Opportunities for Direct Utilization of Geothermal Resources in the Itasy and Antsirabe Areas, Central Madagascar

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Abstract – Geothermal energy in the Itasy and Antsirabe areas, central Madagascar, is related to the volcano-tectonic origin. There are many identified surface thermal manifestations from the major thermal areas in the region, some of which may be used for non-power use. The direct-use applications of geothermal energy are limited to bathing, swimming and balneology.

There are availability of geothermal sources of energy in these areas which can be tapped for power and non power applications. The development and implementation of new programs and strategies should be placed to help provide the industry with an appropriately trained workforce and the necessary technology and to improve the socio-economic condition of the Itasy and Antsirabe people and help mitigate the impacts of climate change. In this view, there are opportunities where researchers and technology developers can play a major role in bridging this gap. The researchers and the academe can position themselves as strategic service providers to the industry in terms of capacity building, training, information and knowledge sharing, resource and capability build-up and mobilization aside from its mandate of knowledge and technology generation, research and extension. Researches can be done along: enhancing the competitiveness of business and industry, food security and poverty reduction, gender and development, environment and natural resource management and developmental researches. The presence of specialists capable of conducting such research and development studies may maximize the indirect uses of geothermal energy.

The main opportunities and innovative proposals for direct use of geothermal resources in the Itasy and Antsirabe areas are: (1) space heating and cooling; (2) agricultural applications such as greenhouse and soil heating; (3) aquaculture application; (4) industrial applications such as mineral extraction, food and grain drying; (5) geothermal heat pumps (GHP) used for both heating and cooling ; (6) irrigation and drinking water supply ; (7) environmental studies; and (8) waste management.

Keywords: Geothermal resources, geothermal engineering, geothermal utilization, Itasy and Antsirabe areas.

Résumé – L'énergie géothermique dans les régions d'Itasy et d'Antsirabe, centre de Madagascar, est considérée comme d'origine volcano-tectonique. Il y a plusieurs manifestations thermales identifiées dans des secteurs thermiques majeures de la région, dont quelques-unes peuvent être utilisées pour usage direct. Les applications directes de l''énergie géothermique sont limitées à la baignade, la piscine et la balnéothérapie.

Il y a des sources d'énergie géothermique disponible dans ces régions qui peuvent être utilisées dans la production d'électricité ou non. Le développement et la mise en œuvre de nouveaux programmes et de stratégies devraient être placés pour aider à fournir une main-d'œuvre convenablement compétente à l'industrie et la technologie nécessaire à l'industrie ainsi que pour améliorer la condition socio-économique des gens et aider à atténuer les impacts du changement climatique. Dans cette vue, il y a des occasions où les chercheurs et les promoteurs de technologie peuvent jouer un rôle majeur pour combler ce retard. Les chercheurs et les académiciens peuvent se placer comme fournisseurs de services stratégiques à l'industrie en termes de renforcement de capacité, formation, information et partage de la

connaissance, ressource et intensification de la capacité, et mobilisation à part son mandat de connaissance et génération de la technologie, recherche et extension. Les recherches peuvent être faites de la façon suivante : rehaussement de la compétitivité des affaires et de l'industrie, sécurité de la nourriture et réduction de la pauvreté, genre et développement, environnement et gestion des ressources naturelles et recherches de développement. La présence de spécialistes capable de mener de telles recherches et études de développement peuvent maximiser les usages indirects de l'énergie géothermique.
Les occasions principales et propositions innovatrices pour usage direct des ressources géothermiques dans les régions d'Itasy et d'Antsirabe sont : (1) chauffage et refroidissement d'espace, (2) applications agricoles telles que serre et chauffage du sol; (3) application dans l'aquaculture; (4) applications industrielles telles que extraction minérale, nourriture et séchage de grain; (5) pompes de chaleur géothermique utilisée pour chauffage et refroidissement; (6) irrigation et provision d'eau potable; (7) études environnementales; et (8) gestion des déchets.

Mots clés: Ressources géothermiques, ingénierie géothermique, utilisation géothermique, régions d'Itasy and d'Antsirabe.

