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LaGeo S.A. de C.V.

## **GEOLOGICAL FIELD MAPPING FOR GEOTHERMAL EXPLORATION**

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### **ABSTRACT**

A geological map shows the various rock types of an area, structural features, geological formations, hydrothermal manifestations, age relationships, etc. With the development of technology, geological maps today are more precise than ever as a combination of accurate satellite imagery, aerial photographs, high-tech geological equipment and Geographic Information Systems (GIS) advancements. Field mapping activity is usually carried out in four phases, which have a stepwise relationship: a) planning/research; b) field data collection; c) laboratory analysis and d) report writing.

At the beginning of a geological study of a new geothermal area, in the reconnaissance and prefeasibility stages of a geothermal project, the question is: what geological aspects should be looked for? In volcanic environment, the presence of evolved magmas related to the presence of acidic rocks increases the possibility of having huge magmatic chambers that are not so deep. If the age of these rocks is preferably less than 500 000 years, this can give enough heat for a geothermal system (*heat source*). The study of the types and the kinematics of geological faults in geothermal exploration is very important as the faults and fractures control the movement of the hot fluids at depth (*flow pattern*). On the basis of other characteristics like degree of fracturing and permeability of the rock deposits observed at the surface, which can be extrapolated at depth, the possible *caprock* and lithologic units can be inferred, where a *geothermal reservoir* can be hosted.

### **1. INTRODUCTION**

A surface geological study for geothermal exploration has to be oriented to get the main geological elements, which should lead to the construction of a geological conceptual model. Normally, a geological map shows the distribution of rock units and structures across an area of interest, represented usually on a plane surface.

Geological field mapping is the process of selecting an area of interest and identifying all the geological aspects of that area, with the purpose of preparing a detailed geological report and a map to

summarize all the aspects identified. A geological map will thus show the various rock types of the area, structures, geological formations, hydrothermal manifestations, age relationships, etc.

With the development of technology, however, geological maps today are more precise than ever as a combination of accurate satellite imagery, aerial photographs, high tech geological equipment and Geographic Information Systems (GIS) advancements. The ability to form a three-dimensional image from a two dimensional plan is in real sense the major part of geologic map interpretation (Njue, 2014).

The basic concept of geological mapping is to present the stratigraphy, rock types and structural features of the exploration area. Geological mapping in geothermal exploration focuses in particular on establishing the volcanic history of the area, the type of volcanic eruptions and their tectonic setting, the volume of the eruptions, their frequency and changes in volcanic and tectonic activity through time. Volcanic activity and type of rocks erupted can shed a first light on the geological conditions within the geothermal reservoir and the size and configuration of its heat source (Mortensen, 2013).

## **2. OBJECTIVES OF GEOLOGICAL FIELD MAPPING**

Geological field mapping for geothermal resource exploration, in the first stage, is carried out in order to know the geological environment where the geothermal resource can be. To obtain this, it is necessary to study the relation between the volcanic structures and the tectonic setting, emphasizing the most recent volcanic episodes and to know the hydrogeological conditions and the origin and paths of the circulation of the fluids.

During the office and field works, the main lithological types and the geological and volcanic structures must be identified, including evident and inferred faults, fractures, craters, phreatic explosion craters, caldera rings, etc. Furthermore, it is important to see the relative quantity of acid volcanic deposits and to analyze the types of hydrothermal surface manifestations.

Exploration and exploitation of geothermal resources require the appreciation of basic geology of the area being studied; and the optimum utilization of a potential area requires that the resource is mapped out. Understanding the spatial distribution and deformation of rock units at the surface is critical in order to develop three dimensional models of the subsurface geology (Njue, 2014).

In most cases, at the beginning of a geological study in a new geothermal area, as well as in the reconnaissance and prefeasibility stages of a geothermal project, the question is: what geological aspects should be looked for?

## **3. PHASES OF GEOLOGICAL MAPPING**

Field mapping activity is carried out in four phases which have a stepwise relationship: a) planning / research; b) field data collection; c) laboratory analysis; and d) report writing.

