CHARACTERIZATION OF THE RESERVOIR OF THE LOS HUMEROS, MEXICO GEOTHERMAL FIELD

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ABSTRACT

A general charactertzation of the Los Humeros, Mexico geothermal field is presented, based upon the reservoir engineering analysis. Well test data from 33 wells are analyzed and interpreted. The results indicate two production intervals: An upper interval between 1400 masl and 900 masl and a *lower* interval located below 700 masl. The area of the reservoir is 15.2 km^2, divided in two sectors: Colapso Central and Mastaloya. The first one is hotter than the second one. Reservoir conditions locate thermodinamically the reservoir fluid in the subcooled region. very close to saturation conditions. Low formation conductivity generates high pressure losses and fluid reaches saturation conditions in the formation. As a consequence surface enthalpy values are higher than the enthalpy of the fluid *in situ.* Evolution to two phase in the formation causes dissolved salts concentration in the liquid phase and precipitation in the wells. This phenomena is severe when wells are producing from both production intervals. In causes corrosion in the wells, as shown in the Colapso Central sector,

INTRODUCTION

When a geothermal field is in exploitation, it is important to know what will the reservoir behaviour in the future be In practice it is difficult to know this behaviour with precision To reach the best approximation the investigated system it is necessary that the theoretical model selected for the analysis includes most of the data of the real system This data are generated by the different disciplines involved in the geothermal project Each one generates interpretation model, whose characteristics are assumed to represent the characteristics of the actual reservoir (Gringarten,1982) Fig.1 shows the four models that are needed to understand and predict reservoir behavior Geological data yield a geological model; Geophysical data yield a geophysical model; Geochemical data yield a geochemical model and well test data yields a reservoir engineering model. Each a model is independent because it contemplates different aspect of reservoir behavior. When the four models are integrated the result is a reservoir model, that attempts to be the best explanation of the processes occurring in the reservoir.

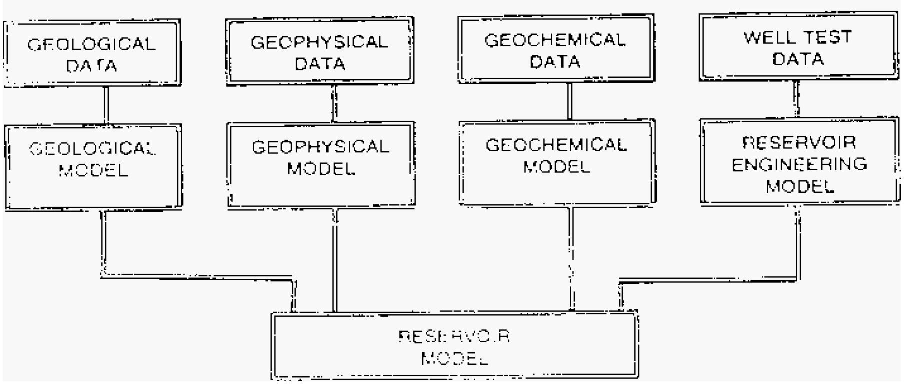
To construct the reservoir engineering model it is necessary to know the specific attributes of the reservoir: Area, thickness. average pressure and temperature, productivity index of the wells and conductivity of the formation. The definition of these attributes is known as the characterization of the reservoir. To reach this characterization well test data from the different stages are analyzed: Drilling, warming-up and production. Testing includes temperature profiles, injection testing, pressure profiles, production testing and butld-up testing.

The objective of this paper is to show the characterization *of* the reservoir of the Los Humeros, México, geothermal field from well test data analysis.

