Tiako P.F. (ed) *Smart and Sustainable Applications*. Chronicle of Computing. OkIP

https://doi.org/10.55432/978-1-6692-0005-5_8

GEOTHERMAL POTENTIAL ASSESSMENT OF THE BARE-BAKEM REGION (CAMEROON VOLCANIC LINE): CONTRIBUTIONS FROM GEOPHYSICAL AND GEOTHERMOMETRIC STUDIES

A.M.G. MEGUEDONG*, D. BISSO, L. MBIDA,
Departement of Earth Sciences, University of Yaoundé 1, P.O.Box: 812 , Yaounde-Cameroon

ABSTRACT: In order to determine the geothermal potential of the municipality of Baré-Bakem, located in both the sedimentary basin of Moungo and the volcanic region of Nkongsamba (Cameroon Volcanic Line), geophysical measurements using electrical resistivity tomography were conducted along a 1km profile between two opposing thermal sources spaced 20 meters apart. The profile was acquired in the SW-NE direction using a 945m-long array with 64 electrodes spaced at 15 meters intervals. The ZZRes2Dinv44 software was employed to generate investigative images. The obtained results along the profile reveal the presence of two geothermal zones of interest trapped within permeable sedimentary formations at depths ranging from approximately 20 to 110 meters and close to the surface. From a geothermometric perspective, chemical geothermometers such as silica and Na-K-Ca were calculated by collecting water samples from these thermal sources and analyzing the physicochemical parameters at the Laboratory of Geochemical Analysis of Waters (LAGE/IRGM) in Nkolbisson. The calculations indicate that the Baré-Bakem locality exhibits temperatures ranging from 51 to 90°C for near-surface anomalies and temperatures ranging from 283 to 300°C for deeper anomalies. These geothermal resources possess high energy potential suitable for electricity production.

Keywords: geothermal, tomography, chemical geothermometers, geothermal energy.

I. INTRODUCTION

There are several renewable energy resources in Cameroon, including hydropower, wind energy, solar energy, biomass, and geothermal energy. However, geothermal energy is the only one that has not yet experienced significant development. Geothermal energy is an abundant and nearly inexhaustible thermal energy derived from the Earth's interior, typically in the form of hot water or steam (Andrianaiko, 2011). In Cameroon, research conducted by ORSTOM in 1971 revealed a geothermal potential associated with the magmatic vents of the Cameroon volcanic line. In the locality of Baré-Bakem, this geothermal potential is characterized by several hot.

According to Maréchal, the surface temperature of these sources varies between 25.5 and 26°C. Recent studies by Tagheu et al. (2005) have revealed that in addition to their geothermal potential, the hydrothermal springs of Baré-Bakem are rich in cations (Ca2+, Mg2+, K+), which give them therapeutic properties.Despite the importance of this work, the geothermal reservoir index model is still poorly known, in fact it is difficult at the current state of knowledge to determine whether these indices are carried by dyke primary reservoirs as in the Piton de la Fournaise in France or by sedimentary channels as in Mexico or if the temperatures observed in surface area increase or decrease with depth. Geothermal potential in the municipality of Baré-Bakem is still insufficiently explored. Therefore, this study aims to characterize from a geophysical and geothermometric point of view the hydrothermal springs of BaréBakem.

II. GENERAL CONTEXT

A. Geographical context

The locality of Baré-Bakem is located in the Mungo department, Littoral region. It is situated between the coordinates 4°58'00" to 5°10'30" North latitude and 9°56'00" to 10°06'30" East longitude (Figure 1). The geomorphology is characteristic of volcanic regions, with hills, plateaus, lowlands, and valleys (Tsewoue, 2020). The hydrographic network is very dense and of a radial type. The climate of the study area is characterized as equatorial, with two seasons (Olivry, 1986): a rainy season (from March to October) and a dry season (from November to February). The study area is covered by shallow brown and dark gray ferric soils (approximately 50cm thick) developed on the altered lava flows present in the study area exhibit a clay-sandy or clay-loamy structure (Njeuya & al., 2016)

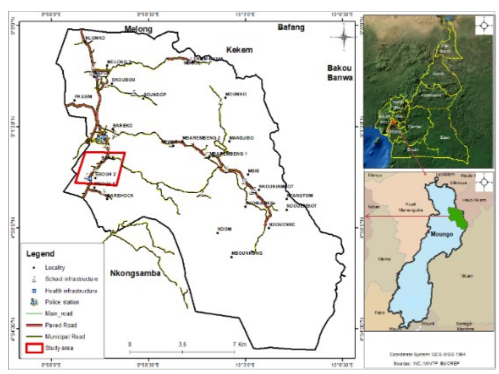


Fig 1 : Location of the study area.