1. INTRODUCTION

1.1. Regional geologic setting

Itasy and Antsirabe areas are part of a continental divergent zone (Fourno and Roussel, 1994; Bertil and Regnoult, 1998; Piqué et al, 1999; Rakotondraompiana et al, 1999), a zone where spreading occurs resulting to the thinning of the crust hence eruption of lavas and associated volcanic activities. The basaltic formations lay over an old basement made of gneisses and migmatites. Late tectonic movements associated with the basaltic eruptions induced a fault system oriented NNE-SSE (Joo', 1968; Sarazin et al, 1986; Andrianaivo and Ramasiarinoro, 2010) or a generally N-S trend (Brenon and Bussiere, 1959; Mottet, 1982). These faults may play the role of thermal water paths at deep levels.

In these regions, there are at least sixty identified eruptive centers (Rufer et al, 2006) and volcanic complexes (Figure 1). The volcanic centers in Itasy area are inactive but are considered relatively young (Holocene age) based on radiometric dating and morphology (Ratsimbazafy and Rakoto, 1996). The geothermal activity in Antsirabe area is likely related to Plio-Pleistocene volcanic phase which has led to the formation of the Ankaratra massif. Geothermal energy is related to these young volcanism and transtensional tectonic regime (intracontinental rifting) (Bertil and Regnoult, 1998; Andrianaivo and Ramasiarinoro, 2010).

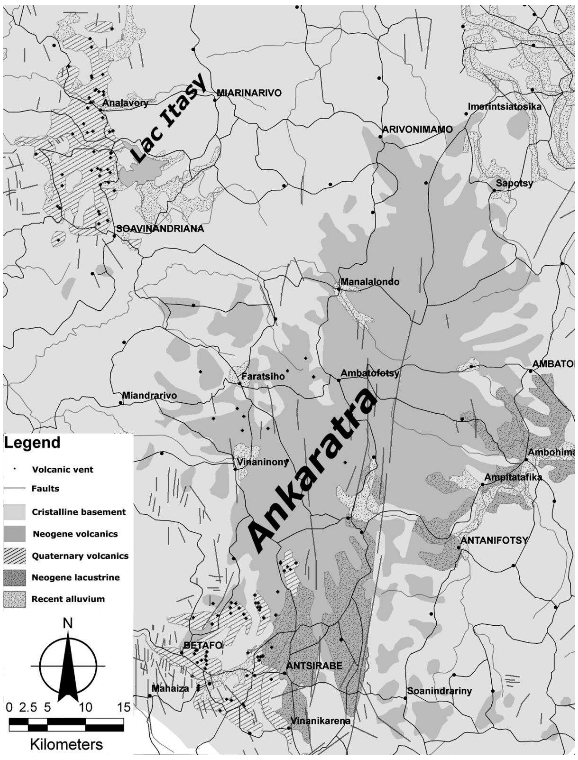

Figure 1: Simplified geological map showing the volcanic fields of Itasy and Ankaratra in the central highlands of Madagascar (Rufer et al, 2006)

Geothermal activity is widespread in the entire region as indicated by presence of strong thermal surface manifestation (Figure 2). They occur in form of geyser, hot springs, altered grounds and silica sinter deposits (Besairie, 1959a). These manifestations indicate presence of an enormous geothermal energy resource potential for both electric and non-electric or direct utilization in the country.

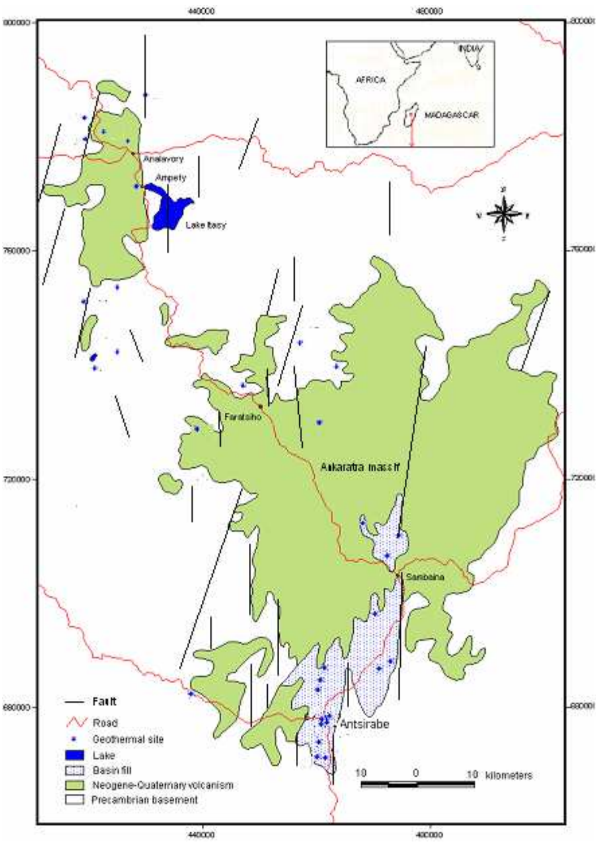

Figure 2: Simplified geological map of the study region showing the tectonic and geothermal sites

