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SUBMARINE GEOTHERMAL SYSTEMS IN MEXICO

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ABSTRACT

Deep geothermal energy is a theoretically infinite energy potential. Hydrothermal reservoirs at certain places along the rifts between tectonic plates of oceanic crust are notable examples. Submarine geothermal systems in Mexico are located between two extreme depths: shallow resources near to the continental platform at 20-50 m depth and deep resources at more than 2000 m below sea level. Both types of systems exist in the Gulf of California and in the Mexican coast of the Pacific Ocean. In these regions a considerable geothermal potential was discovered in past years that could be accessible and exploited in the future. Movements between the tectonic plates forming the oceanic crust, allow vertical transfer of magmatic heat toward the sea floor. At the same time, geothermal energy is the basis of rich food chains at those places. Cold sea water enters through fissures in the oceanic crust, where it becomes hot and is chemically changed. After, this heated sea water is ejected upward through hydrothermal vents, containing hydrogen sulphide. Chemosynthetic bacteria use this hydrogen sulphide as a metabolic source of energy and form food for clams, mussels and worms. These submarine geothermal prolific gardens are like "*oases in a cold sunless desert*". Recent research clearly points out that one possible location for the synthesis of chemicals needed for the origin of life is submarine hydrothermal systems.

Other privileged submarine thermal areas are located offshore from the port of Ensenada, Baja California, where temperatures up to 102°C have been measured at 25 m depth and less than 100 m from the coast. In the Wagner Depression, submarine hydrothermal reservoirs are located at less than 30 m depth; both geothermal zones are accessible to explotation by installing offshore platforms, similar to those used by the oil industry. Rough estimations indicate that the geothermal potential of this submarine zone, could be 100 times larger than the Cerro Prieto reservoir. The submarine heat flow measured in the Gulf of California is of the order of 0.34 W/m^2. The average heat flow in the Mexican Volcanic Belt is about 0.10 W/m^2. Some authors estimate a geothermal submarine potential of almost 100,000 MW_t for 30 years, at an average temperature of 330°C. Another supplementary interest for the study of geothermal submarine systems comes from the chemical analysis of sea water in contact with submarine hydrothermal manifestations. For example, lead, manganese and iron of this hydrothermal fluid, increase about 8000 times, 50,000 times and 59,000 times respectively. In this paper we present a general updated description of such natural systems.

1.- INTRODUCTION

Geothermal energy in Mexico embraces superficial traditional reservoirs located between 500 to 3000 meters depth, as well as deep geothermal resources at more than 3000 meters depth (Suarez, 1998). Non-traditional geothermal energy sources in Mexico includes the deep portions and boundaries of traditional hydrothermal reservoirs, systems in hot dry/wet rock, geopressured reservoirs in the Gulf of Mexico and hydrothermal submarine systems located mainly in the Gulf of California and in the Mexican coast of the Pacific Ocean (Figure 1). Hydrothermal submarine reservoirs contain a theoretically infinite energy potential. There are two kinds of such systems: deep resources, located at certain places along the rifts between tectonic plates of oceanic crust at more than 2000 m below sea level, and shallow resources near to continental platforms at 20-50 m depth. Deep submarine energy is related to the existence of hydrothermal vents emerging in many places along the oceanic spreading centers between tectonic plates. These systems have a total length of about 65,000 km in the Earth's oceanic crust (Marshall, 1979). Shallow submarine heat is related to superficial faults and fractures in the sea bottom close to some coasts. This type of system was found offshore near Ensenada in Baja California. Both types of resources exist in the Gulf of Calfornia.

2.- GEOTHERMICS IN THE MEXICAN COAST OF THE PACIFIC OCEAN

In Punta Banda, Ensenada, Baja California (Fig. 1), at 100 m from the coast and at 25 m depth several submarine thermal manifestations have been detected. Those manifestations are formed by discharges of hot water escaping through fissures, which are associated with an important regional fault. The measured temperatures of discharges are between 90°C and 102°C (Lira, 1999). This geothermal area would be accessible to explotation by installing offshore platforms, similar to those used by the oil industry in the Gulf of Mexico. The construction of a dual injection-extraction system would be very simple and relatively cheap. Since the area is naturally fractured, it would be easy to drill parallel or deviated wells at less than 1000 m depth and attain temperatures close to 200°C. The injection/ production loop could be created by the natural reservoir pressure or by injecting marine water into the oceanic rock.

