandstones and reflect the prevalence of increasing aridity (Beaufort Formation). The Karoo system terminates in voluminous continental flood basalt layers of the Karoo-Farar Large Igneous Province (LIP) of ~180 Ma (Stormberg Formation). The volcanism is attributed to the impact of the Karoo-Farar mantle plume, which eventually led to Gondwana fragmentation, in analogy with the present development of the EARS under the influence of the Afar and Kenya plumes.

3.3 Thermal Spring Activity in the Karoo Sedimentary Basins

3.3.1 Luama Rift, E. DRC.

This rift extends from Kalemie, the port-city on the western coast of L. Tanganyika, northwestward across the DRC provinces of S. Kivu and Maniema. Its faults may extend further to the northwest to the eastern margin of Congo Craton in the Congo River Basin. This is indicated by a number of northwestward bends in the course of the Lualaba River, a major tributary of the Congo River. From Google Earth imagery, major SW-facing normal faults that extend from the zone lying to the southeast of L. Tanganyika are seen to make up the rift's northeastern border zone. There are also NE-facing normal faults in its southwestern part. This gives the rift an asymmetric, quasi half-graben aspect. NNE-SSW to NNW-SSE trending faults extend into the area of the graben from the Kamituga-Mwenga branch of the Kivu Rift sector of the Albertine Rift arm. The alignment of the lower courses of some rivers and of thermal spring occurrences indicates that these broadly N-S oriented faults cross Luama graben and extend to the Lualaba River.

The graben floor lies at an elevation of ~800 m a.s.l., ~400 m higher than that of the Congo River Basin lying in the west. The land surface rises to higher elevations to the northeast, to ~1,500 m at Bukavu. The highest elevations reached in the general region are more than 3,000 m and are in Kahusi area on the Mitumba Mountains. The average annual precipitation is 1,300 mm in Bukavu. The region is thus well watered and drained by numerous tributaries of the Lualaba River, the principal eastern tributary of the Congo River lying about 250 km to the west. Many tributaries of the major Elila River drain the western flank of the Mitumba Mountains and the Kamituga-Mwenga graben in the northeast. The Elila is the northwestern-most river that is part of the drainage system surrounding the rift. In the southeast, the Lubuka River drains L. Tanganyika at Kalemie and flows southwest to the Lualaba. This river is young and developed as an outlet of L. Tanganyika when inflow into the lake increased upon the blockage of north-flowing river courses that drained L. Kivu to the Nile basin by the construction of the Birunga volcanic field during the Late Pleistocene. Luama River rises in the southeastern part of the graben and flows to the northwest along the graben floor and then southwestward to the Lualaba. Numerous other rivers and streams start on the upper slopes on the southwestern side of the graben.

Luama Rift is the western segment of the TRM rift zone, as the 150-200 km wide southeastern arm of the Western Rift is known since recently (Dulveaux et al, 2004). The TRM is a structure that has its ancestry in a Proto-Rukwa-Tanganyika rift that has been developing along the Ubendian Belt since Permian times. This belt extends into E. DRC from the northern part of L. Malawi along the zone that lies between the Tanzanian Craton and the Bangweulu Block of Zambia. Recognizable major precedent tectonic events in the rift zone started with sinistral shear faulting during the Paleoproterozoic Ubendian orogenic cycle. During the Panafrican orogenic cycle of the Neoproterozoic-Early Paleozoic, shear faulting took place along the Miose (a.k.a Mugesse) Shear Zone. This was the result of the oblique impact of the East Gondwana continental block on the eastern margin of West Gondwana late during the amalgamation of the Supercontinent. Permian rifting exploited the Miose Shear Zone. This formed the Proto-TRM rift in which a considerable thickness of Karoo and Mesozoic sediments were deposited. Dulveaux et al, (2012) defined the latest stage of deformation as involving SW-facing normal faulting during the Late Miocene to the present. Thus, the TRM has remained in the rift-forming mode with orthogonal extension throughout its evolution to its present state. The continuity of faults across L. Tanganyika is marked by the high-standing sub-lacustrine ridge offshore Kalemie, a probable extension of Ubende Horst, that separates the northern and central basins of L. Tanganyika. In addition to the structural continuity between the two segments of the TRM, continuity in Karoo and Mesozoic sedimentation is also in evidence, the later preserved near Kalemie and the Lualaba.