1.2. Direct use in Madagascar

The direct-use applications of geothermal energy in Madagascar are limited to swimming, bathing and balneology. Temperature of geothermal resources being utilized ranges from 28 to 75 degrees Celsius. Direct use of geothermal heat is currently at a low level and is limited to numerous hot springs.

Most of those accounted under bathing and swimming are the hot springs in Antsirabe. There are, however, operational hot springs in other regions of the country which have not yet been assessed and hence were not included in the study.

The direct utilization of geothermal energy is difficult to determine since there are many diverse uses of the energy and these are sometimes small and located in remote areas in Madagascar. There is difficulty in finding knowledgeable persons except for indigenous knowledge among the people. This is especially true of geothermal waters used for swimming pools, bathing and balneology. In addition, even if the use can be determined, the low rates and temperatures are usually not known or reported; thus, the capacity and energy use can only be estimated (Lund, 2007).

We reported (Andrianaivo, 2008b) that the country has yet to take off in terms of development of non-power applications of geothermal energy resources. This is due to a lack of financing and public awareness.

People have yet to realize the benefits of using geothermal heat, especially in terms of time saved in drying owing to its high temperature and non-seasonality compared to sunlight.

Since most of the remaining geothermal prospects of the country are of the intermediate to low-enthalpy types (Gunnlaugsson et al, 1981; Andrianaivo, 2008a), there is a need to refocus on the development of small-scale geothermal resources for direct utilization.

1.3. Relevant direct use technology

Direct-use of geothermal resources worldwide is primarily for direct heating and cooling. Geothermal direct-use systems use a fairly simple and established technology (Figure 3) that generally involves three basic elements: (1) A production system that brings water up through a well to the surface; (2) A delivery system that distributes hot water through pipes; and (3) A disposal system where the cooled water is injected back into the reservoir (GHC, 2004).

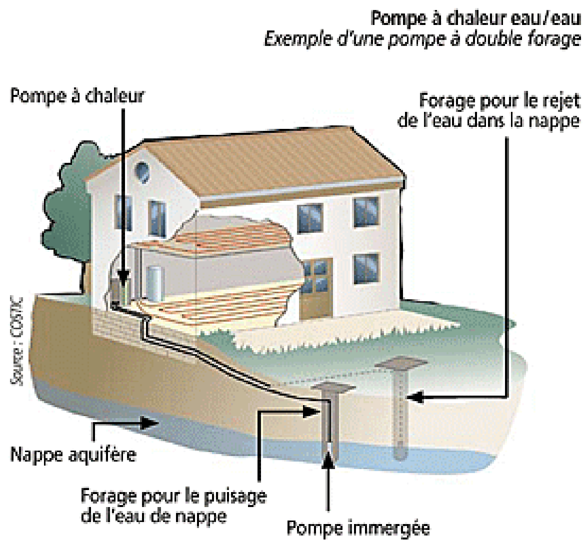

Figure 3: Direct-use system principle and scheme

The main utilization categories are: (1) swimming, bathing and balneology; (2) space heating and cooling ; (3) agricultural applications such as greenhouse and soil heating; (4) aquaculture application ; (5) industrial applications such as mineral extraction, food and grain drying; and, (6) geothermal heat pumps (GHP), used for both heating and cooling (Lund et al., 2005).

In agriculture, geothermal water is used mainly as a source of heat and moisture. Agricultural applications make direct use of geothermal water, using it to heat and water plants, warm greenhouses, or to dry crops. The aim of geothermal aquaculture is to heat water to an optimum temperature for animal growth. Species typically raised include carp, catfish, tilapia, eels, salmon, shrimp, lobster, crayfish, crabs and oysters. In addition there is a rising interest in aquaculture crops, such as water hyacinth, duckweed, algae species and *spirulina* (NZ GNS, 2007). The experiences of some countries in utilizing geothermal energy for industrial applications have been well documented.