B. Geological context

According to Tagheu & al. (2005), the geological formations in the Mungo department are primarily characterized by volcanic rocks, which constitute approximately 65% of the outcrops. Additionally, there are granitic-gneissic basement rocks and extensive plutono-volcanic massifs, covering around 30% of the spatial extent. Minor sedimentary formations cover

* Corresponding author E-mail: guediaangemerveille@gmail.com

Presented at the 2023 OkIP International Conference on Green Research & Technology (CGRT) in Oklahoma City, OK, USA, and Online, on October 2-5, 2023

approximately 5% of the surface area. Regarding their petrography, the basalts discovered within the study area exhibit a dark gray hue and possess a solid, dense composition. They also feature a weathered surface with shades of yellow and reddish tones. These basalts showcase a porphyritic microlitic structure, with olivine crystals that are discernible without magnification (Njueya & al., 2016). Geophysical surveys have produced apparent resistivity measurements spanning from 15 to 2500 Ω.m. These fluctuations in resistivity have enabled the division of the study area into six distinct zones/terrains (Njueya & al., 2016): the initial zone, ranging from 0 to 2 meters, corresponds to the weathered layer; the second zone, spanning 2 to 7 meters, pertains to the aquifer characterized by pozzolana; the third zone, extending from 7 to 10 meters, corresponds to the aquifer formed by slightly or non-fractured basalts; the fourth zone, from 10 to 50 meters, aligns with the presence of volcanic ash; the fifth zone, spanning 50 to 85 meters, pertains to fractured basalts; and the final zone, ranging from 85 to 100 meters, corresponds to the presence of red clays. The Mount Manengoumba, one of whose flanks houses the locality of Baré-Bakem, is a large polygenic stratovolcano that reaches an altitude of 2411m and covers an area of approximately 500 km2 (Nyueya & al., 2016). It was formed along a volcano-tectonic line with a fault direction of N-S; N30° to 50°E and N140°. This volcanic structure is bounded by normal faults and the Mbo and Tombel plains.

C. hydrogeological context

The hydrogeological studies conducted in the study area by Njueya & al. (2016) mention a generally multilayered aquifer system. This aquifer system would consist of: (1) an aquifer represented by the pozzolana and (2) an aquifer represented by the fractured basalts.

III. METHODOLOGY

According to Amana's research in 2013, geothermal exploration aims to identify hot water reservoirs. To achieve this, these reservoirs must consist of a combination of a heat source, an actual reservoir, and water with favorable thermodynamic properties. The current techniques used for prospecting such deposits involve employing geophysical methods, which are similar to those used in aquifer exploration (Charré-Meza et al., 2000). Additionally, geothermometric methods are employed to detect temperature anomalies. As a result, the methods used for these studies are respectively the direct current electrical method and the geothermometric method.

A. Direct Current Electrical Method

This method involves injecting a direct current of a specific intensity (I) or alternating current at very low frequency into the ground through two electrodes, labeled C1 and C2, and measuring the induced potential difference between another pair of electrodes, conventionally denoted as P1 and P2. In this study, the 2D electrical tomography method using the Wenner-Schlumberger configuration was employed due to its ease of implementation and low cost. Practically, a series of metal electrodes are implanted into the ground along a profile with a regularly spaced interval (Hebbache, 2017). All the electrodes are then connected to a resistivity meter, which performs measurements for different configurations according to a pre-established measurement protocol (Bisso al., 2019) (Figure 2). In this study, a line was acquired in a SW-NE direction along a 945m traverse, with 64 electrodes spaced at 15m intervals. The software Res2Dinv was used to generate images of the investigated subsurface.

