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BOREHOLE GEOLOGY AND HYDROTHERMAL ALTERATION OF WELL CHA-1, CHIPILAPA GEOTHERMAL FIELD, EL SALVADOR, C.A.

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ABSTRACT

The report describes the borehole geology of the directional well CHA-1, located inside the Cuyanausul graben, in the southern part of the Chipilapa geothermal field, and approximately 8 km southeast of the Ahuachapan geothermal field. The well had a total measured depth of 2750 m and was designed to be drilled directionally in order to intersect the Cuyanausul fault. The stratigraphic sequence found was mainly alternate sequences of basalts - basaltic andesite to andesite lava flows with interlayering of lithic tuff. The formation found at the bottom of the well is basically a sequence of fine grained lithic tuff and lithic tuff with andesitic breccias. The main aquifer in well CHA-1 is at 650-734 m depth, with a measured temperature of 200°C. This aquifer is actually cased off and therefore it is not possible to exploit it. Minor feed zones were identified at 866, 1037 and 1377 m depth. No circulation losses were found below 1400 m depth and the well showed very low permeability. Furthermore, three probable minor feed zones were identified by hydrothermal alteration, at 1900, 2200 and 2550 m depth. They were not noticed during drilling and probably sealed off by mud or mineralization.

Through analysis of clay minerals with X-ray diffraction and by analysis of secondary minerals in thin sections with a petrographic microscope, two geothermal episodes were found; an early alteration episode and a late one. Temperature measurements correlated with alteration temperatures show:

a. Actual mineral temperatures are in equilibrium with measured temperatures in the upper 1200 m, with a maximum temperature of 200°C. Late geothermal episode suggests a probable cooling occurring between 650-1000 m.

b. Mineral temperatures are higher than the measured temperatures in the depth range of 1250-2580 m.

c. Actual mineral temperatures show evidence of a probable cooling occurring near the bottom of the well, between 2580 and 2660 m, by fluids of lower temperature than 230°C or by a mixing of groundwater flow. The presence of mixed layer clays in this zone, is suggestive of a zone with higher permeability than the upper layers. Just as in other wells north of the Chipilapa field, the alteration mineralogy of well CHA-1, suggests an inflow of colder fluids in the uppermost 1200 m. Only CHA-1 shows a probable cooling at 2580-2660 m depth. With respect to the three aquifers found in the Chipilapa field (shallow, intermediate and probable deep aquifers), including well CHA-1, the maximum temperatures reached are in the range of 175-220°C.

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1. INTRODUCTION

1.1 Introduction and scope of work

Exploration of geothermal resources in El Salvador was initiated in the late fifties with a regional reconnaissance study carried out by experts of the United Nations. These studies led to the selection of geothermal areas for further studies, including Ahuachapan-Chipilapa, Berlin, San Vicente and Coatepeque. As a result of these investigations the Ahuachapan geothermal field has been producing 60 MW_e since 1975, but has an installed capacity of 95 MW_e. The Berlin geothermal field, has been producing 5 MW_e since 1992.

Due to the limited natural energy resources in El Salvador, the Comisión Ejecutiva Hidroeléctrica del Rio Lempa de El Salvador (CEL) has developed geothermal projects in order to fulfil the Expansion Plan of Generation of Electricity up to the year 2002. These projects include prefeasibility studies in the areas of Coatepeque, feasibility studies in the areas of Chipilapa and San Vicente and developing and exploration projects in the Ahuachapan and Berlin fields. Intensive exploration work has been carried out in these areas, including production and reinjection drilling, with the purpose to reach an installed capacity of 165 MW_e by the year 2000. In order to accomplish this aim, more than 28 wells with a depth of 1500-2500 m are scheduled to be drilled in the four areas mentioned above, in the next four years (Campos, 1990).

Drilling is one of the principal tasks in the development of geothermal systems. It is important to have an appropriate design of the well as well as complete control of the subsurface lithology through cuttings and cores. Through this information it is possible to know how the geological structures control the movement of geothermal fluids in the reservoir, as well as the relationship between the alteration minerals and the present-past conditions of the hydrothermal system. CEL considers the training of its technical staff an important part of a successful drilling stage, and with the aid of the United Nations University it was possible for the author to participate in the training course in Borehole Geology held at Orkustofnun - The National Energy Authority of Iceland. The course included introductory lectures on general aspects in geothermal research, specialized lectures on alteration minerals, field excursions to the different geothermal areas in Iceland, theoretical and practical analysis of X-ray diffraction (XRD), separation of mineral clays, analysis of cuttings by binocular microscope and analysis of thin sections by a petrographic microscope, as well as an introductory training in the analysis of fluid inclusions.

This report deals with the borehole geology of a deviated well CHA-1 drilled at the Chipilapa geothermal field with a comparison to an adjacent vertical well CH-A. The completion of the report is very important for the Area of Petrology, Research Center of Geothermal Resources of CEL, because it includes and summarizes the procedures and methodology to apply in the future for control of the lithology in the next wells to be drilled in the geothermal projects mentioned above.

1.2 Regional geology and tectonic setting of El Salvador

El Salvador, the smallest country in Central America (21,000 km^2), is tectonically one of the most active regions due to the interaction of the Cocos Plate beneath the Caribbean plate on the Atlantic side. All the tectonic and volcanic events around the country, are controlled by the subduction process between these two plates and by the tectonic movement of transcurrent faults between the Caribbean Plate and the North American Plate through the Motagua-Polochic-Jocotan fault system (Campos, 1987) (see Figure 1). The subduction process is responsible for the calc-alkaline volcanic rocks and a series of extensional faulting which create a graben structure crossing the region with a WSW-ENE trend. Figure 2 shows the two major volcanic systems parallel to the Pacific coast. These are located north and south of the central graben respectively and provide a potential source of geothermal energy. The Tertiary volcanic system north of the central graben consists basically of a sequence of agglomerates, tuffs and acidic intrusions. This area is characterized by hot springs which indicate low to intermediate subsurface temperatures less than 200°C. The Quaternary volcanic system located at the south of the central graben, consists of agglomerates, basaltic and andesitic lavas and tuff.

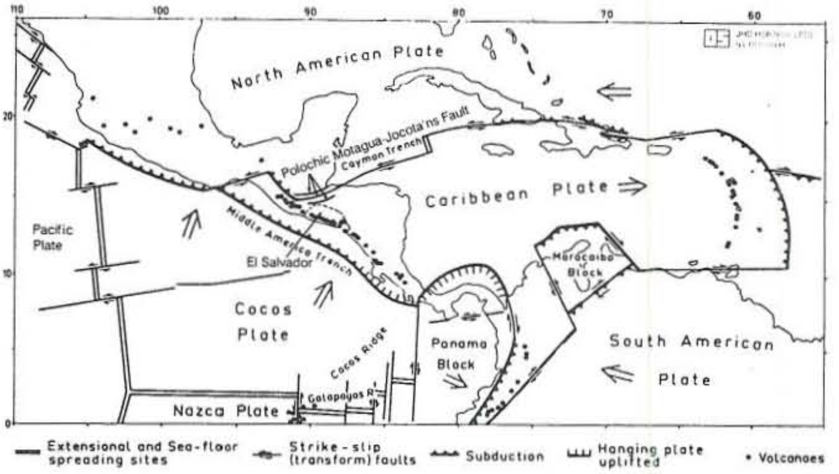


FIGURE 1: Plate tectonics in Central America and the Caribbean region (Weyl, 1980)

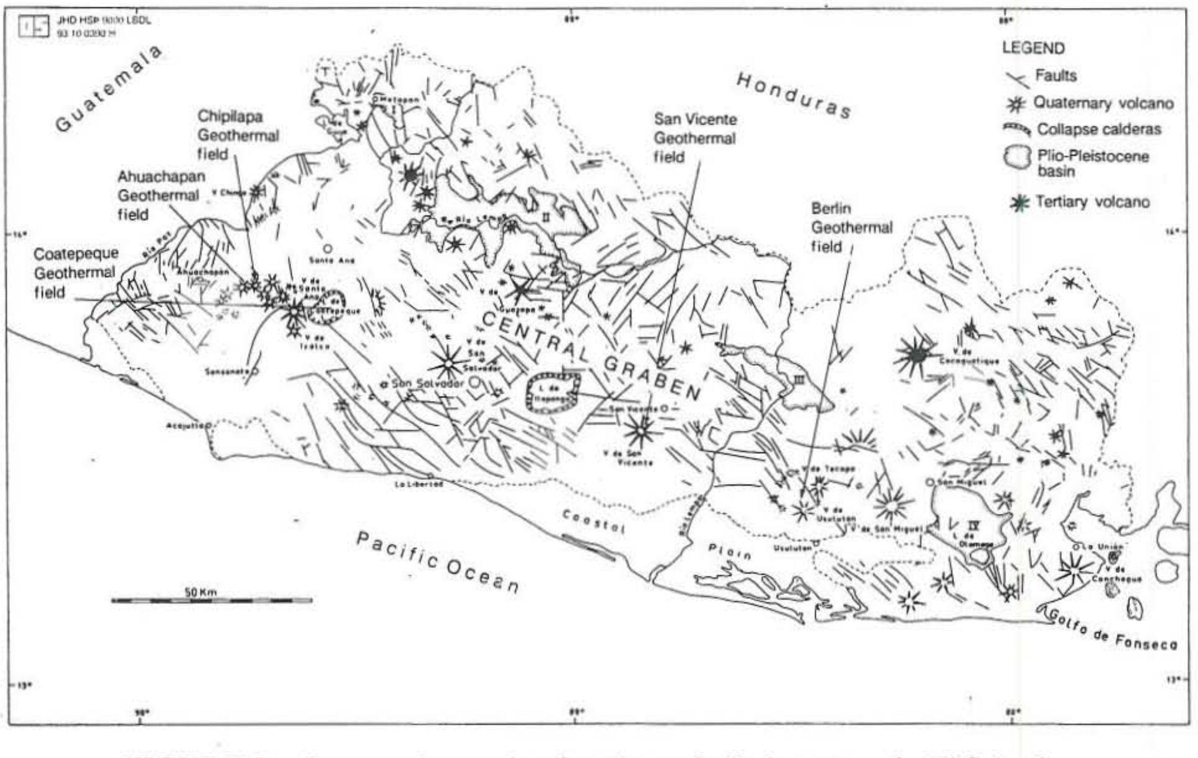


FIGURE 2: Structural map showing the main fault systems in El Salvador (Weyl, 1980)

All high temperature geothermal fields are located north of this volcanic chain and surface manifestations of hot springs and fumaroles indicate temperatures higher than 200°C. Besides the WSW-ENE structural system which formed the central graben, there are four predominant structural fault systems N-S, NNW-SSE, NE-SW and NW-SE; the N-S and NNW-SSE being the most active systems which give the region a great geothermal interest (Weyl, 1980).

2. CHIPILAPA GEOTHERMAL FIELD

2.1 Location and wells

The Chipilapa geothermal field is located in West El Salvador, nearly 5 km to the east of the Ahuachapan geothermal field within the coordinates 13°56'N and 89°47'W. It covers an area of about 10 km^2. The field is at a feasibility stage, where geoscientific studies (volcanology, geophysics, geochemistry, hydrogeology, as well as passive seismic studies, reinjection and tracer test) have been done to evaluate the potential of the area. Since 1968, two shallow exploratory wells and eight wells designed for production and/or reinjection have been drilled, most of them in 1989-1993. General data of the eight wells, excluding the exploratory wells, are listed in Table 1.

TABLE 1: General characteristics of wells in the Chipilapa geothermal field

Well	Elevat. (m a.s.l.)	Coord. x,y	Year drilled	Max. temp. (°C)	Location 9⅝" OD (m)	Depth (m)	Remarks
CH-1	757.94	414828 311748	1968	200	-	984.85	Not known if the well was put into production, probably not able to produce.
CH-7	765.70	415490 311638	1989	195	543.0	1500.0	Permeable, but has not been able to produce.
CH-8	914.20	415733 310730	1989	225	980.0	2556.0	Not producing, permeable zones at 1000-1300 m and possibly at bottom, probable cooling at 1000-1300 m.
CH-9	741.00	415000 312177	1990	210	998.78	2001.0	Not in production, permeable zone at 1037-1999 m, possible cooling at 1750 m.
CH-7b	757.93	414755 311800	1991	170	423.75	1349.0	Not in production, permeable zone at 1117-1344 m.
CH-A	1148.50	416687 309544	1992	239	1128.31	2700.0	Not in production, small circulation losses indicate low permeability.
CHA-1 direct.	1148.50	416687 309544 BHCoor: 417313 309200	1992	200	1592.57	MD:2750 VD: 2543 HD:730.8 S61.31°E	Not in production, small circulation losses, possible cooling and self sealing.
CH-D	869.0	414350 310620	1993	220	749.0	1500.0	Not able to produce, total circulation losses 829-1500 m, low well head pressure.

Note:			
BHCoor.	- Borehole coordinates	MD	- Developed depth in m
VD	- Real vertical depth in m	HD	- Horizontal displacement in m

The well CH-1 was drilled in 1968 and two shallow exploratory wells CHE-1 and CHE-2 during 1975-1976 with a continuous sampling of cores. Drilling in the area was then suspended for more than ten years. In 1989-1991, four wells were drilled in the northern part of the area, with the purpose to find steam to supply a proposed backpressure plant. As a result of these investigations, a medium enthalpy geothermal reservoir was found with temperatures between 180 and 200°C.

New drilling areas were then selected in order to find higher temperatures. Wells CH-A and CHA-1 are located in the southern part of the area, inside a small NW-SE trending graben, close to the Cuyanausul fumarole, the most active of the region. Well CH-A was drilled vertically intersecting the Agua Shuca fault, while well CHA-1 was deviated to the east to intersect the Cuyanausul fault. These were the first attempts to drill in areas above 1100 m a.s.l. (CEL, 1993a).

The last well drilled, CH-D, is located at the eastern margin of the Ahuachapan geothermal field, approximately 1 km east of well AH-14. The purpose was to find possible connections between the two fields. The well, with a depth of 1500 m, has a permeable zone starting at 850 m depth reaching to the bottom (CEL, 1993b).

2.2 Geology

Two types of volcanism can be identified in the Chipilapa area, Plio-Pleistocene and Quaternary volcanism. Regionally, since the Pliocene to the end of Quaternary, different volcanic groups have been formed at the southern margin of the central graben (IIE, 1992a).

Geochemical data was used to define the different volcanic units observed on the surface. The geological map describing the lithological units as geochemical units is shown in Figure 3. The main geochemical units from the Chipilapa area are the following.

Geochemical unit	**Volcanic unit**
D - Dacite	Domes and dykes
Cl - Basalt-andesite	Ash falls and lapillis, Las Ranas
Bef - Andesite	Phreatic explosion deposits, Laguna Verde
B-Af - Andesite	Fluidal basalts, Laguna Verde
Bpn - Basalt	Las Ninfas
Pp - Dacitic-rhyolite	Pyroclastic deposits
BCy - Basaltic-andesite	Cuyanausul
Ba - Basaltic-andesite	Basement

Plio-Pleistocene. The local basement is characterized by a sequence of agglomerates of lava fragments embedded in ash matrix, lava flows with basic-intermediate breccias and scorias. Petrographically these rocks are andesitic lavas with a holocrystalline texture with microlithic matrix and phenocrysts of labradorite and pyroxene. This unit is not seen in Figure 3, but is found in the southern part of the Chipilapa area.

Quaternary. According to the regional studies of surface geology of the Ahuachapan and Chipilapa areas, the main lithological units exposed in the Chipilapa area are as follows, listed in a chronological order from the oldest to the youngest groups.

D: Inside the Cuyanausul volcanic complex. Mainly composed of several andesitic-dacitic domes and dykes, dykes are mostly trending NW-SE. The group of domes east of Chipilapa are also affecting the El Tortuguero and Las Termopilas hydrothermal areas. The San Lazaro dome, located north of Cuyanausul volcano, is considered to be a very shallow intrusion that did not reach the surface, but instead affected the lava flows from Laguna Verde on the surface by giving them a semicircular and dome shape. It is associated with the Cuyanausul dome.