Luama Rift developed along a high standing Ubendian (termed Rusizian in its northwestern part) terrane that separates the Mesoproterozoic Kibaran belt of Katanga in the southwest and the coeval belt of the Western Burundi-Rwanda-Kivu-SW Uganda region that was long considered as constituting the Northeastern Kibaran belt. The rifted Rusizian terrane is pierced by probable Kibaran granite intrusions and overlain by Carboniferous-Permian Karoo System and Mesozoic sediments. The sediments are most preserved in the nearly flat and low-lying Congo River Basin. The stratigraphic succession in its eastern zones starts with the 900-1,400 m thick Carboniferous to Permian Lukuga Group, made up of diamictites, dark siltstones and black shales. It is correlated with the Dwyka and Lower Ecca Groups of the lower Karoo Supergroup. It is separated by an unconformity from the overlying 600-1,800 m thick Haute Lueki Group, a sequence of fluvial conglomerates, quartz sandstones, and red shales that is correlated with the (Beaufort Group). Unconformably overlying this Karoo succession are the 500-1,000 m thick Jurassic to Cretaceous deposits of the Congo Supergroup: shallow marine to fluvial red sandstones followed by the Dukessi Group aeolian sandstones during the Late Jurassic to Early Cretaceous, followed in the Mid-Cretaceous by the deposition of the 40-240 m thick progressively lacustrine to fluvial sediments (Loia-Bokungu-Upper Kwango Group). The Congo Basin sequence ends with the deposition of the Kalahari Group sediments during 50-30 (Linol et al, 2013). The unconformities reflect in-field and far-field epeirogenic effects.

In the Luama Rift, the Mesozoic sediments have been mostly removed by erosion, surviving only along fault blocks in the southeastern part of the rift lying the northwest of Kalemie. The outer northeastern border fault of Luama Rift limits the Karoo sedimentary in-fill of the graben floor in the northeast. These sediments are partially preserved on the rift floor extending over a distance of about 250 kms northwest of Kalemie. On the slope that descends toward the Lualaba, they have been eroded away and large expanses of the Rusizian basement are exposed. It is however notable that, based on the 1:5 million scale Geologic Map of Africa (CGMW, 1985) Karoo sediments seem to occupy the river valleys while the Rusizan metamorphics and granites make up the ridges that rise between them. This indicates that the rivers probably incised their present courses along sediment filled depressions or Permian grabens that had developed in Rusizian basement. The exposed high standing basement ridges may thus be pre-Karoo inselbergs or Permian horsts.

Undoubtedly, the highest concentration of thermal springs in the region occurs in the Luama Rift and the slopes that descend from it toward the Lualaba. While a large number of these features occur along the valleys of the numerous eastern tributaries of that river, the mid-upper reaches of the Luama and Elila Rivers exhibit most of the high temperature, often boiling, springs, as can be seen Figure 1. These thermal springs are aligned along the graben-forming fault zone that apparently controls thermal water rise from depth at points spread over a 23 km long zone. This becomes plausible when viewed together with heat flow measurement data from L. Tanganyika, that is crossed by this fault zone off-shore Kalemie. Values of 151 mW/m^{-2} for average heat flow and $193^{O}C/Km$ for average temperature gradient (IASPEI-IHFC database) were determined for a site situated on the sub-lacustrine ridge referred to above. The average heat flow value for African Precambrian terranes is ~52 mWm^{-2} (Nyblade, 1990). The ~25 km wide zone of broadly NW-SE aligned high temperature thermal springs is orthogonally crossed by faults that extend south-westward from the Kamituga-Mwenga branch of the Albertine Rift. This fault zone may also play a complementary role in the localization of thermal water upwelling from depth in the graben. The upper Elila River basin in the Kamituga-Mwenga graben has numerous thermal springs, the most outstanding being Lubuka that discharges boiling thermal water. The lower middle course of the Luama River flows along a narrowly meandering course along what appears to be a southern extension of a fault from that graben. The numerous thermal springs occurring along this section of the river's course, and along other rivers and streams that flow down-slope from the graben, appear to be outflow structures from the zone of boiling spring activity in the north.

