THE PREFEASIBILITY STUDY OF THE SAN MARCOS GEOTHERMAL AREA, GUATEMALA

Enzo Ducci[1], **Otto García**[2], and **Julio Palma**[3]

[1]European Co-Director, [2]Coordinator, [3]National Co-Director

[1]Geotermica Italiana s.r.l
Pisa, Italy

[2, 3]INDE, Unidad de Desarrollo Geotérmico
Guatemala City, Guatemala

ABSTRACT

The Geotergua project is a joint venture between the European Community and INDE. Its objective is the prefeasibility study of the San Marcos geothermal area. The area is located near the Mexican border, 250 km west from Guatemala City and is sited in a calderic depression originated in the late tertiary - lower Pleistocene age as a result of various strong pyroclastic eruptions. Numerous thermal springs with a temperature ranging from 23°C to boiling point have been found. The great majority of these springs are along or near the Palatza and the Naranjo rivers, they are isotopically heavy. The geothermometry indicates temperatures of 225°C/255°C for the main reservoir, probably located within the dioritic basement. In order to evaluate all possible electrical production scenarios, different ranges of temperature, depth and flow of the wells, and discount rate were considered. The result of the economic evaluation provides, for the different types of plant evaluated, average costs lower than those of alternative energy sources in Guatemala (Thermal and Hydro). The study indicates the existence, in the San Marcos area, of a geothermal field suitable for electric production, of industrial capacity, and of economic value.

Key Words: Geotergua, Geovulcanology, Geochemistry, Conceptual Geothermal Model.

1. INTRODUCTION

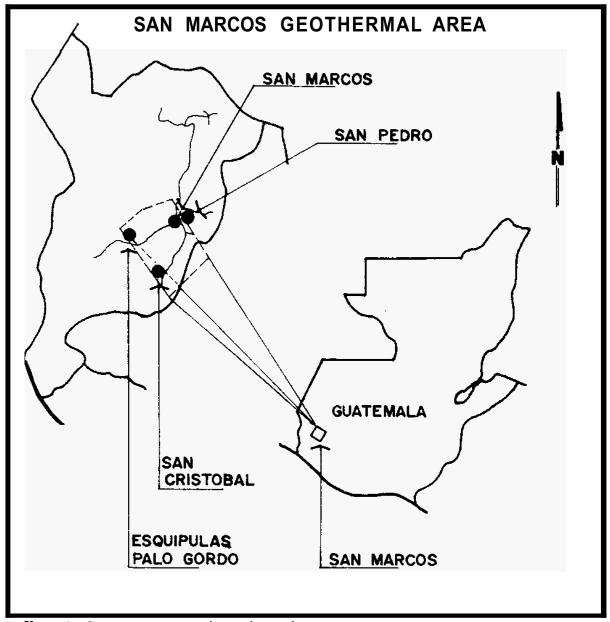
The Geotergua project is a joint venture between the European Community and INDE, the national utility company of Guatemala. Its objetive is the prefeasibility study of the San Marcos geothermal area.

The work carried out to date includes: geo-vulcanology, geochemistry, a limited geo-electric survey, an environmental impact evaluation, and a technical-economic study.

The program was undertaken by the below mentioned personnel of INDE and the EC contractor Geotermica Italiana: Ing. Julio Palma National Co-Director, Ing. Otto Garcia-Coordinador, Ing. Victor Ortiz-Geologist, Ing. Alfredo Roldán-Geochemist, Ing. Carolina Grajeda-Geochemist, Techn. Hugo González-Geophysicist, Tech. Tulio Rosas-Geophysicist, Tech. Franklin Escobar-Computer Analyst, Dr. Enzo Ducci-European Co-Director, Dr. Antonio Frullani-Geovulcanologist, Dr. Marcello Ghigliotti - Geovulcanologist, Dr. Michela Milletto-Geophysicist, Dr. Luigi Marini-Geochemist, Dr. Massimo Guidi-Geochemist, Dr. Roberto Cioni-Chemist, Ing. Riccardo Corsi-Environmentalist. Ing. Giuseppe Valleggi-Economist.
This paper is the result of their work.