### **3.1 Planning / Research**

This phase is mostly carried out in the office, although a short reconnaissance through a previous field trip may be included. All possible geological reports and data that are available must be obtained, including aerial and satellite photographs, digital elevation model (DEM), topographical maps, etc. A budget must also be prepared indicating the number of personnel to be involved in mapping, their daily allowance, fuel costs of vehicles to be used and likewise, all consumables. A local guide for each

geologist has to be considered to support and help in taking samples and carrying materials and equipment in the field.

In tropical countries such as El Salvador, it is advisable to carry out the field studies during the dry season, however, if it is not possible, the geologist has to work under the rain.

### **3.2 Observing / Mapping / Collecting**

The goal of this phase is to collect geological data. In the study area, the geologist has to look for outcrops (its location where they are exposed) and describe them, which include the lithology, volcanic sequences, the geometry and kinematics of the geological structures; and also to take samples of rocks.

Normally, the field geologist has to use the following equipment like compass, 10x hand lens, geologist' hammer, GPS, field book, map of the area, distance meter, altimeter, field camera, measuring tape, sample bags, some markers and black and colored graphite pens.

It is very important to do the field work in a team, usually two or more geologists together, in order to discuss and share the aspects observed in the field, and during the work in the office about the geological issues.

A mapping activity must be qualitative as well as quantitative. Geological data must be taken, described and measured with accuracy. No amount of information is too much, therefore all possible data should be collected (Njue, 2014).

### **3.3 Laboratory analysis**

During the field work, many samples of rocks are collected, which are sent to the laboratory for petrographical analysis using thin sections and a petrographic microscope, in order to get the classification of the rocks from the different lithological units mapped. This kind of analysis can be checked using the results from the chemical analysis of the rocks (by means of the major elements). Some of these samples are also sent to a specialized laboratory to obtain the age of some units of rocks in order to provide information on the volcanic episodes.

### **3.4 Report writing**

When all the possible available data has been collected, it is time to go back to the office to organize all the information. The rock samples are then selected and sent to the geology laboratory and external laboratory for chemical analysis and dating; this can be done while the field work is on-going. Using the results of the analysis and the other field data collected, the analysis and interpretation are then carried out.

At the end of this activity, a geological report is presented. A geological map, some geological cross sections and a preliminary geological model useful for the geothermal exploration are included. The results are then integrated with the geochemical and geophysical results in order to get an integrated geothermal conceptual model (Figure 1).

## **4. PARAMETERS TO CONSIDER IN GEOLOGICAL MAPPING**

### **4.1 Lithology**

One of the main objectives of the mapping is to identify the types of rocks that exist in the area of interest. Before going to the field, it is important to do a careful study of aerial photographs and

topographical maps to avoid areas that are difficult to access or impossible to climb because they are too steep.

In order to get more information about the type of rocks, it is necessary to search the outcrops in the eroded walls of rivers and creeks, as well as the rocks exposed in the slopes, in the roads and in quarries.

Geological descriptions must not be ambiguous, moreover, every fine detail must be included whether it is geologically relevant or not. In volcanic deposits, it is very important to describe the mineralogy, texture and structure of the lava flows, and describe the relative abundance of joints and other structures that produce fractures in the rocks. In pyroclastic rocks, the size of the pumice, the size of the lithics (or rock fragments) and the thickness of the beds have to be described.