THE LOS HUMEROS GEOTHERMAL FIELD

The Los Humeros geothermal field is located in the eastern portion of the Mexican volcanic belt in a caldera structure (Fig 2) In 1968 Comision Federal de Electricidad (C.F.E) began geological, geophysical and geochemical studies in the area and in 1982 the first well was drilled At present there are 34 wells at 2500 m average depth supplying 450 t/h of steam to 7 back pressure units of 5 MW each. In 1990 the operation of the first unit of 5 MW was started Fig.3 shows the location of wells and units in the field

Fig.1.- The four models needed to construct the reservoir model



CHARACTERIZATION OF THE RESERVOIR

LOSS OF CIRCULATION.- Losses of circulation during drilling are the first indicator of permeable zones. These zones are defined more accurately with temperatures profiles. In all wells, loss of circulation greather than 60 m^3/hr occurred between 2800 and 2700 masl. This zone is behind the 9 5/8"Ø casing. From 1350 to 1100 masl loss of circulation of 8 m^3/hr average occurred in the wells. Wells H-1, H-4, H-17 and H-23 are the exception, where if was on the order of 30 m^3/hr at the same elevatron. Top of the permeable interval is at 1350 rnasl.

TEMPERATURE PROFILES: Temperature profiles during drilling are useful in identifying permeable zones. The criterion is based upon the changes in slope. These changes depend on the mechanism of heat transfer (conduction, convection) and the thermal conductivity of the rock (Grant,1982,1983). Fig.5 shows a simplified theoretical temperature profile When heat transfer is controlled by conduction, a slope of constant profile is observed; When it is controlled by convection a vertical (1) or an inverted (2) profile is observed. Convection occurrs when a permeable zone with fluid is intersected (Drury 1982, Ripperda 1987, Ingebritsen 1987).

Fig.5.- Theoretical temperature profile affected by the mechanism of heat transfer and rock thermal conductivity in a well.

Two factors affect the magnitude of an inverted profile (2): Permeability, and the fluid used during drilling. When mud is used, permeable zones may be masked, mainly in reservoirs of low permeability.

Fig.6 shows temperature profiles in some representative wells immediately after drilling and after substantial warming-up. Two permeable zones are identified. Top of the shallowest interval is at 1400 masl and top of a deeper interval is at 700 masl. Wells producing from the shallower interval are H-1, H-15, H-21, H-22, H-23, H-30, H-31 and H-32. Wells producing from shallower and deeper intervals are H-4, H-6, H-8, H-10, H-11, H-13, H-16, H-17, H-19, H-20, H-27, H-28, H-29 and H-30. Well H-7 is producing from the deeper interval only. In wells H-2, H-5, H-21 and H-26 the mechanism controlling the temperature profile is conduction. indicating low permeability. These wells are not productive.

AVERAGE RESERVOIR TEMPERATURE. Stabilized temperature profiles were analyzed to estimate the average temperature at two feed intervals (Fig 6) In all of the profiles selected the elapsed time since completion of the well is 20 days maximum. Because temperatures at 700 masl are very high, in some deeper wells it is difficult to establish an average temperature because profiles are masked by the hotter deep zone. if a short temperature stabilization time was used However it was possible to make an estimation of the stabilized temperature. The shallowest interval with 290°C in the Mastaloya sector and 320°C in the Colapso Central sector The deeper interval with 315°C in Mastaloya and 330 360°C in the Colapso Central A correlation (south north) is presented in Ftg.7 of feed intervals in some wells The shallowest interval is more regular than deeper interval In this figure it is indicated too location of the slotted liner. It is important to observe that well H-7 is producing only from deeper interval

AVERAGE RESERVOIR PRESSURE.- Reservoir pressure was estimated using the pivot point concept and pressure buitd-up tests

During warming up, the pressure gradient in a well decreases wtth the elapsed time, rotating over one point This point is located in front of the feed zone and is named the pivot point When two feed zones are in a well the pivot poin? is located between both, and is an average of those (Grant,1982) Table 1 shows the pivot points calculated in some wells

Table 1.- Pivot point in wells of Los Humeros

WELL	ELEVATION (masl)	PRESSURE (bar)_m
H-1	1585	93
H-6	824	147
H 7	982	124
H-8	990	129
H-20	1107	126
H-22	1575	101
H-23	766	143

