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Review of Geological Studies in the Geothermal Prospect of Bugarama

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ABSTRACT

Geological studies are important for geothermal exploration. Since other surface exploration techniques, such as geophysical and geochemical techniques, require the understanding of geology; geological studies should be the starting point for the geothermal exploration. Different geoscientific studies by Reykjavik Geothermal (2014) and Japan International Cooperation Agency (2016) have been carried out in the Bugarama geothermal prospect which is located in the Rusizi district, SW of Rwanda. These studies have also included geological studies. However, there are gaps in geological studies of the Bugarama geothermal prospect that need to be addressed. Here it is shown that the methodology for geological studies needs to be improved, the deformational history of the Bugarama geothermal prospect requires to be fully addressed, and detailed hydrogeological investigation is necessary.

The improvement in the methodology will ensure that detailed geological mapping of the Bugarama geothermal prospect is achieved. Also, addressing the deformational history fully will contribute to the understanding of the 3D-geology of the Bugarama geothermal prospect which is not well tackled at the moment. In addition, detailed hydrogeological investigations will support other geothermal exploration techniques particularly heat survey. The results of this paper are not restricted to the Bugarama geothermal prospect and can contribute to geological studies in other geothermal prospects of Rwanda.

1. Introduction

Geological studies are essential in any geoscientific exploration task. Lisle *et al.* (2011) mentioned that the basic geology still comes first and if it is wrong, everything that follows will probably be wrong. Wallace (1975) also stated that there is no substitute for the geological map and cross-section(s), absolutely none. This implies that other geothermal surface exploration methods such as geophysical and geochemical methods incorporate geology in their interpretations. If the geological part is overlooked or weakly investigated, geochemical and geophysical interpretations might be very weak. This account draws attention to the identification of geological gaps in the Bugarama geothermal prospect (Figure. 1). Geological gaps are identified based on reviewing various reports on the prospect including JICA (2016), Gestur (2016), Gestur *et al.* (2014), Tadesse *et al.* (2016), and other scientific literatures like journal articles and books. Also, this study incorporates outcomes of a 5 days reconnaissance survey to the Bugarama geothermal prospect. This account consists of the following sections: overview of geological units in the Bugarama geothermal prospect, methodology for geological studies, structural geology study, hydrogeological study, and conclusions.

2. Overview of Geological Units in the Bugarama Geothermal Prospect

Mainly four geological units such as Precambrian metasediments, limestone rocks, Mio-Pliocene volcanic rocks and Quaternary sediments are observed in the Bugarama geothermal prospect. Metasediments are sometimes intruded by granitoids. Also, plant fossils (e.g. tree leaves) and bones of undifferentiated animals are very common in limestone rocks (Figure. 2). Gestur *et al.* (2014, unpublished) suggested that the limestone formation in the prospect is the product of the geothermal activity. In addition, pillow lavas are commonly observed in Mio-Pliocene volcanic rocks. Jerram and Petford (2011) pointed out that pillow lavas are basalts that erupted below water. At some localities, a secondary yellow mineral with conchoidal fracturing is very common (Figure. 3). The yellow mineral is interpreted as chert. Tucker (2009) mentioned that the mineral chert can originate from the submarine volcanism due to direct inorganic precipitation of silica. Basaltic lavas in the Bugarama geothermal prospect formed as the result of fissure eruption. Gestur *et al.* (2014, unpublished) mentioned that NE-SW trending normal faults, dipping towards East, in the Burundian basement facilitated the outpouring of basaltic lavas. Basaltic lavas are affected by N-S striking normal faults that are inherited from Late Burundian shear faults. These shear faults have been reactivated in dip-slip deformation during the EARS tectonic stage.

