Proceedings Ninth Workshop Geothermal Reservoir Engineering
Stanford University, Stanford, California, December 1983
SGP-TR-74

MINERALOGY AND DISTRIBUTION OF HYDROTHERMAL MINERAL ZONES IN LOS AZUFRES (MEXICO) GEOTHERMAL FIELD.

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ABSTRACT

General features of the geometry of Los Azufres reservoir have been defined through the mapping of hydrothermal mineral alteration zones. Hydrothermal alteration has been studied in cuttings and drill cores from most of the active wells. X-ray diffraction microprobe analysis and classical optical methods have been employed for the identification of primary and authigenic minerals in fresh and altered samples. Observed patterns of alteration have been correlated with temperature and patterns of fluid circulation. The resulting model depicts a body of geothermal fluid at depth, which ascends and discharges through two main fracture systems. These two circulation zones are characterized by concentric aureoles of increasing hydrothermal alteration towards quasivertical axes. The overall pattern could be described as a dome structure produced by the abnormal thermal gradient, distorted by the effects of active upward circulation of the fluids.

INTRODUCTION

The Los Azufres (State of Michoacán) field is the second geothermal resource in México to undergo development, after the Cerro Prieto field in Baja California. Los Azufres field has an installed generating capacity of 25 MW, and the nearly forty wells that have been drilled offer ample opportunity for further development.

The primary geology of this field has been described by Camacho (1976), Gutiérrez-Negrin and Aumento (1981) and Oliver (1981). Briefly described, the geologic sequence consists of a series of volcanic layers, mostly andesites of a variety of textures, and rhyolites in the upper levels. Results of early studies of alteration mineralogy have been reported by Gutiérrez-Negrin and Aumento, (1981).

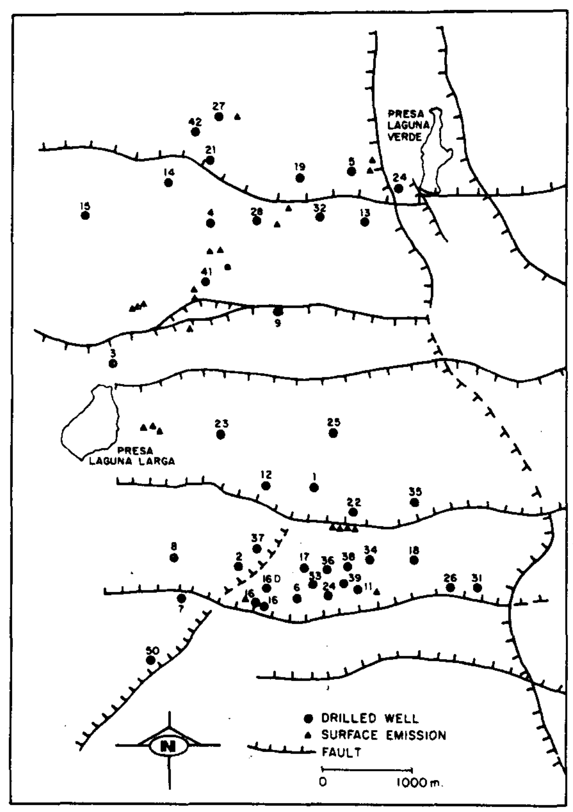


Fig. 1. Map of the Los Azufres Geothermal Field.

The extensive collection of drilling cores and cuttings available from new wells have provided the opportunity to study in more detail the effects of hydrothermal alteration. The present contribution describes the results of these studies, with evidence derived from X-ray diffractometry, microprobe analysis and optical micros copy applied to samples from most of the existing wells. The different associations of alteration minerals and their spatial distributions have been determined. The correlation of these distributions with measured temperature profiles has yielded a model which outlines the general geometry of the field and identifies the zones of circulation and discharge in the undisturbed system.

MATERIALS AND METHODS

Because of the lack of suitable outcrops, and the existence of pervasive weathering and hydrothermal alteration of shallow subsurface rocks, surface sampling was restricted to a few materials directly altered by surface manifestations. Most of the materials studied consisted of cores and cuttings obtained during drilling. Since cuttings from every 20 meters have been collected in the case of most wells, it has been possible to generate almost continuous profiles of nature and degree of alteration with depth.

Clays have been mechanically separated by crushing and centrifugation, and have been studied by classical methods of X-ray diffractometry. Mineralization in veins has been studied by optical methods, employing both reflected and transmitted light. More than 150 electron microprobe analyses have been performed, in order to define the exact composition of authigenic minerals.

Underground temperatures have been obtained from registers provided by field personnel. Only those registers obtained after proper thermal equilibration of the well have been considered. Downhole temperatures have been checked to be in good agreement with the estimates from chemical geothermometers.