2. LOCATION

The San Marcos area is located near the Mexican border, 250 Km to the west of Guatemala City **(Fig. 1);** its elevation ranges from the 4,200 m of the Tajumulco Volcano and the 1,900 m of the Cimarrona hot springs. The topography of this area is mountainous and it is cut by deep valleys with the exception of the caldera plain around the cities of San Marcos and San Pedro.



'ig. 1 Geotergua project location map.

3. GEOVULCANOLOGY

The main geological characteristics of the San Marcos area are described here.

The stratigraphic series includes an intrusive regional basement made up of diorite and an overlying pile of volcanites of tertiary and quaternary age. **(Fig. 2)**

The dioritic basement outcrops 10 km to the west of the city of San Marcos, at an average height of 1000-1500 m a.s.l. and can be found at a depth of kilometres below the San Marcos depression (exact depth unknown).

The tertiary volcanites are mainly made up of andesitic-basaltic and basaltic flows with subordinate pyroclastites aglomerates and lahares. The thickness of this series varies considerably and could range from several hundreds to thousands of metres.

The overlying quaternary volcanites are mainly pyroclastics (ignimbrites and lahares) and breccias reaching a thickness of several hundred metres in the centre of the San Marcos depression, according to an overall interpretation from vertical electrical soundings and geological field data.

The San Marcos depression is the main structural and morphological feature present in the studied area and is considered to be a caldera. It is an eliptical depression with axes approximately 13 and 9 km wide. This caldera originated in the late tertiary lower-Pleistocene age maybe the result of strong pyroclastic eruption of differenciated products, nevertheless the geodynamic

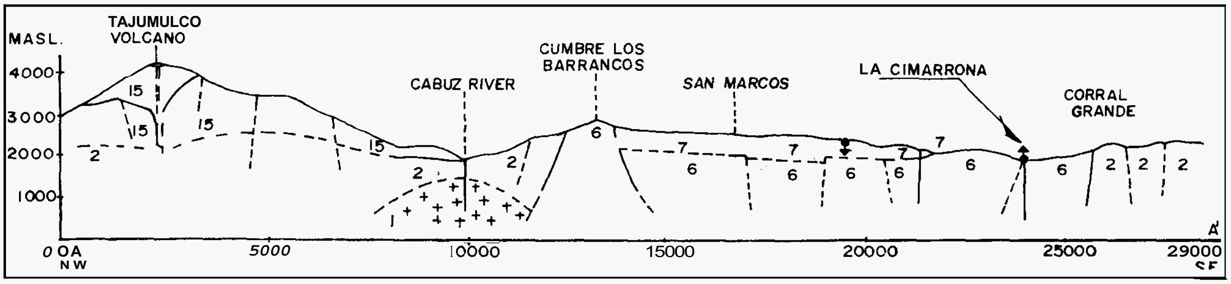


Fig. 2 Stratigraphic series: Tajumulco-Cimarrona cross section.
1 dioritic basement, **2** tertiary volcanites, **6** tertiary lava flows, 7 quaternary intracalderic piroclastites, **15** Tajumulco apparatus.

and structural aspect of its formation must be emphasized. The San Marcos caldera is in fact found in a rim belt between two of the litospheric segments that cut through the Pacific ridge of the Caribbean plate. These areas are zones of structural weakness that cause the formation of large shallow magmatic chambers which are controlled by tectonics. These features are evident in the morphology of the caldera that is a volcano-tectonic depression. Other large pyroclastic eruptions took place later producing acid pyroclastites which partially filled the original depression, producing further collapses along the rim as suggested by the actual irregular shape of the caldera. The latest volcanic episodes caused the emplacement of coalescent lava domes within the southern part of the San Marcos caldera. All the products from these episodes are very evoluted (from dacite to rhyolite) since they are the result of fractioned crystallization processes that took place inside shallow magmatic chambers.

In addition to the ring faults associated with the San Marcos caldera, three systems of directional faults, trending east-west, north west-south east and north east-south west, are present within the area; they are normal faults and/or fractures; in some cases transcurrent movements could have occurred along a few structures.

From a tectonic point of view, it is important to note:

The presence of a north east-south west trending graben that intersects the San Marcos caldera and that probably controlled the emplacement fo the southern domes.

The existence of a three fault system crossing in the central southern sector of the caldera.