The most important energy considerations for an industrial application are the cost, quality, and reliability. Geothermal energy may be attractive to an industry providing: (a) the cost of energy/kg of product is lower than that presently used, (b) the quality of geothermal energy is as good or better than the present supply, and (c) the reliability of geothermal energy is available for the life of the plant. We recommend bringing geothermal heat to industrial installations or bringing industries near geothermal fields (Andrianaivo, 2008b).

The production of biofuels has become a popular issue since it can reduce dependency on imported fossil fuels for the transportation sector. Two types of biofuels can be produced: ethanol and biodiesel, both of which may be used as a blend with conventional fuels to power cars and trucks. Many of the steps require the use of fossil fuels. Geothermal energy can be used by replacing some of the energy inputs. Studies have shown that using heat exchangers, biofuels can be produced economically (GHC, 2007).

In waste management, sewage treatment schemes use geothermal heat to dry digested sludge. Similarly, geothermal energy has been used as a heat source and geothermal water as a mordant in cloth dyeing.

2. OPPORTUNITIES FOR DIRECT USE OF GEOTHERMAL RESOURCES

As in all other studies for direct use of geothermal resources, several elements of direct-use geothermal energy are important: (a) the geologic parameters of the resource; (b) the engineering criteria or the technical practicality of the project; (c) the economics of the venture and (d) the legal frameworks - applicable environmental laws, regulations, ordinances and required permits.

A primary consideration is the cost of finding, developing and utilizing the geothermal resource. These can be done in close cooperation with the local investors, with the local government units and financing institution (Andrianaivo, 2008b).

In designing geothermal energy recovery and utilization systems, alternate possibilities could be considered for various applications. The usual approach for utilization of geothermal fluid by proposed industries is to fit the industry to the available fluids. An alternate approach is to fit the available fluids to proposed industries. This alternate approach requires developing ways to economically upgrade the quality of existing geothermal fluids or the fluids derived from them (Aligan, 2006).

The challenge is to address all aspects of direct use technology with emphasis on improving implementation, reducing costs and enhancing use (Mongillo, 2008). These can be done through: (a) resources characterization, (b) identification of barriers and opportunities for direct use, (c) validation of equipment performance, (d) development of design configurations and engineering standards (Ravaoarisoa, 1984; Andrianaivo, 2008b).

The existence of geothermal energy resources commonly found in mountainous and inland areas of the region have its advantages. There are agricultural plantations and forestry areas in the Region in which the products require processes such as drying, preservation, heating, sterilization, etc. The agricultural and plantation product processing requiring heat are for example: rice, corn, etc. Geothermal waters can be utilized to improve post harvest operations for these products. Traditionally, the energy demand in processing these products would have been satisfied by fossil fuels or by using biomass fuels which are abundant. Therefore, substituting these with geothermal heat helps not only to reduce the need to import hydrocarbons, but also to reduce the emission of the greenhouse gas carbon dioxide to the atmosphere (Andrianaivo, 2008f).

Economic activities in the Itasy and Antsirabe areas consist mainly of agriculture, fishing, hat/mat weaving and pottery/brickyard. Several non-power applications of geothermal brine such as a multi-purpose drying facility for the hat/mat raw material and pottery/brickyard, fish canning and refrigeration, and spa development maybe applied in these areas.

The experiences of other countries in the utilization of these resources have shown that only the hottest water can be used to generate electricity. However, some places have naturally heated groundwater that is not hot enough to produce the steam needed to turn turbines. These type of water is still usable for other purposes but not as a workable power source. This is the area where the researchers and developers can make the most out of what Antsirabe-Itasy Region has.

In some situations where available geothermal fluid temperatures are lower than those required by the industrial application, the temperatures can be raised by means of integrating thermal systems. In designing geothermal energy recovery and utilization systems, alternate possibilities could be considered for various applications. The usual approach for utilization of geothermal fluid by proposed industries is to fit the industry to the available fluids. An alternate approach is to fit the available fluids to proposed industries. This alternate approach requires developing ways to economically upgrade the quality of existing geothermal fluids or the fluids derived from them (Aligan, 2006).