MINERALOGY

Primary mineralogy: The authors distinguish two main groups of volcanic rocks in the area. One consists of spherulitic, glassy and pumicitic rhyolites, rhyolitic tuffs or ignimbrites, with essential constituents such as quartz, potassic feldspar, plagioclase, iron-rich biotite, zircon and glass. Other group is constituted by andesitic rocks, which show a variety of textures, grain size (aphanitic to porphyric) and mineral orientations. Essential constitutents of this second group include quartz, plagioclase, pyroxenes (augite, enstatite), magnetite, ilmenite, olivine and hornblende. Other volcanic units present are of minor interest and abundance, and occur as by lenses of basalt and dacite.

There are slight differences between previous reports (Camacho, 1976; Gutiérrez-Negrin and Aumento, 1982), and the primary mineralogy features described in this contribution. However these concern mainly nomenclature and terminology and the differences will not be discussed here.

Secondary mineralogy: The identification of alteration paragenesis has been facilitated by the lack of interference between primary and secondary mineralogy. Little evidence is found of the effect of external factors of alteration such as meteoric (except in shallow levels), sedimentary or diagenetic processes, which are normally important in geothermal fields located in sedimentary basins, e.g., Cerro Prieto (Elders et al , 1979), Salton Sea (McDowell and Elders, 1980).

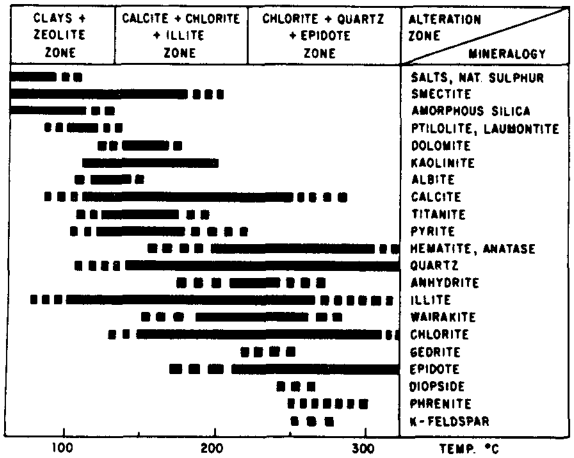


Fig. 2. Mineral Zonation in Andesites as a Function of Temperature.

Progressive changes in the mineralogy of the original andesites seem to be a function only of the temperature (Fig. 2), and of other chemical and physical conditions of the hydrothermal alteration process.

PARAGENESIS

Studies of veins and altered rocks show a regular sequence of mineral associations, which correlates with temperature and depth. Width of mineral zones varies as a function of local thermal gradients (Fig. 3). The observed mineralogy is compatible with metamorphism of Ca-Fe-Mg rich rocks. Signs of Na-K metamorphism apparently are absent in Los Azufres hydrothermal system, in contrast with findings in other current systems such as Salton Sea (Muffler and White, 1969) and Wairakei (Steiner, 1977), and fossil systems (Cathelineau, 1983; Cathelineau, 1984). Paragenesis corresponds to the zeolite, greenschist and amphibolite facies. The observed mineral associations, listed in order of increasing temperature of formation, are as follows:

- amorphous silica + native sulphur + smectites + gypsum + alunite.
- smectites + quartz + laumontite + ptilolite.
- calcite + chlorite + titanite + albite.
- calcite + wairakite + quartz + chlorite + anhydrite.
- chlorite + epidote + quartz + hematite + anatase.
- epidote + gedrite + chlorite.
- quartz + microcline + phrenite + epidote.
- epidote + diopside + quartz.

GEOMETRY OF DISTRIBUTIONS OF ALTERATION MINERALS

The information obtained from individual wells has been integrated in a three-dimensional map of distribution of alteration minerals. Horizontal cross-sections at 9 depth levels are shown in Fig. 3. Vertical cross-sections are shown in Fig. 4. Zero depth in these diagrams as well as in subsequent discussion corresponds to 2900 meters above sea level. The isobaths show the morfology of the surfaces of first appearance and the walls of dissapearance of selected minerals. Correlation of these mineral distributions with temperature profiles yield the following observations:

- Carbonates: Dolomite is scarce and replaced entirely by calcite at depths other than at the surface. Calcite disappears after a certain depth, yielding a flat, circumscribed zone of appearance.

- The level of appearance of epidote follows the isotherm 210-250°C. The epidote zone covers the entire horizontal spread of the field. Other calcsilicates such as amphibole and pyroxenes are found in localized sites, at depth greater than 2000 meters.

- Chlorite is distributed over the entire horizontal spread of the field at deep levels, but is restricted to two columns of alteration at levels shallower than 1500 meters. Detailed chemical composition data show a continuous evolution of chlorite solid solution parameters with temperature (Cathelineau and Nieva, 1983).