3.- GEOTHERMAL SUBMARINE SYSTEMS IN THE GULF OF CALIFORNIA

In 1969 a "clustered" earthquake occurred in the Gulf of California. It consisted of more than fifty quakes of average magnitude 5 (Richter). Analysis of their seismic waves (Grijalva, 1986) indicated that the basin could be a geothermal field of great magnitude. In the decade of 1980, oceanographic cruises carried out detailed studies in this area (Grijalva, 1986; Mercado, 1990). These studies included thirteen dives in a special American submarine called *Alvin*, and constituted the first deep submarine geothermal explorations carried out in Mexico. The reservoirs in the Gulf were formed by the movements between tectonic plates forming the terrestrial crust in that region, allowing the vertical transfer of magmatic heat toward the sea floor. The famous San Andrés fault is the boundary between the Pacific and North-American plates. The tectonics of both plates coincide in that seismic zone where the crust has about 10 km thickness. Their combined motions caused breaks in the oceanic crust, transporting deep magma upwards. The temperature of this magma is about 1000 °C. This natural process formed a gigantic geothermal submarine reservoir.

The first oceanographic cruise was organized by the Scripps Institution of Oceanography of California and the Woods Institution Hole Oceanographic from Massachusetts. Sergio Mercado, a Mexican engineer, participated in that cruise and reported (1990) sampling of sea water in a region located between 21 °N and 109 °W, at 200 km to the south of Cape San Lucas (Fig. 1), covering an area of 50 km radius. From these samples anomalies of methane, helium and hydrogen associated with geothermal fluids were measured. The submarine flow of heat measured in the Gulf of California was of the order of 0.34 W/m^2. The flow of hot water expelled by the white and black chimneys, has an approximate speed of 2.5 m/s flowing through a diameter of 10 to 20 cm. Mercado (1990) estimated a geothermal marine potential of about 97,000 MW_t for 30 years, assuming reservoir dimensions of 5 km wide by 1600 km longitude and 0.6 km thickness, within the Gulf of California, at an average temperature of 330 °C.

The geochemistry of the marine manifestations at 350 °C, could help to better understand the geochemistry of terrestrial geothermics. The chemical composition of sea water is known. On the other hand, hot rocks of the marine bottom cause chemical reactions, changing the "natural" chemical composition of sea water. Analysis performed by Mercado (1993), indicates that water-rock interaction and magmatic fluids cause variations of salts dissolved in sea water. For example, lead, manganese and iron of the hydrothermal fluid, increase about 8000 times, 51,000 times and 59,000 times respectively, in the sea water in contact with submarine hydrothermal manifestations.

4.- GEOTHERMICS IN THE WAGNER DEPRESSION

Another study on the Gulf of California was done by Nicolás Grijalva between August and November, 1986, together with the Center of Marine Sciences of the National Polytechnic Institute of La Paz, Baja California, and the Scripps Institution of Oceanography of the University of California in San Diego. This oceanographic investigation was done in the Wagner Depression located between latitudes 31° 00' and 31° 15' and longitudes between 113° 50' and 114° 10' (Fig. 1). The first cruise was carried out in the NW of the Gulf accomplishing studies of geomorphology, oceanography, geophysics, geology, geochemistry, and sedimentology. The studied zone is located in sedimentary deposits, having approximate dimensions of 10 km wide by 20 km long and 180 meters thickness. This region is of great scientific and economic interest. Its average depth is about 80 m. The region is of quick sedimentation and the sediments of delta layer have a thickness between 12 km and 20 km. So in contrast with the profound basins in the south of the Gulf, whose immense resources are inaccessible, the basin presents reachable resources, whose exploitation is possible with the existent technology.