Geothermal waters contain many dissolved chemicals, most notable of which is silica. Not only are these metals often available in significant quantities in geothermal brine, but they provide a new and important source of such mineral produced through solution mining in an environmentally responsible manner (Bloomquist and Porarov, 2008). How to extract and utilize these chemicals is one of the challenges of the industry.

In 2008, the government was moving towards a policy environment that will facilitate the transition of the country's energy sector to a sustainable system by developing renewable energy as a viable and competitive fuel option. There are plans to utilize geothermal drying for spa (Ravaoarisoa, 1984) and balneological applications which are being coordinated with hot spring resort owners and developers. With the numerous hot springs in Madagascar, balneology may become one of the top industries in the country. Other countries have used this strategy in developing their tourist industry.

One of the difficulties in coming up with an updated profile on the extent of direct use of geothermal resources in Madagascar and specifically Itasy and Antsirabe areas is the lack of adequate data. An inventory and survey of surface thermal manifestations such as springs, vents, etc. and their physical and chemical characteristics is of primary importance. A socio-economic profiling of geothermal prospect areas hosting the untapped geothermal resources can also be undertaken simultaneously with these inventories. The challenge, for public agencies (University, Ministry of Energy) and the private sector alike, is to assess the amount and distribution of these resources, to work toward new and inventive ways to use this form of energy, and to incorporate geothermal into an appropriate energy mix for the Nation and the world.

In this view, there are opportunities where researchers and technology developers can play a major role in bridging this gap. The researchers and the academe can position itself as a strategic service provider to the industry in terms of capacity building, training, information and knowledge sharing, resource and capability build-up and mobilization aside from its mandate of knowledge and technology generation, research and extension.

3.1 Geothermal Resource Characterization Studies

3.3.1. Itasy Thermal Area

Verbal and several reports mentioned that thermal manifestations (hot springs) are present in the Itasy prospect. Since there were no existing studies about the thermal occurrences, the researchers utilized the protocol procedure of data gathering through sampling of thermal waters from different reported sites. The sites were properly located using a Global Positioning System. Field analysis of unstable parameters such as pH and temperature were conducted *in-situ*. Documentation and familiarization of the site and field checking of existing geologic maps of the area were conducted. Related studies and literature were adopted, especially those pertaining to the geology of the Itasy thermal area. Interviews with local residents were also made to obtain historical background data of the site. Chemical analyses of the water samples were conducted and the geochemistry was evaluated using a ternary diagram and geothermometers (Andrianaivo, 2008a; Ramasiarinoro and Andrianaivo, 2010).

Results of the study indicated that most of the major geothermal sites occur along or near the north-striking faults (Itasy transtensional zone) that roughly parallel the volcanic area. A few other north-northern-trending faults have been mapped by previous workers around the thermal area and these faults could have acted as conduits of hot water that were derived from the same magma source that feeds the magmatic fluids to Itasy Volcano. The study identified that thermal sites are composed of bicarbonate and sulphide waters. Employing the quartz, chalcedony and Na-K-Ca geothermometers the calculated subsurface temperature ranged from 92-176°C (Andrianaivo, 2008a; Ramasiarinoro and Andrianaivo, 2010).

Considering the medium to low estimated subsurface temperatures, the geothermal potential of Itasy thermal areas is medium to low in terms of power generation (Andrianaivo, 2008a; Ramasiarinoro and Andrianaivo, 2010). However, the low-enthalpy fluids can be utilized for aqua-culture and drying of fish, crops and related products produced in the area. The study further recommended the conduct of geophysical surveys in these cited areas to identify the location, size and depth of the possible reservoir. Likewise, a more detailed chemical analysis of the thermal waters involving other chemical parameters not used in the study (such as isotope, B and Li) must be conducted. Results of the study can be used in the development and promotion of the sites as potential eco-tourist areas and balneological center.

3.3.2. Antsirabe Thermal Area

Previous studies showed an extensional tectonic regime, in the context of intracontinental rifting, in central Madagascar. Multiple indications for this east-west extension can be observed on the central highlands of the island. Extensional structures e.g. grabens and basins (Piqué et al. 1999) as well as extensive Tertiary to Quaternary volcanism can be found in the Lake Itasy area and Ankaratra-Antsirabe area. Geothermal manifestation is related to these young volcanism.

