**LITERATURE REVIEW**

**Morphological Indicators For Geothermal Sites**

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Although geothermal surface and subsurface features do not indicate in a definite way geothermal sites, morphological features are critical and important indicators for the determination of a geothermal site [(Moeck, 2014); (Papadopoulos & Karagiannidis, 2008); (Qu, Zhang & Guo, 2017)]. The geological features and their surrounding properties have strong spatial relations with the geothermal sites (Tüfekçi, Lütfi Süzen, & Güleç, 2010). Fluid flow, the temperature effect of springs, physical effect of springs on or around sites, chemical and physical properties of springs shape the sites and surroundings. Most of the geothermal researchers claim that geologic and geochemistry are important key factors for geothermal sources. Faults, fractures and rock mechanics are examples of morphological features indicated above. Additionally, porosity, permeability, fluid flow, etc. are key geochemical features for geothermal sources (Moeck, 2014).

Therefore, selection and consideration of indicators from those physical and chemical features are critical for the determination of geothermal sites. For that reason, a very detailed literature survey is required in order to select these indicators. Table 1 indicates the potential morphological features that may be related to geothermal energy sites. Several types of research indicate that there is a strong relationship between fracture patterns and drainage [(Andrianaivo, 2015) (Mikkola & Niini, 1968); (Niini, 1968); (Fourno and Roussel, 1994); ]. The fracture is due to hydraulic pressure created by water (Graben, Basin, Rhine, & Buntsandstein, 2009). Not only the fault or fracture but also the direction of these features also indicate the potential geothermal energy sites. Morover, Qu, Zhang & Guo (2017) say that fracturing methods have strong relationships with the fracturing morphology. In the same study by Qu et.al (2017), it is also stated that different fracture morphology affects the heat mining performance of the geothermal sites.

Each indicator is actually the result of other indicators which means that indicators have relationships between each other that can be described. For example, fractures and faults are causes of deformations, and the opposite is also true (Henkel, 2002).

Faults affect the permeability of the sites, which may be accounted as an important indicator. Porosity, permeability and the rock type are also studied and given attention for geothermal energy site investigation (Graben, Basin, Rhine, & Buntsandstein, 2009).

Andrianaivo (2015) states that North-northeast-striking (NNE) faults occur along or along range-bounding the geothermal energy sites and NNE-strikings are associated with geothermal sites [(Andrianaivo, 2015); (Bussiere, 1960); (Laplaine, 1951); (Joo’, 1968); (Ramasiarinoro, 2008); (Faulds, et.al, 2010); ]. The Brady geothermal area, which is one of the geothermal sites in this study, has also NNE-striking fault blocks (Faulds, et.al, 2010). For that reason, the geospatial analysis and spatial statistics of patterns in sites can give important clues about the springs and geysers.

Another indicator that points to geothermal sites is volcanism. Volcanism and geothermal sites have been studied by many scientists recently. The result interestingly shows that there is an obvious relation with the volcanism and geothermal sites [(Andrianaivo, 2015); (Fourno and Roussel, 1994); ]. Moeck (2014) also asserts that tectonic movements shape the geothermal play and most of the morphological properties are controlled by these tectonic movements.

The hydrological formations are strongly related to the rock type and its properties such as porosity and fracturing (Gemelli, Mancini Adriano & Longhi 2011).

In addition to the physical properties of rock, several other studies find some other important indicators such as hydraulic conductivity having direct relation with the geothermal formation (Henkel, 2002). Most of these studies also mention sedimentation of crystalline rock types around the geothermal energy sites. As mentioned above, each indicator actually creates or indicates other features for geothermal potential. For instance, the fractures in crystalline rock (Henkel, 2002) is result of porosity so affects the electric resistivity of the rock which is another indicator for geothermal sites. Some researchers claim that electric resistivity and magnetization (Henkel & Guzrnan, 1977) and fracturing have similar maps (Henkel, 2002). The same study claims that electric resistivity and porosity are strong related. Moreover, Henkel explains the faults with the magnetization and electric resistivity (2002). Henkel claims that lineaments also reflect geothermal sites.