The marine bottom in that zone, presents slight slopes at the depression sides, with some abrupt reliefs and chains of volcanos 4 to 18 m height. During this cruise, small mountains surrounded by trenches and traces of faults discharging gases, hydrocarbons and hot water, flowing from the sea bottom to the sea surface, were observed. At 180 m depth water pressure in that zone is about 15 bar at a temperature higher than 200°C. Plumes of upward bubbles that could be formed by gas, high viscosity hydrocarbons or water at high temperature, were detected. Volcanos of mud associated with hydrothermal springs were also observed. It was proven experimentally that the observed bubbles are hydrocarbons in the form of butane gas (Grijalva, 1986). Water samples contained manganese, while in the samples of sediments, sulfur, iron and nickel were found.

In seismic profiles of the sea floor, concentric patterns of geological collapse structures could be observed. At greater depth penetration is higher and cracks exist through where hydrothermal circulation is generated and hydrocarbons are produced. This geologic formation gives rise to the emergence of magmatic material and metals. The results suggest the presence of three sources: metals, hydrocarbons and geothermics. According to Grijalva (1986), the cracks correspond to transformed faults and the sinking corresponds to a dispersion center. From his own unpublished data Grijalva estimated that the geothermal potential of this submarine zone, could be 100 to 500 times larger than Cerro Prieto potential.

4.1.-The ^{3}He Isotope in this Basin

Water samples collected during the above-mentioned cruise in the NW part of the Gulf of California were analyzed for the isotope ^{3}He. It is known that natural rich sources of ^{3}He only exist toward the center of the planet at temperatures of about 4000 °C. This isotope is indicative of magmatic sources and is rarely found in the Earth's crust. Helium is relatively insoluble compared to other gases. There is only 5 ppm in air, but can be 1000 ppm in geothermal gases. The only possible explanation for its detection in the Gulf is that this Helium comes from local sources of magmatic origin. The ^{3}He sampled in the referred expedition, after being expelled by the mantel, must be transported by vertical streams of bubbles forming plumes. In spite of mixture processes of marine waters with different densities and of immense tides (up to 10 m height) occurring in the Gulf, the values of $^3He/^4He$ found in the basin under study were higher than the atmospheric value. This quotient coming from hydrothermal springs in the bottom of the ocean can be up to nine times greater than the same quotient in the terrestrial atmosphere, whose value is $1.4\ 10^{-6}$. Grijalva (1986) estimated an average quotient $^3He/^4He$ of 4.5 times higher than same quotient in air at 150 m depth for the whole Gulf (Fig. 2).

5.- HANGING GARDENS, DEEP SEA LIFE AND GEOTHERMAL ENERGY

During the dives with the submarine Alvin, diverse hydrothermal manifestations were observed. The so called

"*Hanging Gardens*" were discovered 2600 m depth. Impressive natural chimneys up to 6 meters high, approximately at the same depth, were also observed. Those almost metallic natural chimneys are formed partly by sulphur iron and copper, and are discharging spouts of water at 350 °C (Mercado, 1990 & 1993). Hundreds of photographs taken by Corliss and Ballard (1977) and by Mercado (1990) show that close to a vent or chimney the joints and fissures in the rock of the sea bottom are encrusted by bright yellow and white accumulations of chemical precipitates. Within l5-20 metres of the fissure there are communities of large and abundant benthic organisms. The plumes of warm water produce conditions in adjacent water to be rich in suspended materials and nourishment for large suspension-feeding bivalves. In the Hanging Gardens and at the Eastern Pacific Rise photographs show large sea-anemones and sea-pens. There are local pockets of sediment burrowed and tracked by deposit-feeding animals.