The hot springs are being used as source of potable water, for bathing, laundry, and dish washing while the Ranovisy Hot Spring has become a tourist attraction because of the bats inhabiting the place and the hot spring waters inside. The primary forms of direct use include swimming (Antsirabe), bathing (Betafo) and balneology (Antsirabe). Prior to the study, there had been no previous studies which characterized the sites which can be used as basis for effectively utilizing the geothermal waters and developing the place.

The results of the chemical analyses were used to determine the hot springs' water chemistry which in turn were used to reflect the hydrology of the system.

Tests conducted on the thermal waters revealed a neutral pH Chemical analysis conducted by the Geological Survey (Besairie, 1959a) likewise revealed that the hot springs are classified as bicarbonate waters. The hot springs plotted as steam heated and volcanic waters in the SO_4-CL-HCO_3 ternary diagram (Andrianaivo, 2008a; Ramasiarinoro and Andrianaivo, 2010).

The study was intended to provide an updated reliable data on some existing hot springs in the area which can be used in development planning of the area.

3.2 Other Studies

Other opportunities for direct use include development initiatives along the conversion of thermal areas and existing hot springs into eco-tourism, bathing, swimming and balneological centers (therapeutic use), technology development initiatives on the utilization of geothermal brine / waters /steam as heat sources for various agri-industrial applications to ensure food security and poverty reduction.

Development of the following thermal areas into ecotourism parks:

- Improvement of thermal ponds for existing hot spring resorts in Itasy and Antsirabe
- Tilapia and hot spring heated fish pond in Itasy hot and cold spring resort (Ravaoarisoa, 1984)

Agri-industrial applications for food security and poverty alleviation include:

- Cloth dyeing using natural dyes
- Poultry dressing and brooding system
- Drying technology in agriculture (Ravaoarisoa, 1984) and hand-paper making
- Irrigation and distilled drinking water from treated geothermal waste water.

Given the geothermal and other non-conventional and renewable sources of energy in the Itasy and Antsirabe areas which can be tapped for power and non-power applications, including the incentives that maybe provided by Renewable Energy Act of 2007 (in "Madagascar Action Plan"), growing importance should therefore be placed on the development and implementation of new programs and technologies to help provide the industry with an appropriately trained workforce and the necessary technology.

4. CONCLUSIONS

Geothermal energy in the Madagascar is related to the volcanic origin and tectonic setting (extensional structure) of the island. There are many identified surface thermal manifestations from the major thermal areas in the Itasy and Antsirabe areas some of which may be used for non-power use.

Direct use of geothermal resources the Itasy and Antsirabe areas is minimal except for some hot springs for bathing, for swimming, balneological centers and cleaning purposes.

There are availability of geothermal sources of energy in the Itasy and Antsirabe areas which can be tapped for power and non power applications. The development and implementation of new programs and strategies should be placed to help provide the industry with an appropriately trained workforce and the necessary technology and to improve the socio-economic condition of the Itasy and Antsirabe people and help mitigate the impacts of climate change.

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REFERENCES

Andrianaivo, L., (2008f): The Environmental Impact Evaluation for Geothermal Project in the Itasy Prospect, central Madagascar: Preliminary Review. *Advanced report*, *Unpublished Project Study*, June 2008, MCC, Antananarivo

Andrianaivo, L., (2008b): Geothermal Energy for Sustainable Development: An Expanded Role in Madagascar's Energy Supply Chain. *Final report*, *Unpublished Project Study*, February 2008, MCC, Antananarivo

Andrianaivo, L., (2008a): Geothermal system and Resource in Madagascar: Preliminary Results. *Advanced report*, *Unpublished Project Study*, January 2008, MCC, Antananarivo

Andrianaivo L. and Ramasiarinoro V.J., (2010): Relation between Regional Lineament Systems and Geological Structures: Implications for Understanding Structural Controls of Geothermal System in the Volcanic Area of Itasy, Central Madagascar. *Proceedings World Geothermal Congress 2010*, 25-30 April 2010, Bali – Indonesia, Paper 1218, 1-9.

Aligan, M., (2006): Geothermal Engineering Education in the Philippines: The Bicol University Experience. *Proceedings 27th Annual PNOC-EDC Geothermal Conference*, Makati City, Philippines

Bertil, D. and Regnoult, J.M., (1998): Seismotectonics of Madagascar, Tectonophysics, **294**, 57-74.