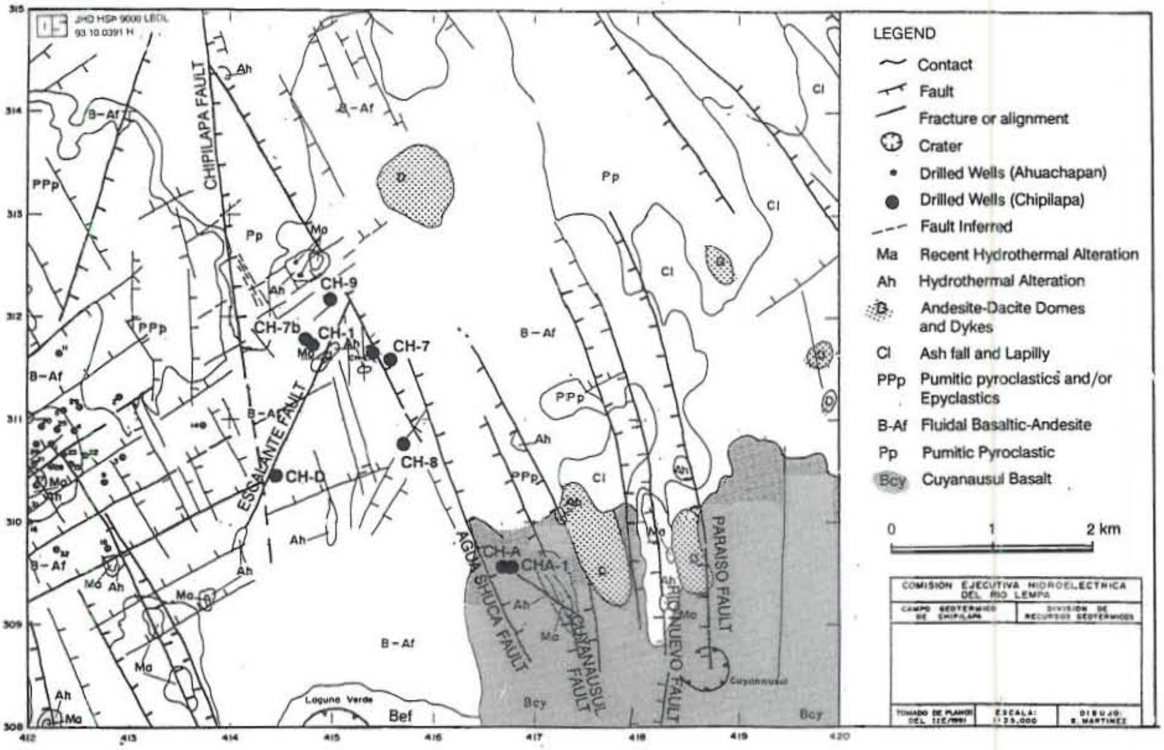


FIGURE 3: Geological map of Chipilapa geothermal field (IIE, 1992a)

Cl: Ash fall and lapilli from the Las Ranas volcanic group, located east of Cuyanausul. Its composition is mainly basaltic-andesite.

PPp: Pumitic pyroclastics and/or epiclastic deposits. It is basically an agglomerate unit with local ignimbrite rock and tuff with basalt-andesitic fragments.

Bpn: Las Ninfas volcanic group consisting basically of basaltic lava flows. It is located west of Chipilapa.

B-Af: Laguna Verde volcanic complex. Basalt-andesite lava flows characterize this unit. The explosive crater ("maar") Hoyo del Cuajuste, located between Laguna Verde and Las Ninfas, at the same elevation, emitted basaltic ash fall and surge deposits that covered the slopes close to the craters of Laguna Verde and Las Ninfas.

The late stage lava flows from Laguna Verde and Las Ninfas, extend widely to the north inside the central graben covering an area of 39 km^2 and have a collective thickness of 80-120 m (IIE, 1992a and b).

Pp: Pumitic pyroclastics. These are mainly base surge deposits with ignimbrite layers, characterized by "fiammes" structures. It is mostly a sequence of pink pumice inside a fine matrix of acidic ash fall. In the stratigraphic sequence of the area, these deposits overlie the basement south of Chipilapa and their origin is related to a caldera structure located 15 km west of Chipilapa. The caldera is not shown in the map.

BCy: Cuyanausul Plan-Hernandez. It is basically a sequence of andesites and scoria deposits. Cuyanausul was a stratovolcano with strombolian activity. The formation mainly overlies the local basement. The crater was eroded and the original conical shape, is not seen.

The stratigraphic sequence observed in the area shows a calco-alkaline type evolution, defined by a deposition of lavas with basalt-andesitic composition, following the dacitic-rhyolitic (ignimbrite) event. It corresponds to an explosive event after the Cuyanausul volcano was formed. Afterwards, an intensive formation of domes and dykes with andesitic and basaltic composition took place.

2.3 Geochemistry

The major fumaroles in the Ahuachapan-Chipilapa area are the Cuyanausul in the northern slopes of Cerro Cuyanausul, El Sauce on the northern slopes of Laguna Verde volcanic complex, Agua Shuca and El Playon near the Ahuachapan well site; and La Labor and Chipilapa in the Chipilapa region. Chemical analysis of gas samples from Ahuachapan and Chipilapa, show similar gas composition implying a common geothermal source fluid. Gas geothermometry of Cuyanausul fumaroles gives evidences of temperature greater than 240-250°C.

A general model of the hydrothermal system has been developed, which gives the estimated subsurface temperatures and the genetic origin of the fluid with respect to the other types of waters from the area. This includes the chemical analysis from hot springs, water from domestic wells and geothermal wells and chemical and isotopic analysis (oxygen 18 and deuterium) of natural water and volatile components of the fumaroles (Geotermica Italiana, 1992). The model states that an upflow of hot water through faults mostly trending NW-SE, gives origin to the fumaroles of El Tortuguero, Las Termopilas and El Playon, which by gas geothermometers give temperatures greater than 200°C. The hydrothermal manifestations of Agua Shuca, El Sauce, La Labor and Chipilapa are fed by steam at low temperature conditions (140-180°C). Whatever the origin of the steam the feeding zone of the second group corresponds to a "reservoir" with less geothermal interest with respect to the feeding zone of the first group (Nieva et al., 1990).

A higher hydrogen content in surface manifestations, southeast of the area, suggests that the Ahuachapan-Chipilapa system is fed by an upflow zone, probably located beneath the Laguna Verde volcanic complex. The temperature of this upwelling fluid is believed to be 250°C or higher, as suggested by geochemical temperatures of the discharged fluid (Laky et al., 1989). Only a small branch of this upflow feeds the Chipilapa area, possibly through the Escalante fault, where it mixes with shallow waters. These mixed fluids could laterally emerge very diluted through the hydrothermal manifestations of La Labor and Chipilapa.

Most of the upwelling fluids from Ahuachapan flow to the north. The main outflow for this system is in the El Salitre spring area, located about 7 km north of the Ahuachapan well site. The discharge is a mixture of geothermal and shallow aquifer fluids. The mixing is believed to occur in the vicinity of the springs rather than close to the geothermal field. Domestic wells and cold springs to the north of the area (Turin-Atiquizaya), are characterized by a content of chlorides between 150-350 mg/l. This may indicate a probable mixture of the sodium chloride rich geothermal fluid (probably derived from Ahuachapan-Chipilapa) and shallow water with low salinity. A maximum temperature of 250-270°C (Na-K geothermometer) can be estimated (see Table 2).

Geochemical results from the analysis of deep water from both wells, define three different aquifers:

TABLE 2: Geothermometry of deep samples from wells and hot springs (data from CFG, 1992)

Sample	SiO_2 (°C)			Na/K (°C)			NaKCa (°C)		NaKCa (°C)	Mg (°C)	Na/Li (°C)
	Am	Cal	Q	Fo	Ar	Tr	4/3	1/3			
CH-7b:											
520 m	78	154	202	201	176	168	223	198	223	198	161
1200 m	83	160	208	169	139	129	197	175	196	174	139
CH-9:											
1370 m	110	188	235	212	189	182	233	206	233	206	179
1700 m	83	160	208	215	193	185	247	211	246	210	164
La Labor	63	138	187	238	221	215	123	189		60	159
Salitre	45	118	168	211	188	181	149	185	185	99	151

1. A shallow aquifer at approximately 500 m, probably biphasic;
2. An intermediate aquifer at approximately 1200 m, influenced by colder fluids;
3. A deep aquifer at a depth greater than 1700 m, rich in gases and giving evidence of temperatures higher than 200°C.

Fluid geochemistry shows that scaling may occur in wells from Chipilapa. Calcite scaling occurs at a flashing zone at 720 m and amorphous silica scaling when the temperature of the fluid is lowered to 85°C, and less than 120°C for the separated water. Chemical data from wells CH-A and CHA-1 are not reported, because water and gas samples could not be collected.

2.4 Geophysics

Many surveys have been done in the area during the last 20 years. These include gravimetric surveys with 27 stations, magnetometric, geoelectric with 132 Schlumberger soundings, 5 lines with dipole-dipole soundings and magnetotelluric survey carried out by Geosystem with 82 soundings. The last study was a magnetotelluric survey, done by CICESE in 1991. The data gathered by these recent studies and resistivity measurements can only identify horizons of aquifers down to a depth of about 1000 m. The high resistivity layer identified at the maximum depth has been interpreted as the deep reservoir. It also has been interpreted as the top of the alteration zone of chlorite-epidote. Microseismic studies carried out in the years of 1988 and 1989, define a high seismicity zone characterized by events with shallow epicentres (1.5 km deep), localized inside the area of the Cuyanausul graben. The interpretation of this data predicts an upflow of geothermal fluid associated with Agua Shuca and Cuyanausul faults trending NNW-SSE (Figure 4). A new interpretation of gravimetric and geoelectric data was done in 1992, using all data obtained from previous surveys. Gravimetric modelling assumes that anomalies found inside the caprock (possibly the presence of a dense body) might be related to the existence of dykes, domes or intrusions at depth (Figure 5). Geoelectric data has a good correlation with the lithological units found in the stratigraphy of wells as well as with the mineral alteration zones (Geotermica Italiana, 1992).

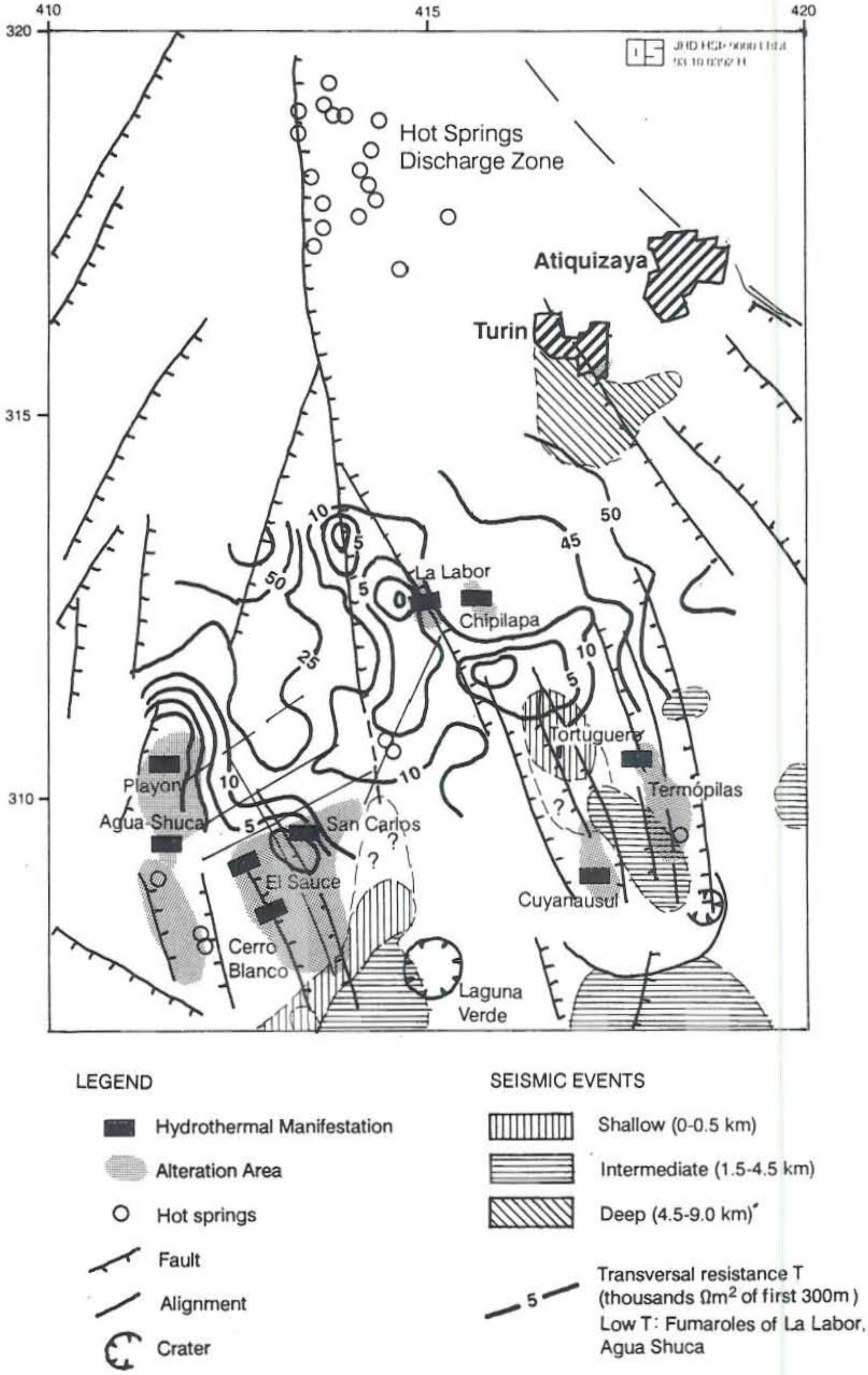


FIGURE 4: Map for the Chipilapa field showing hydrothermal manifestations, microseismic zones and geophysical data (CFG, 1992; Geotermica Italiana, 1992)

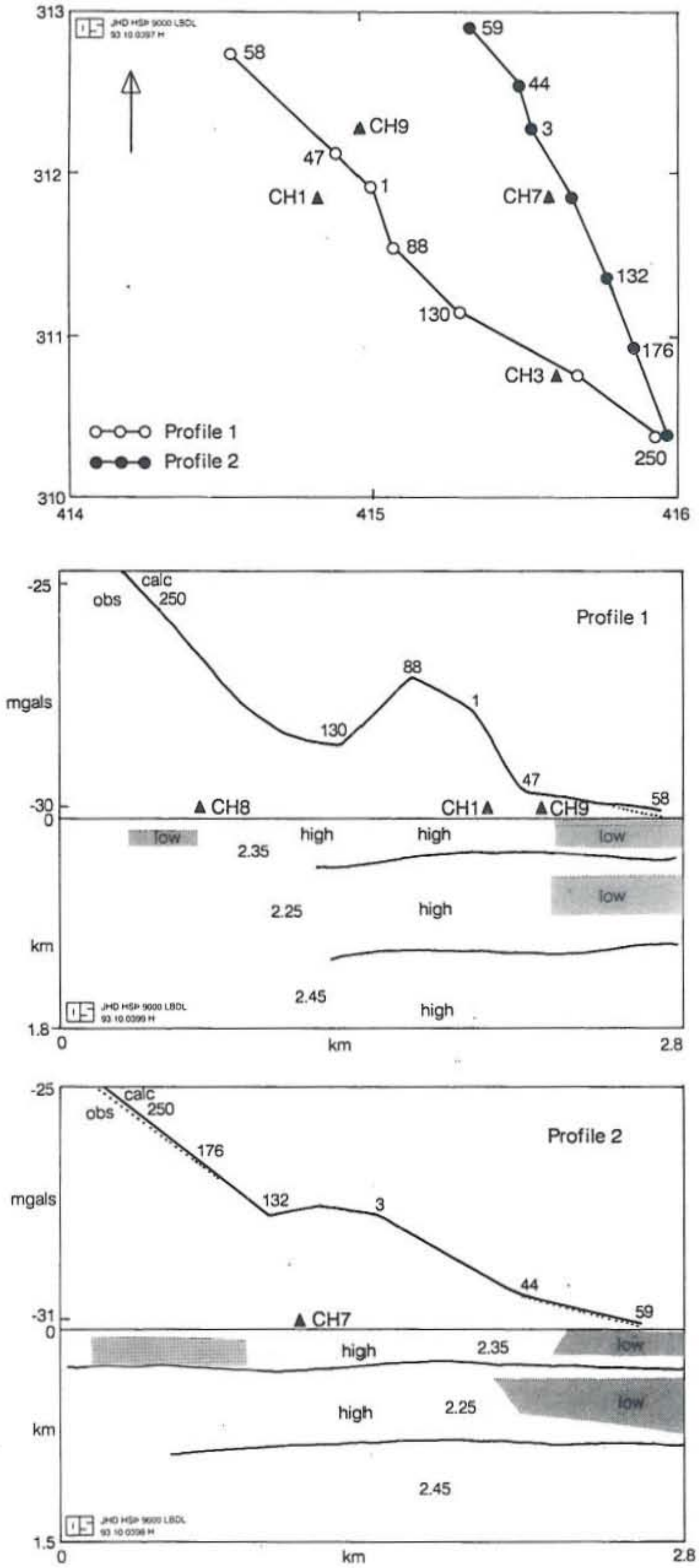


FIGURE 5: Gravimetric models for the Chipilapa geothermal field (Geotermica Italiana, 1992)

3. BOREHOLE GEOLOGY OF WELL CHA-1

3.1 Location and design of well CHA-1

Well CHA-1 was located just 10 m from the vertical well CH-A. Well CH-A was sited inside Cuyanausul graben in order to explore the geothermal resources at the southern part of the Chipilapa area. This zone belongs to the Cuyanausul volcanic group, which according to recent geovolcanological studies is older than the Laguna Verde and Las Ninfas volcanic group, of which the Ahuachapan geothermal field is a part.