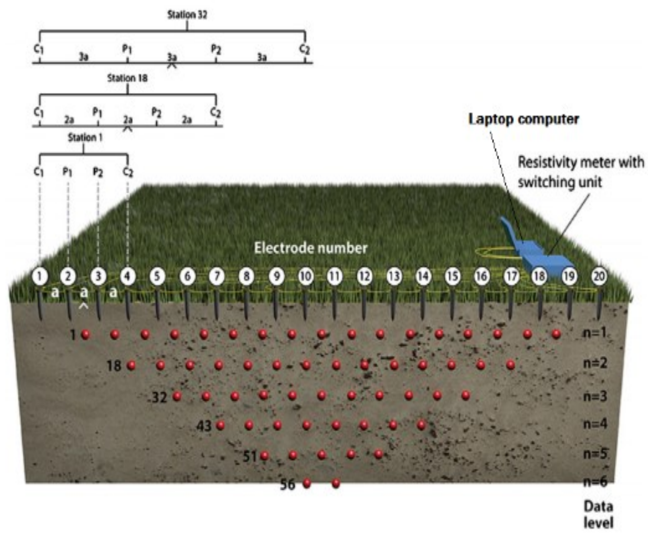


Fig 2 : Electrode arrangement for 2D acquisition and measurement sequence for the Wenner configuration (adapted from Marescot, 2004).

B. Geothermometry Method

To determine the subsurface temperature of hydrothermal waters, several researchers, including Fournier, Rowett, and Truesdell (1973 1974), have developed chemical geothermometers. These methods rely on formulas that take into account the chemical composition of waters that come to the surface. There are various types of chemical geothermometers, but this study focused specifically on silica and sodium-potassium-calcium (Na-K-Ca) geothermometers. These tools utilize specific chemical parameters to estimate the subsurface temperature of the hydrothermal system. By analyzing the concentrations of silica and certain elements such as sodium (Na), potassium (K), and calcium (Ca) in water samples, it becomes possible to calculate an approximation of the temperature at depth. These geothermometers play a crucial role in geothermal exploration and contribute to understanding the thermal properties of hydrothermal systems.

a) Silica Geothermometer (T1): This particular geothermometer computes the temperature at which minerals such as quartz, chalcedony, cristobalite, or silica derived from the hydrolysis of crystalline rock feldspars dissolved, using the surface-recorded silica content as a basis (Khiter, 2018).

$$Tmin(°C) = \frac{1522}{5,75 - \log [SiO_2]} - 273$$

with SiO2 in mg/l

b) Na-K-Ca Geothermometer (T2): Endorsed by Fournier, Rowett, and Truesdell in 1973, this geothermometer relies on the anticipated solubility of ions (Na+, K+, Ca2+) within processes that impact crystalline minerals, notably feldspars (Khiter, 2018).

$$Tmax\ (°C) = \frac{1647}{\log (Na/K) + \beta \log \sqrt{(Ca/Na)} + 2,24} - 273$$

Na, Ca, K in mol/l, with :

β : 1/3 if the water temperature is above 100°C

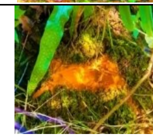
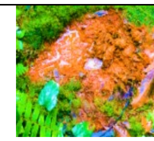
β : 4/3 If the water temperature is below 100°C.

Water samples from the sources of Baré-Bakem were collected in July 2021. The two samples intended for physico-chemical analysis were collected in 1.5L plastic bottles that had been rinsed with distilled water and then five times with the water to be sampled, filled up to the brim following standard procedures (Ndam Ngoupayou & al., 2016). All these samples were carefully labeled and transported to the Laboratory of Geochemical Analysis of Waters (LAGE/IRGM) in Nkolbisson, Yaoundé. The equipment used is of the ORSTON brand.

IV. RESULTS AND DISCUSSION

The reconnaissance work on the study site confirmed the location of the two hydrothermal springs, but geological exploration has led to the discovery of other potential sources in the long term (Table 1). Although the temperatures of these springs at the surface are low, which raises doubts about the geothermal potential of the study area (Marechal, 1976). The presence of the geothermal vents indicates that the geothermal potential of this area should not be overlooked (Labeau, 2018).

Table 1: Observations of Hydrothermal Springs and Outcropping Griffons

		
		
1.Spring 1 2.Griffon 2	**1.Spring 2 2.Griffon 2**	**1.Griffon 3 2.Griffon 4**

The petrographic study focuses on basalt (Fig 3 and 5) samples to identify signs of hydrothermal alteration. The samples reveal a porphyritic microlitic texture with indications of alteration, particularly in olivine.