Organic material in the deep seas cannot be made through photosynthesis from solar energy. It is now clear that energy derived from geothermics is the basis of rich food chains not only in the Gulf of California, but at many other places along the rifts between tectonic plates of oceanic crust. Besides the eruption of lava at these places, sea water enters fissures, becomes hot and is chemically changed by interaction with the rock. This heated sea water is ejected upward through chimneys and hydrothermal vents. It contains hydrogen sulphide derived from the breakdown of sulphates. Chemosynthetic bacteria that use hydrogen sulphide as a metabolic source of energy (Marshall, 1979) are thus able to flourish, forming food for suspension feeding invertebrates such as clams, mussels and polychaete worms. These prolific places can be regarded as "*oases in a cold sunless desert*". Recent experimental research (Imai et al, 1999), clearly points out that *one possible location for the synthesis of chemicals needed for the origin of life is submarine hydrothermal systems*, where sea water circulates through and reacts with the oceanic crust.

Corliss and Ballard (1977) report evidence that hydrogen sulphide emerging from the vents energizes the metabolism of chemosynthetic bacteria, which may well go far to meet the needs of suspension-feeders. Whatever the basic sources of food, it is clear that hydrothermal oases are richly enough to support local populations of large beard-worms. In the series of fascinating photographs taken by Mercado (1990) and in the article by Corliss and Ballard (1977), there appear clusters of 46 cm long beard-worms, several cancroid crabs, a reddish brotulid fish and lava pillows encrusted with limpets and sponges, all living at temperatures near l7°C. Perhaps the limpets browse on bacterial films on the lava. In another photograph, the crabs can be seen feeding on serpulid worms. Beside serpulids, other suspension-feeders include mussels, giant clams and octocorals. There are also large, 3.8 cm wide organisms "*resembling dandelions gone to seed*", which are unknown forms of protozoa. They are attached by filmaments to the rocks and from the body emerge long radiating translucent threads. Beside the crabs, the squat-lobsters, and brotulid fish, there are other carnivores in the shape of an octopus, a skate and a rat-tailed fish.

6.- CONCLUSIONS

- In the Gulf of California and in the Mexican coast of the Pacific Ocean, a considerable geothermal potential exists. This resource is probably part of a gigantic hydrothermal system embracing the Gulf itself, Cerro Prieto and the California geothermal fields, all related to the San Andrés Fault. This system seems to be the superficial manifestation of lateral motions in process, causing the separation of Baja California from the Mexican continental portion.

- In the bottom sea waters of the Wagner Depression, hydrothermal and magmatic processes of great importance are occurring: horizontal and vertical magmatic flows, hydrothermal activity, formation of minerals and generation of hydrocarbons coming from organic sediments of great extent. These processes could have some impact in the national economy, because the basin is in relatively shallow waters where conventional methods used for the exploitation of hydrocarbons could be applied to extract minerals and geothermal energy.

- The ^{3}He content in the marine water of the Wagner Depression, is from magmatic origin and comes directly from the sea bottom carried by vertical submarine streams. Water-rock interaction and magmatic fluids cause variations of salts disolved in deep sea water. Lead, manganese and iron of the hydrothermal fluid, increase about 8000 times, 51,000 times and 59,000 times respectively, in the sea water in contact with submarine hydrothermal manifestations. This constitutes another supplementary economical attraction of great interest for the study of geothermal submarine systems.

- Natural chimneys photographed by Mercado (1990) at 2600 m depth in the Gulf of California, discharge spouts of water at 350°C. These plumes of warm water generate conditions in adjacent water to produce suspended materials as source of nourishment for different living organisms. Deep marine water circulating through and reacting with oceanic rocks could produce the first chemicals needed for life to emerge.

- Submarine geothermal energy is the basis of rich food chains not only in the Gulf of California, but in many other places along the rifts between tectonic plates of oceanic crust. Chemosynthetic bacteria use hydrogen sulphide from the heated sea water ejected by the chimneys and hydrothermal vents, forming food for suspension feeding invertebrates such as clams, mussels and worms.

- Within 20 metres of fissures and chimneys large communities of plants and animals exist, forming some kind of deep sea oases, attracting abundant populations of animals like beard-worms, suspension-feeders, roving carnivores, crabs, squat-lobsters, brotulid fish, skate, rat-tailed fish and some kind of octopus. All living at temperatures near l7°C.