4 GEOCHEMISTRY

Numerous thermal springs with a temperature ranging from **23** °C to boiling point have been found. The great majority of these springs are along or near the Palatza and the Naranjo rivers at elevations over 2,000 m a.s.l. The thermal manifestations show a varying composition from ,Ca-Na bicarbonate, while at lower elevations, thermal springs discharge typical sodium chloride waters and mixtures of these with cold and/or thermal bicarbonate waters.

The bicarbonate thermal waters are reheated by conduction or by the addition of hot gases or vapours that rise up from a very deep chloride liquid.

The typical sodium chloride thermal waters contain high levels of B, Li, K, F and SiO_2, low concentrations of Ca and Mg and are isotopically heavy. These characteristics indicate fluids coming from high temperature geothermal circuits. The application of various geothermometric methods (Na/K, K_2 Mg and SO, F_2, Chiodini et al) allows the calculations of the following temperatures:

- 2251255 "C for the geothermal circuit that feeds the most easterly boiling springs of the Cimarrona and contributes to the alimentation of the thermal springs to be found along the Palatza river at an elevation of 2,040 and 1,855-1,865 m a.s.l.
- 185/190 °C for the geothermal circuit that partially feeds the most westerly boiling springs of the Cimarrona.
- 170/185 °C for the geothermal circuit connected to the boiling springs of Castalia.

The geothermal fluids that are associated with the alimentation of these sources rapidly cool down due to vapour separation in the Cimarrona springs, and due to mixing with superficial cold waters in the west Cimarrona and Palatza springs.

Furthermore the geothermal fluids discharged in the Castalia springs first cool slowly, due to conduction, and then more rapidly due to boiling.

It should be pointed out that geothermal waters have:

- Low chloride contents (550-600 mg/l), which suggest their coming from circuits that mainly develop within the dioritic basement.
- Low levels of PCO_2, lower than those suggested by the coexistance of calcite and Ca-AI silicate.

The stable water isotopes show that the geothermal circuits are recharged at 75 % by local rain waters and at *25* % by magmatic andesitic water (according with Giggenbach 1992). This fact suggests the possible presence of a degassing magma underground in the studied area.

The natural total discharge of sodium chloride liquid (with Cl = 550 mg/l), proceeding from deep geothermal circuits, is approximately 19-24 l/s, corresponding to a convective capacity of 16-24 MWt.

5 CONCEPTUAL GEOTHERMAL MODEL

According to the interpretation of the before described geoscientific data a conceptual model of the geothermal system **is** examined by analysing its fundamental elements.

HEAT SOURCE

In the area there **is** the superposition of two geothermal anomalies:

- The first, of a regional type, is due to the position of the San Marcos area along the converging edge of the Coco and Caribbean plates, where intense magmatic activity developed from the Tertiary age till now.

The second, of a local nature, is caused by the transfer of heat from superficial magmatic chambers situated at depth in the project area, continuosly active during the quaternary age.

Thermal regional anomaly probably prevails over the local one, notwithstanding the probable existence of a degassing magma within the area as is suggested by the δ D and δ^{18}O values from waters flowing from the geothermal circuits.

Furthermore it is important to note that the rise of the geothermal fluids along faults and subvertical fractrures that develop in the intrusive rocks, gives locally a displacement of the thermal anomaly towards the surface.

CAP ROCK

The recent intracalderic pyroclastites may act as an effective cover, and even more so where they are affected by alteration processes. It should be pointed out that despite of primary and secondary characteristic (porosity and fracturation) any lithotype can acquire impermeability due to the development of hydrothermal alteration phenomena of the argillitic and phyllitic type. Jn effect, episodes of argillification have been recognized within the studied area, for example near the Cimarrona springs and in some areas along the Palatza river.

Furthermore it is possible that, due to intense alteration, even the tertiary lava sequence could act, at least in part, as a cap rock.

RESERVOIR

The main geothermal reservoir develops, most probably, in the dioritic basement, along faults and subvertical fractures.

The low chloride content of the geothermal fluids suggests in effect, that these have interacted almost exclusively with intrusive rocks. It should be pointed out that the chloride concentration in the geothermal waters of San Marcos is lower than that of Zunil which comes from a granodioritic reservoir.