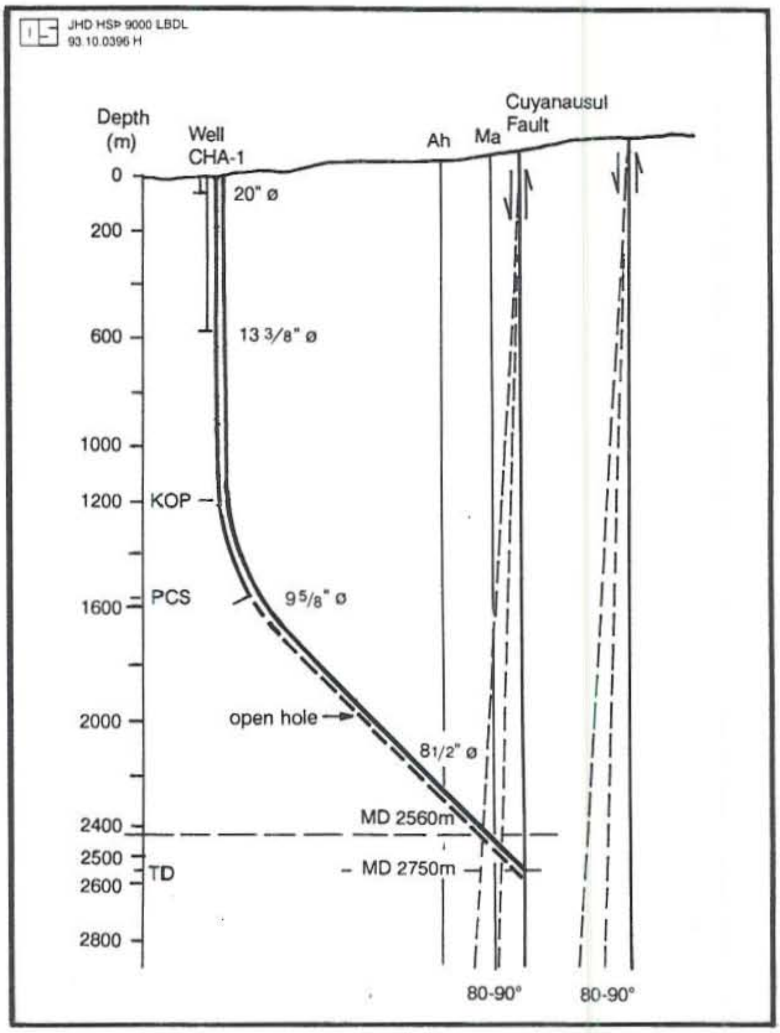


FIGURE 6: Location and design of well CHA-1

The shallow aquifer intercepted by well CH-A and cased off, indicated a medium enthalpy reservoir with temperatures around 200°C, because of low permeability and low temperature. The well probably intercepted the Agua Shuca fault at approximately 2100 m depth. There are minor circulation losses found at that depth. Well CHA-1 was sited nearby and designed as a directional well with the purpose of intercepting the Cuyanausul fault. Both wells are located approximately 1.5 km from the present drilling area. Figure 6 shows the design and location of well CHA-1

3.2 Drilling history

Well CHA-1 is located at 416.687 m latitude and 309.544 m longitude, at 1148.5 m a.s.l. It is the first directional well to be drilled in El Salvador. It has a bottomhole coordinate of 417.313 m latitude and 309.200 m longitude, a vertical depth of 2543 m, and a measured depth of 2750 m trending S61.31°E. The drilling was done with the aim of intercepting the Cuyanausul fault to evaluate the possibility of finding a geothermal reservoir in the Cuyanausul graben with a NW-SE trend. The drilling started May 23rd, 1992 and ended February 5th 1993. The activities can be summarized as follows:

First stage: The drilling from surface to 49 m was done with a 26" bit. The casing of 20" was sunk down to 44.9 m depth.

Second stage: Formation was drilled from 48.93 to 614.8 m with a 17 1/2" bit. A few minor circulation losses occurred at 400-460 m which were controlled by obturants (coffee shells). The 13 3/8" casing was sunk to 600 m.

Third stage: Formation was drilled from 614.8 m to a measured depth of 1595.3 m, with a 12 1/4" bit. Several minor circulation losses occurred at 660-730, 866, 1086 and 1374 m depth. All were sealed with cement. The 9 5/8" casing was sunk to 1592.6 m depth. The kick off point of the well started at 1200 m depth. The inrun survey data by minimum curvature done in the well is included in Appendix I.

Fourth stage: Formation was drilled from 1595.3 m to a total measured depth of 2750 m with a 8 1/2" bit. No circulation losses were identified in this part. This last part of the well was left as an open hole. The time table for the complete drilling is shown in Figure 7.

Several problems occurred during drilling, as is evident by the long drilling time of seven months. This is mainly attributed to the frequent breakdowns of the drilling equipment and drill bits, which often took a long time to repair. The control of the inclination and direction of the drilling was one of the main concerns during all stages, as the aim was to intercept the Cuyanausul fault at a reasonable depth. Appendix II summarizes the main drilling activities of well CHA-1. Drilling mud was mostly used as a circulation fluid with an additional diesel to increase the rheological properties.

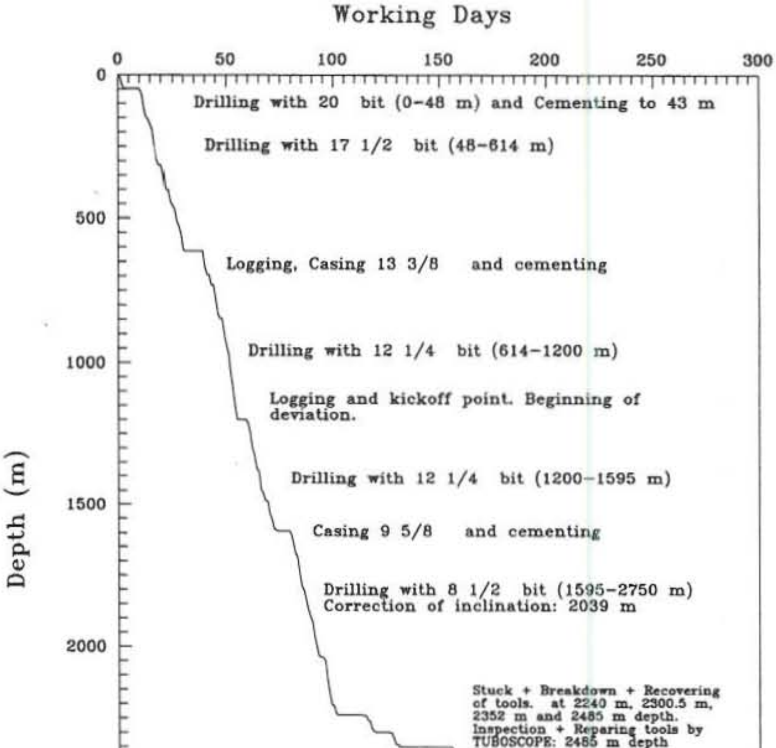


FIGURE 7: Time table for drilling directional well CHA-1

3.3 Stratigraphy

The lithology of well CHA-1 was first studied in 1992-1993 through stereoscopic microscope analysis of cutting samples taken every meter. In this report, a review of each lithological unit is done, through the analysis of cuttings every 10 m. Thin sections were made at a 20 m interval or in some cases 10 m, especially in zones of interest and later analyzed under a polarizing microscope.

Based on the study of cuttings and thin sections, the strata is divided into seven stratigraphic series for simplification. The stratigraphic units encountered are:

1.	**0-48 m**	**Superficial layer of a pyroclastic deposit with fragments of andesitic lava, scoria and lithic tuff at the base.**
2.	**48-559 m**	**Alternate sequence of basaltic-andesite lavas, andesitic lavas grey maroon and medium-light grey lithic tuff.**
	49-140 m	Basaltic-andesite lava scoria and grey lithic tuff; occasionally vesicular, fractured and sealed.
	40-196 m	Basaltic-andesite lava, low density of fractures and low alteration.
	196-268 m	Andesite lava grey-reddish with fragments of lithic tuff increasing at the bottom.
	268-296 m	Basaltic andesite lava, dark grey, fractured.
	297-365 m	Sequence of grey maroon andesite lava with grey lithic tuff medium grey.
	366-445 m	Medium light grey lithic tuff with grey maroon andesite lava, low fracturing at the bottom.
	446-559 m	Dark grey basaltic andesite partially fractured and sealed; small horizons with grey brown fine lithic tuff.
3.	**559-820 m**	**Lithic tuff with thin layers of andesitic lava.**
	560-606 m	Grey-brown interstratified lithic tuff with thin layers of grey andesite lava.
	607-679 m	Grey maroon andesite lava with light green-grey lithic tuff; at the bottom andesites are mostly altered with chlorite minerals.
	679-734 m	No samples were taken
	734-820 m	Grey-brown lithic tuff fine grain, with rare fragments of andesitic lava at the bottom; laminar structure between 734-765 m.
4.	**820-1292 m**	**Grey-brown lithic tuff fine grained with grey-green andesitic and basaltic andesite lavas.**
	821-894 m	Light grey lithic tuff with basalt-andesitic blocks.
	895-964 m	Grey green andesitic lava, very fractured.
	965-1195 m	Sequence of grey-green fine grained lithic tuff, with grey andesitic lavas at the bottom.
	1195-1292 m	Sequence of grey-green basaltic andesite, with brown-green lithic tuff, interstratified; at the bottom, grey maroon scoria is observed.
5.	**1292-1867 m**	**Sequence of dark grey-green andesite and basaltic andesite with brown-green lithic tuff, fine grained with layers of andesites and basaltic andesites very fractured at the bottom.**
	1293-1455 m	Brown-green lithic tuff, unstable and interstratified with dark grey andesites basaltic andesites.
	1460-1475 m	Basaltic andesite lava, fresh and low density of fractures.
	1476-1497 m	Dark grey andesitic and basaltic andesitic lava with fragments of a dark grey lithic tuff.
	1497-1646 m	Sequence of a light grey lithic tuff fine grained with brown-maroon andesites. Occasional voids at the bottom, unstable intervals of lithic tuff.
	1647-1709 m	Dark-grey fractured basaltic andesite with small horizons of brown-maroon fine grained lithic tuff; unstable and high content of scoria fragments; first appearance of epidote in the lithic tuff at 1666 m.
	1709-1820 m	Light grey-brown maroon lithic tuff with thin layers of dark grey basaltic andesite; rare fracturing.
	1820-1867 m	Grey-green andesite and basaltic-andesite with thin horizons of brown lithic tuff at the top; fractures filled with quartz.

6.	**1867-2492 m**	**Alternate sequence of grey-green lithic tuff fine grained with thin andesite lava flows.**
	1868-1901 m	Alternate sequence of grey-green lithic tuff and grey-green andesite lava, intensive alteration.
	1902-1983 m	Sequence of light grey-green lithic tuff and fine lithic tuff with fragments of grey-green andesitic lava.
	1984-2062 m	Sequence of grey-green andesitic lava and volcanic breccia, with small thin layers of fine tuff.
	2063-2153 m	Sequence of a grey-green lithic tuff and light grey fine lithic tuff with andesitic fragments; possibly a volcanic breccia at the bottom.
	2154-2262 m	Light grey fine lithic tuff; rare horizons of grey-green andesitic lava.
	2263-2363 m	Sequence of light grey fine grained tuff and grey-green andesitic lava; light grey lithic tuff at the top of the sequence.
	2364-2492 m	Sequence of fine grained tuff, coloured light grey and fragments of grey-green andesite lava; small horizons of brown-maroon lithic tuff at the top; grey green andesitic lava with fine lithic tuff at the bottom.
7.	**2492-2750 m**	**Sequence of fine grained tuff and lithic tuff with andesite breccias.**
	2493-2555 m	Light grey fine grained tuff with green andesitic lavas, very altered and predominant at the bottom.
	2556-2636 m	Sequence of a fine grained tuff together with lithic tuff and andesitic breccias at the top; grey-green moderately altered andesites; at the bottom an increase of milonitic fragments.
	2637-2750 m	Grey-green to light grey andesites; microfractures increase and are filled with epidote and chlorite; at the top small thin layers of tuff and andesitic breccia.

From 734 m to the bottom of the well, the presence of thin layers of a fine lithic tuff within andesitic lava flow are notable. The formation of fine lithic tuff with well developed laminar structure was seen at 750 m and was used as a marker to correlate with the formations in well CH-A. The horizon that draws a limit between the basement rocks and the basaltic andesite upper layers (Cuyanausul volcanic group) can be identified in well CH-A and CHA-1 at approximately 600 m depth. Basement rocks consist mostly of andesitic lavas with some interlayering of lithic tuff. In well CHA-1, the andesitic breccias with fine grained lithic tuff are very common from 2556 to 2750 m depth (Figure 8).

Two probable intrusions were identified by thin sections, one at 905-935 m and the second one at 1460-1475 m. At both locations, the rock type is a very fine grained basaltic andesite with fresh fenocrysts of pyroxene (augite) and amphiboles (hornblende). These intrusions are fresher and show a distinctive lack of alteration compared to the surrounding rocks. The presence of intrusions (probably dykes) found in this well, agree with results gathered through surface geological studies done in 1991 and also with geophysical data, which infers the presence of domes and/or dykes at different depths. The occurrence of intrusions at depth in a radial and circular pattern are common features in volcanic areas. Therefore, more intrusions may be found in other nearby wells. The identification of intrusions is very important, as they may be responsible for increasing the permeability in most geothermal reservoirs. For example in Svartsengi and Nesjavellir high temperature fields in Iceland, the main aquifers below 800 m depth are found along fractures and near sub-horizontal intrusive contacts (Franzson, 1988; 1990).

Figure 8 shows the distribution of hydrothermal alteration mineralogy as well as the stratigraphical column. The relative abundance of some hydrothermal minerals is shown in Figure 9.

