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GEOLOGICAL SURVEYS FOR GEOTHERMAL EXPLORATION IN COSTA RICA

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ABSTRACT

The knowledge of the geological characteristics of a region is of particular importance during the evaluation of a geothermal prospect. Field mapping is essential in the reconstruction of the geological framework of an area, which in complement with geochemical surveys represent the basics for the incoming studies. Geological surveys will give clues regarding the relationship between field characteristics and the probable existence of a geothermal resource. A brief guide concerning a methodology in geological surveys applied to geothermal investigations is presented. As an example the results of a geothermal reconnaissance study carried out in the central north sector of Costa Rica is exposed.

1. INTRODUCTION

The knowledge of the geological characteristics of a region is of particular importance during the evaluation of a geothermal prospect. Compilation and collection of field information is essential for the elaboration of the geological framework that will represent the basic for future investigations. In this sense is important to have a methodology applied to the exploration, and particularly to the geological mapping. The short guide presented here is based on the Latin American Energy Organization approach to geothermal energy exploration (OLADE, 1994) and Wohletz and Heiken (1992).

2. DEVELOPMENT OF A GEOTHERMAL PROJECT

According to OLADE (1994) in general terms the execution of a geothermal field involves two phases: one of high risk (incertitude) associated to the exploration aimed to identify the probable reservoir; and the other of less risk is related to the development and exploitation. At the first stage, during the reconnaissance, the low detail studies take place in a large area and as investigations advance the area is reduced and studies are of greater detail (prefeasibility and feasibility) but in smaller area. First part involves high economical risk levels, to be faced with progressively crescent inversions but that are of relatively low cost. Second part, involves minor risks but requires major investments (Figure 1).

In the different stages of the geothermal exploration, from reconnaissance to feasibility studies (Figure 2), geological surveys plays a very important role because is an inexpensive tool useful for identifying the different elements of the geothermal system.

Geological field surveys in conjunction with geochemical sampling of hydrothermal waters and gases are extremely cost-effective and represents the first step before the incoming more expensive geophysical studies and exploration drilling campaigns (Wohletz and Heiken, 1992).

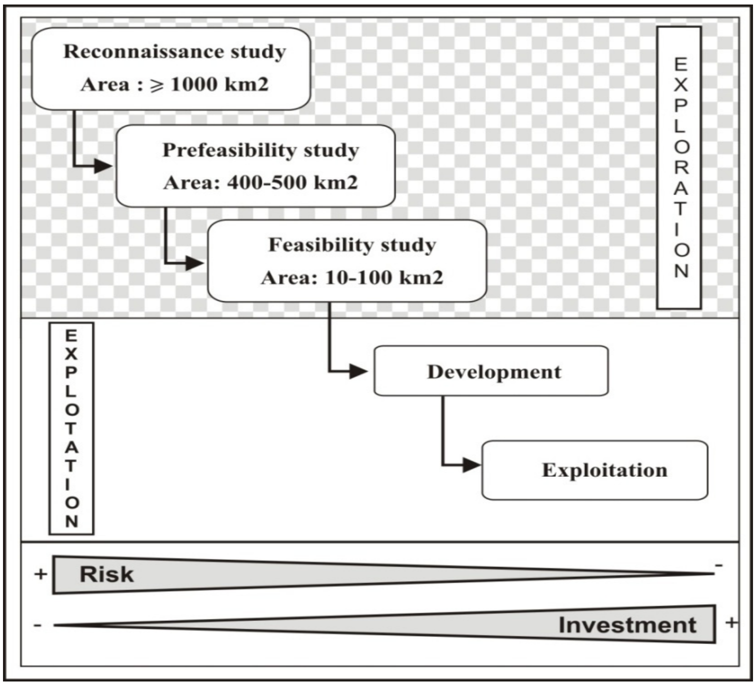

FIGURE 1: Flow chart showing the stages in the execution of a geothermal project and the risk and investment associated, according to the OLADE (1994) methodology