Gabbro (Fig 3 and 5 samples show a porphyroid granular texture with similarly altered minerals. The observed opaque minerals and carbonates result from alteration processes. Microscopic observations highlight the prevalence of altered olivine, along with the presence of pyroxene and amphibole. Plagioclase forms the matrix of both basalt and gabbro samples, displaying partial alterations. Opaque minerals are abundant and stem from mineral transformations. In summary, the study aims to identify hydrothermal alteration within the samples by examining characteristic altered textures and minerals.

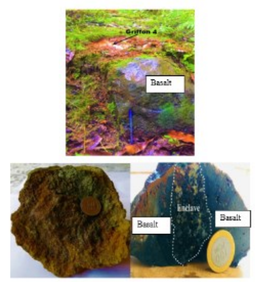


Fig 3: Macroscopic Appearance of Basalt: (A) Basalt sample; (B) Altered basalt sample; (C) Basalt sample containing gabbroic enclave.

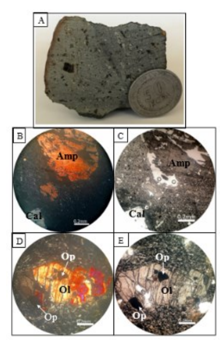


Fig 4: Macroscopic and Microscopic Appearance of Basalt: (A) Basalt sample;(B and D) Olivine alteration in LPA and LPNA (C and D).

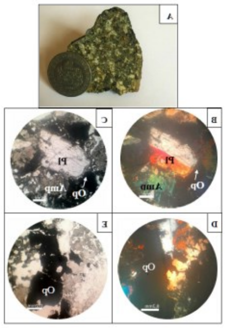


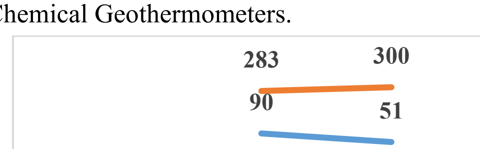
Fig 5: Macroscopic and Microscopic Appearance of the Enclave: (A); (B and D) Alteration of ferromagnesian minerals in LPA and LPNA (C and E).

The figure 6 presents the obtained result and interpretation after the processing-inversion of the profile. The tonality of the section obtained from the inversion process allows distinguishing 3 color ranges: (1) dark colors represented by blue; (2) intermediate colors represented by green; and (3) bright colors represented by yellow, brown, red, and purple. The resistivity scale associated with these different colors reveals that dark colors correspond to geological formations with low resistivities, intermediate shades represent average resistivities, and bright shades illustrate terrains with high resistivities.

Geoelectrical Unit 1: This unit has resistivities ranging from 90-486 Ω.m. Its base is not visible on the profile, but its roof exhibits a wavy character. Its geoelectrical attribute corresponds to a semiconducting ensemble. This unit includes an anisotropy of high conductivity and resistivity, which could correspond to the intrusion zone inside which there is a low conductivity anomaly that illustrates a geothermal zone or a geothermal reservoir.

Geoelectrical Unit 2: This unit has resistivities ranging from 0.5-300 Ω.m. Its geoelectrical attribute corresponds to a conducting ensemble inside which there is an anisotropy of turquoise blue with low conductivity (10 to 20 Ω.m) and an anisotropy of dark blue with very low conductivity less than 8.59 Ω.m, which could correspond to the geothermal reservoirs. This conducting ensemble also exhibits the unity of permeable sedimentary formations from the Cretaceous period and alluvium (Figure 6) where the reservoirs are located. Table 2 present the results from a geothermometric perspective.

Table 2: Depth Temperature Evaluation of the Two Springs Using Chemical Geothermometers.



	Spring 1	Spring 2
T min	90	51
T max	283	300

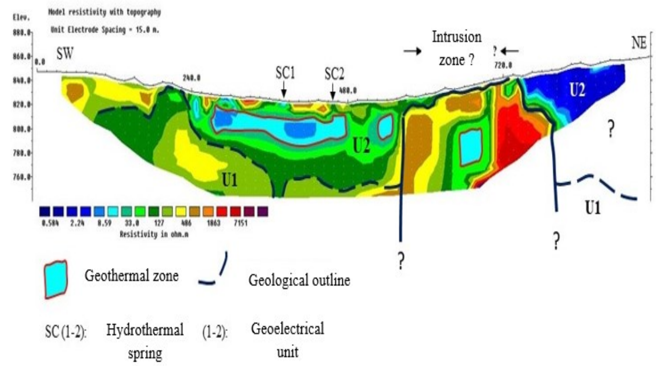


Fig 6 : Deep structure of hot springs in the locality of Baré-Bakem (Cameroon).