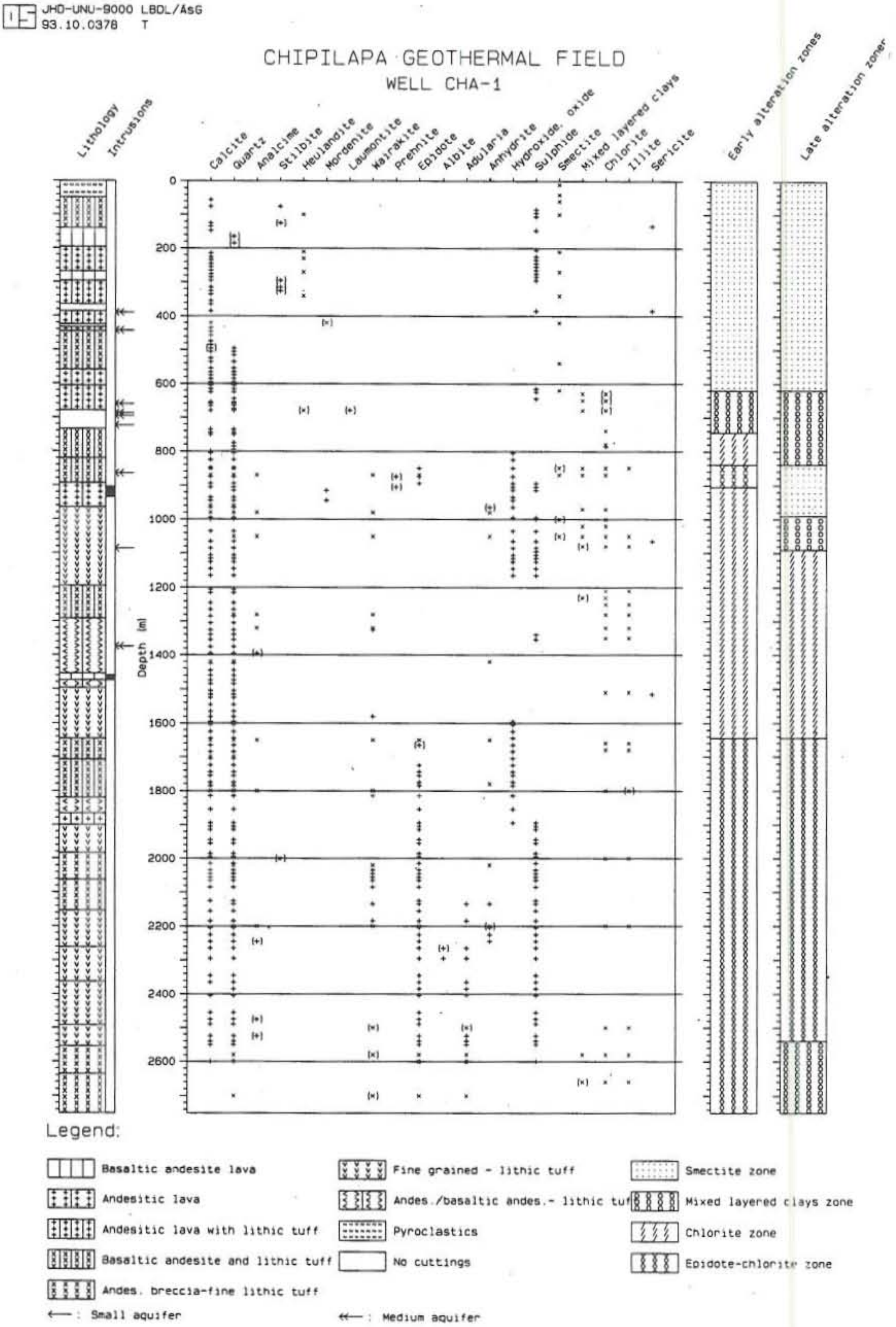


FIGURE 8: Stratigraphy and hydrothermal alteration of well CHA-1

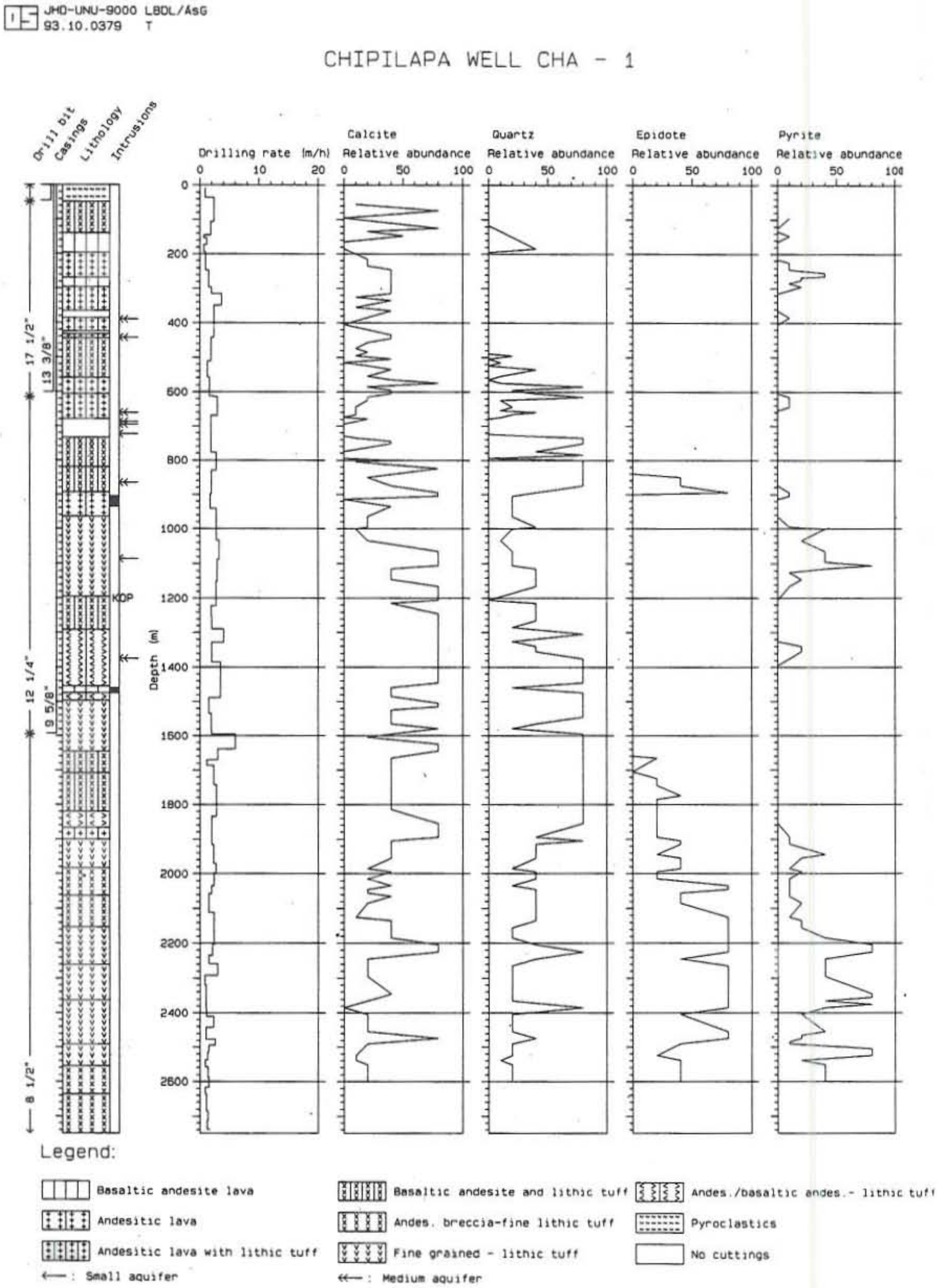


FIGURE 9: Relative abundance of some secondary minerals in well CHA-1

4. HYDROTHERMAL ALTERATION OF WELL CHA-1

4.1 Analytical methods

Various analytical techniques were used to develop a stratigraphic column of the lithological sequence and to study the type and degree of rock alteration. The analytical techniques can be divided into three parts and can either be applied to drill cuttings or cores.

Binocular microscope: The analysis of cuttings by binocular microscope help to determine the boundaries of the formations, identification of permeable and fractured zones and the degree of alteration of the rock. It is mostly used to identify minerals such as epidote, zeolites and sulphides.

Petrographic microscope: Analysis of samples by thin sections through a petrographic microscope is very important to identify the rock texture and microstructural relationships of minerals. This technique is used to identify the alteration of primary minerals and the difference between zeolite types (e.g. wairakite from analcime).

X-ray diffractometry (XRD) is a very useful technique to identify for example clay minerals and chlorite that are difficult to identify by other methods. It can also give quantitative information of the minerals present. Clay analysis by XRD is done in three stages: 1) untreated samples in a constant humidity with $CaCl_2$, 2) glycol saturated samples and 3) heating the samples to 550-600°C. The conditions for XRD analysis of minerals and clays are shown in Appendix III. The X-ray diffractometer used was Philips PW 1050/25 wide range goniometer connected to a PW 1130/00 X-ray generator. Representative XRD patterns of the 37 samples analyzed are shown in Figure 10. The results of all the XRD analysis are shown in Appendix IV.

4.2 Distribution of hydrothermal alteration minerals

The degree and type of alteration minerals in rocks depend basically on the permeability of the rock, rock composition and temperature. These parameters are closely related. The hydrothermal minerals observed in well CHA-1 include calcite, analcime, heulandite, stilbite, mordenite, wairakite, prehnite, epidote, albite, adularia, anhydrite, sericite, hematite, pyrite, chlorite and the clay smectite, mixed layer clays and illite. The occurrence and distribution of these minerals are shown in Figure 8 and discussed as follows:

Calcite occurs as quartz continuously from surface to the bottom of the well filling veins, voids, and replacing plagioclase. The relative abundance of calcite is shown in Figure 9, where its abundance appears to correlate with depth of circulation losses.

Quartz is observed from surface to the bottom of the well. At upper levels it is seen filling mostly voids together with zeolites. It often alters the matrix, plagioclase and is associated continuously with calcite. In the depth interval 850-2400 m, it is seen filling fractures together with wairakite and analcime. The higher relative abundance of quartz coincides with locations of small circulation losses (Figure 9).

Zeolites are calc-silicate minerals formed in geothermal systems and their occurrence is mostly dependent on temperature. The zeolites found in this well are analcime, stilbite, mordenite, heulandite, laumontite and wairakite. A sporadic occurrence of analcime along with wairakite was recognized by XRD analysis from 870 to 2200 m depth, showing the distinct d/Å 5.61 and d/Å

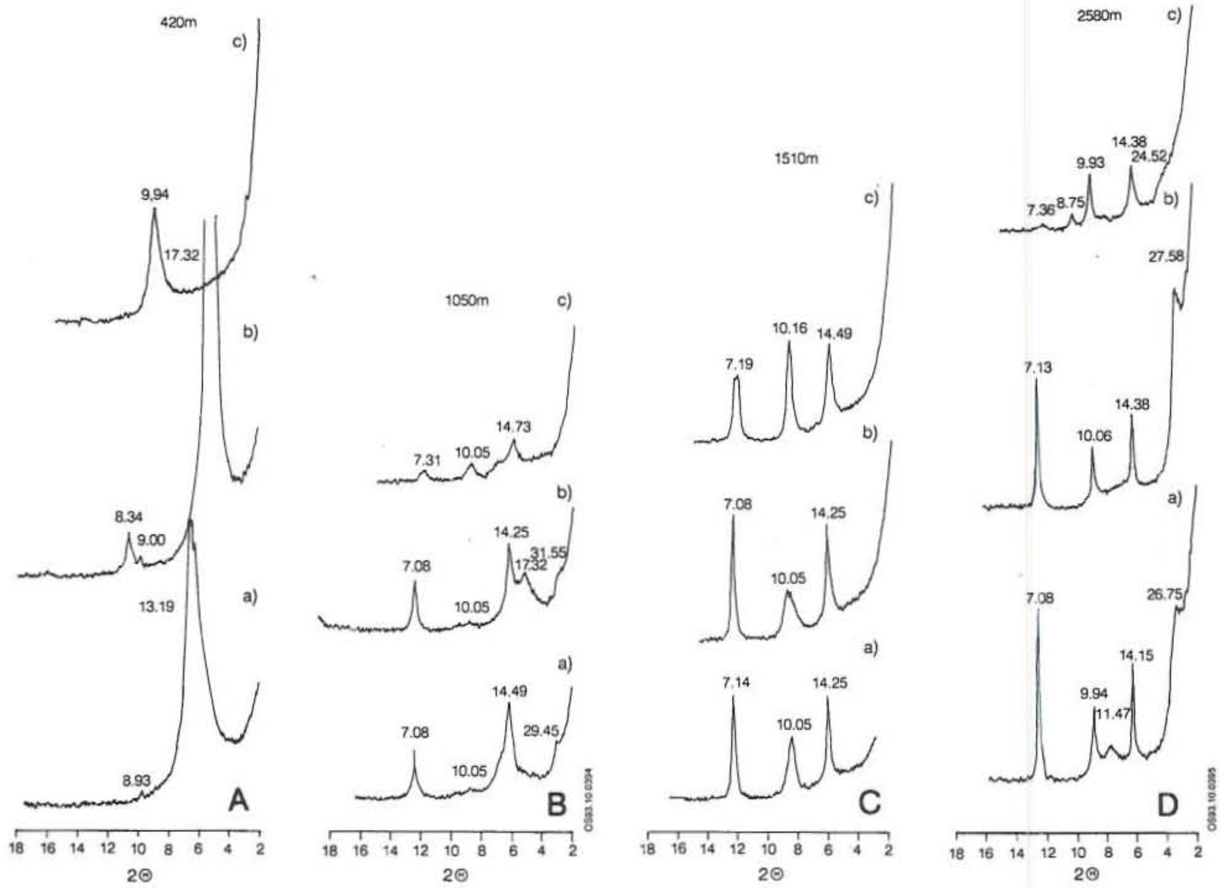


FIGURE 10: Characteristic XRD patterns for clay samples in well CHA-1 (see text for further explanation)

3.40-3.41 peaks. In thin sections the analcime is generally isotropic, an optical property which distinguishes it from the wairakite. The zeolites stilbite, mordenite, heulandite and laumontite were mostly identified by XRD analysis, where they either tend to accompany in the clay mineral separation or by separation of white mineral in drill cuttings. The petrographic identification of these minerals in some instances is doubtful, due to the thickness and poor quality of the thin sections. **Stilbite** was only identified by XRD analysis at 2000 m depth, showing a main peak of d/Å 9.11. In thin sections it is possibly present down to 300 m depth. **Mordenite** was recognized by XRD analysis at 420 m showing a main peak of d/Å 9.00. In thin sections it may be present at 915 and 945 m depth. Mordenite was also found embedded by quartz at 960-980 m depth. **Heulandite** was confirmed by XRD in the uppermost 400 m showing a characteristic d/Å 8.93-9.00 peak. **Laumontite** was only recognized by XRD analysis showing a peak of d/Å 9.40 at 420 m depth. It was not positively identified in thin sections.

Wairakite was observed by XRD analysis starting at a depth of 870 to 2700 m showing a characteristic peak of d/Å 3.41-3.43. Its presence was verified in thin sections and it is seen filling veins and vesicles together with quartz. Wairakite has a very weak birefringence, undulose extinction and has a complex twinning.

Prehnite was observed only at 875 and 905 m depth. It is found as an alteration product of plagioclase and minor vein depositions.

Two zones of **epidote** were identified. One at a depth of about 850 m, and the lower starting at approximately 1665 m depth and continues to the bottom of the well. It replaces plagioclase in the rock matrix and calcite minerals and it is also seen filling veins and voids. Epidote is found coexisting with quartz, calcite, illite, chlorite, wairakite, hydroxides and K-feldspars at 1665-2580 m depth, but it was not possible to distinguish a sequence of deposition between them.

The **secondary feldspars** of albite and adularia occur mostly as a replacement of primary feldspars and glass. **Albite** usually replaces primary feldspars in basaltic to basaltic-andesite rocks, preferentially altering phenocrysts of plagioclase. It was found from 1200 m depth to the bottom of the well. **Adularia** was identified first by XRD analysis and later confirmed by thin sections. Its presence is restricted to 2200-2660 m depth. In this zone, it coexists with albite, quartz and epidote.

Anhydrite was identified by XRD by the distinct peak at d/Å 3.50, and occurs sporadically from 980 to 2200 m depth. Its presence was later confirmed in thin sections, where it has a moderate relief, strong birefringence in clusters of anhedral to subeuhedral colourless crystals and rectangular cleavage, altering calcite-plagioclase bearing minerals.

Hydroxides-oxides include minerals like hematite, limonite and goethite. According to thin section analysis and their relative abundance, these minerals are commonly found in all the well, having a high concentration between 800 and 1200 and at 1580 to 1900 m depth. The first zone coincides with the presence of epidote and location of small circulation losses. Polished thin sections are needed to differentiate between hydroxides present.