WELL	AVERAGE RESERVOIR PRESSURE (bar)	INSTRUMENT ELEVATION (masl)	INSTRUMENT
H-1	98	1568	mechanical
H-8	113	1122	mechanical
H-9	175	1315	suspension chamber
H-11	100	1354	mechanical
H 16	110	1315	suspension chamber

PRODUCTIVITY INDEX.- Productivity index is defined as the mass flow rate produced per bar of pressure differential between the wellbore opposite the feed zone and the static reservoir pressure. In other words, productivity index means the ability of a well to produce (Frick, 1962).

Productton testing consists of mass flow rate measurment and pressure and temperature lugs at diverse wellhead pressures. With this Information, productivity index is calculated. The values of productivity index calculated in most of the wells are presented in Table 3. These values correspond to the initial state of the wells, that is before commercial exploitation. No scaling is present in the wells at that time.

The productivity index of wells H 1 and H-9 is greater than in other wells. Mass flow rates are greater, and pressure losses from reservoir to the well are smaller Thts means that conductivity of the formation in the vicinity of the wells is high.

Well H-7 is the case of improvement during productton. The value reported in Table 3 is 0.32 (1984) and two years later is 0.86 (1986)

Well H-1 is the case of a well with scaling effects. In 1983 productivity index was 4 and four years later declines to 1 6 (1987). Caliper testing showed that scaling was the cause of declining.

Table 3.- Productivity index of wells in Los Humeros.

WELL	PRODUCTIVITY INDEX (t/h/bar)	YEAR	MASS FLOW RATE [t/h]	P_r-P_f (bar)
H 1	4.0	1983	86	21.6
H-6	0.35	1986	37	107
H-7	0.32	1984	32	99
H 8	0.42	1985	33	79
H-9	1.8	1986	71	40
H-10	0.1	1986	7	116
H 11	0.61	1986	35	58
H-12	0.73	1386	45	62
H-15	0.69	1988	54	78
H 16	0.63	1985	40	63
H-17	0.47	1986	36	77
H-20	0.45	1988	40	88
H-27	0.1	t988	12	112
H-28	0.24	1989	25	123
H-30	0.35	1989	34	97
H-31	0 58	1989	50	86
H-32	0.43	1989	35	82

P_r Reservoir prcssurc P_f: Flowing pressure

Except wells H 1 and H-9, productivity index in wells is in the range of 0 32 io 0.7 t/h/bar.

Table 4 shows initial mass flow rate of the wells. It can be seen that mass flow rate in the field is in the range of 30 40 t/h of mixture, with wellhead pressures between 20-40 bar,. Mixture enthalpy is on the order of 2000 kj/kg and higher, at the surface.

CONDUCTIVITY OF THE FORMATION.- The product permeability-thickness (kh) is deftned as the formation and is calculated from build-up testing. Knowing the thickness of the feed zone, it is possible to determine the value of the permeability. Unfortunately. in fractured media it is difficult to know accurately the value of thickness Usually it is estimated from temperature profiles and numerical simulation. For this reason only the value of the product of permeability-thickness is commonly reported Values of conductivity of the formation in Los Humeros are low, on the order of 1 to 5×10^{13} m^3 Table 5 shows these values for some wells

Tabte 4. Initial production of wells in Los Humeros at atmospheric conditions.

WELL	WELLHEAD PRESSURE (bar)$_a$	FLOW RATE (t/h)		ENTHALPY (kj/kg)
		STEAM	WATER	
H 1	31	30	56	1190
H 6	25	24	13	1830
H 7	33	31	1	2596
H-8	23	23	7	2105
H-9	65	69	-	2660
H-10	11	11		2660
H-11	38	29	1	2548
H-12	37	36	5	2190
H-13	15	14	11	1622
H-15	39	49	5	2456
H 16	38	39	-	2661
H-17	36	35	-	2660
H-19	27	37	-	1660
H 20	35	36	3	2435
H-23	8	10	5	1812
H-28	24	21	7	1983
H-29	19	22		2660
H 30	35	34	-	2661
H-31	42	47	3	2488
H-32	25	25	10	1997
H-33	34	28	1	2594

Table 5. Conductivity of the formation (kh) in wells of Los Hurneros.