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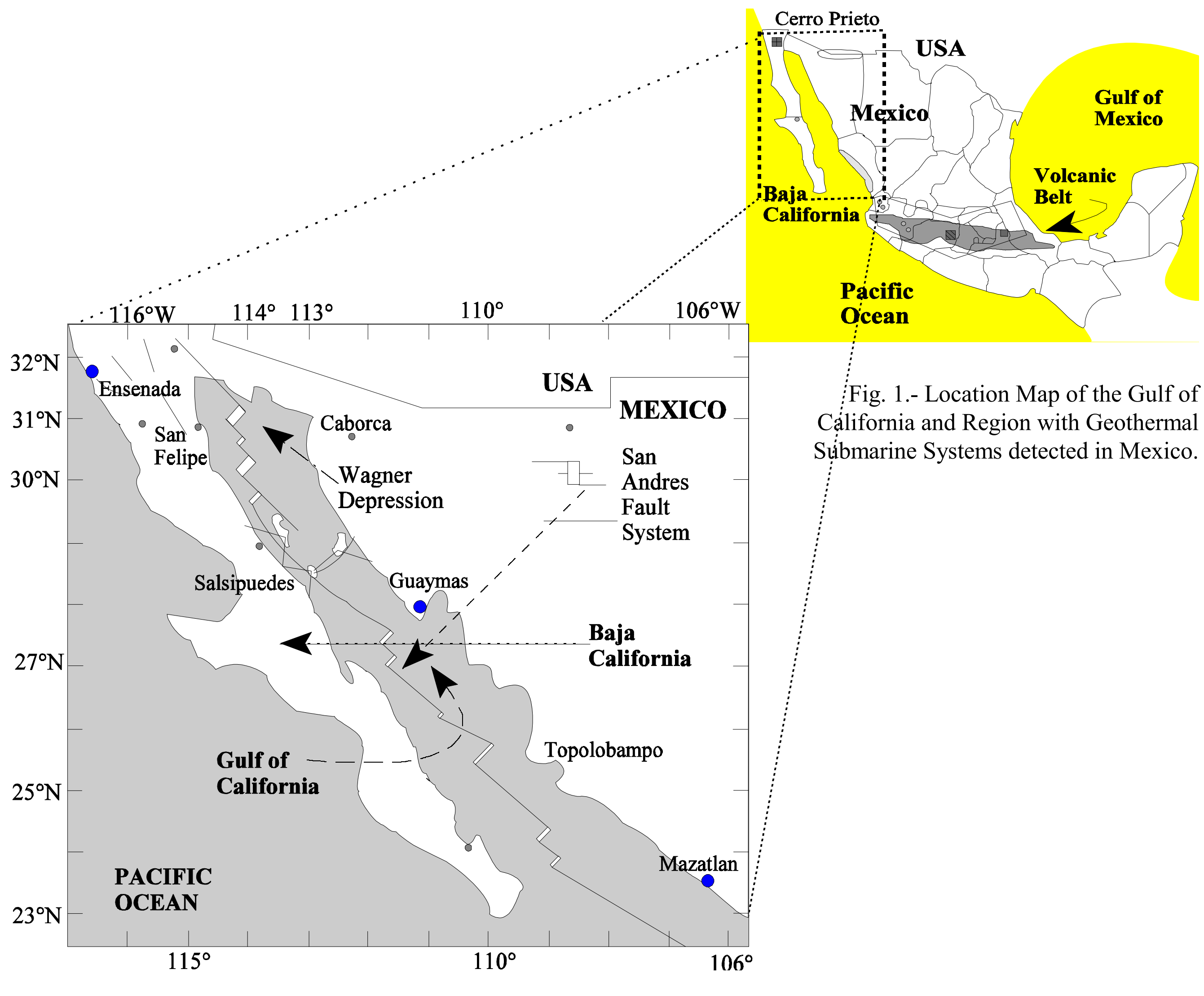

Fig. 1.- Location Map of the Gulf of California and Region with Geothermal Submarine Systems detected in Mexico.

Fig. 2.- Isotopes of HELIUM-3 in the Gulf of California (Data from Grijalva, 1986)