Two types of **sulphides** were found, pyrite and chalcopyrite. Other sulphides are present, but pyrite is far the most abundant. Pyrite is rare in the uppermost parts of the well. Three zones of high pyrite abundance were identified, at 225-295, 995-1165 and below 1865 m. The first two zones conform with the location of small circulation losses. The exception is at the deepest part of the well where it has a very high relative abundance but no circulation losses were intercepted in this range during drilling. Pyrite is a mineral which is often related to past or present permeability. In thin sections, it is found filling veins and as small cubic crystals disseminated in the matrix but polished thin sections are needed in order to verify whether pyrite and chalcopyrite are the only sulphides present in the rock.

Chlorite is a sheet silicate mineral, which usually forms as a replacement of primary ferromagnesian minerals, glass or as direct deposition in vesicles and veins. Chlorites were analyzed by XRD. During glycolation and heating of samples, chlorites often show peaks ranging from d/Å 14.15-14.717, d/Å 7.07-7.28 and d/Å 4.72-4.79, and do not encounter any change during treatment. The best method to distinguish chlorite minerals is by XRD. Chlorite was identified from a depth of 740 m to the bottom of the well where it coexists with illite and mixed layer clays (2580-2660 m) (Figure 10d).

In thin sections two types of chlorites appear to be present. One with green pleochroism and unusually high birefringence occurring as sheavelike aggregates and the other with a light to grass green pleochroism and exhibits typical grey to bluish anomalous interference colour and commonly occurs as fibrous aggregates (probably pumpelleite and/or penninite).

The **clay minerals** are the most abundant alteration minerals. They respond relatively quickly to changes in temperature, pressure and chemical conditions in the geothermal systems. A detailed study of clay minerals as well as their relation to other alteration minerals, is used to interpret the thermal history of a geothermal area (Kristmannsdottir, 1978; Elders et al., 1979; Reyes, 1990).

Smectite clay minerals include saponite, nontronite and montmorillonite. Figure 10a shows a typical XRD result of smectite peaks in a sample taken at 420 m depth a) at constant humidity ($CaCl_2$), b) with glycol saturation ($C_2H_6O_2$) and c) after heating at 550-600°C. The behaviour of smectites during the treatment shows that a) the common peak is usually d/Å 13.192, then expands with b) to d/Å 17.32 and shrinks with c) to d/Å 9.936. It is often seen that smectites collapse while heating.

The occurrence of smectite is independent of rock type and in well CHA-1 it is found continuously from surface down to 620 m depth. It is found as a minor component at 850, 870, 1000 and 1050 m depth along with chlorite, mixed layer clays and illite. These depths correspond to locations of small circulation losses (Figure 10b). Smectites are seen in thin sections with green to brown colours changing to yellowish green colour in polarized light. Smectites often replace glass and primary minerals such as feldspars and/or ferromagnesian minerals and also can be found filling veins and voids.

Mixed layer clays are defined as clays having interstratified layers usually of chlorite-smectite-illite. Mixed layer clays were found at 870 m depth. With constant humidity the common peak is d/Å 29.622, with glycol d/Å 32.69 and after heating, it drops to d/Å 12.617. These minerals are interstratified with pure chlorite, illite and smectite minerals. In this well these clays are seen at two depth intervals, at 630-1230 and at 2580-2660 m, where it is interlayered with pure chlorite and illite (Figure 10d).

Illite starts appearing locally at 850 m, sporadically in the interval 1050-1210 m and continuously from 1230 m to the bottom of the well where it is mostly interstratified with chlorite, except at 2580-2660 m where it is seen coexisting with mixed layer clays. Illite is usually common in the potassium rich rock types and alters plagioclase and groundmass but also fills voids and veins. Pure illites are defined as having peaks at d/Å 9.93-10.155 and do not show any change upon glycolation and heating treatment. Illite peaks are often broad and jagged but may change to a sharp peak when heated, due to the breakdown of some smectite layers (Reyes, 1979). This is the case of the illite at 2580-2660 m depth where it is found with mixed layer clays (Figure 10d).

4.3 Hydrothermal mineral zonation

General overview

The degree and the amount of hydrothermal minerals formed, depend generally on parameters like temperature, type and permeability of the rock, pressure, chemical composition of the fluid and the age of the geothermal area (Kristmannsdottir, 1978; Elders et al., 1979; Reyes, 1990; Browne, 1984).

According to Browne (1984) the minerals mostly used as geothermometers are the zeolites, clays, epidote and amphiboles. In Icelandic regions, most zeolites are common before 100°C and disappear before 200°C (stilbite, heulandite, mordenite). Laumontite replaces other zeolites at 100-120°C. Wairakite, just as in Cerro Prieto, Mexico, starts appearing at 180°C and is recorded up to 300°C (Kristmannsdottir, 1978; Elders, et al., 1979). On the other hand, in New Zealand wairakite is identified at temperatures between 200-250°C (Steiner, 1977).

Chlorites in the New Zealand geothermal fields are common minerals and have a wide range in composition. They are not used as geothermometers. However, in Iceland, according to Kristmannsdottir (1978) chlorite becomes the dominant sheet silicate at rock temperatures of 230-250°C and in geothermal areas where the maximum temperature does not exceed 240°C, chlorite is only found sporadically. The clay minerals such as smectite are seldom recorded at rock temperatures above 200°C. Mixed layer clays of smectite and chlorite are dominant at 200-230°C. In New Zealand, clays such as montmorillonite (a type of smectite) are stable at about 140°C and illite above 220°C.

Among the minerals that occur at higher temperatures (above 250°C), epidote seems to be the most reliable and consistent temperature guide. In Icelandic active geothermal fields, epidote occurs sporadically at 230-250°C. But it appears in high quantity at rock temperatures above 250°C. According to Browne, (1984) epidote first appears in many fields at 250°C and the lithology does not influence its formation. Variations regarding prehnite, are seen in New Zealand where it appears at greater temperatures than 220°C. In Cerro Prieto, Mexico it occurs, on the contrary, at higher temperatures than 300°C. This probably is due to the difference in the pH and calcium contents of the geothermal fluids.

The intensity and type of alteration usually reveals the degree of permeability. Minerals such as adularia and albite are often related to permeable zones, especially if these are present individually in association with quartz and calcite, (Tongonan, Philippines and all New Zealand geothermal fields). This relationship can be used when these minerals are present in veins and fractures (Browne, 1984). If they are, however, altering plagioclase, this relationship does not apply. Albite is also a useful geothermometer only when it occurs in veins. Otherwise the albitization of plagioclase occurs within a wide range of temperatures (Reyes, 1990). It has been observed that in zones where both albite and adularia occur together, the permeability of the rock tends to decrease through self sealing. Therefore, the former relationship should be used carefully. The original mineralogy of the rock seems to have a minor effect on the type of mineral assemblage in permeable zones. It is controlled mostly by the permeability. For instance the association of minerals such as albite, quartz, epidote, chlorite, adularia pyrite and illite (260°C), occur in different geological environments. It is seen in andesitic rocks (Philippines and Indonesia), in rhyolites (New Zealand), alkaline lavas (Kenya) and sediments (Cerro Prieto). K-mica and K-feldspar is near absent in Icelandic geothermal fields and adularia less frequent than found elsewhere (e.g. Fridleifsson, 1984).

The occurrence of analcime may be related to the composition of the rock. For instance in Icelandic geothermal fields, the appearance of individual zeolites is influenced by rock composition where analcime is less common in quartz tholeiites than in olivine tholeiites. Instead zeolites such as mordenite, heulandite and laumontite are found in all areas. Browne (1984) also mentions that zeolites as analcime mainly forms in intermediate-acidic rocks. Concerning these factors, temperature and permeability of a system can then be inferred by the assemblage of hydrothermal alteration minerals.

In all active geothermal fields, (New Zealand, Cerro Prieto, Iceland and Philippines), alteration zones were derived by empirical data found between rock temperatures and secondary minerals. For example, in Iceland, different alteration zones were obtained regarding the formation of smectites, mixed layer clays and chlorite than found elsewhere. The temperature ranges for these zones are 0-200, 200-230 and 230-250°C respectively. In New Zealand other alteration zones concerning temperatures have been developed. For instance, smectites, mixed layer clays (smectite/illite) and illite give a temperature range of 0-140, 140-220 and greater than 220°C respectively. These empirical relationships as well as the indicative minerals of temperature and permeability can be applied to other geothermal systems. Nevertheless, it is important, that each area develops its own local zonation of hydrothermal alteration mineralogy vs. temperature relationship.

Chipilapa geothermal field

For the Chipilapa geothermal field, a zonal diagram was made using a combination of a modified diagram made by Elders et al. (1979) on the Cerro Prieto, high temperature fields and a temperature diagram from Icelandic regions, using temperature ranges for epidote, zeolites, calcite, quartz, chlorite and mineral clays (Kristmannsdottir, 1978; Kristmannsdottir and Tomasson, 1978). Figure 11 shows the zonal diagram used in well CHA-1.

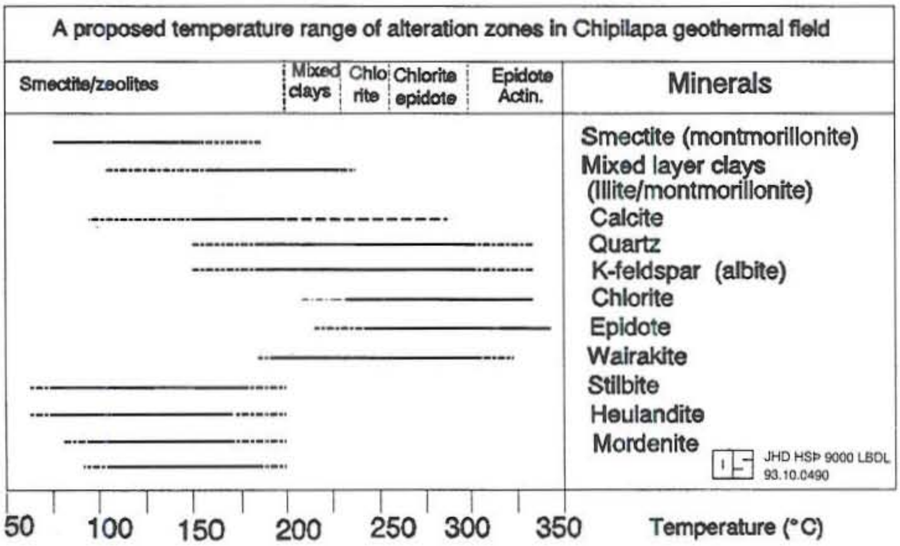


FIGURE 11: Zonal diagram for hydrothermal alteration minerals used for well CHA-1, Chipilapa geothermal field

In well CHA-1, quartz and calcite are generally distributed from the surface to the well's bottom. The temperature range used is 150-300 and 100-270°C respectively. In well CHA-1, analcime is absent above 870 m depth. It appears sporadically between 870 and 2200 m. Therefore, the presence of analcime in this depth interval, conforms with the change in rock type. Above 870 m the rock type is mostly basaltic to basaltic andesite, while below 870 m the rock becomes more andesitic (intermediate). Analcime in Icelandic geothermal areas has a temperature range from less than 100°C and in some rare cases up to 150°C.

Wairakite occurs in association with adularia, albite, epidote, calcite, quartz and pyrite. The temperature range for this mineral is 180-300°C. It is seen also in the range 200-300°C. The estimated temperature range for epidote in well CHA-1 is 230-280°C.

Secondary feldspars such as albite and adularia occur in zones where circulation losses are not recorded. This association may reflect a fossil permeability where all microfractures have been sealed off by mineralization (Browne, 1984). Albite does not occur as fracture fills and will therefore not be used as a geothermometer. Adularia occurs from 180-200°C. Through the distribution of hydrothermal minerals, two geothermal episodes were identified in well CHA-1 and in Figure 8 the alteration zones are marked as follows:

Older alteration zones	**Younger alteration zones**
smectite-zeolites zone	smectite
mixed layer clays	mixed layer clays
chlorite	smectite
chlorite-epidote	mixed layer clays
chlorite	chlorite
chlorite-epidote zone	chlorite-epidote, mixed layer clays

It must be appreciated that it is difficult to make a clear distinction between these proposed alteration zones, and further work is needed in order to separate these better.

Smectite zone. In both episodes this zone reaches from surface to 620 m depth, where probably the most common smectites are saponite and montmorillonite. Low temperature zeolites, such as heulandite, mordenite and stilbite were seen. A temperature range of 70-120°C is proposed. This range is within the measured rock formation temperature. In the late alteration zone the smectite zone is seen at 840-1020 m depth. Smectites are stable at temperatures below 200°C.

Mixed layer clay zone. The early alteration zone starts from 620 and extends to 740 m depth and the assemblage includes smectite-chlorite. In the late alteration zone it is found at 620-840 m and is seen at the bottom of the well at 2540-2750 m. The expected temperature range is between 200-230°C.

Chlorite. In the early alteration zone, it extends from 740 to 840 m and from 920 to 1655 m. In the late alteration zone it apparently ranges from 1100 to 1655 m depth. The expected temperature range is 230-250°C.

Chlorite-epidote. In the early alteration zone, two ranges have been found. The upper one at 840-920 m depth and the lower one from 1655 m to the bottom at 2750 m depth. It is quite likely that both of these zones represent an early alteration zone. In the upper one, smectite is coexisting with epidote, which infers a temperature decrease from above 250°C to below 200°C.

Chlorite-epidote dominates in the depth range from 1655 to 2580 m depth, with no indication of a lower temperature alteration assemblage. The absence of the latter, may either infer a present low permeability or that the evident cooling in this depth range has not yet produced a lower temperature alteration assemblage. The reappearance of mixed layered clays at the bottom of the well, suggests a lower temperature conditions (200-230°C), succeeding the higher chlorite epidote alteration (greater than 250°C).

5. TEMPERATURE

5.1 Temperature profile of well CHA-1

Figure 12 shows the recovering temperatures of well CHA-1 during three months of warming up. It shows a reversal temperature gradient at 600-1100 m depth with a maximum temperature of 200°C. When interpreting the temperature profile of well CHA-1 two possible explanations were found.

Explanation 1: At about 1200 m depth, a change in the temperature curve can be seen, which is coincident with the kickoff point. This probably corresponds to a small feed zone of slightly less than 200°C and its heating up progressively with time. This small feed zone was not recorded during drilling. The temperature log shows a characteristic behaviour of a temperature profile that is proximating an upflow zone. Therefore, the rock formation temperature of this well, after 1200 m depth could be the same or slightly higher than the ones recorded.

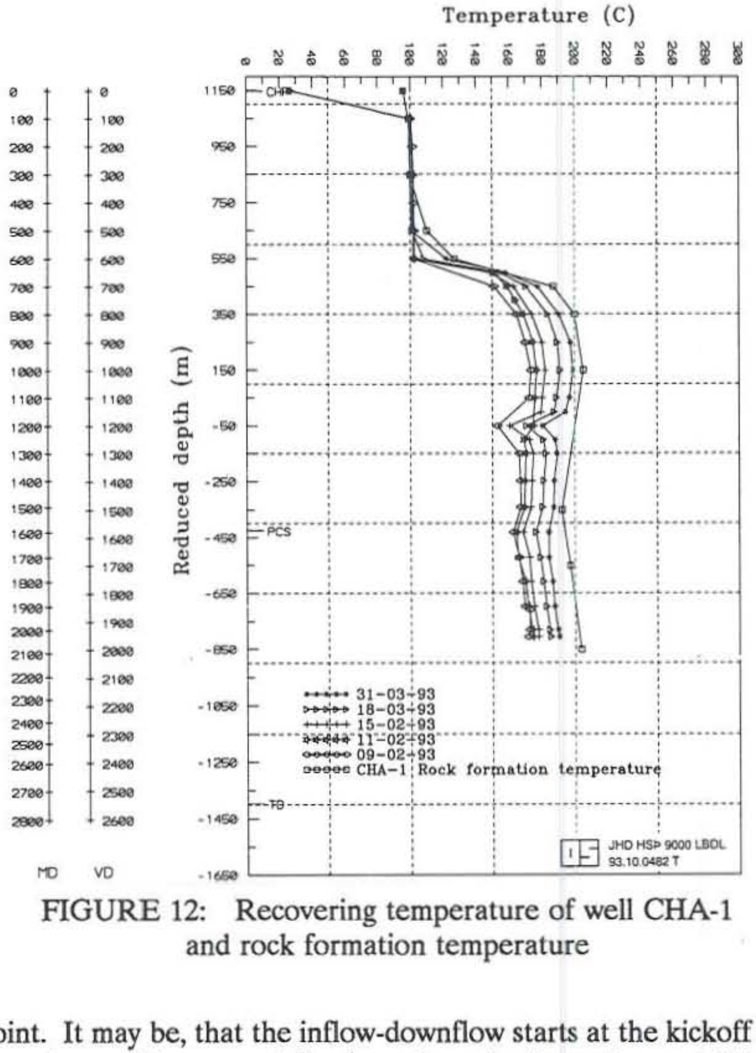


FIGURE 12: Recovering temperature of well CHA-1 and rock formation temperature

Explanation 2: The apparent aquifer or feed zone occurring at the kickoff point, can also be explained by a probable small inflow inside the 9 5/8" casing, occurring at 1200 m depth at the kickoff point. It may be, that the inflow-downflow starts at the kickoff point, due to a rupture of the casing, and later partially enters into the formation at 1600 m depth allowing some of the fluid to flow to deeper levels. If this is the case, a permeable zone must exist at the bottom of the well which is able to accept this fluid. This inflow inside the casing may be due to bad cementing at upper levels. This explanation is less likely, but can be proven by lowering a spinner down the well, in order to identify the inflow. If this is the case, the rock formation temperatures between 1500-2030 m depth, may not be representative, due to the downflow. The temperatures in that range might then be almost the same or slightly higher than the ones measured.

