PROCEEDINGS, Twenty-First Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 22-24, 1996
SGP-TR-151

A RESERVOIR ENGINEERING ASSESMENT OF THE SAN JACINTO-TIZATE GEOTHERMAL FIELD, NICARAGUA

S. Ostapenko, S. Spektor, H. Dávila, E. Porras, M. Pérez
INTERGEOTERM, S.A.
Managua, Nicaragua

ABSTRACT

More than twenty years have passed since geothermal research and drilling took place at the geothermal fields in Nicaragua. The well known Momotombo Geothermal Field (70 MWe) has been generating electricity since 1983, and now a new geothermal field is under exploration, the San Jacinto-Tizate.

Two reservoirs hydraulic connected were found. The shallow reservoir (270°C) at the depth of 550 - 1200 meters, and the deep one at > 1600 meters. Both of theme are water dominated reservoirs, although a two phase condition exist in the upper part of the shallow one.

Different transient tests and a multi-well interference test have been carried out, very high transmissivity value were estimated around the well SJ-4 and average values for the others.

A preliminar conceptual model of the geothermal system is given in this paper, as the result of the geology, geophysics, hydrology studies, drilling and reservoir evaluation.

INTRODUCTION

The San Jacinto-Tizate Geothermal Field is located at the north-western area of the cuaternary Chain of Nicaragua (Figure 1), 115 kilometers from Managua city. The San Jacinto graben is elongated in a SSW-NNE direction and filled mainly with volcanic and volcanic sedimentary products of Oligeon?-Quaternary age (Internal Report, 1995).

During the period 1953-1992, several companies (TEXAS INSTRUMENTS, OLADE, ONU, PHOENIX GEOPHYSICS, etc.) carried out different exploratory survey. The results gave an interesting area of exploitation; the location of drilling for the first two wells was done based on this studies. The results were not satisfactory since the highest temperature of 190°C (at 1200 meters) in well SJ-1 was not of commercial interest.

During the period from September 1992 to May 1995, a major survey was carried out by the INTERGEOTERM company, as a result a new area of interest was found at the Tizate geothermal field. Five new wells were drilled giving an excellent result.

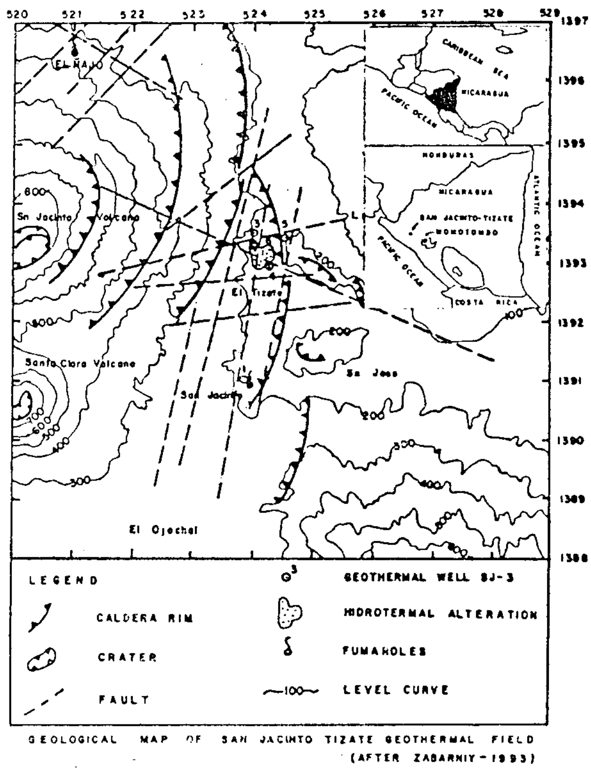

Figure 1: Location of San Jacinto-Tizate Geothermal Field

GEOLOGYCAL OUTLINE

The geothermal field is limited by four volcanic cuaternary structures, one of them (El Chorro-Tizate-La Bolsa, 240 m a.s.l) is partially eroded and collapsed; and three inactive volcanic structures called Santa Clara (Figure 1), San Jacinto (824 m a.s.l) and Rota (700 m a.s.l).