- Iron minerals: Magnetic and ilmenite are unstable and replaced by pyrite and titanite below the very shallow levels. The latter are replaced by hematite and anatase at deeper

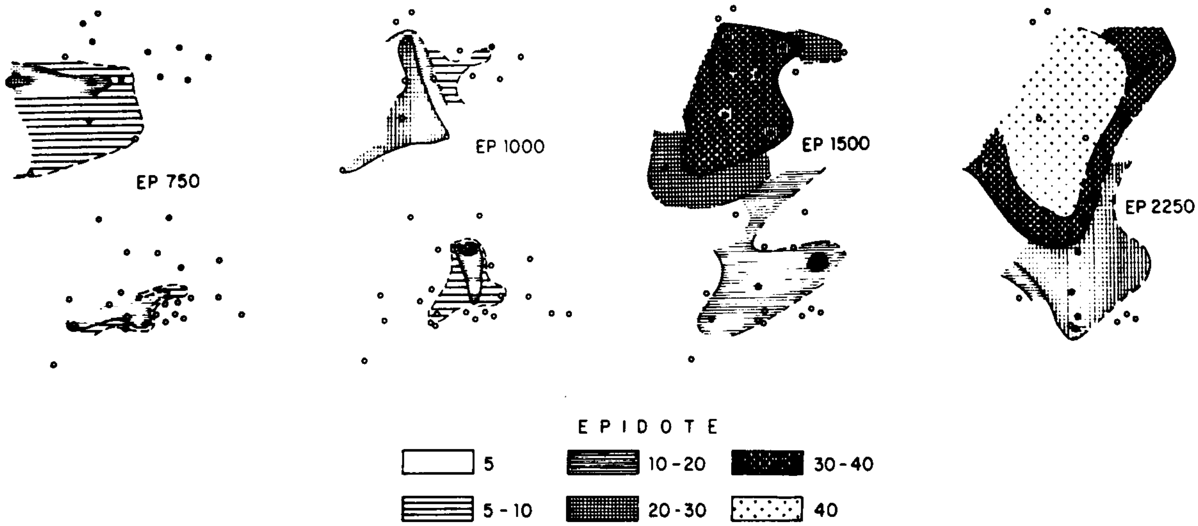
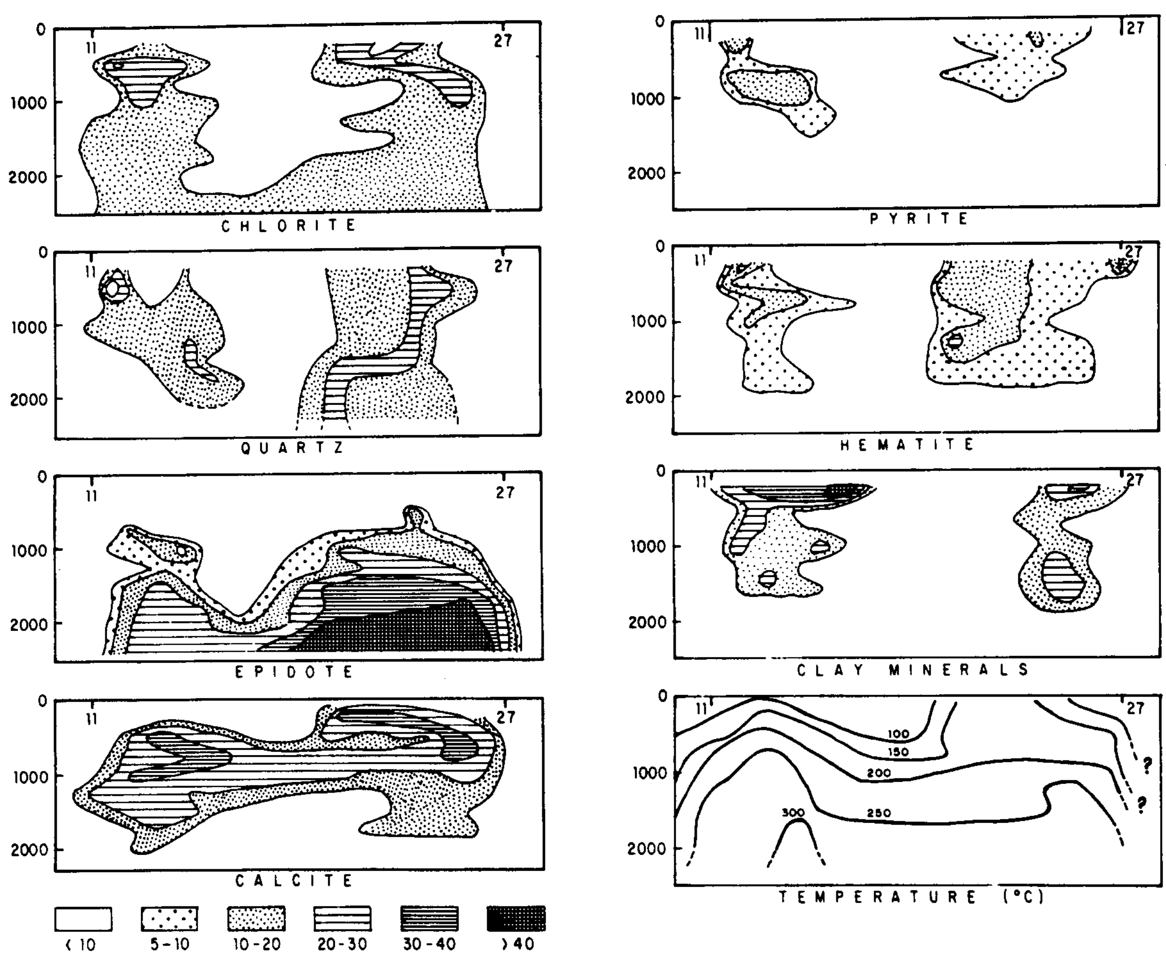