The possible deep origins the thermal waters may be considered here in the context of two unique thermal springs that occur in the adjacent Western Rift. The Pemba and Cap Banza thermal springs of S. Kivu, DRC, have been reported to discharge brines of "magmatic origin" (Tiercellain et al, 1993). The juvenile first parent geothermal fluids that support the region's thermal spring may be may be similar to these. The two springs are situated on the S. Kivu side of the N-S oriented graben that is occupied by the Rusizi River and northern L. Tanganyika basins. They respectively occur on the western border fault and at the tip of an adjacent narrow horst that projects northward into the lake. The faults are inherited from Late Mesoproterozoic age N-S directed transpressional shear faults that have been widely activated during the Neogene – Quaternary rifting stage. The fault system intervenes between the TRM and Albertine rift arms as a rift propagation transfer zone from the Kivu-Kamituga rift structure that lies to the west. The NW-SE trending Rusizian faults are known to cross these Kibaran-coeval faults. It may thus be speculated that the system of crossing deep-reaching faults may involve in the transport of Pemba-type fluids from the lower lithosphere to the upper crust and surface. Such fluids may be considered as the progenitors of the parent waters of the thermal springs of the Luama Rift.

The above may be possible under the crust-mantle interaction conditions that prevail in the deep subsurface. The Seismogenic layer in this region is widely accepted to be ~30 km thick. The underlying Sub Lithospheric mantle (SLM) has been coherently shown by petrologic data (Furman, 1999) and gravity and seismic modelling (Simiyu and Keller ,1997) to be significantly delaminated, to ~65 km depth. This is believed to have been caused by the westward refraction of the upward directed upwelling of an arm of the East African mantle plume that is modelled as spreading from beneath the Tanzanian craton (e.g. Weeraratne et al,2003). The mantle plume arm that follows that path is believed to rise beneath the SLM layer beneath the rift at about 5^{O}S latitude (e.g. Nyblade 1996) and to erode it. Such a plume structure would also account for the exceptionally high elevations that the region flanking the Western Rift in these parts attains, including for the prevalence of a negative gravity anomaly that encloses the region (Fair head, 1979). It appears that volatile charged highly buoyant juvenile fluids may rise to upper crustal depths of the region.

3.3.2 The Zambian Karoo Rifts

The structural development of the major Karoo basins of Zambia, Luangwa-Luann and Zambezi rifts are, similarly to the Luama Rift in DRC, attributed to the reactivation of pre-existing shear zones, the Mwembeshi and Sanangoe shear zones. In contrast to the Luama rift, these two rifts have complete sequences of the Karoo sediments that are also similar and reflect the general stratigraphy in the region. The Karoo System of the Zambesi basin, the type area for Zambia, has a total thickness of 4.5 kms (Imasiku and Nkemba, 2004). All four principal rock units occur there. The basal Siankondobo sandstone (equivalent to the Dwyka Group of the CKB) belongs to the Lower Karoo Supergroup, is Late Carboniferous to Early Permian by age, glacial and fluvial by origin and records a period of glacial advance and retreat. It contains the characteristic Coal Formation, Early Permian. The overlying Late Permian Madumabisha lacustrine mud unit (Ecca Group) is the lower sequence in the Upper Karoo Supergroup. The uppermost sedimentary unit is the Escarpment Grit and the interbedded sandstones and mudstones. It is of Triassic age and equated to the Beaufort Group. The succession is topped by the CFB lavas of the Stormberg Formation. The northern part of Luangwa Rift exhibits an equivalent sedimentary succession (Kribek and Kukial, 2004). The above three sedimentary units are divided into nine formations or members. Red beds are recognized in the Upper Madumabisha and Ntawere (lower Grit) formations. The Karoo sediments of the Zambezi were deposited on a surface made up of the probably Ordovician-Silurian age sediments of the Sinacumbe Group e: Sikalamba Conglomerate Formation and the overlying Zongwe fluvial sandstone Formation. This may indicate that Zambezi rifting was preceded by sag basin formation of the Barotse, of which it would have been a part.