WELL	kh [X10^{-13} m^3]
H-9	4.80
H-16	3.00
H-1	5.22
H-7	1.52
H-8	1.08
H-11	2.00

CONCLUSIONS

The characterization of the reservoir of the Los Hurneros geothermal field was carried out using the existing well test data, resulting in a good approximation to explain some **processes** ocurring in the **wells** Obviously, total knowledge of the reservoir is never finished and characterization must be improved when new **well** data is obtained

The total area of the reservoir under exploitation is 15.2 km^2 and is limited by the **area shown** in Fig.9. as further described **below:**

NORTH: Wells H-21 and **H-22** are not productive. In well H **21** tickness of the convective interval is reduced and temperatures are lower than in the Colapso Central. In **well** H-22 tickness of the convective interval is **reduced.**

SOUTH. Wells H 2, H 14 and H 18 **Well** H 2 is not productive It is not **possible** to extend correlation of permeable intervals to this **well. In well** H *18* thickness of the convective interval is reduced. This well produces at very low wellhead pressures and low flow rate. Well H-14 has low temperatures

EAST: Wells H-23 and H-27 Both wells have **low** permeability **and** low productrvity index (0.11 t h/bar). **Temperatures** are lowest. This **stde** of the field has possibilities to produce and is limited hy well H-25 Temperature profile of this well **is** conductive

WEST: Well H 5. Thickness of the convective interval is reduced, with lower temperatures and permeability **It** is not productive

Fig.10 **shows** a cross section of the field indicating location of **feed** zones. Two production intervals are identified: The upper interval between 1400-900 masl and the deeper interval located below 700 rnasl.

From the point of view of temperatures. the **field** can **be** dtvided in two sectors: Colapso Central with higher temperatures. and **Mastaloya** with lower temperatures. The Colapso Central is Characterized by temperatures of 320°C in the upper interval and 330-360°C in the deeper interval. The Mastaloya sector is characterized by temperatures of 290°C in the upper interval and 315°C in the **deeper** interval

The values presented in Tables 1 and 2 are graphed and fitted to a straight line resulting in the vertical pressure distribution in the **field** (Fig 81. This profile corresponds to a hidrostatrc column.

Average productivity index **in** the wells is 0.48 t/h/bar. The exception are **wells** H-1 and H-9, **whose** values are higher, **4** and 1.8 respectively. Average production **is** on the order of 30-40 t/h of mixture, with wellhead pressures on the order of 20-40 bar,,.

The reservoir is a high temperature and **low** permeability system Taking the upper interval m the **Colapso** Central as an example, temperature and pressure reservoir are 320°C and 118 74 bar$_{abs\ respectvc}$, **At** these condttions, the fluid is located thermodinamically in the subcooled lrquid region, very closed to saturation conditions Since the saturation pressure corresponding to 320°C is 112 bar, then to reach saturation conditions it IS **necessary** to depress the fluid *6* bar,,,. Low formation conductivity (2x10^{13} m^3) generates high **pressure** losses in the wells where formation conductivity is low wich amounts to 40 **bar,,** (H-9) to 123 bar,, (H 28), Table 3 When the fluid **flows** from the formation to **the** well, it reaches saturation conditions in the formation and boiling starts When liquid water flashes in fractures the fluid temperature decreases and causes a temperature gradient between the rock and the fluid. This, in turn, can result in an additional heat transfer from the rock to the fluid **As** ***a*** consequence, surface fluid enthalpy values are higher than the enthalpy of the fluid in the reservoir

Evolution into two phase in the formation causes dissolved salts to concentrated **in** the liquid **phase.** precipitating minerals in the well and probably in the formation.