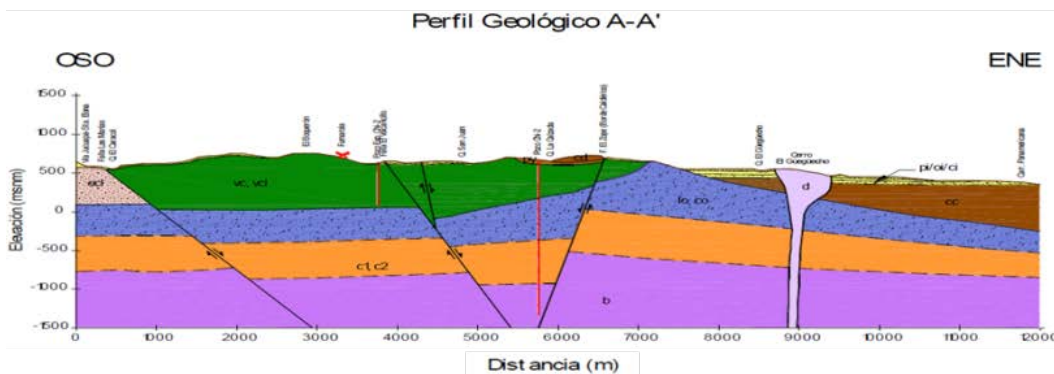
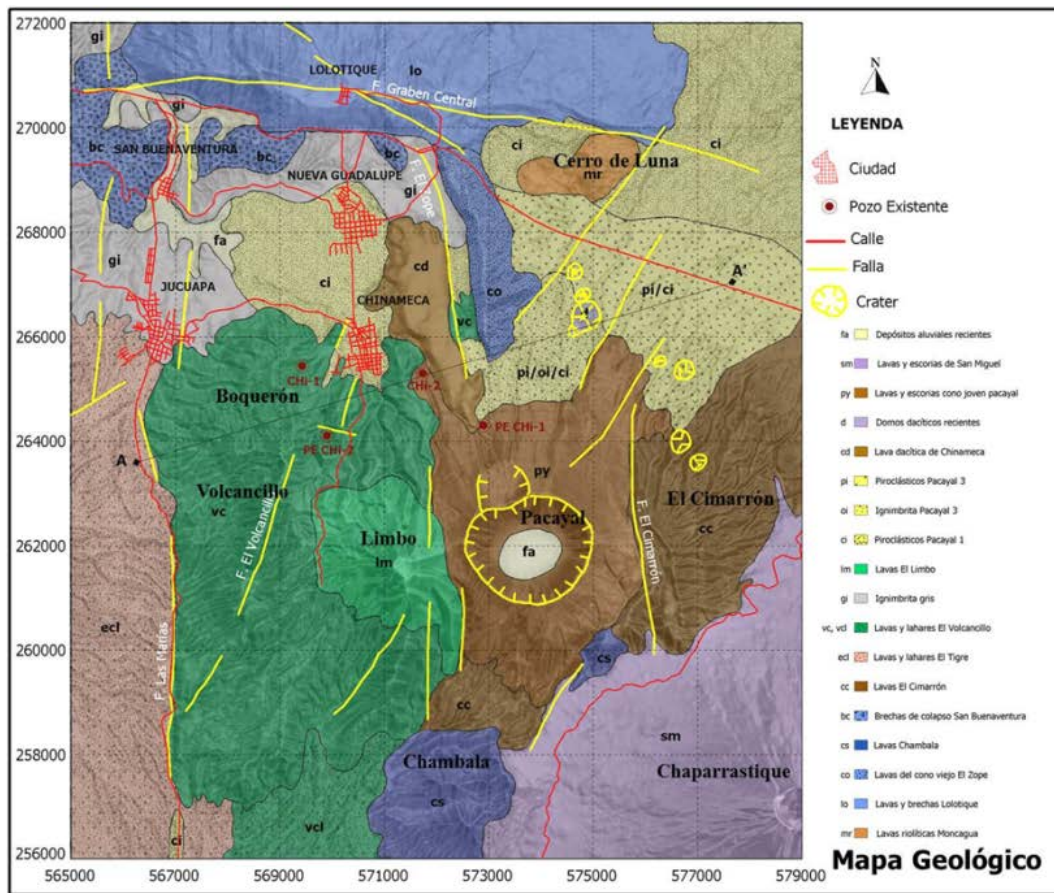


FIGURE 1: Geological and structural map, and cross section from Chinameca geothermal area, El Salvador (LaGeo, 2006)

A measurement of strike and dip is a technique of relating to the orientation of a plane in three dimensional spaces. The technique is usually applied to the orientation of tilted layers of rock, and thus, one can easily see the dislocation a formation has undergone. This is more useful in sedimentary rocks than in volcanic rocks.