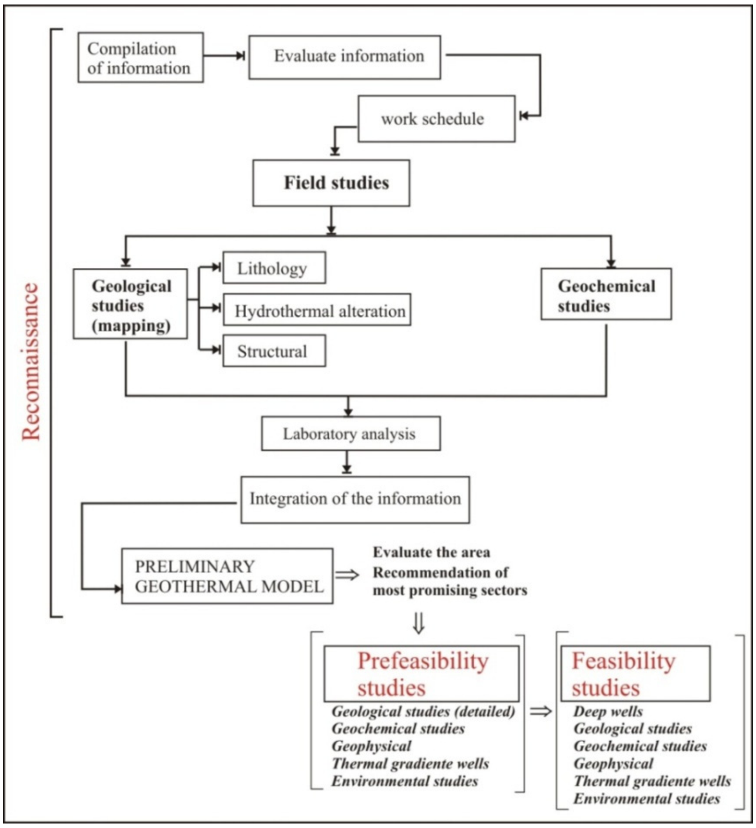

FIGURE 2: General flow diagram of the different investigation steps during the exploration of geothermal resources. Based on the OLADE (1994) methodology

3. GEOLOGICAL SURVEYS

The scope of geological surveys during the exploration of geothermal resources in a general manner could be summarized in the next points (OLADE, 1994):

- Elaborate the regional mapping and define the preliminary volcanic scheme.
- Define the relationship of the regional geodynamic tectonics and volcanism in the area.
- Determine the thermal anomalies at shallow crustal levels.
- Define the regional stratigraphic sequence and lithology types.
- Elaborate the geovolcanological mapping of the identified geothermal areas.
- Describe in a preliminary way the geovolcanological setting of the identified thermal anomalies or geothermal areas.
- Identify the elements that could integrate the geothermal system (heat source, reservoir and cap rock) and formulate preliminary schemes.
- Define, classify and select the geothermal areas of interest.

Geological surveys involve three main phases: 1. compilation and evaluation of the available information, 2. Geological studies (office, field and laboratory investigations) and 3. interpretation and elaboration of the conceptual model.

Phase 1
Compilation and evaluation of the available information.
According to OLADE 1994 and Wohletz and Heiken, 1992 this process includes the compilation of:

- All published and unpublished including stratigraphy, volcanology, structural geology, tectonics, geochemistry and geophysical data. Is important to have the available information on ages of volcanic and intrusive rocks (dating information).
- Topographic and geological maps at any scale, preferable 1: 100.000 and 1:1000000.
- Satellite and radar imagery, aerial photography and digital terrain models (DTM). It is convenient to count with digitized information for post processing.
- Specific information regarding the presence and characteristics of hot springs, fumaroles, and hydrothermal alteration.
- Subsurface information on drillholes or coreholes from any source, including water well drilling, petroleum drilling, and coring by mining companies.

The use of geographic information systems (GIS) is recommended due to the facilities in displaying, combining and updating of the information (OLADE, 1994).

Phase 2
Office, field and laboratory investigations.

Based on the information compiled in phase 1 is necessary to carry out the following activities (OLADE, 1994):

- Evaluation and synthesis of the information.
- Morphological and structural studies by remote sensing (identification of faults and volcanic structures).
- Elaboration of a preliminary geologic-structural map.

The information has to be evaluated in order to identify the known geothermal areas and prospects and define the areas where the field geological studies will take place.
In accordance with OLADE (1994) and Wohletz and Heiken (1992) in volcanic regions, it is important to focus the geological observations on a number of points:

- Recognize areas with episodes of recent volcanism. Definition of "recent" varies according to the volume of material erupted because large magma bodies retain heat much longer than small ones.
- Evaluate the relative quantities of silicic and mafic or intermediate volcanic products (volumes estimations).
- Define the relationship between the volcanic structure and the regional tectonic setting.
- Incidence of recent episodes, mainly of phreato-magmatic origin.
- Sampling of all lithologic types for laboratory analysis, including petrographic and chemical analyses.
- Collect lithic clasts (xenoliths) from pyroclastic units for petrographic analysis.
- Determine the absolute ages of representative lithologic units (dating).
- Study in preliminary way all possible reservoir and caprock units.