The Luangwa-Luano rift system was opened along the Mwembeshi Shear Zone. The structure was initially created by the activation of the structural boundary that separated the Mesoproterozoic Irumide and Tete-Chipata belts. Shearing had been due to the oblique impact of the already unified South Gondwana continental block (Kalahari and Antarctica continents) on East Gondwana during the Panafrican orogeny. This structure crosses Zambia from the southwest to the northeast passing along the southeastern margin of the Hook Granite and the southeastern zones of the Luano and Luangwa basins to cross into Malawi at about 12^{O}S latitude. It provided the zone of crustal weakness that facilitated the development of the Luano and Luangwa half-grabens between the above two belts during the Carboniferous-Tertiary Karoo rifting stage. It traverses various sites of thermal spring activity and may influence their localization. In the Malawi part of this structure, the Chiweta and Chiwe thermal springs, the highest temperature features in the country, are located where this structure crosses the western shore of L. Malawi, probably accounting for their occurring there. Heat flow values of 109-121 mWm^{-2} (IHFC database) are from the part of the lake that is crossed by this structure directly offshore the thermal springs.

Luangwa and Luano are two separate rifts that opened in right-stepping en-echelon dispositions. Luangwa is the larger of the two and extends from close to the border with Tanzania in the NNE to the bend to the east of the Luangwa River in the DSE.

Luano graben is much smaller and lies to the southwest of Luangwa. It forms a narrow and arcuate valley that is concave to the NNW. The two rifts may have similar histories of development but also contrast in thermal spring activity and temperatures

Of the high temperature springs of Zambia, Chongo and Musaope occur in the Luangwa rift together with other groups or individual springs that issue at lower temperatures. Chongo is the second hottest spring in Zambia next to Bwanda in the Lochinvar group, and produces the largest flow in the Luangwa Rift. Chongo and Musaope discharge close to the shear zone, and may owe their higher temperatures to their proximal locations to it.

Spring temperatures are lower in the Luano rift. The hottest are three 60^{O}C thermal springs that occur in a zone where Karoo sediments are separated from Irumide metamorphics by a northern rift border fault. A number of others discharge thermal waters at lower temperatures.

Other, smaller Karoo basins occur along what appears to be a southwestern zone of influence of the rift faulting in the Luano graben area. Isolated exposures of Karoo deposits occur in this zone. There are numerous thermal springs, a number of them issuing high temperature waters. They often discharge in faulted areas where Karoo deposits lie adjacent to Precambrian metamorphic or plutonic rocks, or may underlie the alluvial cover.

Chinynyu is an example of the above as it occurs in a fault-structured area in the contact zone of probable Irumide basement and Karoo rocks. The numerous Lochinvar springs occur in a Karoo sediment-filled down-faulted basin bordering on up-thrown probably Neoproterozoic basement. One of the group, Bwanda issues at 94^{O}C, near the boiling temperature of water for the elevation, and the highest reported temperature in Zambia. Longola thermal spring occurs about 120 kms to the WNW, on the southern margin of the Neoproterozoic Hook Granite where it may be bordered by the Mwembeshi structure. The land surface lying to the south appears to be alluvial, possibly underlain by Karoo rocks. These springs appear to all belong to the Karoo basin geothermal regime, with relatively high temperatures coupled with the expectation of favorably high permeability being encountered in the subsurface. They also lie in the zone where the two shear zones come closest to each other

Lubingu spring, situated about 100 km to the NNE of Longola, occurs about 20 kms to the east, on the margin of a body of granite, probably of the same generation as the Hook Granite, with a tract of Karoo rocks extending westward. Lupiamanzi is located on the east side of the granite body on an alluvial margin. Other, lower temperature springs also occur in the area. One of these Chibemba is reported to occur in an area of past siliceous sinter deposition, indicative of high subsurface temperature condition of the past. There is a dam in the area, which may have partially quenched the subsurface by water percolating from the impounded lake or by razing the cold water table. The Mesoproterozoic Choma-Kolomo granite pluton is bordered by a thrust fault on its northern side, a probable Panafrican structure. Three thermal springs occur in an area of crossing faults on an alluvial surface outside this northern margin. It is uncertain whether the thermal springs owe their relatively high temperatures to radioactive heating during circulation in the granites, although the temperatures may be a bit too high for that to be the case. Notably, among those springs where it was detected, radioactivity was found to be high at the Lubingu spring.

The Zambezi Rift sedimentary basin is not considered here as the areas of past thermal spring activity reported in Waring's compilation of 1966, do not deem to be listed in the 1974 reconnaissance survey report, probably because they might have been inundated by L. Kariba by that time.