In volcanic environment, the presence of evolved magmas related to the presence of acidic rocks increases the possibility of having huge magmatic chambers that are not so deep. If the age of these rocks is preferably less than 500 000 years, this can give enough heat for a geothermal system (*heat source*).

#### **4.2 Rock sampling**

Collecting fresh samples is a process performed carefully by geologists, ensuring that the sample is not altered. The samples are used for petrographical analysis and chemical analysis, in order to get the classification of the rocks. Also, samples of fresh rocks are collected for dating.

#### **4.3 Geomorphology**

Before the fieldwork stage, the analysis of aerial and satellite photographs, the digital elevation model (DEM) and topographic maps helps the geologist to identify the main geological landforms, like craters, caldera rim, scarps, lava flows, hydrothermal alteration areas, domes, scoria cones, etc. During the fieldwork, these features of landforms have to be checked.

#### **4.4 Geological structures (faults and fractures)**

The study of the types and the kinematics of faults in the geothermal exploration is very important because the faults and fractures control the movement of the hot fluids in depth (*flow pattern*). To understand how the main stresses are distributed inside the crust aids the geologists to infer the orientation of the possible permeable faults.

Geological features like faults are not always obvious on the surface. In volcanic areas, they may manifest as volcanic centers or fumaroles oriented in a linear direction which become obvious once a map is completed (Figure 2).

Initial work on the geological structures can be outlined with the aid of satellite images and aerial photos, followed by field work; mapping includes determining the movement and amount of displacement along the faults (normal/reverse/strike-slip/oblique), so that the stress regime and orientation can be determined (Mortensen, 2013).

#### **4.5 Hydrothermal manifestations**

In the surface above a geothermal system, hydrothermal manifestations can exist, however, it is also possible to have a geothermal system at depth without hydrothermal manifestations being manifested at the surface. The extension of hydrothermal manifestations, like hot springs, fumaroles, altered or hot grounds, geysers, steam jets or sulphur deposition must be mapped. Temperature measurement must also be done, as well as collecting samples for mineralogical analysis using the X-ray diffractometry.