The first 200-250 meters are mainly covered by pyroclastic products and reworked deposits, by altered and nonaltered volcanic rocks of andesitic and andesitic-basaltic composition, and locally by aglomarates and pumiceous litoclastic composition.

This first unit belongs to Upper Pleistocen-Holocen age. (Q_{III-IV}). A second unit was found between 250 and 950 meters, this unit consist of andesitic lávas from Pleistocen age (Q_{I-III}). The third unit (950 to 2000 meters) consist of volcanic sedimentary rocks of andesitic composition, this unit belongs to a Neogenic age (upper-middle Miocen). At the levels of 2000-2300 meters was found volcanomictic sandstone and gravelitic deposits, and in some cases organic fragments.

An intrusive body was intercepted at 450 meters depth in the center part of the field, this body is microdiorite of middle grain composition.

GEOLOGICAL STRUCTURE

The geothermal area is limited on its east border by a calderic fault, as a result of the collapse of the west side of the volcanic structure El Chorro-Tizate-San Jacinto, and the partially collapse of the west side of the San Jacinto volcano. This calderic fault has a general N-S direction, and is related to the two hydrothermal areas San Jacinto-Tizate. Moreover, exist another two important fault systems with E-W and NE-SW directions, related with the geothermal reservoir at Tizate field (Figure 1).

GEOPHYSICAL STUDIES

The recent geophysical sounding carried out (1993-1994) on San Jacinto-Tizate geothermal field consisted in two types of geoelectrical soundings (time sounding and frecuency sounding), and a magnetoteluric sounding. Those studies have developed a preliminar geoelectric structure of the field:

- A preliminar area of 4 km^2 was delimitated
- A layer of high resistity values (20-100 ohm.m) existes between 0-300 meters; this layer is intercepted by vertical tectonic faults.
- A low resistivity layer (1-20 ohm-m) was found below 300 meters.
- It's clearly seen the existance of a reservoir with permeable volcanic rocks on the depth 500-1000 meters. The boundary of the reservoir is agree with the boundary of the graben. Vertical channels are clearly seen, which could be related to circulation fluids or with hydrothermal alteration of the rocks.
- Two independent vertical channels were found at the depth of 5 - 6 kilometers.

GEOCHEMICAL STUDIES

The discharge fluids from the San Jacinto-Tizate wells are neutral to slightly alkaline with almost similar chloride concentrations, ranging from 1700 to 2700 mg/kg. The SO_4 concentration ranges from 13 to 23 mg/kg (Table 1).

Table 1: Chemical Analysis results

	Unit	SJ-1	SJ-3	SJ-4	SJ-5	SJ-6
WHP	Bar			21.0		9.0
pH			8.28	7.97	7.84	7.8
Ht	kJ/kg					
Cl_{res}	mg/kg		1784	2637	1722	1954
SO_{4res}	mg/kg		33.68	13.16	16.77	26.81
Cl/Ca			57.74	100.3	178.0	56.82
Cl/B			19.17	35.17	27.42	17.94
T_{SiO2}	°C	192.3	-	264.3	286.7	263.1
T_{NaKCa}	°C	221.0	237.0	270.6	278.3	239.2
T_{NaK}	°C	243.8	256.6	281.6	288.2	257.4
T_{KMg}	°C	146.4	193.9	212.6	203.4	175.1
Na/K		14.77	12.72	9.68	9.05	12.61

Non condensable gases concentration in the San Jacinto - Tizate wells are relatively low and uniform, ranging from 0.18 to 0.26 w/w Total Discharge.

The Cl/Ca ratio of wells SJ-4 and SJ-5 are between 100 and 170, indicating lower degree of meteoric mixing, compared with wells SJ-3 and SJ-6 which is around 57, this showes us that cooler fluid is flowing throughout the reservoir along regional fault NW-SE, this can be confirmes by the Cl/B ratio, which has a values of 18 for wells SJ-3 and SJ-6, and between 27 and 35 for wells SJ-4 and SJ-5.