5.2 Alteration temperatures compared to measured temperatures

Figure 12 also shows the probable rock formation temperature of well CHA-1 calculated by a computer program called Berghiti. Temperature logging could only be extended down to 2030 m depth, due to several "dog leg" patterns formed in the deviated part of the well. This lack of information temperature below 2030 m limits the correlation of hydrothermal alteration temperatures with measured temperatures and makes the former the only method presently available to estimate the possible temperatures in that part of the well.

Figure 13 shows the temperature measurements correlated with alteration temperatures:

1. Actual mineral temperatures are roughly in equilibrium with measured temperatures at the first 1250 m (200°C), though evidence of cooling is possible.

2. Mineral temperatures are higher than measured ones from 1250 to 2500 m depth. As permeable zones are negligible, it is probable that the hydrothermal system causing that alteration has been clogged up by mineral deposition. A very low original permeability of the system is possible but less likely.

3. Mineral temperatures evidence a probable cooling occurring at 2500-2660 m depth. This cooling may be due to a fluid of lower temperature than 230°C. This zone may be more permeable than the upper zone due to the presence of the mixed layer clays.

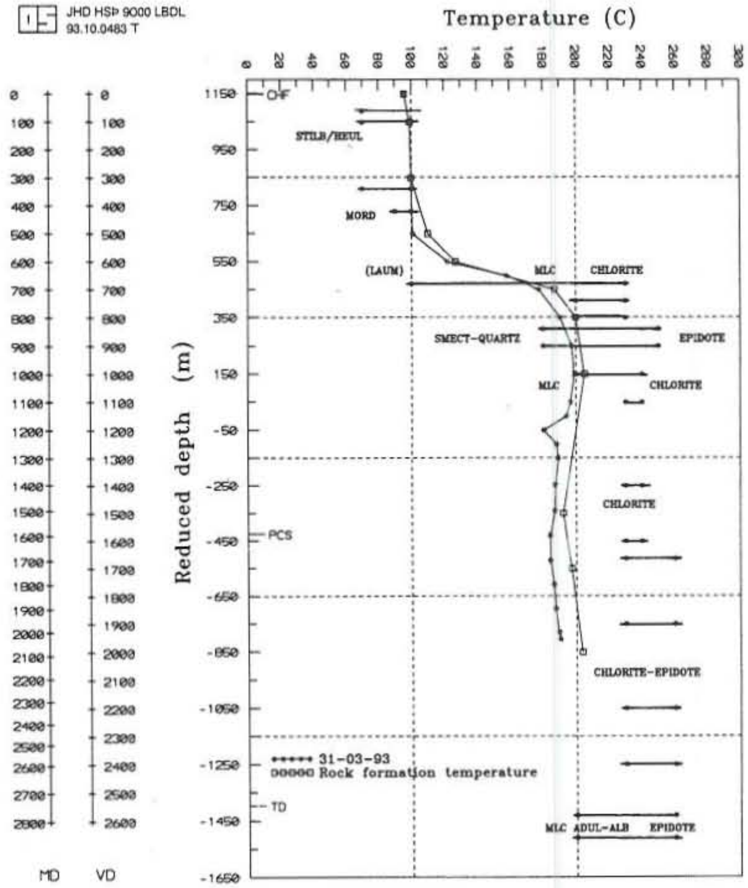


FIGURE 13: Correlation of alteration temperature and measured temperature

6. AQUIFERS

Small circulation losses were intercepted during drilling of the well near the surface at 130-138, 390-400, and 450-460 m. These generally correspond to changes in lithological units between basaltic andesite rocks and lithic tuff layers. A circulation loss at 660-730 m depth was intercepted and corresponds to a hot aquifer related to fractured andesites. This aquifer also coincides with the first appearance of epidote, pyrite, quartz and calcite and can be identified in the temperature graph from the well. Cuttings were not recovered from 679-734 m depth. The circulation loss at 866 m corresponds with the high relative abundance of epidote and pyrite.

Minor circulation losses occurred at 1087 and 1377 m and probably correspond to small feed zones. These may also be evidenced in alteration mineral distribution by the relative abundance of pyrite, quartz and calcite and concentration of veins. No further circulation losses were identified below 1380 m depth. These circulation losses may not have been evident, due to the drilling with mud. Figure 14 shows a correlation of circulation losses, relative abundance of alteration minerals and feed zones from temperature graphs. This correlation shows that probable minor feed zones may be present at 1900, 2200 and 2550 m depth. These were not recorded during drilling and may have been sealed off by drilling mud or by mineralization.

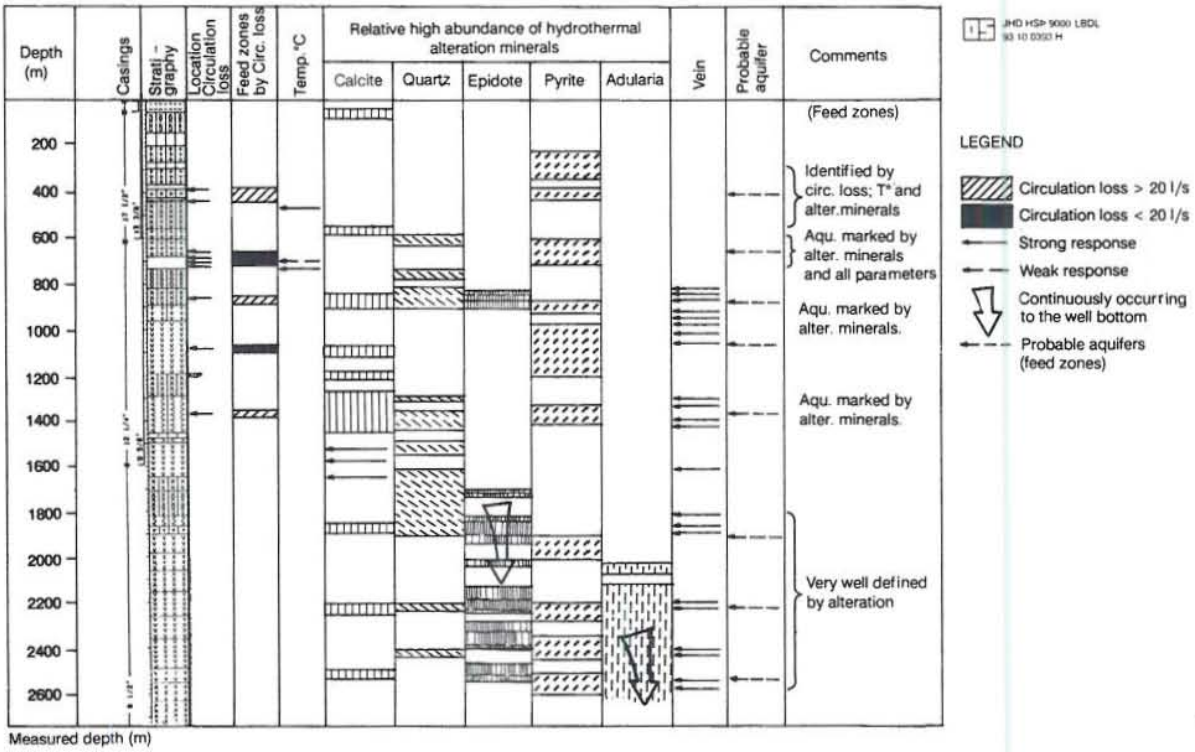


FIGURE 14: Location of probable aquifers (feed zones) in well CHA-1

7. CORRELATION OF CHA-1 WITH NEIGHBOURING WELLS

7.1 Correlation of CHA-1 with vertical well CH-A

CHA-1 and CH-A are located inside the Cuyanausul graben, and drilled from the same platform. At deeper level the horizontal distance increases after the kickoff point of well CHA-1, reaching a distance of 743 m at a depth of 2543 m. Two aquifers can be identified in both wells, at 800-900 and 1000-1100 m and show almost the same temperature of approximately 200-210°C. Similarities are also found in lithology and hydrothermal alteration mineralogy.

Both wells present the same behaviour in the upper 1200 m. Well CH-A has a localized minor feed zone located at 2100 m depth, which was not recorded in well CHA-1.

A comparison of rock formation temperatures for well CH-A and CHA-1 is shown in Figure 15. The rock formation temperatures in the first 1200 m are considered to be almost the same. Between 1600-2000 m CHA-1 has a slightly higher overall temperature than well CH-A.

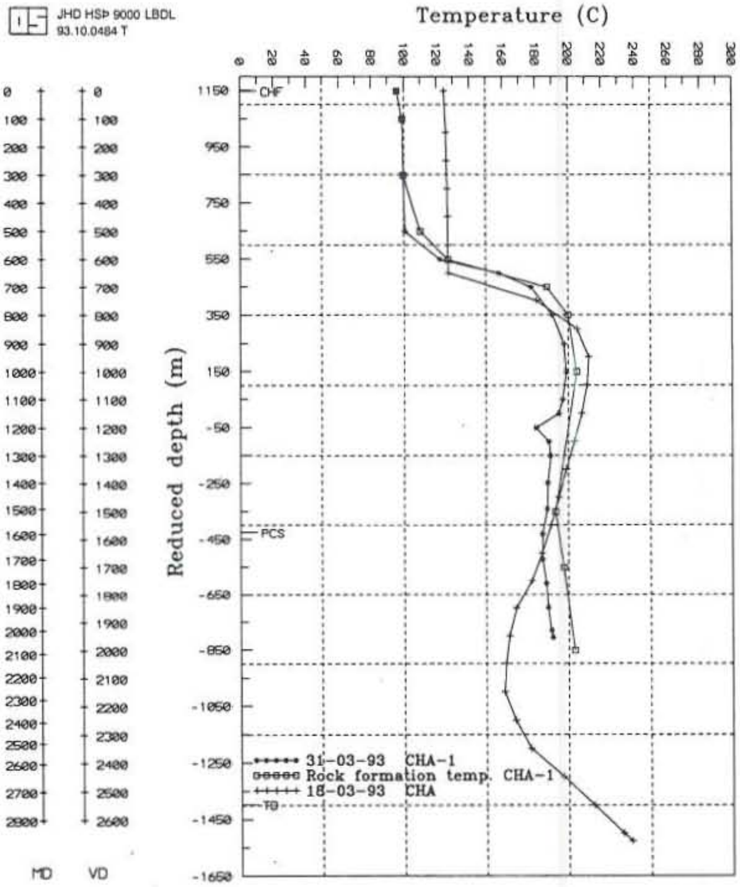


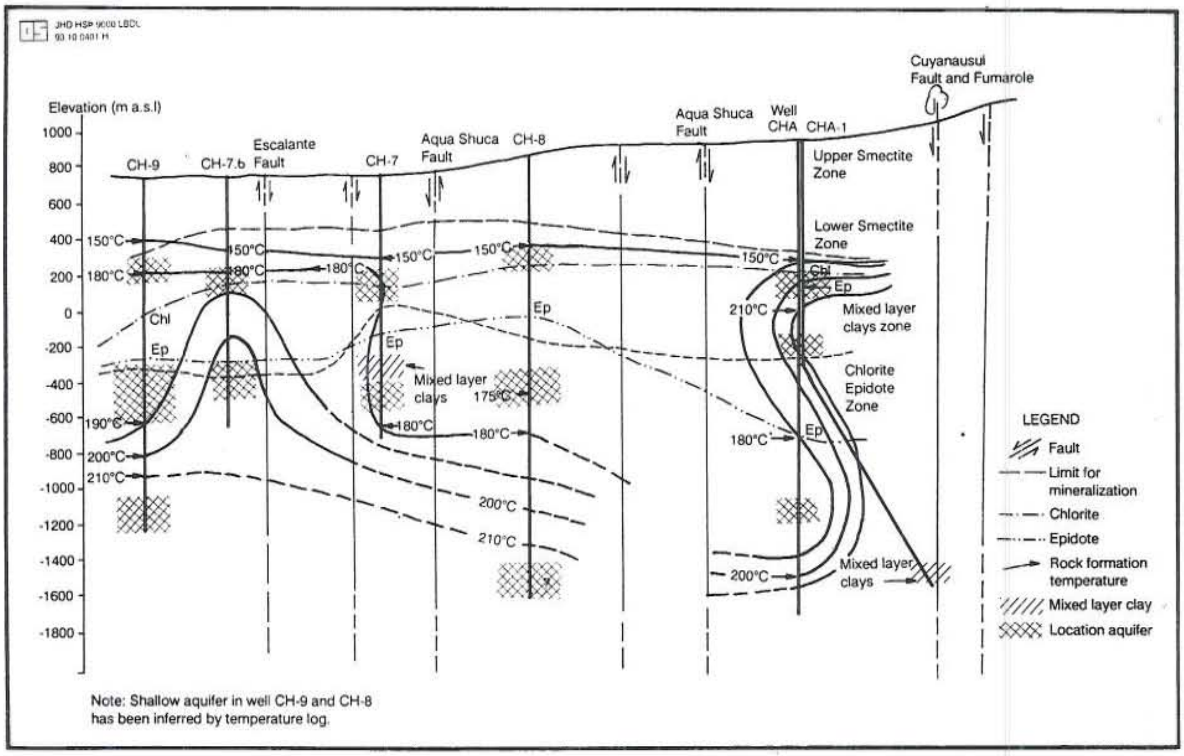
FIGURE 15: Temperature measurements of wells CH-A and CHA-1

7.2 Temperature distribution in the Chipilapa field

Figure 16 shows a correlation of temperature measurements and circulation losses of wells CH-A and CHA-1 with wells CH-7, CH-8, CH-9 and CH-7b. (Temperature logs for each of the wells are shown in Appendix V). Well CH-9 has a permeable zone between 1100 and 1300 m with a maximum temperature of about 190°C. After two months of production tests, this zone reached a maximum temperature of about 200°C. The deepest aquifer is located below 1800 m with a maximum temperature of 214°C. This temperature is practically constant. The well has a lower permeability than the other wells near by.

According to the temperature profile two main permeable zones were identified in well CH-7b. One zone, vapour dominated or with two phase flow, at 550-650 m with a maximum temperature of 197°C. The second zone, liquid dominated, below 1040 m depth, with a maximum temperature of 203°C at the bottom of the well. According to a production test the flashing zone is located at 710-768 m depth (CFG, 1992).

Minor feed zones are common in the uppermost part of well CH-7. At 200 m depth a small



Note: Shallow aquifer in well CH-9 and CH-8 has been inferred by temperature log.

FIGURE 16: Correlation of temperature measurements and alteration zones between wells in the Chipilapa geothermal field

steam cap was found. From warming up temperature profiles, two main aquifers were identified, a shallow one at 543-650 m with a maximum temperature of 180°C and another at 1200-1400 m depth, with a maximum temperature of about 175°C. This well has good permeability between 650-1500 m.