The main geothermal reservoir has a temperature of 225-255 °C.

The high priority areas for the explotation of the geothermal resource are those where the chloride thermal springs outcrop. These springs are alimented, at least in part, by waters coming from the main reservoir, which cool fairly rapidly by vapour separation or dilution processes. The occurrence of these phenomena suggests a direct upward flow to the surface of those fluids from high temperature geothermal circuits, without stationing in secondary reservoirs and without lateral discharge.

Springs of this kind are to be found at the Cimarrona and along the Palatzá river (at 2,040 and 1,855-1,865 m a.s.l)

A secondary reservoir, with a temperature of 185-190°C, directly feeds the most westerly sources of the Cimarrona. Another secondary reservoir, with a temperature of 170-185°C, flows less directly into the springs of Castalia.

The posible areal extension of the geothermal reservoirs **(Fig. 3)** can be inferred on the basis of the geographical distribution of

The chloride springs, which are directly connected to the main and secondary reservoirs.

The bicarbonated springs which are reheated conductively or by addition of hot gases and vapours originated from deeper chloride fluids; sources of this last type are found along sections of the Palatza rivers (2,000-2,340 m a.s.l.), at the Agua Tibia thermal baths and 1 Km north-east of Castalia.

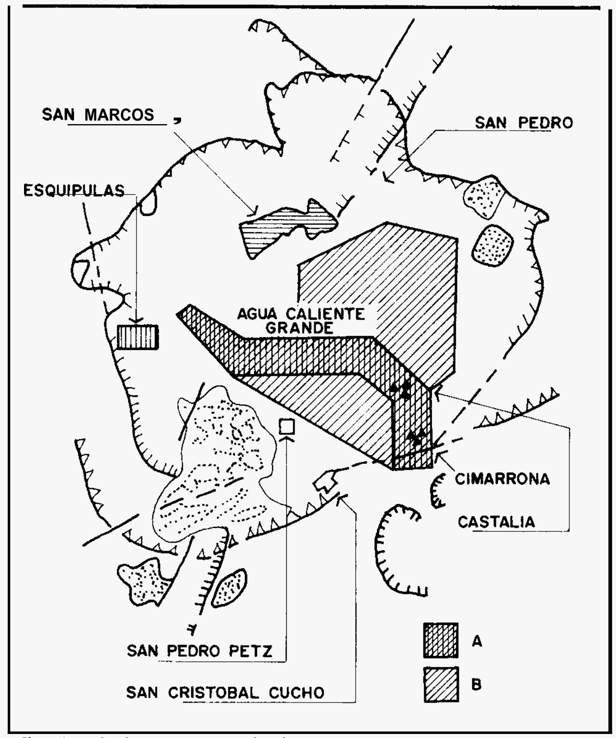


Fig. 3 Priority areas; synthesis map.

6 ECONOMIC EVALUATION

Based on data emerging from the conceptual model and from realistic assumptions, a preliminary techno-economic evaluation of the geothermal resource was attempted.

Moreover, three different types of development and electric production were assumed: one 25 MW single flash condensing plant, *5* **x** *5* MW Back Pressure units, 7 x 3.6 MW binary modules.

The sensitivity analyses were based on the following central data: Temperature = 240°C; depth of wells = 1,500 m; flow of wells = 175 T/h (water and steam); discount rate = 9%.

The result of the economic evaluation indicates, for the three types of plant, average costs lower than those of alternative energy sources in Guatemala (Thermal and Hydro).

In fact the most probable calculated costs are: US mills 41.6 for the condensing plant; US mills 43.7 for the back pressure plant; US mills 52.3 for the binary plant.