From the analysis we can say that the up-flow zone is closer ot the SJ-5 and SJ-4, as the highest temperature (290°C - 270°C) has been measured in these wells.

Silica geothermometer has an excellent agreement with the downhole temperature measurement. Using the graphical techniques by Na-K-Mg (Giggenbach, 1986) the water discharged from geothermal wells are partially equilibrated. NaK geothermometer gives values between 240°C and 290°C, and KMg geothermometer ranges from 145°C to 212°C (Figure 2).

Wells SJ-4 and SJ-5 have the lowest Na/K ratio, and hence calculated temperature from 282°C to 288°C, comparing with 243°C - 257°C in the rest of the wells; these ratios suggest that mixing possible take place in the vicinity of wells SJ-

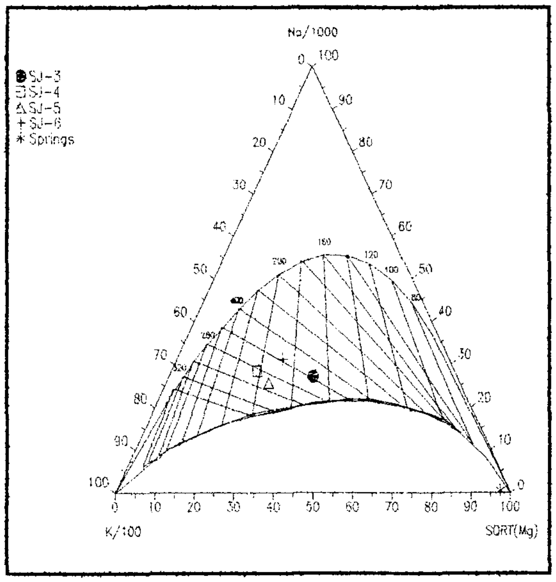

Figure 2: The Na-K-Mg diagram for the San Jacinto-Tizate waters

3 and SJ-6 with a relative cold water.

GENERAL INFORMATION OF WELLS

Drilling in the San Jacinto-Tizate area began in January, 1993 until March 1995 by the INTERGEOTERM Company. Seven wells have been drilled, one of them, SJ-4, is a shallow well (728 meters), and intersected a geothermal reservoir of 270°C with excellent permeability. Other two wells were drilled deeper than 2000 meters (SJ-1 and SJ-5); well SJ-5 reached a temperature of 290°C and a relatively lowpermeability; on the other hand, SJ-1 had to be closed at the depth of 1216 meters where the main feed zones was found, the highest temperature is 190°C and a good injection index was estimated (35 kg/s/MPa).

Wells SJ-3 and SJ-6 were drilled until 1865 meters. From the interference test we know that these wells are directly connected each other with a relatively good permeability; the maximum temperature is 269°C.

Well SJ-2 was drilled down to 1471 meters unsuccessfully because the very low temperature and no permeability. This well is located out of the geothermal area (Figure 1).

Table 2 gives an overview of the wells drilled so far, showing the drill date, location, well design, depth and elevation.

PRESSURE AND TEMPERATURE PROFILES

A total of sixty temperature logs and sixty pressure logs were carried out since 1993 until 1995, using the well known KUSTER equipment. Dynamic pressure-temperature profiles and build-up tests are available from wells SJ-4, SJ-5 and SJ-6.

The drilling for most of the wells was stopped when a major circulation loss was reached, most of the main feed zones are located at the well bottom. Table 3 gives the information about maximum measured temperatures and pressure at the pivot point, with feed zone depth. Figure 3 shows the temperature profiles after some hours of drilling and the estabilized ones. The reservoir pressure al the feed zone depth are also showed in the same graphic.

PRODUCTION DATA

The productive wells have all undertaken flow tests from several days until months. Water samples and noncondensable gases measurements have been took during the flowing test.