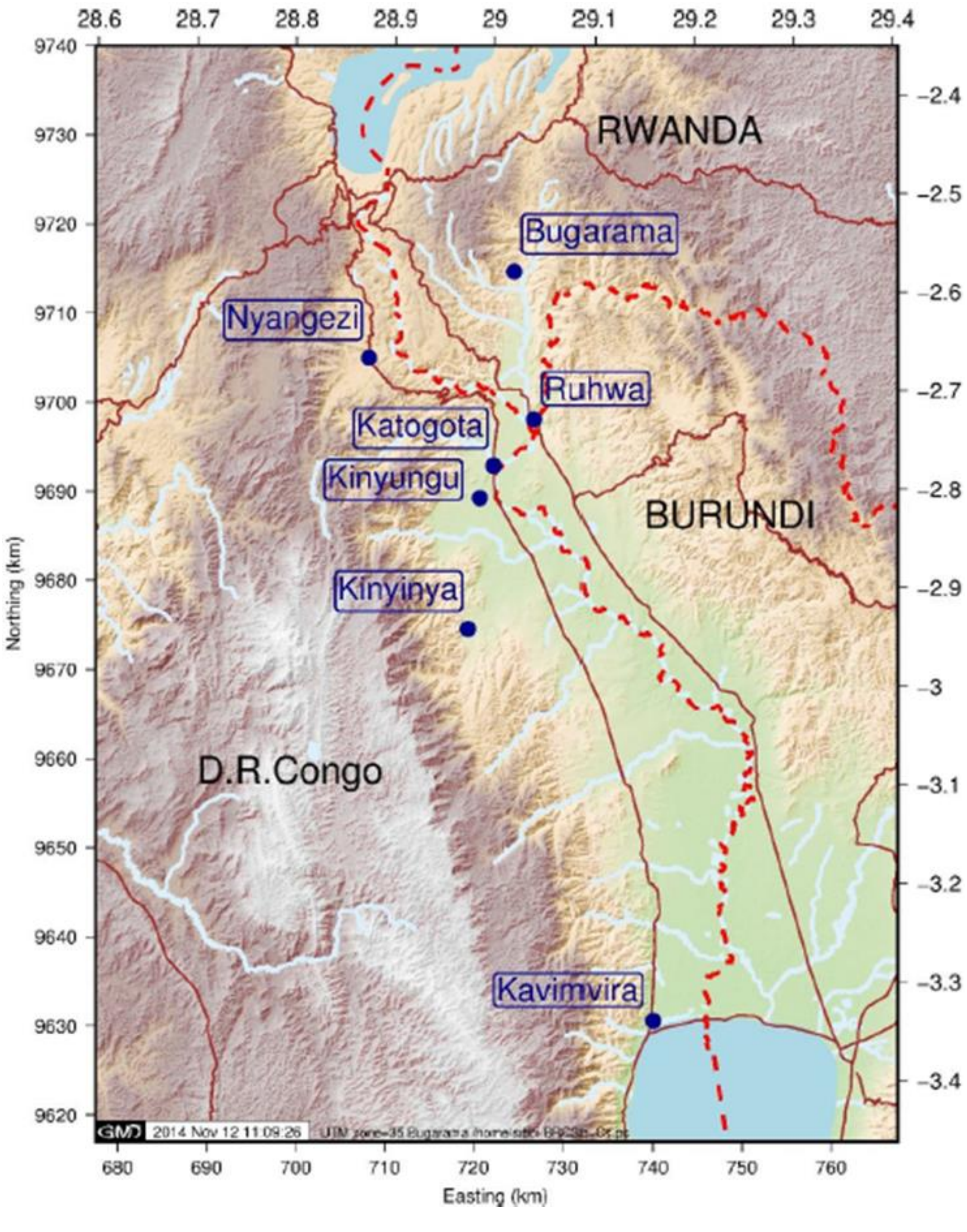

Figure 1. Illustration of Rusizi graben between lake Kivu in the North and Lake Tanganyika in the South. Taken from Gestur *et al.* 2014 (unpublished).