Table 1. Potential Indicator List

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| INDICATORS | Source |
| Surface Deformation |  |
| Fault, farcture | [(Andrianaivo, 2015); (Mikkola, & Niini, 1968); (Niini, 1968); (Fourno and Roussel, 1994); (Ramasiarinoro, 2008); (Graben, Basin, Rhine, & Buntsandstein, 2009); (Henkel, 2002); (Moeck, 2014); (Qu, Zhang & Guo, 2017); ] |
| Competent Rocks (such as greywacke, lava, welded ignimbrite) |  |
| Volcanism | [(Andrianaivo, 2015); (Fourno and Roussel, 1994);] |
| Direction of Fractures (N to NNE) | [(Andrianaivo, 2015); (Bussiere, 1960); (Laplaine, 1951); (Joo’, 1968); (Ramasiarinoro, 2008); (Faulds, et.al, 2010); ] |
| Salt |  |
| Porosity | [(Gemelli, Mancini Adriano & Longhi 2011); (Moeck, 2014) ] |
| Anomalies |  |
| Type of Rock | [(Gemelli, Mancini Adriano & Longhi 2011); (Henkel, 2002) ; ] |
| Lineament Pattern | [(Henkel, 2002); ] |
| Permeability | [(Faulds, et.al, 2010); (Moeck, 2014); ] |
| Mineral alteration |  |

**REFERENCES**

* Andrianaivo, L. (2015). Relations between drainage pattern and fracture trend in the Itasy geothermal Relations between drainage pattern and fracture trend in the Itasy geothermal prospect , central Madagascar, (July).
* Bussiere, P., (1960). Le massif volcanique de l’Itasy, Rapport annuel, Service Géologique, Antananarivo, 61-62.
* Faulds, J. E., Coolbaugh, M. F., Benoit, D., Oppliger, G., Perkins, M., Moeck, I., & Drakos, P. (2010). Structural controls of geothermal activity in the northern Hot Springs Mountains, western Nevada: The tale of three geothermal systems (Brady’s, Desert Peak, and Desert Queen). *Transactions - Geothermal Resources Council*, *34 2*, 622–630.
* 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.
* Gemelli, A., Mancini Adriano, A., & Longhi, S. (2011). GIS-based energy-economic model of low temperature geothermal resources: A case study in the Italian Marche region. *Renewable Energy*, *36*(9), 2474–2483. https://doi.org/10.1016/j.renene.2011.02.014
* Graben, U. R., Basin, M., Rhine, U., & Buntsandstein, M. (2009). Geothermal energy from sedimentary rock, 1–4.
* Henkel, H. & Guzrnan, M. (1977). Magnetic features of fracture zones. Geoexplora tion 1S,173-181.
* Henkel, H. (2002). The Bjorko geothermal energy project, 45–50.
* Joo’, J., (1968). Prospection de la Feuille M47 Soavinandriana au 1/200,000, Rapport Annuel, Service Géologique, Antananarivo.
* Laplaine, L, (1951). Etude géologique des feuilles Tsiroanomandidy et Soavinandriana, Travaux du Bureau Géologique No.20, Service Géologique, Antananarivo.
* Mikkola, A.K., & Niini, H., (1968). Structural position of ore-bearing areas in Finland . Bulletin Geological Society Finland, 40, 17–33.
* Moeck, I. S. (2014). Catalog of geothermal play types based on geologic controls. *Renewable and Sustainable Energy Reviews*, *37*, 867–882. https://doi.org/10.1016/j.rser.2014.05.032
* Niini, H., (1968). A study of rock fracturing in valleys of Precambrian bedrock. Fennia 97, 6, 60pp
* Papadopoulos, A., & Karagiannidis, A. (2008). Application of the multi-criteria analysis method Electre III for the optimisation of decentralised energy systems ଁ, *36*, 766–776. https://doi.org/10.1016/j.omega.2006.01.004
* Qu, Z., Zhang, W., & Guo, T. (2017). ScienceDirect Influence of different fracture morphology on heat mining performance of enhanced geothermal systems based on COMSOL. *International Journal of Hydrogen Energy*, *42*(29), 18263–18278. https://doi.org/10.1016/j.ijhydene.2017.04.168
* Ramasiarinoro, V.J., (2008). Tectonique et morphopédologie de la région d’Antananarivo (centre de Madagascar) – Rhéologie des latérites et mécanisme de formation des lavaka, Thèse de doctorat nouveau régime, Université d’Antananarivo, Madagascar, 190p.
* Tüfekçi, N., Lütfi Süzen, M., & Güleç, N. (2010). GIS based geothermal potential assessment: A case study from Western Anatolia, Turkey. *Energy*, *35*(1), 246–261. https://doi.org/10.1016/j.energy.2009.09.016