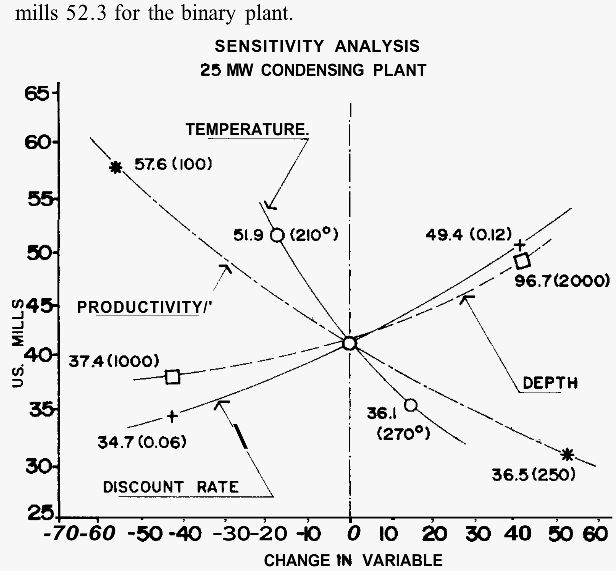


Fig. 4 Sensitivity Analysis. *25* MW Condensing plant.

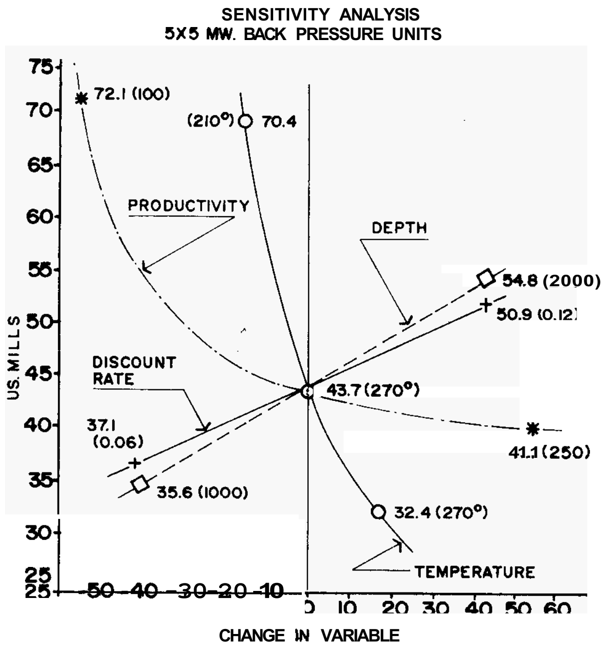


Fig. 5 Sensitivity Analysis. 5 X 5 MW Back pressure units.

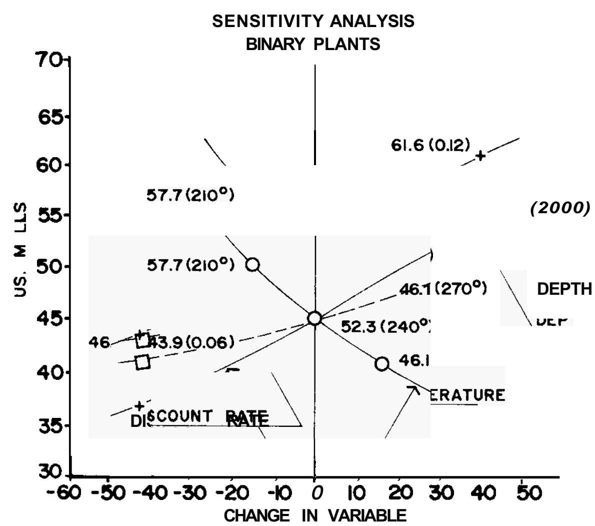


Fig. 6 Sensitivity Analysis. 7 X 3.6 MW Binary modules.

Moreover the sensitivity analysis shows that, by changing the parameters in the spider plots (Figs. 4,5,6) acceptable ranges of costs can be obtained in most cases.

7 CONCLUSIONS

Data analysed in the preceeding sections confirm the existence in the San Marcos area, of a geothermal field suitable for electric production, of industrial capacity and of economic value; this is due to its temperature (225-255°C), its areal extension (Fig.3) and its considerable natural discharge (convective capacity of 16-24 MWt).

The high priority area, is located along the Palatza river, from its source, near Esquipulas Palo Gordo, to the Cimarrona hot springs. This area is mainly controlled by tectonic structures and here all main geothermal manifestations occur.

In order to better define the location of exploratory, commercial size, deep drillings, it is necesary to carry out detailed geophysical survey (V.E.S., gravity and magnetometry) and multipurpose slim holes in the priority areas (A in Fig.3) and in adjacent zones (B in Fig.3). This program is now under way in the second phase of the Geotergua Project.

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