Table 2: Overview of the wells

Well	Drill Date		Location		Well Design			Depth	Elevt m asl
	From dd/mm/yy	To dd/mm/yy	N-S (m)	E-W (m)	Casing	Liner		(m)	
					9⅝"	8⅝"	6⅝"		
SJ-1	13/01/93	12/09/93	1390.83	523.8	0-915	-	885-1216	1216	197
SJ-2	08/02/93	03/06/93	1388.83	521.8	-	-	812-1866	1471	238
SJ-3	30/09/93	14/12/93	1393.52	524.1	0-956	-	-	1866	186
SJ-4	30/12/93	14/02/94	1392.94	524.30	0-481	481-721 -	-	721	161
SJ-5	05/05/94	24/07/94	1393.40	524.50	0-1214	74-989	159-2278	2278	167
SJ-6	12/08/94	15/12/94	1393.30	524.07	0-74	-	989-1879	1879	175
SJ-7	09/02/95	26/04/95	1391.80	523.51	0-1262		-	1263	216

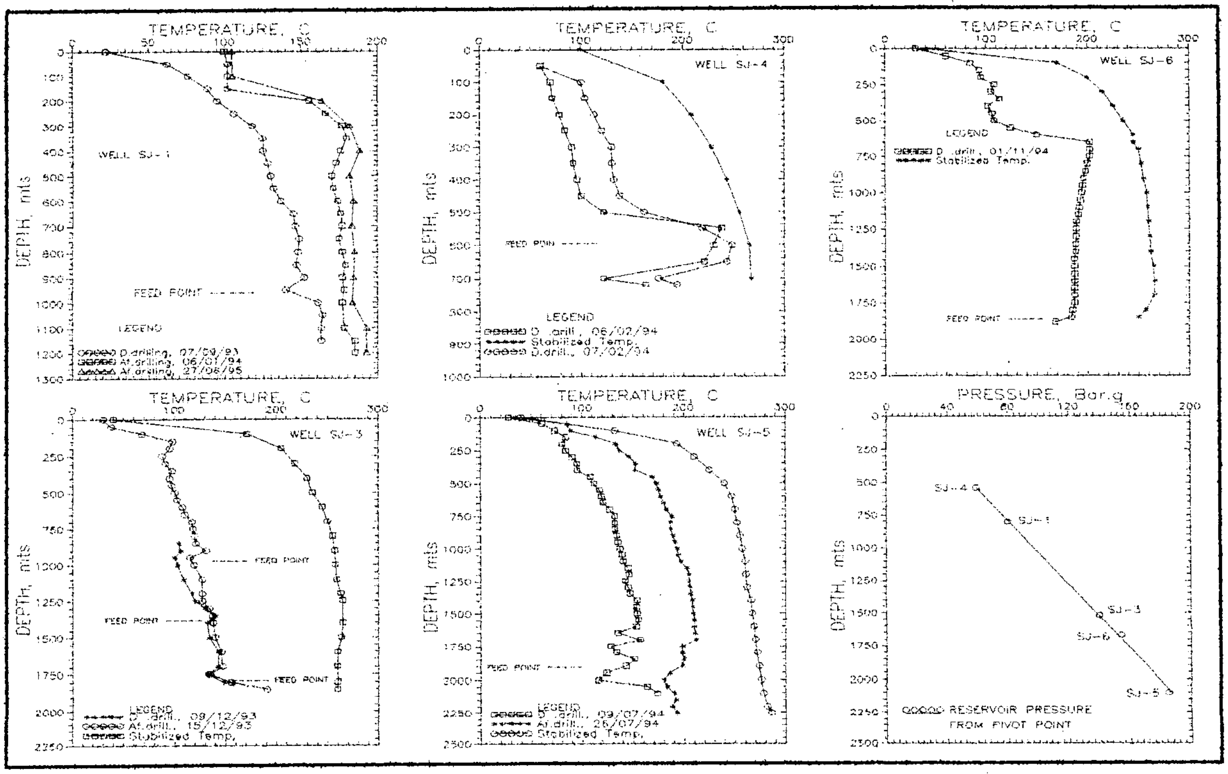

Figure 3: Temperature Profiles and hidrostatic pressure

Table 3: Feed zones, maximum temperature and pressure at the pivot point.