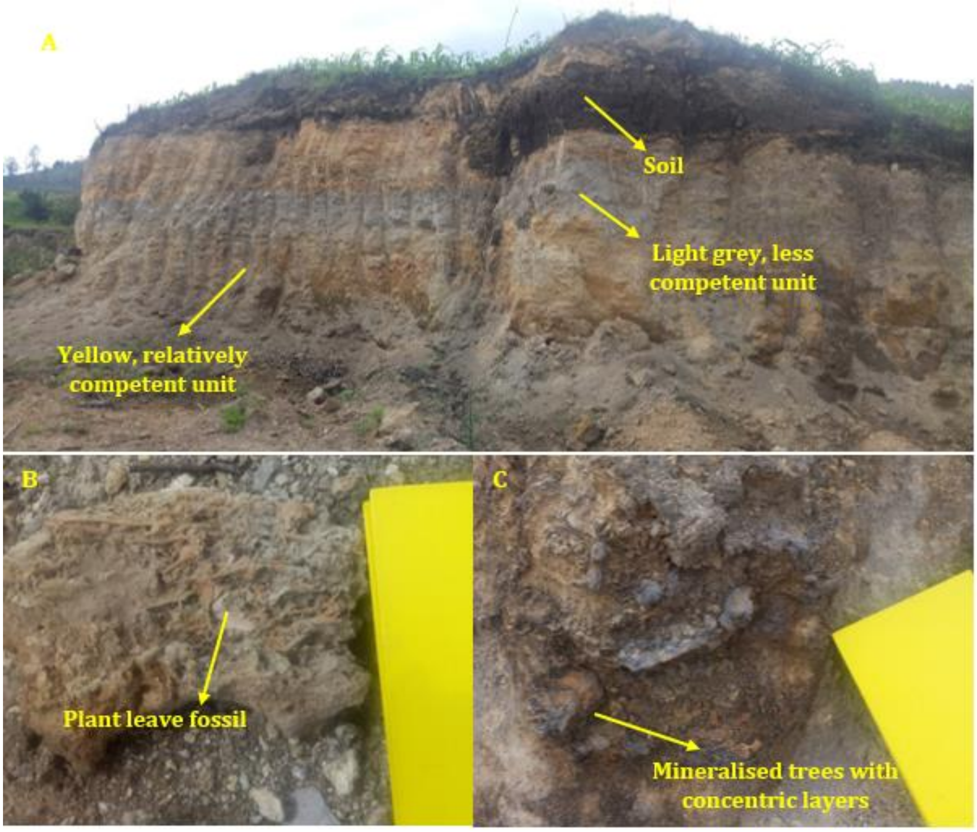

Figure 2. (A) Layered outcrop of carbonate rocks in the Cimerwa quarry at [07246 97146]. (B) and (C) Plant fossils are very common in carbonate rocks, sometimes with tree leaves. At some localities (e.g.: [07250 97135]), bones of undifferentiated animal are found in carbonate rocks.

Figure 3. (A) Basaltic lavas in a road cut outcrop at [07263 96975] near the border with Burundi. Pillow lavas, the characteristic of subaqueous volcanism, are very common in this outcrop. (B) A close view picture of pillow lavas with vesicles. (C) The outcrop of basaltic lavas in the Cimerwa quarry at [07259 97003] with layering. Note that the bottom layer has a yellowish appearance. The top layer has m-scale blocks of lavas without the yellowish appearance. (D) A close view of the yellow mineral in C; it has the conchoidal fracturing and it is a secondary mineral. It is interpreted as the mineral chert.

3. Methodology for Geological Studies

The availability of the existing geoscientific data varies across geographical boundaries. Whereas some areas are intensively studied, others are not. When undertaking a geological study, the level of the existing data is very critical. The low level of the existing data in the area strongly affects the quality of the study to be undertaken. In the effort of maximizing the quality of any geological study, all the existing data available, for a study area under consideration, should be covered. A thoroughly prepared desktop study tends to result in a well investigated geological study.