3.3.3 High Temperature Springs from Outside the Karoo Basins

In DRC, Katanga Province is well-endowed with thermal springs. Three rifts-in-the-making are situated in the region lying to the Southwest of Lake Tanganyika. From the northwest to the southeast, they are Upemba Rift in E. DRC, Bangweulu Rift in N. Zambia and Moero Rift lying astride the boundary between the two countries. They are amagmatic and only Moero is a full graben with border faults on its two sides. Their opening seems to have been initiated by normal faulting with SE down-throw orthogonally to the TRM during the Late Miocene (Dulveaux et al, 2012). Yet they are not structurally effectively integrated with the Western Rift. They are all situated along or close to the fault contacts between the younger Panafrican belt of the Kundelungu Trough and the older Kibaran and Bangweulu metamorphic terranes respectively in the West and East.

Upemba Rift is a half graben with its single NNE-SSW trending border fault limiting it in the southeast. The half graben's disposition is dictated by the NNE-SSW orientation of the characteristic NNE-SSW tectonic fabric of the Kibaran, a Mesoproterozoic orogenic belt made up of metasediments, metavolcanics, and granites. Moero is situated on the southeastern margin of the Kundelungu Trough, a low lying region occupied by flat-lying Neoproterozoic (Panafrican) sediments of the early depositional phase that has escaped deformation by the Panafrican orogeny. Moero is a full-fledged graben bound in its west by a NNE-SSW trending border fault in Panafrican terrane and in the east by a parallel border fault that separates it from the Bangweulu Block. Bangweulu Rift is situated on the eastern margin of Bangweulu Block, in flat lying Panafrican terrane covered by Quaternary continental sediments. No thermal springs are reported to occur in these two rifts.

The lakes in the grabens are hydrologic discharge areas for large tracts of Proterozoic basement. However, only Upemba Rift hosts four high temperature thermal springs. Kiabukwa and Kafungwe discharge onto a surface of lacustrine sediments at the base of the SE border fault while Kayumba spring issues at the bottom of the NW flexure zone. Basimakule spring occurs independently outside and to the NE of the graben at the base of a major fault that separates the Kibaran belt from the Kundelungu Panafrican belt in the Northeast. It appears that all springs discharge thermal waters from subsurface sources that are hosted in Kibaran belt rocks. Numerous lower temperature springs occur in the region to the south southwest and east of Upemba

Records show that the first geothermal power plant in Africa, 200 KW capacity, was established close to Kiabukwa spring. No detailed information is available except that shallow production wells were drilled. The plant had not been operating since some unknown time in the past. Le bail et al (1969) report that it had been operational but with an unfavorable result. It is uncertain whether the problem was related to the resource or to the technologies that were applied to its development and utilization.

The region of these three rifts is under crust extension in the NW-SE direction (Fairhead, 1979). The post-Rodinian sediments of Kundelungu Trough that remained un-deformed by Panafrican orogeny are of potentially higher degree of the propensity-to-rift under these conditions. Rifting in this region seems to be hindered by the presence of a rheological barrier to southwestward rift propagation across the Lufillian Arc. The subsurface of the Lufillian Arc and of the zone extending to the Bangweulu Block to the northeast and the entire Kundelungu Trough is believed to be underlain by a still un-exhumed thick and rigid Archean cratonic block, recognized by the dating of detrital and xenocrystic zircons from Likasi, Katanga. This craton would resist rifting in the same manner that the southward propagation of the Eastern rift across the northeastern margin of the Tanzanian craton aborted. The insulating effect of such a thick cratonic subsurface from mantle-sourced heating of the upper crust may be the cause for the paucity of thermal spring activity in some areas of the region.

