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GEOTHERMAL CHART OF MEXICO
SCALE 1:2,000,000

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ABSTRACT

The Geothermal Chart of Mexico is based on results of geological and geochemical analysys of 1451 thermal sources known until 1999 in Mexico and of their location on the Tectonic Chart of Mexico (Padilla *et. al*., 1994).

The map contains information on temperature of thermal waters, direct heat flow outcropping, major geologic structures and Quaternary volcanoes. All data are registered on proper datasets which are compatible with comercial geographic information systems and data bases computing programs.

The thermal waters are placed on major tectonic provinces. Its geological distribution allow to define nine geothermal provinces: East Pacific Rise and San Andreas Fault, Western Sierra Madre, Eastern Sierra Madre, Mexican Volcanic Belt, Gulf Coast Plain, Central America Volcanic Belt, Southern Sierra Madre, Motahua-Polochic, and Bravo River Rift.

1. INTRODUCTION

The production of geothermal energy in Mexico during the year 1997 was of 5476 GWh, which represents the 3.4% of total of the electric energy generated (Hiriart-Le Bert and Gutiérrez-Negrín, 1998). The geothermal fields that supplied those energy were Cerro Prieto (Baja Balifornia), Los Azufres (Michoacan) and Los Humeros (Puebla).

The investment in Mexico for the development of new geothermal fields diminished in the 90s decade. The investments were restricted to increase the installed capacity of the existing fields and to direct exploration of some places: Las Tres Virgenes (Baja California Sur), Las Derrumbadas and Acoculco (Puebla), Maguarichic and San Antonio El Bravo (Chihuahua), and Volcán Ceboruco (Nayarit).

However, some changes have been proposed in the 2000 year's electric program of energy (in discussion at the Mexican Congress). Those changes would place the geothermal energy as the renewable energy source of greatest potential assesed in Mexico. This would trigger new governmental investments in exploration and development of new geothermal zones in Mexico.

Since the operation in 1959 of the first geothermal power plant of America in Pathé (Hidalgo), the exploration of the main thermal zones of the country was initiated. As result of extensive geological and geochemical surveys are known up to date 1451 localities with some type of thermal activity. In only 21 zones of them feasibility studies have been performed, and only three of which are being exploited. It is evident that the Mexican geothermal potential is very high.

As a contribution to the research and investment for geothermal development of Mexico, a condensed version of the new Geothermal Chart of Mexico, scale 1:2,000,000, is presented here. Infomation is updated to 1999.

(It may be a good idea re-write the Introduction avoiding aspects not directly related to the main subject of the paper, i.e. the geothermal provinces and map of Mexico.)

2. PREVIOUS STUDIES

An inventory of thermal wells and hot springs in Mexico was done by the Comision Federal de Electricidad (CFE, Federal Commission of Electricity) between the years 1959 and 1986, covering near the 90% of the localities. In 1988 Herrera and Rocha (CFE, 1988) prepared the Hot Spring Chart of the Mexican Republic, in which 1380 hot places were included. In 1993 Torres-Rodríguez *et al.* published the first Geothermal Chart of Mexico under the sponsorship of the University Program of Energy (UNAM). In 1994 Torrres and González presented the characteristics of the 25 geothermal zones with the best possibilities.These authors estimated proven geothermal reserves of 1400 MW and probable reserves of 4600 MW. They also stated the Mexico presents large possibilities for direct use of geothermal heat, and considered that the inventory of thermal sites in Mexico (including low temperature resources) was concluded in more than 95%.

3. DATABASE STRUCTURE

It was carried out a complete documental revision and some field studies of the thermal localities (T> 30°C) known in Mexico. A number of 1451 places were identified. It conformed a data base with the following information for each place: Identification and location, lithology, water chemistry, temperature, pH, electric conductivity, heat transported by the fluid, type of source, possible heat source, geothermometer's temperatures, and type of geothermal system.

4. MEXICAN GEOTHERMAL PROVINCES

Based on the Tectonic Chart of Mexico (Padilla *et al.*, 1994 and the structural and geological distribution of the thermal sources, nine geothermal provinces were defined (Figure 1)

East Pacific Rise and San Andreas Fault Geothermal Province

It includes the thermal sources of the Baja California peninsula, the hot fluids of centers at the interior of the Cortes Sea (Basin of Guaymas) and hot springs of the coastern plain of the states of Sonora, Sinaloa and Nayarit. Geothermal activity of this province (continental and oceanic seems to be related to transform faults connecting spreading centers of the East Pacific Rise, and some pull-apart basins.

In this province is located the Cerro Prieto geothermal field, the most important of Mexico, with an installed capacity of 620 MW. Other important localities are the following:

- The Tulechek Geothermal Area, which is a medium enthalpy field with fluids geochemically similar to those from Heber geothermal system in California; exploratory boreholes obtained low temperature (165°C) at 1250 m (Elders 1996 (Missing reference)).
- Las Tres Vírgenes, where exploratory surveys done by CFE indicate a potential of 25 MW (Quijano, 1999); drilling results indicate temperature of 240°C at 1142 m depth (López *et al*., 1994).
- The Laguna Salada, where the first exploratory well (2404 m) registered 126°C (Venegas and Alvarez, 1994).