The objective of the scientific study includes to make the contribution to the existing knowledge. When the familiarity with the existing data on the study area is achieved, the fieldwork for the geological mapping is intended to collect enough raw data to either support or contradict the current consensus. Chamberlin (1897) argued for developing multiple hypotheses in the early stages of a study. Frodeman (1995) mentioned that the hypothesis testing is one of the tools that geologists use to understand past events. For every mature field geologist, a fieldwork day is always prepared beforehand. The aim and expected challenges are clarified in the preparation. Interestingly, field geologists with a solid experience are always interested in tracking how ideas were developed when they are assessing a geological project. For example, experienced field geologists will not comment much on the quality of the geological mapping project when they cannot access the field notebook(s) and field slips.

The methodology section focuses on four sub-sections. Initially, it considers the desktop study sub-section. Then, the fieldwork sub-section is addressed. Next, digitising the final map and cross-sections sub-section is stressed. Finally, a report writing sub-section is emphasised.

3.1. Desktop Study

Planning of the geological study is very necessary. This planning includes a review of the existing literature. The report for the desktop study of the geological project, particularly geological mapping, should consider the illustrated account of the geology of the area, work plan and key scientific targets, logistics and, hazards and risk assessment. The account of geology aims at increasing the familiarity with the stratigraphy and structure of the area. Then, the work plan and key scientific targets part of the report emphasises on the preliminary plan of actions and key areas that may require more attention. Next, the logistics part focuses on the transport to/around the area, accommodation, topography and financial aspects. Finally, the hazards and risk assessment part draws attention on how to manage health and safety during the fieldwork.

3.2. Fieldwork

Fieldwork is a very important component of the geoscientific project. Mogk and Goodwin (2012) indicated that learning in the field results in cognitive and metacognitive gains. The same applies for geological studies. Field maps and notebooks are valuable documents that constitute the part of the record of the field evidence on which the interpretation of geology depends. Both are the property of employers and will be retained by employers as the part of their permanent records. There are many obvious reasons for this. For example, if the former employers wish to reinvestigate the studied area, then it will be necessary to refer to original records.

3.3. Digitising the Final Map and Cross-sections

When geological mapping has been completed a fair-copy map, interpreted from field slips, notebook notes, follow-up laboratory work on rock and fossil specimens, and library research, must be compiled. This fair-copy may be a hand-drawn ‘manuscript’ map, or it may be aided and drawn by a computer program. The advantage of a computer-drafted map is that it can be easily modified and redrawn to accommodate new data. Computer drawing packages such as Inkscape, Adobe illustrator, CorelDraw, and AutoCAD allow field slips to be converted into professional-looking fair-copy maps.

However, geological mapping involves more than just producing a colourful map to show the distribution of formations within a given area. Lisle *et al.* (2011) pointed out that no geological map can be considered complete until at least one geological cross-section has been drawn to illustrate the geology at depth. The trained geologist can produce an interpretation of not only the surface rocks but also of their sub-surface structure. This skill of being able to extrapolate to depth is clearly of immense value in the exploration and exploitation of geothermal resources, mineral resources, engineering projects, hydrogeology and environmental geology. Geological cross-sections illustrate the structure of a region far more clearly than a planimetric map. Nevertheless, the geological mapping in the geothermal prospect of Bugarama seems to overlook geological cross-sections.

3.4. Report Writing

Lisle *et al.* (2011) mentioned that a geological map is not, as is sometimes supposed, an end in itself. The whole objective is to explain the geology of the area and the map is only a part of that process. A geological report is also needed to explain the geological phenomena found in the area and the sequence of geological events. In fact, professional geologists probably spend more time preparing the geological report than they do in the field. However, existing geological reports for the Bugarama geothermal prospect are not well structured.