Besairie, H., (1959a): Contribution à l'étude des sources minérales et des eaux souterraines de Madagascar, *Travaux du Bureau Géologique*, n°**92**, Service Géologique Antananarivo

Bloomquist, G., and Porarov K., (2008): "Mineral Extraction: Results from International Conferences ", *Geothermal Resources Council*, Reno, Nevada, October 5-8

Brenon, P., and Bussiere, P., (1959): Le volcanisme à Madagascar, *Bulletin volcanologique*, **21**, 77-93

Fourno, J.P., and Roussel, J., (1994): Imaging the Moho depth in Madagascar through the inversion of gravity data: geodynamic implications. *Terra Nova*, **6**, 512-519.

Gunnlaugsson, E., Arnorsson, S., and Matthiasson, M., (1981): Madagascar. Etude de reconnaissance des ressources géothermiques de Madagascar, *Projet MAG/77/104, Contract 141/79 VIRKIR*, Traduction française, **1**, 1-101.

GHC, (2004): Geothermal Education Center and Geo Heat Center. Geothermal Direct Use

Joo', J., (1968): Prospection de la Feuille M47 Soavinandriana au 1/200,000, *Rapport Annuel*, Service Géologique Antananarivo

Lund, J. W., (2007): Characteristics, Development and Utilization of Geothermal Resources. GHC *Bulletin Geo-Heat Center*, Oregon Institute of Technology, June 2007

Lund, J., Freeston, D. and Boyd, T., (2005): Direct Application of Geothermal Energy: 2005 Worldwide Review, *Geothermics* **34** 691–727, 0375-6505

Mongillo, M.A., (2008): Accelerating Sustainable Development of Geothermal Energy through International Cooperation, IEA NEET Workshop Moscow, Russia; 30 Sept-1 Oct 2008

Mottet, G., (1982): L'Ankaratra et ses bordures (Madagascar), Recherches de géomorphologie volcanique, *PhD thesis*, Université Jean Moulin de Lyon 3, France

NZ GNS, (2007): Geothermal Energy: Using Low Temperature GeothermalResources,http://www.gns.cri.nz/ research/geothermal/low temperature.html

Piqué, A., Laville, E., Chotin, P., Chorowicz, J., Rakotondraompiana, S., and Thouin, C., (1999): L'extension à Madagascar du Néogène à l'Actuel: arguments structuraux et géophysiques, *Journal African Earth Sciences*, 28, **4**, 975-983

Rakotondraompiana, S., Albouy, Y., and Piqué, A., (1999): Lithospheric model of the Madagascar island (Western

Indian Ocean): a new interpretation of the gravity data, *Journal of African Earth Sciences*, 28, **4**, 961-973.

Ramasiarinoro V.J. and Andrianaivo L., (2010): Geochemical Characteristic of Thermal Springs in Volcanic Areas of Antsirabe-Itasy, central Madagascar: Preliminary Results. *Proceedings World Geothermal Congress 2010*, 25-30 April 2010, Bali – Indonesia, Paper 1413, 1-6

Ratsimbazafy, J.B., et Rakoto, H., (1996): Mesures d'aimantation et de datation de quelques échantillons de roches dans la région volcanique de l'Itasy. *Journées Scientifiques du Projet Campus « Le Rifting Malgache »*, Académie Nationale des Arts, Lettres et des Sciences, 24-25 juin 1996, Antananarivo

Ravaoarisoa, P.J., (1984): Possibilité d'utilisation de l'énergie géothermique dans les régions d'Antsirabe-Itasy. *Mémoire de fin d'étude en ingéniorat*, Etablissement d'Enseignement Supérieur Polytechnique, Antananarivo

Rufer, D., Schreurs, G., Berger, A., Gnos, E. & Villa, I., (2006): Cenozoic alkaline volcanism in central Madagascar in the context of intracontinental rifting. *4th Swiss Geoscience Meeting*, Bern 2006, Switzerland

Sarazin, L., Michard, G., Rakotondrainy, and Pastor L., (1986): Geochemical study of the geothermal field of Antsirabe (Madagascar), *Geochemical Journal*, **20**, 41-50.

http://www.protegeonslaterre.com/photogallery/energie-geothermique.htm (2010)