Well	Feed zone depth, m b.s.l	Tmax/Depth (°C/m)	Pivot point pressure Bar.a
SJ–1	603.4	190/1200	80
SJ–3	1336.3	265/1500	140
SJ–4	386.4	269/700	59
SJ–5	1932.6	288/1750	187
SJ–6	1475.2	264/1600	155

WELL SJ-1

This is a low enthalpy well, since the maximum temperature is 190°C. No production has been measured from it.

WELL SJ-2

This is not a geothermal well, since a normal thermal gradient was found. This well is located far away from the interesting area (Figure 1).

WELL SJ-3

This is a producer well within a permeable zone between 910-1810 meters depth; a maximum temperature of 265°C was measured. During the discharge (February, 1994) a total flow of 5.5 kg/s was measured. After a couple of days the well was discharging solid material from the formation. Since that time, the well flows just for a couple of hours and then stoppes. A formation collapsed is expecting to be the cause of such behaviour of this well.

WELL SJ-4

This is the best producer well in the field, been measured (Table 3). Two flowing tests has been carried out. The first test took place on April, 1994 and finished on May 1994; the well showed a very high flow rate (>140 kg/s) at 21 Bar.g in the well head. Figure 4 shows the production curve of the second flowing test, wich was carried out for sixteen days.

The productivity index wascalculated using the wellbore simulator HOLA (Bodvarsson, Bjornsson, 1987), the values are given in table 4.

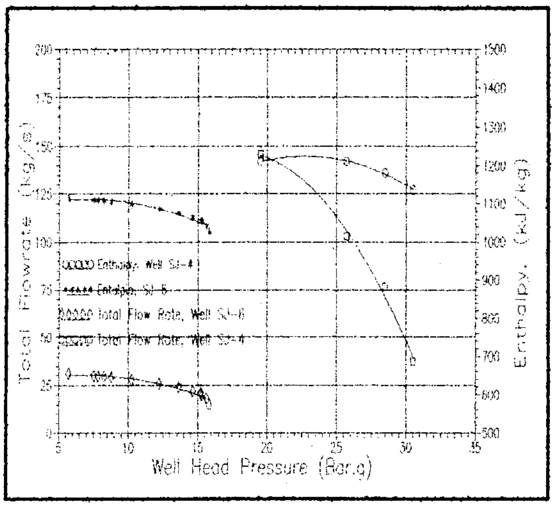

Figure 4: Output curves for wells SJ-4 and SJ-6

WELL SJ-5

This is the deepest producer well with a feed zone down to 1606-2040 meters (Table 3). This well was discharging to the atmosphere by a horizontal discharge for a short period of time; the total flow rate was 38.6 kg/s at 12 Bar.a in the well head. A complete flow test is planned to be carried out in the next months.

WELL SJ-6

This well was used as a producer during an interference test. During this time, different flow rates and well head pressure were measured; in order to get an extrapolation of the productive curve of the well, a well bore simulation was carried out, Figure 4 gives the results of the simulation. The low productivity (Table 4)can be explain by problems during the completion of the well as the damage of the formation around. The above assumption can be supported by a very high skin effect estimated by the build-up test (s > +20).

RESERVOIR PERMEABILITY

The permeability - thickness (kh) has been estimated for the surronding of the wells of the Tizate area. The estimation is based on build-up data after flow, injection test, a multi wells interference test which was carried out in order to know the connection between wells and also to know the average values of kh an storativity in the reservoir. Table 5 gives the different values of kh and s estimated by the transcient tests carried out since 1994 until now.

INTERFERENCE TEST ANALYSIS

The major objectives of the interference test was to determine the pressure communication between wells, and if the communication exists, estimate the transmissivity (kh) and storativity (ϕch) in the reservoir of the wells.

Table 5: kh values calculated by transcient tests

Well	Inject	Build up	Interference	
	kh, dm 10^{-12}	kh, dm 10^{-12}	kh, dm 10^{-12}	s, m/Pa 10^{-6}
SJ-1	3.0	-	-	-
SJ-3	0.6	-	13.55	2.9
SJ-4	17.0	-	-	-
SJ-5	3.0	0.1	11.00	2.1
SJ-6	4.2	7.0	-	-

Table 4: Production data for the producer wells at total discharge.