The geology part of existing surface study reports for the Bugarama geothermal prospect emphasises mostly on the regional geology; there are no chapters on the stratigraphy, structure, metamorphism, and igneous activity at the local scale. The stratigraphy chapter deals with a systematic description of mapped geological formations. The stratigraphy chapter is usually followed by the structure chapter describing the more specific structural details of the area mapped based on the field evidence. The metamorphism, in the mapped area, may deserve a section of its own; but logically, it may often be part of the structural section. Igneous activity covers both intrusive and extrusive activity. Whereas extrusive units are dealt with in the stratigraphic chapter, intrusive bodies are normally considered in a separate chapter.

The conclusion of the geological mapping report is usually concerned for a great part with the geological history of the mapping area. This is not the case for existing geological studies in the Bugarama geothermal prospect. Woodcock and Strachan (2012) pointed out that the characteristic of geology is its use of historical analysis which recognizes that Earth processes depend on their place in the geological time. In particular, geological processes may be strongly influenced by preceding events. For example, a new fault system may favorably follow an old weakness in the crust or the chemistry of the magma will be affected by the compositional history of the source mantle or crust. Thus, the geological history is important for a thorough understanding of the geology.

4. Structural Geology Study

The understanding of the 3D distribution of rock units with respect to their deformational history is very essential in any geological application such as geothermal, oil and gas, and mineral explorations. Every detailed geological study should consider the structural geology part with respect. Lisle (1996) indicated that to make deductions on the geology beneath the surface, the knowledge of the characteristic form of common geological structures such as faults and folds is very important. The structural geology in the Bugarama geothermal prospect has some gaps that need to be addressed. This section empasises on those gaps in the prospect.

Kearey *et al.* (2013) indicated that the continental rifting takes place in the extensional setting where the decompression melting is favourable. The asthenosphere is brought to higher levels due to crustal thinning caused by rifting, therefore the magma chamber is emplaced at the shallow depth. Also, igneous intrusions such as dykes form along extensional openings. This highlights the importance of extensional structures such as normal faults and fractures in the geothermal prospect. Extensional structures are expected to have high heat flow and fracturing enhances the permeability. The permeability is very necessary for the fluid flow. Barton *et al.* (1995) indicated that fractures and faults provide permeable pathways for fluids at a variety of scales, from great depth in the crust to flow through fractured aquifers, geothermal fields, and hydrocarbon reservoirs. However, other geological structures such as compressional structures are also important if the structural geology is concerned (Figure. 4). The primary aim for the investigation of the structural geology should be the understanding of the deformational history of the prospect.

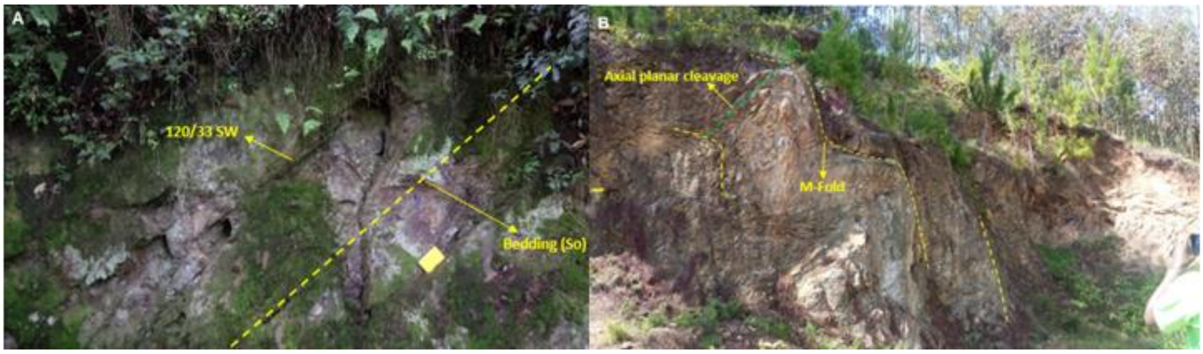

Figure 4. Illustration of some geological structures which are common in the geothermal prospect of Bugarama. (A) Tilted quartzite as the result of geological deformation in the cross-section view of a road cut outcrop at [07203 97170]. The facing direction for the picture is W. (B) Folded metasediments in a quarry at [07222 97167]. Parasitic folds in the outcrop (e.g.: M-fold) suggest that there are large scale folds in the study area. The facing direction for the picture is S. Note a yellow field notebook for the scale.