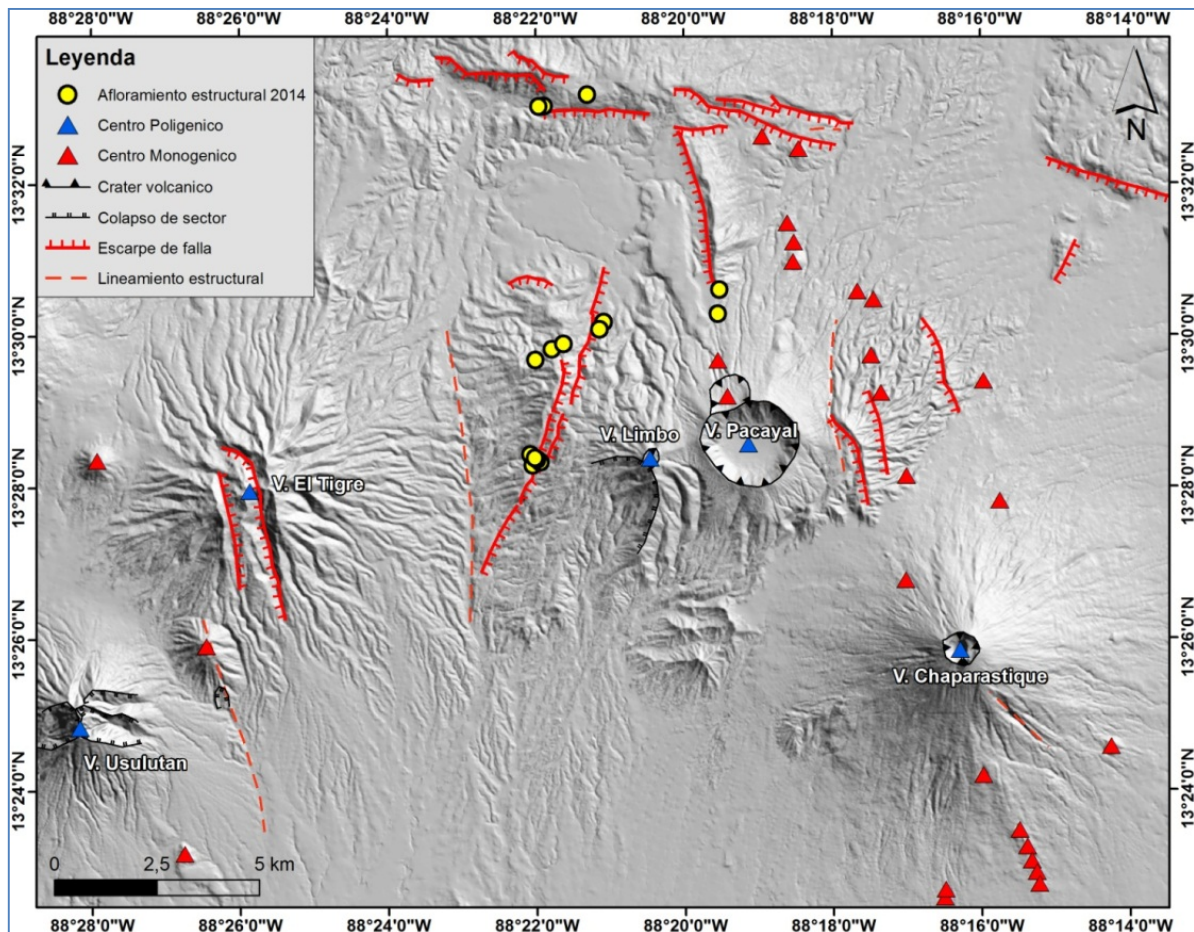


FIGURE 2: Morpho-structural map from Chinameca, El Salvador. The monogenetic eruptive centers are represented by red triangles whereas the polygenetic eruptive centers by blue triangles. (LaGeo, 2014)

## 5. REPORT, GEOLOGICAL MAPS AND GEOLOGICAL SECTIONS

At the end of the study, a comprehensive geological report is presented. A geologic and structural map and some geological sections are included. A Geographic Information System (GIS) is very useful in order to produce maps of good quality and great accuracy. These results of the geologic map should have the necessary geological elements to define a geothermal conceptual model that will be obtained after the integration with the results of the geochemistry and geophysics. The ability to form a three-dimensional image from a two dimensional plan is in real sense the major part of geologic map interpretation (Njue, 2014).

On the basis of the characteristics like degree of fracturing, permeability of the rocks observed at the surface, which can be extrapolated at depth, a possible *caprock* and lithologic units can be inferred, where a *geothermal reservoir* can be hosted.

## 6. CONCLUSIONS

Field mapping activity is carried out in four phases, which have a stepwise relationship: a) planning/research, b) field data collection, c) laboratory analysis, and d) report writing.

The parameters to be considered in geological mapping are lithology, geomorphology, geological structures, hydrothermal manifestations, rock sampling, age of the rocks, etc.

In volcanic environment, the presence of evolved magmas related to the presence of acidic rocks, increases the possibility of having huge magmatic chambers that are not so deep. If the age of these rocks is preferably less than 500 000 years, this can give enough heat for a geothermal system (*heat source*).

The study of the types and the kinematics of faults in the geothermal exploration is very important because the faults and fractures control the movement of the hot fluids in depth (*flow pattern*).

From the observations of the rock deposits on surface, it may be possible to infer the existence of possible *caprock* and the possible lithologic unit where a *geothermal reservoir* can be hosted.

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