Of the high temperature thermal springs of Zambia that occur outside the Karoo sedimentary basins, the principal one is Kapisya. It occurs on the northeastern margin of the Bangweulu Block. The margin in this area comprises the border faults of the southeastern basin of the half-graben that is occupied by the southeastern L. Tanganyika basin. Kapysia occurs on a surface made up of lake sediments with the un-deformed Post-Rodinian/ early Proterozoic supracrustal sediments, the Plateau Series, exposed on the border fault that lies to the southwest. It has been pointed out earlier that this margin of the Bangweulu Block has been affected by shear faulting along the Miose Shear Belt during a number of occasions since 1.7 Ga. The tectonic behavior of this shear belt during the Phanerozoic has been studied in its Ufipa Plateau part and show to have been active in various modes of deformation but it has been, since the Late Miocene, involved in the NE-SW directed extension that evolved the shear zone into a regular, normal fault bound rift zone - the TRM. The tectonic zone is therefor still active. The high temperature at which Kapysia spring is discharging is likely to be related to its proximity to this long-lived and still active tectonic zone, rather than to the mining of heat in the shallow crust, which is likely to be rather cold. How close kapysia is to this structural regime is however unknown in detail.

Luano thermal spring, issuing inside the arcuate southern margin of the Lufillian fold belt appears to be the only high temperature feature of the Zambian and DRC Panafrican belt and may owe its genesis to the compressive tectonic regime of the Lufillian Arc. there.

4. CONCLUSIONS

The exercise at relating the areas of thermal spring activity in the E. DRC-Zambia region to its geologic makeup and structural fabric encourages the proposition that geothermal provinces that are associated with major long-lived and periodically activated structural features are discernible. These structures have later developed into rift structures or influenced their development. The region has remained amagmatic since Mesozoic times. These ancient structures, repeatedly subjected to later activations in various modes of deformation are thus believed to serve as pathways for passage to the upper crust of the heat of the anomalously tumescent mantle that underlies the region. That heat is relayed to the surface by deep circulating meteoric waters to emerge at the surface at the thermal springs. These major structures were also instrumental in the location and disposition of Karoo sedimentary basins that host anomalous thermal spring activities. Arenaceous horizons in the sedimentary piles, and where still preserved, the overlying flood basalts, may provide adequate permeability for the circulation and storage of the thermal fluids. Where the Karoo might have been thinned by erosion, the underlying basement rocks may provide permeability where they are faulted and fractured. This situation would however be also the case I areas of thermal spring activity situated in the Kibaran belt of Katanga or in the region of Kapisya in NW Zambia. By virtue of the concentration of high temperature springs, its geologic-structural makeup and its position within the realm of the indicated crust-mantle interaction, the Luangwa Rift in DRC ranks ahead of other prospect areas as a geothermal prospect area. The detailed situation in Zambia is not sufficiently known to allow the reliable ranking of the areas of thermal spring activity as prospect areas. In all cases, however, follow-up for adding to the exiting knowledge is warranted.

It is recommended that preliminary surveys of the most attractive target areas be made for clarifying the geologic-structural frameworks of the high temperature thermal spring areas. General geochemical sampling and analyses are best carried out concurrently. The results from these surveys should determine any detailed surveys that may be needed to be completed for determining the most favorable areas that should be targeted by geophysical surveys for determining exploratory drilling sites.

REFERENCES

Delvaux, D.; Kervyn, F.; Macheyeki, A. S. and Temu, E. B. (2012) Geodynamic Significance of the TRM Segment in the East African Rift (W-Tanzania): Active Tectonics and Paleostress in the Ufipa Plateau and Rukwa Basin, Journal of Structural Geology (37) 161-180

Delvaux, D. and Kervyn, F. (2004) Active Tectonics of the Tanganyika–Rukwa–Malawi Rift in Western Tanzania: A Review, International Conference on the East African Rift System (extended abstract), Addis Abeba, Ethiopia, pp 53-54

Fauld, J. E. and Varga, R. J. (1998) The Role of Accommodation Zones and transfer zones in the regional segmentation of extended terranes, Geological Society of America Special Paper 323.

IASPEI-IHFC Heat Flow Database, accessed 14/12/2009

Imasiku, A. N. and Nkemba, S. (2004) Permo-Carboniferous to Early Jurassic Karoo Rifts in Zambia: Lessons for the East African Rift Valley, *Proceedings, 20th Colloquium on African Geology* – CAG-20 (abstract volume), June 2-7, 2004, Orleans, France.

Kribek, B. and Kukial, Z. (2004) Sedimentology of the Karoo Supergroup: the Upper Luangwa River Valley, Zambia, *Proceedings, 20th Colloquium on African Geology* – CAG-20 (abstract volume), June 2-7, 2004, Orleans, France.