By taking an example from RG geological studies, the geological map of the geothermal prospect of Bugarama is somehow simplistic (Figure. 5). Apart from faults, there are no other geological structures shown on the map; for the studied area with Precambrian metasediments, the level of details should have been far beyond than what is shown on the map. Also, offsets of rock formations are not shown on the geological map as the result of faulting. In addition, a detailed stratigraphic division of geological units is very necessary. The geological map of 5Kmx5Km area should not be as if it was mapped at 1: 100 000 scale. Moreover, it seems like the geological map is only interested on the locating of geothermally active springs; it does not emphasize the importance of geology. For example, it should show the relationship of faults with springs. The map should as well indicate subsurface relationships of rocks. Furthermore, geological cross-sections are required to understand the 3D geology of the Bugarama geothermal prospect.

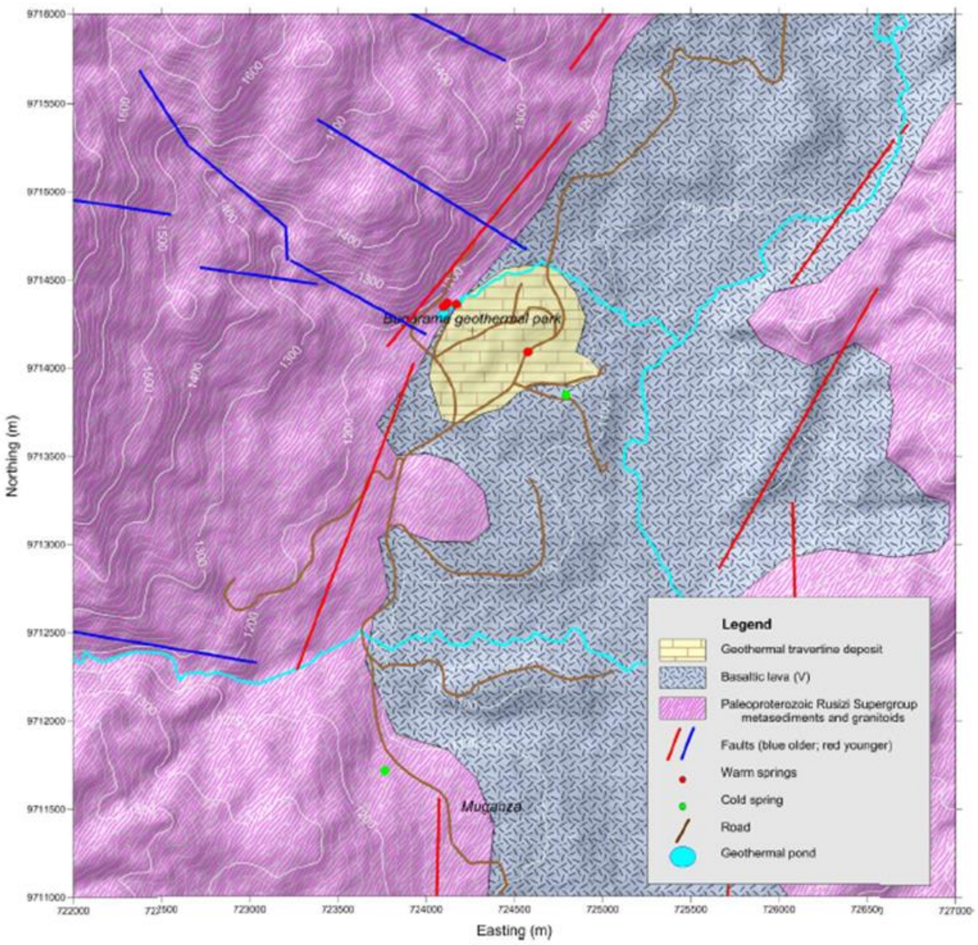

Figure 5. The geological map of the geothermal prospect of Bugarama (5Km x 5Km). Taken from Gestur *et al.* 2014 (unpublished).