Some important aspects regarding the field and laboratory investigations are mentioned by Wohletz and Heiken, 1992:

1. The study of thermal anomalies in the upper crust implies mapping and sampling young volcanic eruption sequences, especially rock types indicative of shallow magma bodies. Mapping and sampling of all areas of hydrothermal manifestations (both fossil and active) in conjunction with hydrogeochemical sampling. All volcanic structures have to be mapped, including craters, domes, phreatic craters, and related faults.

2. In areas with surface hydrothermal manifestations, potential caprocks are mapped and sampled, and their origin is determined. In volcanic zones is necessary to emphasize the search of explosion craters.

3. The extent of potential geothermal reservoirs can be estimated by:
   - A study of lithic clasts (xenoliths) in the pyroclastic units; which provide information on the nature of rocks underlying the volcano.
   - Identification and mapping of recent faults. This effort is essential because active faults frequently represent zones of fracture permeability.
   - Determination of the degree of hydrovolcanic activity responsible for pyroclastic deposits in the volcanic field. This work may identify aquifers beneath the volcano during recent eruptions. These aquifers could be current hydrothermal reservoirs.

4. In tropical countries geological mapping is considerably more difficult due to rapidly soil formation and thick vegetation coverage. In these environments, several additional approaches are necessary:
   - Landform mapping. These maps are based primarily on the interpretation of aerial photographs and satellite images, especially in young volcanic fields. The interpretations are field checked along road cuts, stream bottoms, and shorelines, as well as in quarries.
   - Radar imagery is extremely useful in mapping faults and volcanic landforms in tropical areas because their outstanding surface penetration.

Phase 3
Interpretation of the information and elaboration of the conceptual model.

The information resulting from the interpretation should lead to the development of a preliminary conceptual model of the geothermal system, which will be the basis for the development of subsequent investigations.

The conceptual model has to be oriented in answering questions about (based on OLADE, 1994):

- The existence and probable location of a heat source, indicating its nature, possible extension, depth and age (based on the volcanological conditions complemented with geochemical geothermometers and dating).

- The existence of favorable structural and stratigraphic conditions for the accumulation and movement of geothermal fluid in the ground, it means the existence of a geothermal reservoir and its relation to the heat source. The evaluation must be based on the degree of tectonic fracturing of the rocks and/or the primary permeability characteristics.

- The extension and depth of the inferred reservoir. These parameters allow tentatively estimating the volume of the reservoir, which in fundamental to approximate energetic capacity of the area and determine the magnitude of the drilling costs to reach the reservoir.

4. STUDIED CASE: ARENAL - POCOSOL GEOTHERMAL AREA

The area is located at 75 km NW of San José, Costa Rica (Figure 3), corresponding to the NE border of the Tilaran Range (which consist of a NW-SE Tertiary-Quaternay magmatic belt), adjoining to the Arenal active volcano to the North.

This area in the geothermal reconnaissance study of the Republic of Costa Rica in 1989 was classified as a priority sector for medium-high geothermal prospecting.

The Instituto Costarricense de Electricidad (ICE) in the evaluation of new prospects for future developments finalized a new geothermal reconnaissance study in 2011(Chavarría et al., 2011). The study was carried out in an area of 690 km^2 and includes the compilation of the geocientific available information combined with geologic and geochemical field and laboratory investigations.

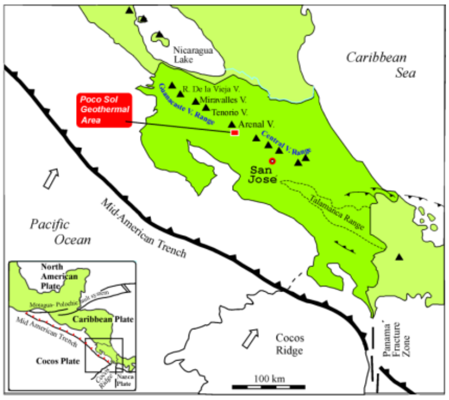

FIGURE 3: Location of the Arenal- Poco Sol geothermal area

4.1 Regional geology

Using the compiled information the regional geologic setting was defined and reflected in a general geological map including the regional geological units and main structures. In a general way, most of the area corresponds to Tertiary to Quaternary volcanic sequences composite mainly of lavas minor pyroclastic deposits. Locally to the north of the Arenal active volcano is the outcropping of marine sediments related to an old sedimentary basin of Miocene age. This suggests the existence of intense tectonic episodes with the consequent development of important structural controls.