Linol, B; de Wit, Maarten; Guillocheau, F.; Dauteuil, O.; Robins, C. and Barton, E. (2013) New Stratigraphic Analysis of the Intracratonic Congo of Central Africa Reveals a Multiphase Phanerozoic Subsidence and Uplift History, *Proceedings, 24th Colloquium on African Geology*-CAG-24 (abstract volume), January 8-14, 2013, Addis Abeba, Ethiopia

Craig, T. J.; Jackson, J. A.; Priestley, K. and McKenzie, D. (2011) Earthquake distribution patterns in Africa: their relationship to variations in lithospheric and geological structure, and their rheological implications, Geophysical Journal International (185, 1) 403-434.

Furman, T. and Graham, D. (1999) Erosion of lithospheric mantle beneath the East African Rift system: geochemical evidence from the Kivu volcanic province, Developments in Geotectonics, Lithos (48) 237-262

IASPEI-IHFC heat flow database, accessed 14/12/2009

Lenoir et al. (1994), On strike slip faulting in the Ubendian Belt, Journal of African Earth Sciences (6, 6), 869-880.

Nyblade, A.A.; Owens,T. J.; Gurrola, H.; Ritsema, J. and Charles A. Langston (2000) Seismic evidence for a deep upper mantle thermal anomaly beneath east Africa, Geology, July 2000

Passau, M. G. (1933) Les Sources thermales de la Province Orientale (Congo belge), Bulletin des Seances, 4-1933-3, Institute Royal Colonial Belge, Bruxelles.

Rainaud, C., Master, S., Armastronh, R. A. and Robb, L. J. (2003) A cryptic Mesoarchean terrane in the basement to the Central Africa Copperbelt, Journal of the Geological Society, 160, 11-14

Simiyu, S. M.; Keller, G. R. (1997) An integrated analysis of lithospheric structure across the East African plateau based on gravity anomalies and recent seismic studies, Tectonophysics (278, 1-4) 291-313.

Tiercelin, J-J.; Pflumio, C.; C., Maryse; Boulégue, J.; Gente, P.; Rolet, J.; Coussement, C.; Stetter, K. O.; Huber, R.; Buku, S. and Mifundu, W. (1993) Hydrothermal vents in Lake Tanganyika, East African, Rift system, *Geology*; June 1993; v. 21; no. 6; p. 499-502; DOI: 10.1130/0091-7613(1993)021<0499:HVILTE>2.3.CO;2

UNESCO-CGMW (1985) International Geologic Map of Africa, 1 :5,000,000 scale.

Weeraratne, D. S., D. W. Forsyth, K. M. Fischer, and A. A. Nyblade (2003), Evidence for an upper mantle plume beneath the Tanzanian craton from Rayleigh wave tomography, Journal of Geophysical Research., (108) 2427, doi:10.1029/2002JB002273, B9.

Appendix: List of the higher temperature thermal springs in East DRC and Zambia, Number as in Figures 1 snd 2

Thermal Spring Numbers					**Thermal Spring Name**	**Temperature ^{o}C**	**Approximate Locations**	
This Work	**Passau 1933**	**Le Bail et al 1969**		**Legg 1974**			**Lat**	**Long**
	East DRC		**Katanga**	**Zambia**			**S**	**E**
1	16	10			Mwalo	c 100	4.30	28.14
2	18	11			Kituka	c 100	4.08	27.90
3	22	12			Basimakule	84	4.08	28.27
4	27	15			Lukuka	85	3.30	26.91
5	29	17			Musongwelwa	85	3.90	27.19
6	31	18			Kagele	95	3.90	27.74
7	32	19			Tenge Tenge	95	3.55	27.39
8	56	28			Lubuka, (a.k.a Mubitabo?)	95	3.24	28.89
9					Cap Banza	96	3.97	29.27
10					Pemba	103	3.95	29.09
11			23		Kiabukwa	91	7.80	27.24
12			36		Konkula	very hot	8.11	26.68
13			37		Kayumba	83	8.53	26.71
14			43		Pundu	very hot	8.10	27.15
15			44		Kafinga	100	8.16	27.35
16			49		Kafungwe	84	9.35	25.93
17				1	Kapisya	**85**	8.42	30.51
18				30	Chongo	87	12.47	32.00
19				40	Musaope	75	12.93	32.10
20				73	Chinyunyu	73	15.20	29.13
21				84	Luano	80	12.85	27.37
22				90	Lupiamanzi	**79**	14.54	26.72
23				91	Lubingu (A to G)	**76**	14.45	26.51
24				97	Longola	70	15.74	26.08
25				?103-110	Lochinvar: Bwanda	94	16.08	26.20
26				123	Choma: Muckleneuk Main	74	16.34	26.07
27					Kasho	72	Unknown	