When wells are producing from both feed intervals, corrosion of the casing takes place and in a short time **welts** become unproductive This condition exists, for example, in wells H-11, H 28, H-17 and H-19 When wells are producing frotn only one feed interval no corrosion takes place inside the casing, as is the case fur wells H 1, **H-31,** producing frorn shallowest zone and **H-7** from deeper zone (Sanchez, 1994)

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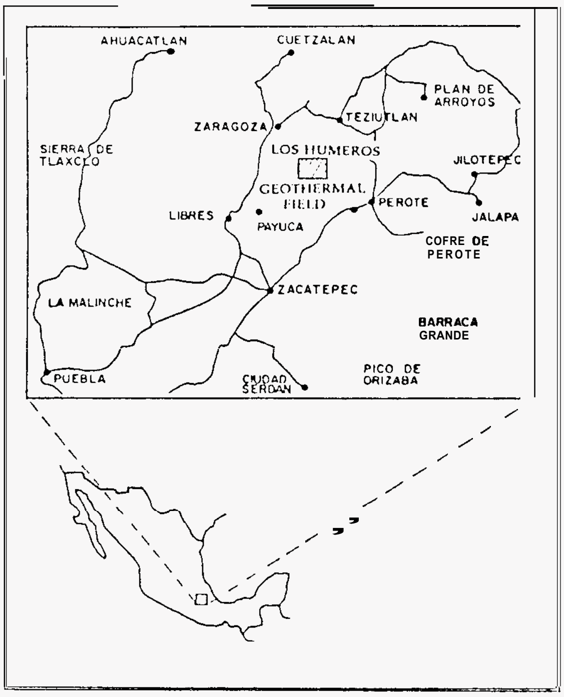