4.2 Geomorphology

The area is dominated by eroded volcanic structures formed during the Pliocene and Pleistocene, however towards the north is located the Arenal active volcano, characterized by a young morphology.

As product of the intense erosive processes that had affected the area, the topography is irregular with evident structural alignments such as the Peñas Blancas river, which is a WSW-ENE straightly lineament of about 20 km long. At the center of the area there is a 10 km diameter morphological ring structure known as Poco Sol Caldera, which is located in a sector of high erosion rate that contrast widely with the young shape of the Arenal volcano (Figure 4). Toward the East sector is notable a flat topography related to the deposition of large alluvium deposits due to the erosion of the volcanic belt.

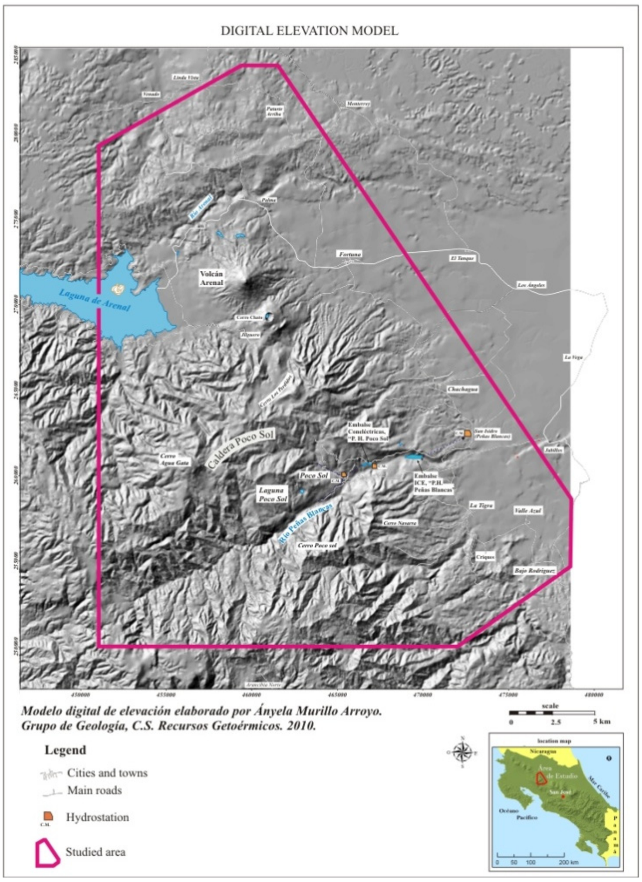

FIGURE 4: Digital elevation model showing the main structural lineaments and morphological features of the area (From Chavarría et al, 2011)

4.3 Geological mapping

After the geomorphological study, where the main volcanic and tectonics structures as well the morphological units were drawn in an integrated map, we proceeded with geological and geochemical field studies, which emphasized the verification of the generated information and collecting of new data. Most of the area corresponds to andesitic-basaltic to andesites lavas and minor pyroclastic products associated to the Monteverde Formation. This unit corresponds to an ancient volcanic plateau which at the present is greatly affected by erosion and landslides. At the centre of the area is clear the existence of semi circular structure (10 km diameter, Poco Sol caldera) whose origin is not yet clear as it could be of volcanic origin or even by erosion processes. This structure is crossed by a 20 km long NE-SW regional lineament knows as Peñas Blancas fault (Figure 5). Just north of the Poco Sol caldera structure there are some minor volcanic centers whose activity seems to have migrated from south to north, until the Arenal volcano.