5. Hydrogeological Study

A detailed hydrogeological investigation is necessary in the geothermal exploration. Serpen (2004) indicated that information on hydrogeology is essential to evaluate any type of water and/or geothermal resource. The hydrogeological study in the Bugarama geothermal prospect is still lacking. This section considers two key elements to be covered in the hydrogeological study of the Bugarama geothermal prospect. Also, a case study on the use of temperature gradient wells in the Bugarama geothermal prospect is stressed to highlight the importance of the hydrogeological investigation.

A hydrogeological map of the Bugarama geothermal prospect is important. The map should contain the groundwater level information and show aquifers, aquitards, aquicludes and likely recharge and discharge areas. The hydrogeological map should have hydrogeological cross-sections to fully represent the hydrogeology of the Bugarama geothermal prospect. Hiscock (2005) pointed out that the occurrence of groundwater and the extent and distribution of aquifers and aquitards in a region are determined by the lithology, stratigraphy and structure of the geological strata present. In the hydrogeological investigation, a clear understanding of the geology of the region is fundamental if the identification of aquifers and aquitards and mechanisms of groundwater flow are to be well understood. The groundwater-surface water interaction in the Bugarama geothermal prospect also needs to be explored. The interaction should consider stream conditions such as loosing and gaining streams and how stream conditions in the prospect are affected by rainfall events. The possible role of topography should be studied. For example, is there a general groundwater flow perhaps to topographic lows such as valleys? However, Price (1996) mentioned that the groundwater and surface water divides do not always coincide each other. The water table relief does not always follow the topography.

Tadesse *et al.* (2016) pointed out that temperature gradient wells were drilled in the Bugarama geothermal prospect. The key objective was to reach down into rocks that are not thermally disturbed by surface or groundwater to be able to assess the geothermal gradient from temperature measurements. However, the progress of thermal gradient drilling in the Bugarama geothermal prospect was much different from ideal conditions for thermal gradient survey. It is arguable that if the detailed hydrogeological study was done before temperature gradient survey, the wells to be drilled might have been located in an aquitard or another alternative, apart from the thermal gradient survey, would have been considered. Coolbaugh *et al.* (2007) also indicated that the 2 m depth temperature measurements can be used to optimise the efficiency and reduce the costs of geothermal exploration and provide a high probability of success by locating heat anomalies in an early stage of exploration, and mapping thermal aquifers in more detail than normally possible with temperature gradient drilling, so that temperature gradient wells can be more accurately sited in areas of potentially upwelling geothermal fluids. Physiographic conditions for the success of the shallow temperature measurements method include relatively deep-water tables and a low influx of precipitation-derived shallow groundwater. The understanding of hydrogeology of the geothermal prospect is a prerequisite for the heat survey.

6. Conclusions

The geology of the Bugarama geothermal prospect consists of Precambrian metasediments, limestone rocks, Mio-Pliocene basaltic lavas and Quaternary sediments. There is a need of making the improvement for the methodology of geological studies in the geothermal prospect of Bugarama. For example, the desktop study report for the existing geological study is not well structured and detailed. The desktop study report of a geological project, particularly geological mapping, should consider the illustrated account of geology, work plan and key scientific targets, logistics, and hazards and risk assessment. Field maps (or field slips) and notebooks are also not considered as the part of deliverables for geological studies; this should not be the case since field maps and notebooks are only components of the geological project where primary data are recorded. In addition, the geological mapping was carried out in the area but there is no digitised and detailed map with cross-sections available for the Bugarama geothermal prospect. Moreover, existing geological reports are not well structured. The geology part of existing surface study reports for the Bugarama geothermal prospect has no chapters on the stratigraphy, structure, metamorphism, and igneous activity at the local scale. The essential chapter for the deep understanding of the geology of the area, the geological history, is not addressed in existing reports of the Bugarama geothermal prospect.