Minor permeable zones are numerable in well CH-8 from 0-1006 m. Large ones are at 1000-1400 and below 2400 m depth. The former has a temperature of about 175°C. Total circulation loss starts at 2100 m and continues down to 2400 m, where there is an evidence of a deep reservoir of approximately 220-225°C. This is separated from the intermediate aquifer by a thick (1000 m) impermeable formation. The aquifers found in all the wells, are listed in Table 3:

TABLE 3: Main aquifers found in the Chipilapa wells

Aquifers	**Depth range (m)**	**T_{max} (°C)**	**Intersected by wells**
Shallow	550-700	175-210	All
Intermediate	1200-1400	175-190	All except CH-A & CHA-1
Probable deep aquifers	a) 1800-2000 b) 2100-2400	214 220-225	CH-9 CH-8 & CH-A

7.3 Alteration mineralogy correlation

Correlation of alteration zones of wells CH-A and CHA-1 with wells CH-9, CH-7b, CH-7 and CH-8 is shown in Figure 16. The hydrothermal alteration zones found for each well are as follows: Smectite zone, mixed layer clay zone and chlorite-epidote zone.

Well CH-9. From 0-475 m no data is reported. Mixed layer clays are observed at 475-1050 m depth. Chlorite epidote zone extends from 1000 m to the bottom of the well. Mixed layer clays such as corrensite are seen at 1000-1050 m, coexisting with epidote.

Well CH-7b. Smectites such as saponite and montmorillonite are observed in the interval 0-600 m. Mixed layer clays are observed at 600-1000 m depth. Chlorite-epidote zone starts at 1000 m extending down to the bottom of the well. Smectite such as saponite coexists with epidote at 1000-1050 m depth. Epidote in this range is not well developed. No data is available below 1150 m depth, due to lack of samples.

Well CH-7. A smectite zone ranges over 0-275 m, mixed layer clays zone over 275-800 m and chlorite-epidote zones in the interval 800-1500 m depth. Mixed layer clays such as corrensite can be observed about 1000-1150 m.

Well CH-8. A smectite zone can be identified in the depth range 0-375 m. Mixed layer clay zone of smectite-chlorite occurs at 375-625 m depth. Chlorite zone ranges from 625 to 850 m. Chlorite-epidote zone starts at 850 extending to 2550 m depth. Mixed layer clays such as corrensite are seen at 1000-1050 m.

Well CH-A. Clays were only analyzed at 1013-2643 m depth. From this data it can be seen that smectites extend down to 1073 m, into the fossil chlorite-epidote zone.

From the sequence of mineral clays and mineral zones found in all wells, a probable cooling in the range 1000-1150 m exists. This cooling is probably a general phenomena in the Chipilapa area, and is probably due to an inflow of a fluid of lower temperature than 230°C.

8. DISCUSSION

A microseismic study showed evidence of active faulting inside the Cuyanausul graben, located at the southern part of the Chipilapa area. Vertical well CH-A was drilled in 1992 and intersected the Agua Shuca fault. This well found an aquifer at 670-740 m depth with a maximum temperature of 210°C. According to borehole geology, it intersected the fault at 2100-2400 m, but only a small circulation loss was found. At these depths the alteration mineralogy indicates a possible aquifer, but the absence of circulation losses implies, that fractures have probably been sealed by mineralization or clogged by drilling mud.

Clays such as smectite and mixed layer clays, imply metastable conditions in active geothermal areas and usually mark a transition zone with more stable and compact structures. The occurrence of smectite-mixed layer clays and mixed layer clays at two depth intervals (800-1100 and 2580-2660 m depth) and coexisting with epidote at 850 and 2580 m, might indicate a possible superimposition of the present system with an earlier hydrothermal episode.

For well CHA-1, hydroxides in the range 800-1200 m suggest the presence of oxygenated groundwaters rather than hypogene geothermal fluids. Hydroxides are also found in this range, coexisting together with smectites and mixed layer clays, implying a probable cooling. A closer study on mineral segments is necessary in order to confirm whether the hydroxides are a part of the present hydrothermal alteration or the older fossil alteration.

Microseismic studies show evidence of active faulting in the Cuyanausul graben, but according to the results gathered from well CH-A and CHA-1, the seismic zones (shallow and intermediate) might instead correspond to the breaking of the formation due to the cooling, rather than to the presence of a high temperature geothermal aquifer (240°C) below 1000 m depth.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The main aquifer in well CHA-1 is located at 650-734 m depth, with a measured temperature of 200°C. This aquifer is actually cased off, and is therefore not exploitable for geothermal utilization. Minor feed zones in well CHA-1 were identified at 866, 1037, and 1377 m depth, but no circulation losses were found below 1400 m depth. Main aquifer and minor feed zones conform very well with alteration mineralogy and temperature measurements.

Breakdowns during drilling caused several keyholes and caves below 1200 m depth, and temperature logging equipment could not be lowered down to the bottom of the well. Temperature measurements and correlations with alteration temperature can only be done down to 2000 m.

Three probable minor feed zones were furthermore identified at 1900, 2200 and 2550 m depth by hydrothermal alteration. These were not recorded during drilling and were probably sealed off by mud or by mineralization.

The mineral zonation of well CHA-1, identified two geothermal episodes. The zonation is divided into an early fossil alteration and a late alteration episode. From this, temperature measurements were correlated with alteration temperatures showing that:

a. Mineral temperatures are in equilibrium with measured temperatures down to 1200 m, giving a maximum temperature of 200°C. Late alteration zone shows evidence of a probable cooling occurring between 650 and 1000 m depth, which might be due to an inflow of cooler water.

b. Mineral temperatures are higher than the measured temperatures at 1250-2580 m depth. Lack of aquifers there may be due to scaling by mineral deposition or drilling mud.

c. Mineral temperatures indicate a probable cooling occurring at 2580-2660 m depth, by fluids of lower temperature than 230°C. According to the design and location of the well, the Cuyanausul fault was probably intersected and the presence of mixed layer clays also gives some evidence that this zone is perhaps more permeable than the upper layers.

Just as in other wells from the Chipilapa area, (CH-7, CH-7b, CH-8, CH-9 and CH-A), alteration mineralogy of well CHA-1, indicates an inflow of colder fluids in the first 1200 m. This cooling is inferred by the presence of smectites and mixed layer clays coexisting with chlorite and epidote minerals in that depth range.

With respect to the three aquifers found in the Chipilapa area, including well CHA-1, the maximum temperatures reached are in the range of 175-220°C.

All wells show a pattern of lateral flow, but the following differences can be established:

a. Probable lateral flows in CH-A and CHA-1 are at 670-740 and 650-734 m depth, respectively. The upflow zone may be near the Tortuguero and Cuyanausul graben. Agua Shuca and Cuyanausul fault are probably the main structures controlling this flow.

b. Lateral flows indicated in the wells to the north (CH-8, CH-9, CH-7b and probably CH-D) are probably branches of the main lateral flow that feeds the Ahuachapan geothermal field. The upflow for this area may be located beneath the Laguna Verde volcanic complex along the active Escalante fault.

c. Lateral flow at well CH-7 might be an intersection of two lateral flows (intersection of the Cuyanausul and Escalante faults). One lateral flow moving NW-SE starts from El Tortuguero and Cuyanausul towards CH-7 along the Agua Shuca active fault. The second flow is probably moving NE-SW through the Escalante fault, having its source beneath Laguna Verde.

9.2 Recommendations

1. A spinner can be used to measure the probable inflow in well CHA-1, inside the 9 5/8" casing occurring at 1200 m depth, to confirm a hole in the casing at that depth.

2. The temperatures in well CHA-1 below 2030 m depth should be measured with an appropriate method, and then compared with the estimated alteration temperatures gathered in this report. One of the methods to apply can be tying a long chain at the end of the logging tool. This will allow the chain to settle in the cave (2030 m) and then slip to further depth, pulling the tool further down the well.

3. Fluid inclusion temperatures of well CHA-1 should be compared with mineral and measured temperatures.

4. Finally, it is necessary to correlate the mineralogy, temperature measurements and fluid inclusion data in all the Chipilapa wells, and in addition study the recently drilled well CH-D at the western margin of the field.

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APPENDIX I: Inrun survey of minimum curvature for well CHA-1

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                    OLEO SERVICIOS Y FABRICACION DE HTAS.
                              CD. DEL CARMEN CAMP.

NUMBER: 21                                                          WELL NAME: CHA-1

                                  INRUN SURVEY
                              BY MINIMUM CURVATURE

 MEAS.    VERT.    VERT.     L/R    INCL  BEARING       COORDINATES        D-LEG  D-LEG   STATION DISPLACEMENT
 DEPTH    DEPTH    SECT     LOG.                     LATITUDE  DEPARTURE    /30    /CL     DISP.   DIRECTION

1200.0  1200.00    0.00    0.000  00.00  N00.00E    0.000 N     0.000 E   0.00   0.00     0.000  AT  N00.00E
1221.0  1220.99    0.32    0.326  02.50  S16.00E    0.440 S     0.126 E   3.57   2.50     0.450  AT  S16.00E
1241.0  1240.85    1.27    1.206  05.25  S16.00E    1.739 S     0.498 E   4.13   2.75     1.810  AT  S16.00E
1284.0  1283.65    5.93    2.476  08.75  S65.00E    5.016 S     4.009 E   4.01   6.61     6.422  AT  S38.63E
1332.0  1330.04   14.06    2.260  12.25  S61.00E    9.029 S    11.774 E   2.23   3.57    14.838  AT  S52.52E

1356.0  1354.23   20.06    2.290  13.75  S61.00E   11.047 S    16.496 E   1.88   1.50    20.193  AT  S54.78E
1384.0  1381.36   26.95    2.335  14.75  S61.00E   14.900 S    22.524 E   1.07   1.00    27.055  AT  S56.36E
1412.0  1408.29   34.61    2.376  17.00  S61.00E   18.701 S    29.223 E   2.41   2.25    34.694  AT  S57.38E
1441.0  1435.93   43.39    2.424  18.25  S61.00E   22.958 S    36.902 E   1.28   1.25    43.461  AT  S58.11E
1490.0  1481.46   61.41    1.610  25.00  S60.00E   30.899 S    53.092 E   4.20   6.99    61.429  AT  S59.80E

1527.0  1514.00   77.27    0.174  26.00  S67.00E   37.240 S    67.700 E   0.88   1.09    77.270  AT  S61.18E
1546.0  1531.90   85.62   -0.732  26.50  S68.00E   40.463 S    75.464 E   1.05   0.67    85.627  AT  S61.80E
1583.0  1565.00  101.80   -2.039  28.00  S68.00E   46.594 S    90.637 E   0.41   0.50   101.912  AT  S62.79E
1619.0  1597.44  117.55   -4.477  28.00  S68.00E   52.505 S   105.209 E   0.00   0.00   117.637  AT  S63.49E
1668.0  1641.93  137.92   -6.907  23.50  S68.00E   60.109 S   124.288 E   1.53   2.50   138.095  AT  S64.16E

1694.0  1665.64  148.54   -8.016  25.00  S67.00E   64.278 S   134.152 E   1.79   1.58   148.757  AT  S64.40E
1721.0  1689.91  160.31   -9.295  27.00  S68.00E   68.804 S   145.088 E   2.27   2.05   160.575  AT  S64.63E
1749.0  1714.00  173.03  -10.901  27.50  S69.00E   73.502 S   157.016 E   0.73   0.68   173.368  AT  S64.91E
1777.0  1739.40  186.16  -12.674  29.00  S69.00E   78.251 S   169.388 E   1.61   1.50   186.590  AT  S65.20E
1789.0  1750.63  196.84  -14.213  29.75  S70.00E   82.029 S   179.497 E   1.22   0.90   197.352  AT  S65.44E

1862.0  1830.07  230.87  -18.343  31.50  S64.00E   98.503 S   218.349 E   1.27   3.52   239.572  AT  S65.70E
1905.0  1849.00  250.90  -19.120  31.75  S66.00E  103.870 S   229.278 E   1.41   1.08   251.630  AT  S65.67E
1932.0  1872.58  265.13  -20.036  32.00  S64.00E  109.704 S   242.198 E   1.21   1.09   265.885  AT  S65.63E
1960.0  1896.27  280.05  -20.069  32.50  S65.00E  116.135 S   255.684 E   0.78   0.73   280.823  AT  S65.57E
1997.0  1927.30  300.17   21.810  33.50  S63.00E  124.972 S   273.791 E   1.20   1.48   300.965  AT  S65.47E

2016.0  1943.14  310.66   22.027  33.50  S62.00E  129.815 S   283.093 E   0.87   0.55   311.438  AT  S65.37E
2068.0  1986.50  339.35   22.623  33.50  S63.00E  143.067 S   308.550 E   0.32   0.55   340.105  AT  S65.12E
2104.0  2016.35  359.47   23.217  34.50  S63.00E  152.206 S   326.487 E   0.83   1.00   360.222  AT  S65.01E
2160.0  2062.36  391.39   23.878  35.00  S62.00E  166.946 S   354.798 E   0.41   0.76   392.113  AT  S64.80E
2200.0  2094.82  414.75   24.160  36.50  S62.00E  177.917 S   375.432 E   1.13   1.50   415.456  AT  S64.64E

2229.0  2117.98  432.20   24.370  37.50  S62.00E  186.110 S   390.842 E   1.03   1.00   432.891  AT  S64.54E
2272.0  2152.44  457.90  -23.578  36.00  S57.00E  199.142 S   413.003 E   2.33   3.36   458.507  AT  S64.26E
2290.0  2167.10  468.31  -22.613  35.00  S55.00E  204.984 S   421.669 E   2.55   1.53   468.853  AT  S64.07E
2339.0  2206.80  496.81  -19.973  36.50  S57.00E  220.903 S   445.404 E   1.16   1.90   497.211  AT  S63.61E
2374.0  2234.06  517.76  -18.579  37.25  S58.00E  232.288 S   463.118 E   0.82   0.96   518.098  AT  S63.37E

2425.0  2275.59  548.41  -16.807  38.75  S58.00E  248.530 S   489.140 E   0.29   0.50   548.664  AT  S63.07E
2472.0  2313.31  576.38  -14.944  36.50  S57.00E  263.595 S   512.794 E   0.41   0.65   576.576  AT  S62.80E
2566.0  2389.60  631.11  -10.348  35.00  S56.00E  293.898 S   558.593 E   0.51   1.61   631.190  AT  S62.25E
2690.0  2492.99  699.19   -3.444  32.00  S55.00E  332.037 S   615.001 E   0.74   3.05   699.195  AT  S61.59E
2750.0  2543.87  730.79    0.050  32.00  S55.00E  350.874 S   641.046 E   0.00   0.00   730.790  AT  S61.31E