Fig.2.- Location of the Los Humeros geothermal field, México

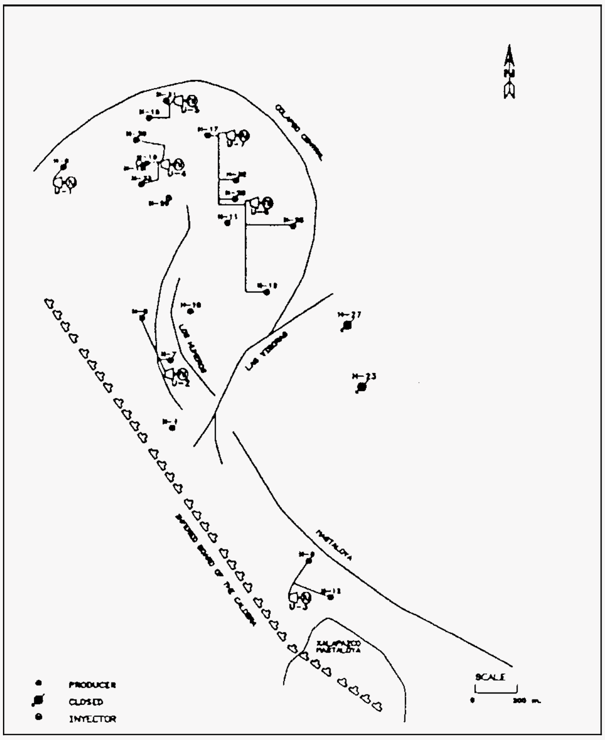

Fig.3.- Location *of* wells and plants in Los Humeros

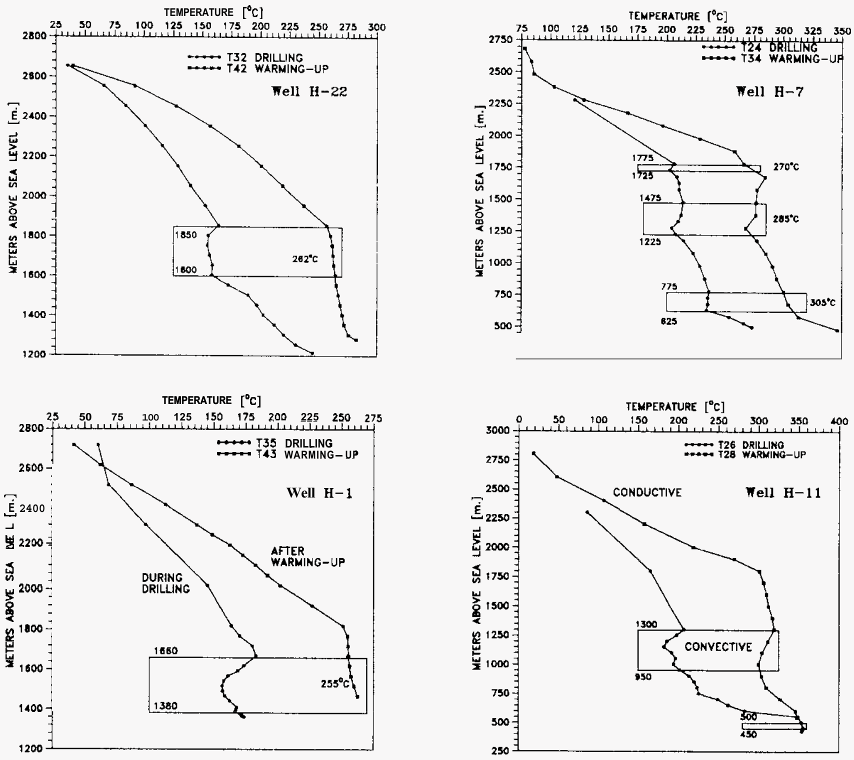

Fig. 6.- Permeable zones in wells of Los Humeros are shown by a convective gradient wich have either isothermal or even negative slope due to circulation and mud inversion. The two graphs for each well show the gradient immediately after drilling and after substantial warm-up time.

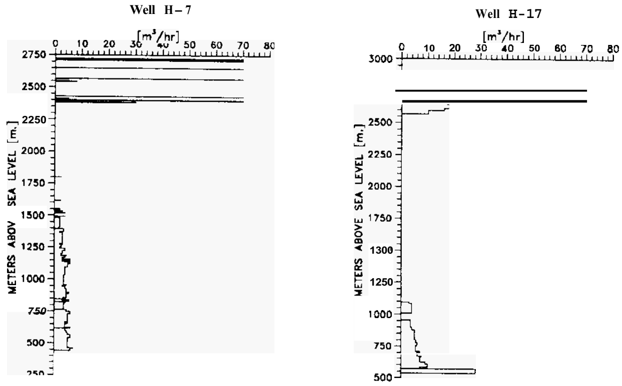

FIG.4.– **Loss** of circulation in **wells** of Los Hurneros

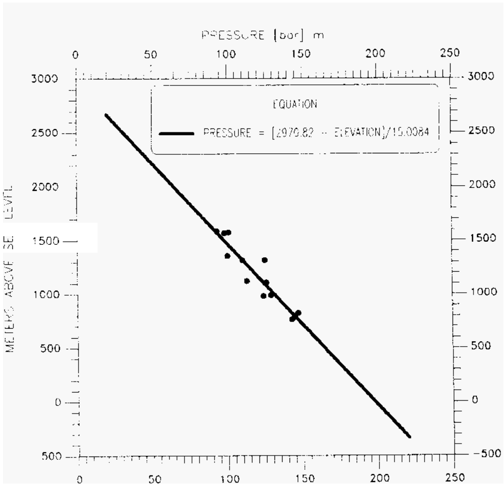

Fig. 8.- Pressure vertical profile in Los Humeros.