V. CONCLUSION

Our nation possesses a limited number of sites with geothermal energy resources. Geothermal resources in Cameroon have the potential for diverse applications such as electricity generation and direct utilization of thermal energy for purposes like heating, agricultural product drying, fish farming, thermal baths, air conditioning, and more. The purpose of this study was to evaluate the geothermal potential within the Baré-Bakem municipality. The findings indicate the presence of two noteworthy geothermal zones confined within permeable sedimentary formations at depths ranging from approximately 20 to 110 meters. These areas exhibit temperatures ranging from 51 to 90°C for near-surface anomalies, while deeper geothermal anomalies showcase temperatures ranging from 283 to 300°C. Such geothermal resources possess considerable energy capacity suitable for electricity generation.

REFERENCES

Andrianaivo L. (2011). Caractéristiques générales des systèmes et des regions géothermiques de Madagascar. Madam ines, ISSN 2220-0681, vol.2

Bisso, D., Arétouyap, Z., Nshagali Biringanine, G., Njandjock Nouck, P., & Asfahani, J., 2019. Variation of Subsurface Resistivity in the Pan-African Belt of Central Africa, in: The Structural Geology Contribution to the Africa-Eurasia Geology: Basement and Reservoir Structure, Ore Mineralisation and Tectonic Modelling: Proceedings of the 1st Springer Conference of the Arabian Journal of Geosciences (CAJG-1), Tunisia 2018. Springer, pp. 25–27.

Charré-Meza A.S., Pèrez-Flores A., & Gomez-Trevino E. (2000). 2-D inversion of resistivity data from the cerro prieto geothermal area, Mexico. (2000). Earth Sciences Division, CICESE, km 107 carr. Tijuana-Ensenada,Ensenada, B.C., México.

Fournier R.O., Rowett J.J., & Truesdell A.H. (1973). An empirical Na-K-Ca geothermometer for natural waters. Geochim.Acta 37, 1255-1275. P,62.

Hebbache. (2017). Contribution à la reconnaissance du sol par tomographie électrique. thèse.Univ.Khider-Biskra.

Khiter F. (2018). Caractérisation hydrochimique de quelques sources thermales de la Wilaya de Guelma Nors-Est Algérien. Mèm. Univ Guelma, 64,65 p.

Labeau Y. (2018). Couplage de la modélisation géologique 3D et de la modélisation hydrothermique : Apport à la compréhension du système géothermique du Lamentin. Thèse. Univ. Antilles, p164

Le Maréchal A. (1976). Géologie et Géochimie des sources thermo minérales du Cameroun. ORSTOM, Yaoundé : thèse. Doct. Etat, Univ. Paris VI,180p.

Ndam Ngoupayou J.R., Dzana J.G., Kpoumie A., Tanwi Ghogomu R., Fouepe Takounjou A., Braune J.J., & Ekodeck G.E. (2016). Present-day Sediment Dynamics of the Sanaga Catchmen (Cameroon) : From the Total Suspended Sediment (TSS) to Erosion Balance. Hydrological Sciences Journal. 26p

Njeuga K.A., Kengni L., Fonteh M.F., Dongmo K.A., Ntankouo N.R., Nkouathio D.G., & Tazo C. (2016). Apport des sondages électriques verticaux à la localisation et la caractérisation des aquifères en zone volcanique au Cameroun : cas d'Ebone et ses Environs. European Journal of Scientific Research. Vol. 138, pp.54-65.

Olivry J. (1986). Fleuves et Rivières du Cameroun. Collection « Monographies Hydrologiques ORSTOM » N°9, Pars, 181p.

Tagheu C.P.J., Wandji P., Bardintzeff J-M., & Laminsi S. (2005). Nature physico-chimique des ressources hydrologiques du stro-volcan Manengoumba (ligne volcanique du Cameroun) : cas de l'eboga et les sources de Baré. Review of the Bulgarien Geological Society, vol.66, part 1-3, 2005, P. 107-114.

Tsewoue M.R., Tchamba M., Avana M.L., & Tamougong A.D. (2020). Dynamique spatio-temporelle de l'occupation du sol dans le Mungo, région du Littoral, Cameroun : influence sur l'expansion des systèmes agroforestiers à base de bananiers. International Journal of Biological and Chemical Sciences. 14(2) : 486-500.

.