Fig. 3 = Maps of distribution of epidote at different levels _ arbitrary scale 0-40 indicates the relative abundance of the mineral.

Fig. 4 = Cross section along the line Well 11 - Well 27 of distribution of minerals and isotherms (depth is indicated in meters).



levels. The epidote-hematite association is noteworthy, since epidote-iron sulphide association are more common in most of the studied hydrothermal systems, such as Larderello (Cavaretta et al, 1980) and the Geysers (Steinfeld, 1981).

- Distribution zones of some of the alteration minerals follow quite closely the distribution of temperatures. The case of epidote is mentioned above. The distribution zone of calcite corresponds to temperatures of 100 - 250°C. Appearance of pyrite corresponds to temperatures of 100 - 150°C.

- Distribution zones of quartz, chlorite and clay minerals are contained within two columnar sections which appear to represent natural circulation and discharge zones.

DISCUSSION

The observed alteration patterns are indicative of prograde metamorphism. There is considerable coherence between temperature distribution and alteration patterns. No evidence was found of superposition of incompatible associations of alteration minerals, or of retrograde metamorphism.

The overall shape of hydrothermal alteration reflects the superposition of two main factors. One factor is the effect of the thermal gradient abnormality which produces a soft dome structure with sub-horizontal alteration zones. The second factor, which distorts this dome structure, is the hydrothermal alteration produced by ascending fluids in two main zones of circulation and discharge. These zones of circulation produce the two areas of alteration in the surface.

The southern zone consists of a well defined, narrow vertical zone of circulation. Short spacing of isotherms, and of lines of mineral stability, define aureoles of increasing alteration toward a center of activity. At the surface, this circulation zone produces hot springs, mud pots and mud lakes, which distribute roughly along the space between the Los Azufres and Agua Fría faults. This area of the field is known as Tejamaniles.

The northern circulation zone has a larger average diameter. It shows the same general pattern of aureoles of increasing alteration towards a center of activity. However, the lack of data points, particularly in the northern and southeastern sections of this zone, do not allow the definition of the horizontal spread of these aureoles. This circulation zone produces surface manifestations, which distribute roughly along the Maritaro fault. This area of the field is known as Maritaro.

SUMMARY

The mineralogy of hydrothermal alteration in Los Azufres field corresponds to that of a young system subjected to prograde metamorphism. A regular sequence of mineral associations is found as a function of depth and increasing temperature. The width of the different mineral zones varies horizontally with the thermal gradient. Some hydrothermal minerals such as epidote and pyrite could be used as indicators of certain ranges of subsurface temperature.

Mapping of the distribution of alteration minerals provides a picture of the general geometry of the field. There appears to be a main aquifer at depth, which discharges through two circulation zones, which probably originate from two main fracture systems. These circulation and discharge zones give rise to the Tejamaniles and Maritaro geothermal areas, which may appear to be unrelated at the surface.

ACKNOWLEDGMENTS

The work described in this report constitutes part of a project supported by Consejo Nacional de Ciencia y Tecnología of México under contract PIT/EN/NSF/1810.

The authors want to express their indebtedness to the personnel of Los Azufres Field and Departamento de Exploración, Gerencia de Proyectos Geotermoeléctricos of Comisión Federal de Electricidad for their general support and assistance during the conduction of these studies.

Authors are indebted also to the Centre de Recherches sur la Geologie de L'Uranium for technical, analytical and scientific assistance.

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