The characteristic fluids of the province seem to be sodic-chloride to sodic-bicarbonate.

Submarine hot brines into the East Pacific Rise comprise a major geothermal resource of Mexico for the 21th century. Their geographical position near to the continent, their extention over more of 1200 linear kilometers and their lower depths, offers favoruable features for future exploitation. Development of techniques for exploration and recovery of thermal fluids are necessary.

Western Sierra Madre Geohermal Province

The Western Sierra Madre is the larger exposition of ignimbrites of the world. It extends along 1300 km from the southwest of the United States to the central part of Mexico. The thermal sources along the Western Sierra Madre adquire characteristical orientations defining alignments in a northwest-southeast direction. Such alignments are more notorious at the states of Sonora, Sinaloa and Durango. Most of the anomalies are associated with normal faults and grabens.

In the State of Chihuahua are known 53 thermal localities. Some of them outcrop in Nuevo Casas Grandes, Madera, Temosachic, Guachochi, Maguarichi and Ocampo. Thermal sources outcropping in the eastern zone of the state belong to Eastern Sierra Madre and Bravo River Rift geothermal provinces, that will be described further. In the State of Sonora are known thermal sources in the localities of Nogales, Moctezuma, Arizpe and Aconchi. The Durango State presents thermal sources in Guanavechi, Santa María El Oro, Tamauzula and Santiago Papasquiaro. In the State of Zacatecas there are thermal springs belonging to this province in Fresnillo and Valparaiso.

Eastern Sierra Madre Geothermal Province

The thermal sources of Eastern Sierra Madre (calcareous rocks) are located in direction of the alignments of thrust faults. The greater concentrations are located in the eastern edge of the range. Some of the sources include Los Angeles (Chihuahua.), Monclova (Coahuila.), Monterrey and Linares (Nuevo Leon), and Cd. Mante (San Luis Potosi).

Mexican Volcanic Belt Geothermal Province

The Mexican Volcanic Belt (MVB) is a plio-quaternary volcanic belt, of east-west orientation, that bisect central Mexico. It is formed by large stratovolcanoes, silicic volcanic centers, and extensive basaltic and andesitic cinder cone fields. This province contains 79% of the geothermal sites known in Mexico. Its origin is related to the subduction of the Cocos Plate under the North America Plate.

The major frequency of thermal sources is located in the northern edge of MBV, coinciding with the presence of calderas and another silicic volcanic bodies in this portion. As examples are cited the Primavera Caldera (Jalisco), and Los Humeros and Acoculco calderas (Puebla). The southern edge is characterized by the presence of large stratovolcanoes (i. e. Colima, Toluca, Popocatepetl, Iztaccihuatl and Orizaba) and a smaller number of thermal sources.

Structural studies indicate that the fluid conducting faults are related mainly to local stress fields, generated during recent igneous events, so they are more directly associated with the local evolution of the volcanic complexes than with regional tectonics (Lopez, 1992).

The MVB contains two producing geothermal fields: Los Azufres (88 MW, 1997) and Los Humeros (35 MW, 1997). In the latter the highest temperature in Mexico (400°C) has been recorded La Primavera is another geothermal field with a power potential of 70 MW (Reference?).

Gulf Coast Plain Geothermal Province (Geopressured)

Large zones of hot, highly pressured fluids occur in Paleocene sandstone strata into the Gulf Coast Plain, principally in the Burgos Basin. The Oasis, Corindon, Pandura, Los Arcos, Huatempo, and Nilo fields are adjacent to the Bravo River and produce geopressured gas from Paleocene sandstone formations equivalent to those of South of Texas. These fields are being studied again by PEMEX to define a Field Development Plan to recover gas, but it should include extraction of thermal and mechanical energy from them.

Central America Volcanic Belt Geothermal Province

The Central America Volcanic Belt (Plio-quaternary) is composed by a chain of parallel volcanoes to the coast line. Its origin is related to the frontal subduction the Cocos Plate under the North America Plate. Inside the Mexican Republic

the Tacana Volcano constitutes the wetern expression of this chain.

Southern Sierra Madre Geothermal Province

The Southern Sierra Madre is characterized for presenting along their coasts an assembly of intrusive bodies, many of them being great batholiths with radiometric ages from Paleozoic to Cenozoic. It is originated by the subduction processes of the Pacific Plate since Paleozoic. Withinthe magmatic arch the thermal sources are located parallelly to the coast line from the Puerto Vallarta Bay to the Gulf of Tehuantepec (states of Jalisco, Michoacan, Guerrero and Oaxaca). Thermal anomalies in this region could be related also to the subduction of the Cocos Plate under the North America Plate. In the proximity of the trench, where the subduction occurs at shallow depth, the thermal process is of a diffusion type. There are scarce thermal sources, mainly sodic-bicarbotate waters. Some localities belonging to this province are: The Tuito (Jalisco), Acapulco, San Marcos and Copalillo (Gerrerro), and Pinotepa Nacional (Oaxaca).