       ************************************************************************
       *                                ********                              *
       *      THE HORIZONTAL DISPLACEMENT AT THE DEPTH OF                     *
       *                                ********                              *
       *   2750.0 METERS EQUALS      730.790      METERS AT   S61.31E         *
       *                                ********                              *
       ************************************************************************
```

APPENDIX II: Main activities during drilling of well CHA-1

Activities	Date	Day no.	Hole ϕ	Comments
First stage				
*Beginning	23-05-92	1	26"	
*Cementing 20"	27-05-92	4	26"	Surface casing
*Installation 17 1/2" drill bit	29-05-92	6		
Second stage				
*Blow out preventer	31-05-92	8	17 1/2"	Repair and installation of BOP
*Drilling	03-06-92	11		
*Change drill bit	06-06-93	14		Change #1
*Circulation loss	13-06-92	21		Cementing circul. loss at 400 m
*Change drill bit	20-06-92	28		Change #2
*Stabilizing/sealing circulation loss	23-06-92	31		Cementing again at 404 m
*Cementing and casing 13 3/8"	26-06-92	34		Temperature logging (1-4)
*Installation 12 1/4"	29-06-92	37		
Third stage				
*Blow out preventer	30-06-92	38	12 1/4"	Problems thread couplings 12 1/4"
*Drilling	01-07-92	39		
*Circulation loss	02-07-92	40		Cementing circulation loss: 662.3 and drilling cement: 596-657.8 m
*Temp log at 847 m	09-07-92	47		Measurements to check cementing.
*Drilling formation	11-07-92	49		Changes in drill strings; repairing damages in electric plant.
*Change drill bit	13-07-92	51		Change #3
*Drilling	14-07-92	52		
*Temp log at 1200 m	18-07-92	56		Identified bad cementing at 643 m Still checked circulation losses at 670-690 m, 710-730 m, re-sealed
*Kickoff point 1200 m Directional drilling	21-07-92	59		Cleaning hole-drilling formation
*Partial circulation loss 1374 m	27-07-92	65		Circ. loss sealed with obturant (coffee shells)
*Change drill bit	29-07-92	67		Change #4
*Drill+change drill bit	02-08-92	71		Change #5
*Cleaning hole to cement 8 5/8"	06-08-92	75		
*Cementing and casing 9 5/8"	07-08-92	76		Deviation measurements to check inclination of well was done almost twice a day during third stage.
*Installation 8 1/2"	09-08-92	78		

Activities	Date	Day no.	Hole ϕ	Comments
Fourth stage				
*Drilling cement with 8 1/2" (1595 m)	10-08-92	79	8 1/2"	Drilling cement
*Change drill bit	11-08-92	80		Change #6
*Drilling: antimagnetic stabilizers DC 6 1/2	11-08-92	80		Drill bit 8 1/2"+DC antimagnetic stabilizers 6 1/2"+2 DC 6 1/2"+ stabili.+9 DC 61/2"+PHW5"+TP5"
*Drill+change drill bit	14-08-92	83		Failure in mud pump, change #7
*Drill+change drill bit	17-08-92	86		Change #8.
*Drill+change drill bit	21-08-92	90		Failure in mud pump, change #9
*Drill+change drill bit	25-08-92	94		Checking well's trend, change #10
*Drilling formation up to 2207 m	31-08-92	100		
*Drill+change drill bit	01-09-92	101		Change #11
*Correction in trend and deviation of well.	03-09-92	103		Reaming and stabilizing well
*Drill bit stuck	05-09-92	105		Pipelax+diesel to recover drill bit
*Repairing mud pump	10-09-92	110		Mechanical repairs
*Drilling 2242 m depth	14-09-92	114		Drilling formation 2242 m
*Drill+change drill bit	16-09-92	116		Change #12
*Downhole motor failed	18-09-92	118		After damaging-repairs
*Drill+change drill bit	20-09-92	120		Change #13
*Drilling+breakdown, drill bit stuck 2255 m	21-09-92	121		Breakdown occurred due to change in arrangem. of drill string make up
*Drilling tool recovered	25-09-92	125		Tool recovered after many attempts
*Drill+change drill bit	26-09-92	126		Change #14
*Drilling 2319-2352 m	28-09-92	128		Tension in drill rig
*Drill+change drill bit	30-09-92	130		"Dogs leg" at 1620 m, change #15
*Checking tools by tuboscope+repairing mud pumps, solid remover, pipes, motors	02-10-92	132		Due to many failures and problems in verifying deviation, overhaul and repairing of tools was done
*Drilling rock: 2360 m	26-10-92	156		Deviation measurements corrected
*Drill+change drill bit	28-10-92	158		Rotary/motors probl., change #16
*Drill+change drill bit (2485 m depth)	01-11-92	162		Again, drill bit stuck at 1666 m, where the "dog leg" was located; by
*Drill bit stuck 1611 m	02-11-92	163		mistake all tools were not recovered, 53.66 m went downhole
*Main activities are concentrating only on recovering tools.	03-11-92	164		* Pipelax+diesel, * washing * Fishing tool-overshot, neg.results * Electric shots (Schlumb), positive
*All tools recovered	19-12-92	210		All tools were recovered
*Drill+change drill bit	20-12-92	211		Change #17, continuous drilling
*Drill+change drill bit, attempts to extract all metals left downhole	08-01-93 11-01-93	230 233		Change #18, problems with drilling rate, metals downhole Able to clear bottom of well
*Different changes in drill bits while drilling	12,17-01-93 24-01-93	234-239 246		Changes #19, 20 Change #21
*Hydrofracturing and attempts to clear well	30-01-93	251	Open hole	Completion of well, attempt to do hydrofracturing.
*Completion of well	31-01-93	252		Temperature logging

APPENDIX III: Preparation and identification of sample minerals by X-ray diffraction

The preparation of samples with hydrothermal alteration and clay minerals can be done by the following procedures:

Procedure A:

1. Hand pick grain from the drill cuttings by using the binocular microscope.

2. The samples are powdered in an agate bowl to a grain size of 5-10 m. Acetone is added in order to prevent loosing samples while powdering.

3. Fill the sample holder for the XRD with the powder.

4. Run the sample by starting at 3-35° on the X-ray Diffractometer.

These techniques can be used specially to separate white minerals such as quartz, zeolites and calcite.

Procedure B: For clay minerals

1. Place approximately two teaspoons of drill cuttings into a glass tube, wash out dust with distilled water. Fill the tubes 2/3 full with distilled water and plug them with rubber stoppers. Place the tubes in a mechanical shaker for approximately 4-8 hours, depending on the grade of alteration of the samples.

2. Allow particles to settle for 1-2 hours, until particles finer than approximately 4 microns are left in suspension. Pipette a few millilitres from each tube and place 10 drops on the suspension in a labelled glass plate. Avoid having the samples very thick. Make a duplicate of each one and let them dry at room temperature overnight.

3. Place one set of samples in a desiccator containing Glycol ($C_2O_6O_2$) solution and the other set in a desiccator containing $CaCl_22H_2O$. Store at room temperature for at least 24 hours. Thick samples will need a longer time in the desiccator, at least 48 hours.

4. Run both sets of samples from 2-25° on the XRD machine.

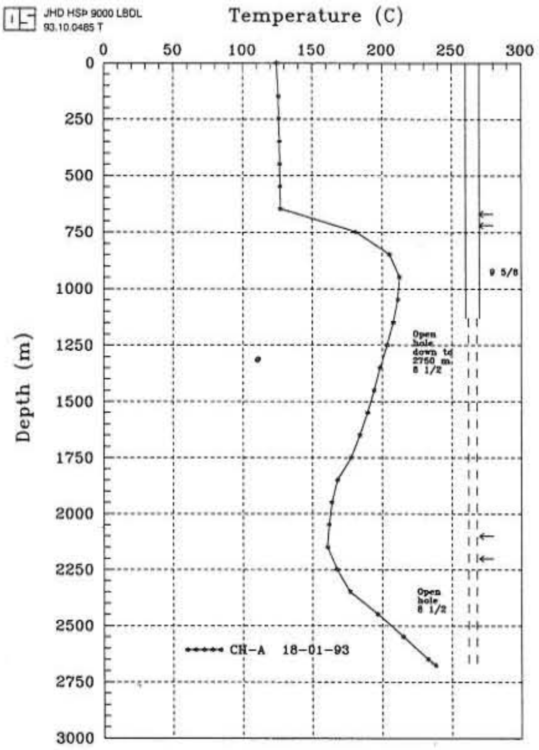
5. Place one set of samples (use the glycol saturated) on an asbestos plate and heat in a preheated oven at 550-600°C. Oven temperature must not exceed 600°C. Exact location of individual samples on the asbestos plate must be known before heating, because labelling will disappear during the heating process. Cool the samples reasonably before further treatment.

6. Run the samples from 2-15° on the XRD

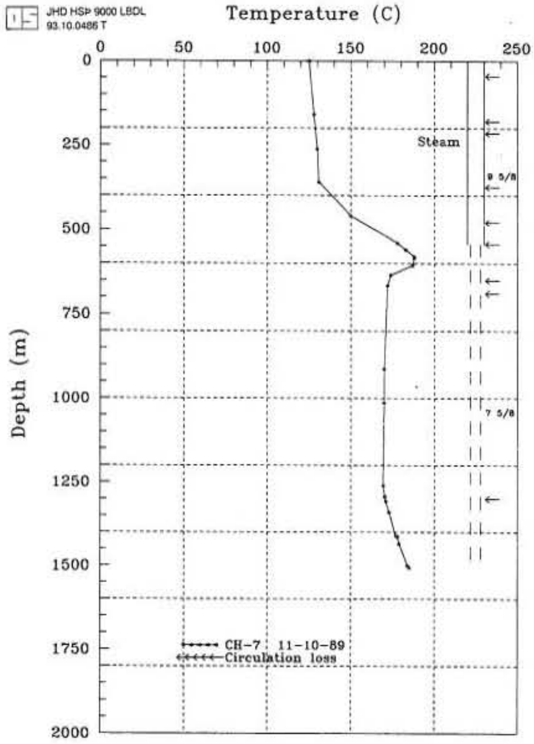
APPENDIX IV: Results of XRD analysis for clay minerals and separation of white minerals

Depth (m)	Treated with CaCl$_2$	Glycolsaturated Lines d/Å	Heated 550-600°C Lines d/Å	Probable mineral
10	16.99	17.67	collapsed	Smectite
40	16.99,8.50,7.2	17.67,8.51,7.19	10.05,4.85	Smectite
60	17.31	16.99	collapsed	Smectite
100	13.60, 8.96	16.99,9.00	10.05,9.00	Smectite
210	13.81, 9.00	17.33,10.05,9.0	9.94,9.00	Smectite, mica
270	16.98,10.06,9.04	16.99,10.04,8.93	10.05,8.93	Smectite, mica
340	13.60, 8.93	16.99,8.96	10.05,8.93	Smectite
420	13.19,8.93	17.33,9.00	9.94	Smectite
540	13.19	16.2,13.39	9.94	Smectite
620	13.79	16.78,14.02	collapsed	Smectite
630	14.48,7.19	14.25,7.14	collapsed	(Chlorite), MLC
650	13.19	14.25,7.14	collapsed	(Chlorite), MLC
679	31.98,14.25, 9.41, 7.14	32.69,14.49,9.41 7.14	14.72,12.61	(Chlorite), MLC
740	14.48,7.19	14.33,7.25	14.34,7.25	Chlorite
780	14.49, 7.25	14.25,7.08	14.25	Chlorite
850	29.42,14.35,9.93, 7.12	31.53,16.98,14.47, 9.93,7.13	14.48,12.62,9.92,	Chlorite, MLC, illite (Smectite)
870	29.62,14.48,7.15	32.69,17.31,14.52, 7.18	14.72,12.44,9.93, 7.24	Chlorite, MLC, smectite
970	30.46,14.49,7.14	31.55,18.41,14.25 7.14	14.25	Chlorite, MLC
1000	14.24,7.13	16.98,14.33,7.13	14.72,9.93	Chlorite, (sm)
1020	29.43,14.24,7.14	30.44,14.24,7.09	14.72,12.69	Chlorite, MLC
1050	29.45,14.49,10.05, 7.08	31.5,25.44,17.33, 14.25,10.05,7.08	14.73,10.05,7.3	Chlorite, MLC, illite (smectite)
1080	30.02,14.48,10.64, 7.13	18.01,14.48,10.08, 7.13	14.48,10.04,7.31	Chlorite, (MLC), illite
1210	14.25,10.05,7.14	14.25,10.05,7.08	14.73,10.05,7.3	Chlorite, illite
1230	29.45,14.25,7.14	29.45,14.255,7.138	14.73,7.3	Chlorite, (MLC)
1250	14.58,10.08,7.13	14.33,10.15,7.10	14.72,10.02,7.31	Chlorite, illite
1280	14.25,10.05,7.08	14.25,10.05,7.14	14.98,10.16,7.5	Chlorite, illite
1320	14.25,10.05,7.08, 5.61	14.25,10.05,7.08	14.73,10.05,(8.84) 7.43	Chlorite, illite
1350	14.25,10.05,7.08	14.25,10.05,7.14	14.73,10.16,7.25	Chlorite, illite
1510	14.25,10.05,7.14	14.25,10.05,7.08	14.49,10.16,7.20	Chlorite, illite
1660	14.25,10.16,7.14	14.25,10.05,7.14	14.49,10.16,7.25	Chlorite, illite
1680	14.25,7.14,4.72	14.25,7.14	14.97,(8.93),7.43	Chlorite, illite
1800	14.25,7.08,4.72	14.25,7.14	14.25,10.05,7.14	Chlorite, illite
2000	14.25,10.05,,9.17, 7.08	14.03,10.05,9.11	14.73,10.05,7.37	Chlorite, illite
2200	14.25,10.05,7.14	14.25,10.05,7.14	14.25,10.05	Chlorite, illite
2500	14.38,10.11,7.14	14.24,9.93,7.12	14.47,10.04,8.9,7.2	Chlorite, illite
2580	26.75,14.75, 11.47,9.95,7.08	27.59,14.38,10.06, 7.13	24.52,14.38,9.93, 8.75,7.37	Chlorite, MLC, illite
2660	29.45,14.49,10.05 7.19,4.74	14.25,10.05,7.14	14.48,10.05,(8.93) 7.25	Chlorite, MLC, illite

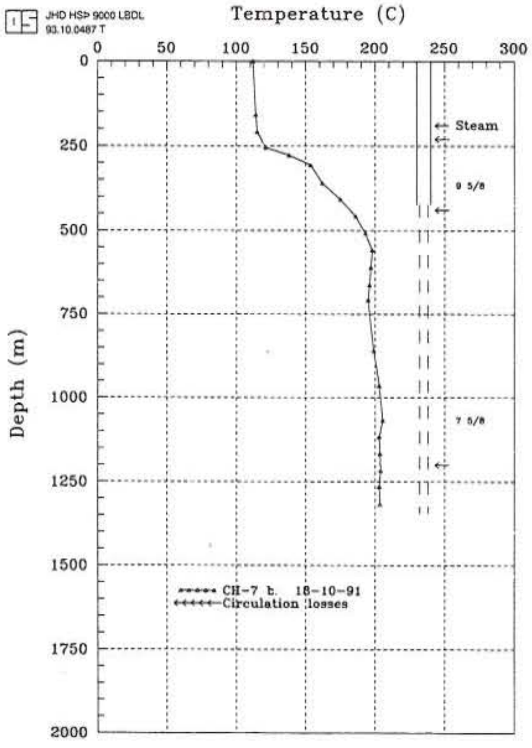
APPENDIX V: Temperature profiles for the Chipilapa wells



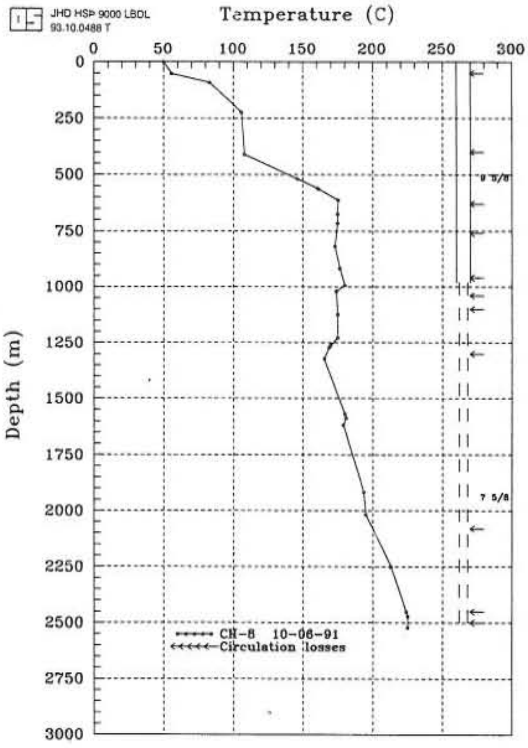
Temperature profile for well CH-A



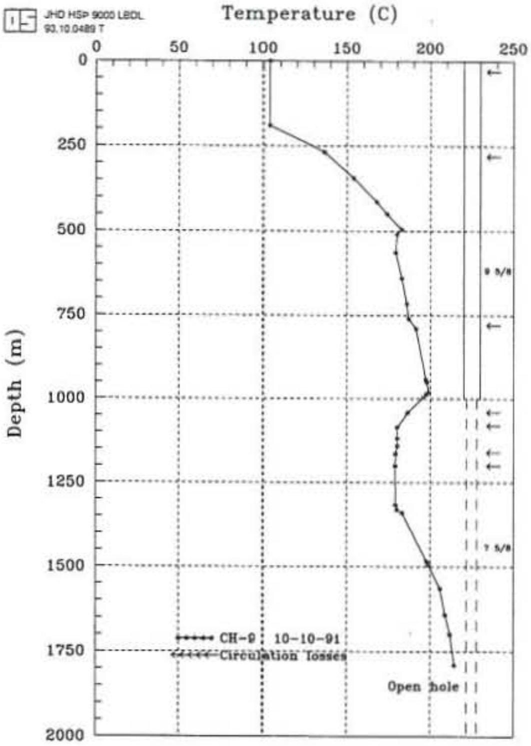
Temperature profile for well CH-7



Temperature profile for well CH-7b



Temperature profile for well CH-8



Temperature profile for well CH-9