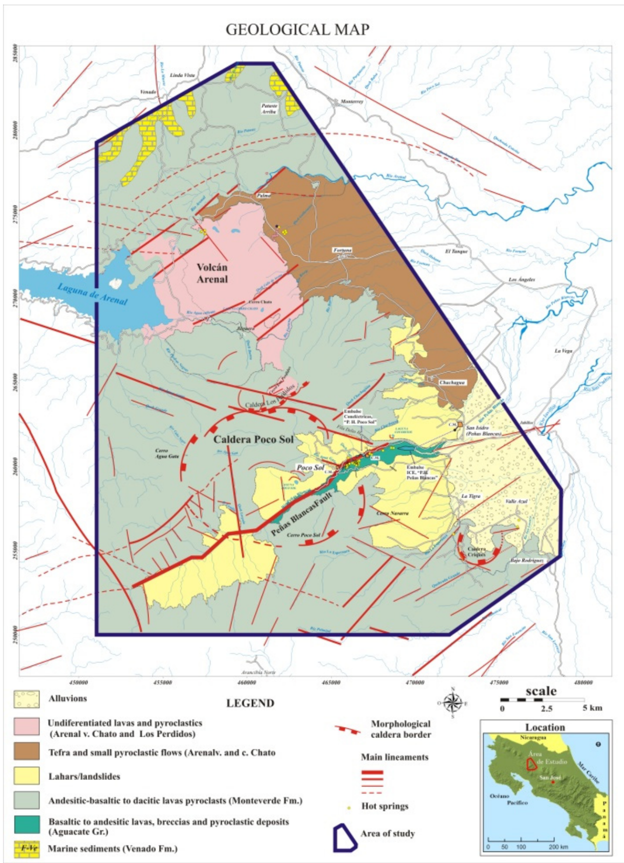

FIGURE 5: Geological map of the studied area (From Chavarría et al, 2011)

According to the available information the area seems to have been exposed to several tectonic phases, allowing the formation of representative structures including faults and caldera structures, evident in aerial photographs and satellite images. The main straight structures are normal faults trending NE-SW direction, some of them with evidence of neotectonic activity. Other important fracture systems are NW-SE and N-S trending. All these tectonic features are positive for the development of secondary permeability.

4.4 Conceptual model

The model was based on the integration of the geological and geochemical information collected during fieldwork and subsequent laboratory analysis, as well relevant data obtained from previews investigations.

The following is an interpretation of the different elements identified:

Heat source
In the north sector of the area undoubtedly there is a local primary heat source related an andesitic magma chamber feeding the Arenal volcano, likewise some recent lava flows and probably shallow intrusive represents secondary heat sources to the formation of shallow thermal hot springs. Toward the center of the area, inside the Poco Sol Caldera structure, is inferred a local heat source in cooling process, which hypothetically could be related to the caldera structure or even to a local intrusion (Figure 6).

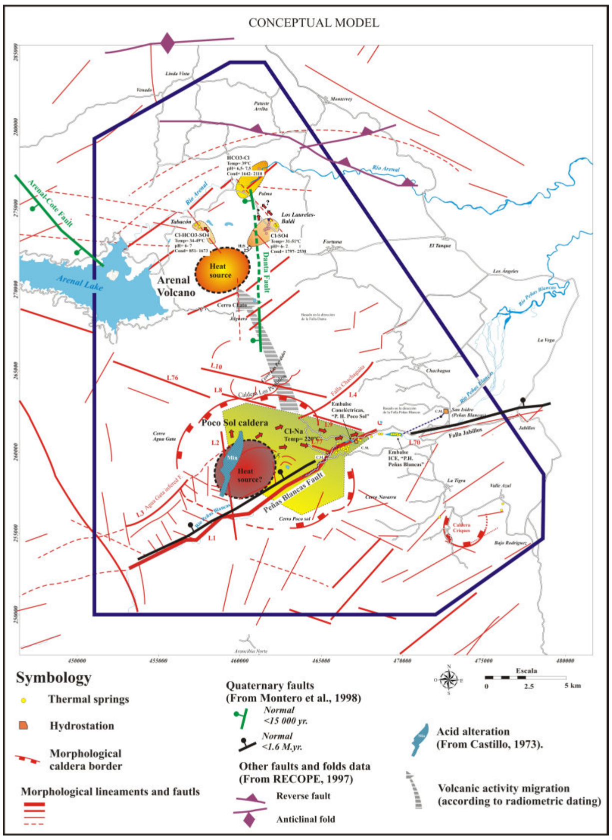

FIGURE 6: Conceptual model (From Chavarría et al, 2011)

Fluid circulation
The circulation of the thermal aquifers in the sector of the Arenal volcano seems to be influenced by N-S structures (Danta fault) and probably local NW-SE fracture systems.

In the sector of the Poco Sol caldera the fluids movement seems to be controlled by regional structures like Peñas Blancas and Jabillos faults (normal faults). Additionally NW-SE fracture systems contribute to the movement of the fluids and outcropping of hot springs along the Peñas Blancas River.

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