Motahua-Polochic Geothermal Province

The Motahua-Polochic Geothermal Provice is formed associated with a major left-lateral fault system roughly parallel to the axis of the Tehuantepec Isthmus. Its origin is due to the eastern movement of the Caribbean Plate respect to the North America Plate. Oceanic portion was studied by Torres-Rodríguez and Gonzalez (1988), and continental one by Barrier *et al.* (1998). The fault are reactived since Neogene time (Guzman et al., 1989) and cut the Chiapas Granitic Batholit and the whole folded sedimentary cover (Barrier *et al*, 1998).

The fault system penetrates in continental Mexico as a parallel series of faults, along ofwhich several thermal sources appear, mainly along the Tehuantepec River fault (Oaxaca State). Some localities with thermal waters include: Ixtaltepec, Jamiltepec and Ixtepec.

Bravo River Rift (Grande River Rift)

The Bravo River Rift started its development 28 or 29 m.y. ago. Distensive tectonic produced andesitic and basaltic lavas. The most recent episode dates from 9 to 3 m.y. ago being compesed by alkaline olivine basalts, and geothermal activity. Geothermal sources have been found in the Basin of Presidio (northwest of Ojinaga), with sodic-choride fluids

CONCLUSIONS

The Geothermal Chart of Mexico and its related data base, is a contribution for the development of geothermal research in Mexico. Its 1451 records offer a documental source on the geological and geochemical properties of thermal localities of the country. The close relation between geothermal heat and tectonic processes contributes to understand the present tectonic frame of Mexico and North America.

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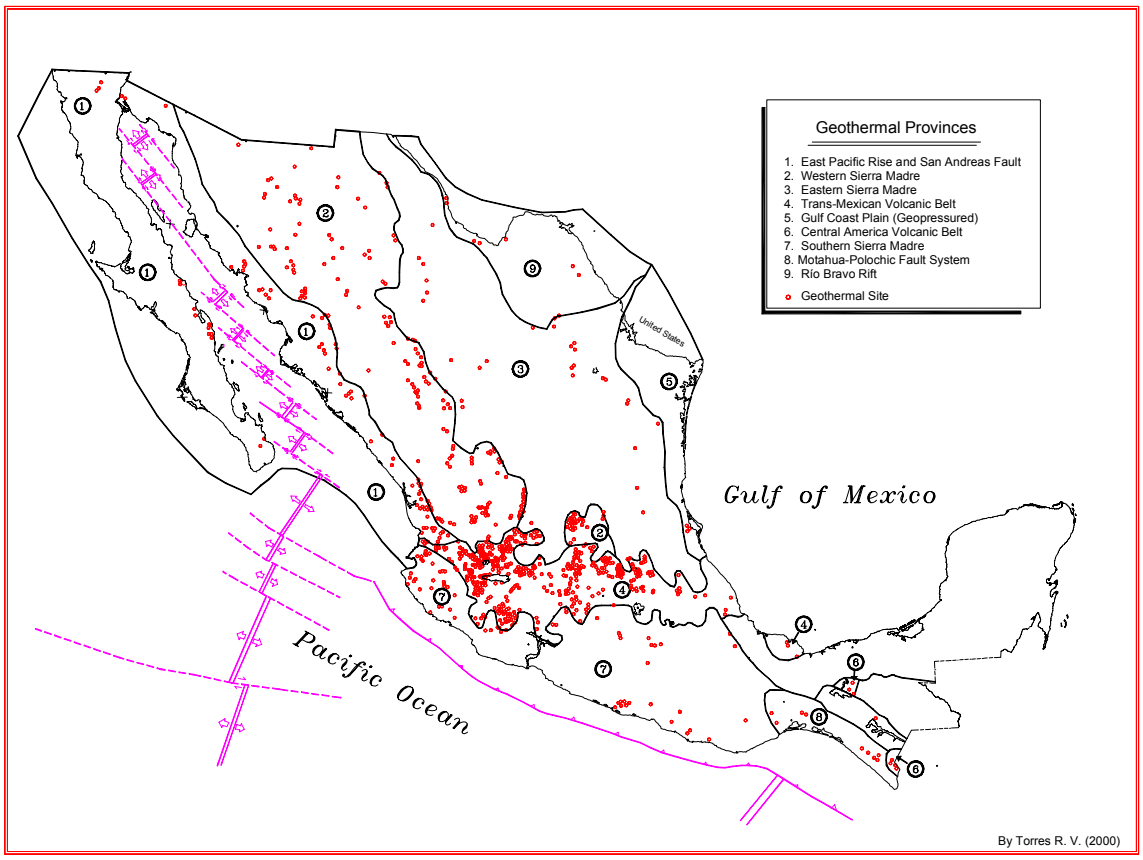

Figure 1. Geothermal Chart of Mexico year 2000. Scale of data 1:2,000,000