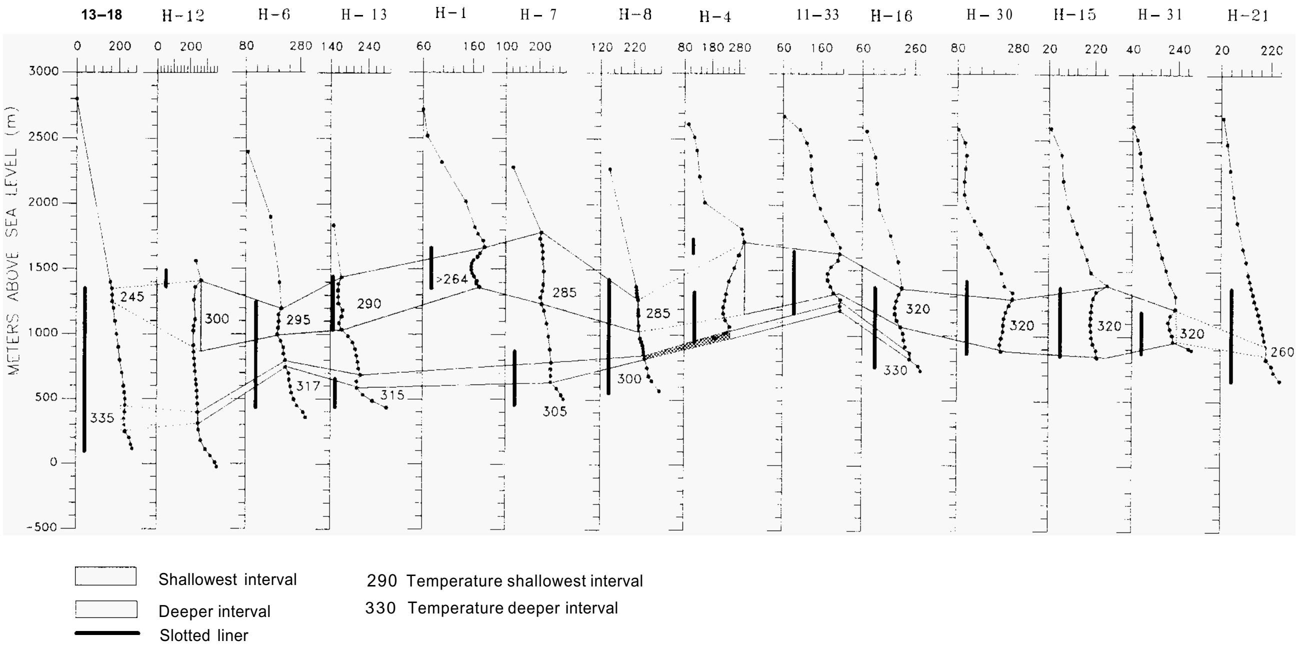

Fig. 7.- South-north cross section correlation of the temperature profiles shows the permeable intervals in wells of Los Humeros.

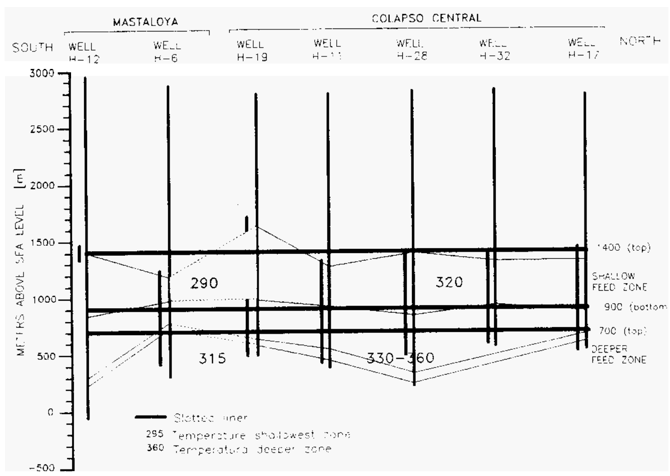

Fig. 10.- South-north cross section showing the permeable intervals.