Sources: As shown above in the Numbers column heading. Kasho thermal spring cited in Musonda and Sikazwe, 2005. Approximate coordinates were measured on small scale maps.

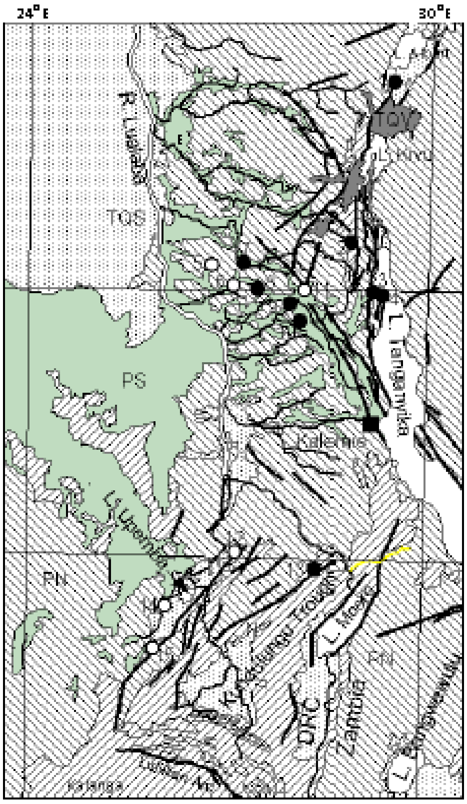

Figure 1. Geologic Outline and High Temperature Thermal Springs of Kivu, Maniema and Katanga Provinces, DRC.

Key

Geology (based on CGMW, 1985)

- TQV Tertiary & Quaternary volcanics
- TQS Tertiary and Quaternary sediments
- PS Paleozoic sediments & minor volcanics (Karoo).
- N Neoproterozoic (Panafrican)
- PN Pre-Neoproterozoic

Thick black lines: Faults

Thin black lines: Rivers

L: R. Luama

E: R. Elila

Thermal Springs and reported temperatures: (From Passau, 1933, and Le Bail et al, 1969).

1. Bitangoha (Boiling)
2. Lubula (Boiling)
3. Pemba (Boiling)
4. Cap Banza (Boiling)
5. Lukuka (85)
6. Musongwelwa (85)
7. Tenge Tenge (Boiling)
8. Kagele (Boiling)
9. Kituka (Boiling)
10. Mwalo (Boiling)
11. Basimakule (84)
12. Kiabukwa (31)
13. Kafinga (Boiling)
14. Kayumba (83)
15. Kafungwe (34)

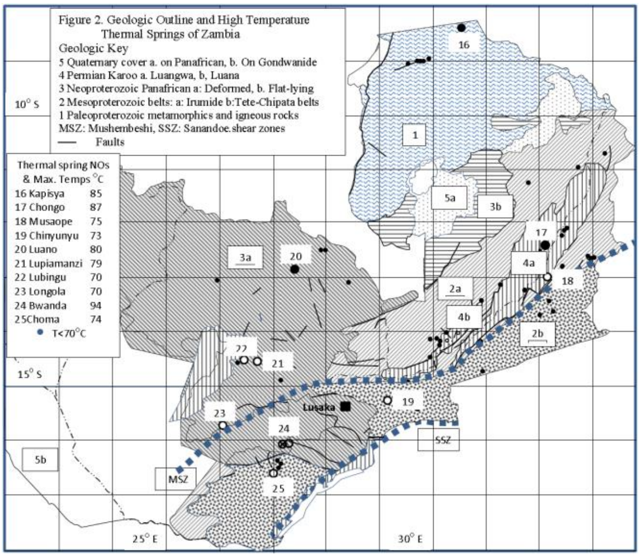

Figure 2. Geologic Outline and High Temperature Thermal Springs of Zambia