The structural geology in the Bugarama geothermal prospect considers only extensional structures such as normal faults. Other geological structures including folds are not emphasised. This results in the incomplete deformational history of the area. The incomplete deformational history has a negative impact on the understanding of the 3D geology of the Bugarama geothermal prospect. The understanding of the 3D geology of the geothermal prospect contributes to conceptual modelling of the geothermal system.

There is a need of the hydrogeological map in the Bugarama geothermal prospect with water table information, aquifers, aquitards, aquicludes, and recharge and discharge areas. The clear understanding of the geology of the prospect is fundamental for the robustness of the hydrogeological map. The study of groundwater-surface water interaction is also necessary; it contributes to the full understanding of the hydrogeology of the prospect. The hydrogeological investigation in the geothermal prospect will contribute to other geothermal exploration surveys including heat survey.

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REFERENCES

Barton, C.A., Zoback, M.D. and Moos, D., 1995. Fluid flow along potentially active faults in crystalline rock. *Geology*, *23*(8), pp.683-686.

Chamberlin, T. C., 1897. The Method of Multiple Working Hypotheses. Journal of Geology v. 5, no. 8, p. 837-848.

Coolbaugh, M.F., Sladek, C., Faulds, J.E., Zehner, R.E. and Oppliger, G.L., 2007, January. Use of rapid temperature measurements at a 2-meter depth to augment deeper temperature gradient drilling. In *Thirty-second workshop on geothermal reservoir engineering*.

Frodeman, R., 1995. Geological reasoning: Geology as an interpretive and historical science. *Geological Society of America Bulletin*, *107*(8), pp.960-968.

Gestur, G., 2016. Conceptual model report: Regional Project for Geothermal Exploration in Rwanda, Burundi and DRC. Report No.: 13006-08

Gestur, G., Hjálmar, E., Snorri, G., Sigurbjörn, J., and Jón Ö. J., 2014. Surface Exploration Report: Regional Project for Geothermal Exploration in Rwanda, Burundi and DRC. Report No.: 13006

Hiscock, K.M., 2005. Hydrogeology: principles and practice. Blackwell: Oxford, 405pp.

Jerram, D. and Petford, N., 2011. The field description of igneous rocks (Vol. 40). John Wiley & Sons.

JICA, 2016. The project for preparation of electricity development plan for sustainable geothermal energy development in Rwanda.

Kearey, P., Klepeis, K.A. and Vine, F.J., 2013. Global tectonics. John Wiley & Sons.

Lisle, R.J., 1996. Geological structures and maps: a practical guide. Butterworth-Heinemann.

Lisle, R.J., Brabham, P. and Barnes, J.W., 2011. Basic geological mapping (Vol. 42). John Wiley & Sons.

Mogk, D.W. and Goodwin, C., 2012. Learning in the field: Synthesis of research on thinking and learning in the geosciences. Geological Society of America Special Papers, 486, pp.131-163.

Price, M., 1996. Introducing groundwater. Springer.

Serpen, U., 2004. Hydrogeological investigations on Balçova geothermal system in Turkey. *Geothermics*, *33*(3), pp.309-335.

Tadesse, M., Gestur, G., and Snorri, G., 2016. Temperature gradient drilling report: Regional project for geothermal exploration in Rwanda, Burundi and DRC. Report No.: 13006-07

Tucker, M.E. ed., 2009. *Sedimentary petrology: an introduction to the origin of sedimentary rocks*. John Wiley & Sons.

Wallace, S.R., 1975. The Henderson ore body – elements of discovery, reflections, *Mining Engineering*, **27** (6), 34–36.

Woodcock, N. and Strachan, R. 2012. *Geological History of Britain and Ireland*. John Wiley& Sons: Chichester, 442pp.