Well	WHP Bar.a	Total flow kg/s	Steam Flow kg/s	Dryness %	Enthalpy kJ/kg	Shut-in Pressure Bar.a	P.I kg/s/Bar
SJ-3							
* SJ-4	20.5	147	23.5	16.0	1211	32	38.1
SJ-5	11.8	40	10.0	25.0	1290	27.5	0.33
SJ-6	9.1	29	5.0	17.6	1100	16.3	0.39

* 50% openning of the valve

Two interference tests were carried out on the Tizate area since March, 1995 until September, 1995. Capillary tubing and quartz crystal liquid filled pressure transducer were used; a PC computer in each well was recording the pressure. During the first test, well SJ-6 was producing and wells SJ-3, SJ-4 and SJ-5 were used to monitor the pressure response (Figure 5). The capillary tube were installed at different depths for each well, depending on the water level, well head pressure and pressure range of the equipment.The static down hole pressure was monitored for about six days before production started.

Well SJ-6 started production on May 5th, 1995, and discharge a total flow of 30.5 kg/s and an enthalpy of 1100 kJ/kg at 9 Bar.a at the well head. Thirty four days after the shut-in of SJ-6, well SJ-4 was open for second stage of the interference test; wells SJ-3 and SJ-5 were monitoring the pressure response (Figure 6).

Well SJ-4 was discharging in average 151 kg/s of total flow, and an enthalpy of 1190 kJ/kg was measured. The discharged period was fifteen days, five steps of flow-pressure were obtained during the test (Figure 6).

RESULTS

First Test

Well SJ-4 did not show any reaction to the production of SJ-6. The data from wells SJ-3 and SJ-5 were plotted on cartesian coordinates (Figure 6), from theme we can see that SJ-3 responde inmediatly to the production of SJ-6, on the other hand the response of SJ-5 took place some time afterdischarge. The reponse of SJ-3 started with an initial sharp decrease in pressure followed by an almost constant pressure, this is a characteristic of steady state, indicating that the reservoir could be gobemed by a strong natural recharge (Earlougher, 1977).

Second Test

Well SJ-3 did not give any reponse to the production of well SJ-4, but well SJ-5 gave a good response, (Figure 6). Table 5 shows the estimated values for kh and storativity for all the wells during interference, injection and build-up. The values are different from single well testing than for the interference test.

Grant (1980) gives an explanation for this; the interference kh is the permeability of the large scale fracture network, while each well may intersect some smaller fracture and its performance would reflect this.

Something very interesting can be see in Figures 6 and 7, when the pressure recovery reached a higher value that the static one, this can not be explained by problems with the equipment.

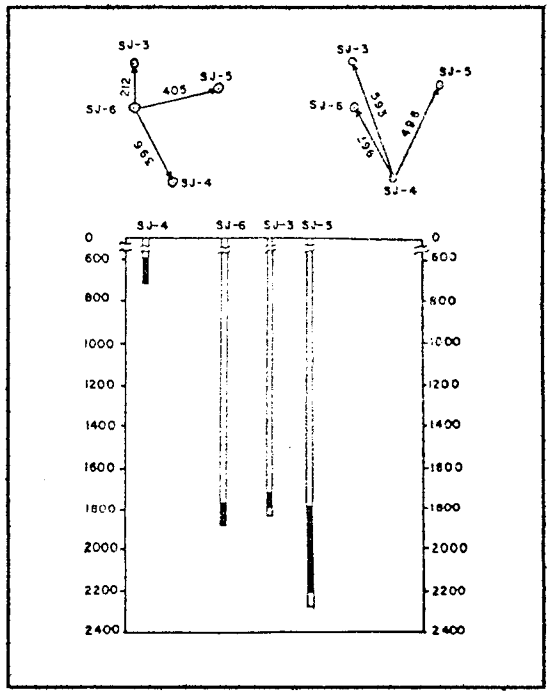

Figure 5: Location and depth of wells

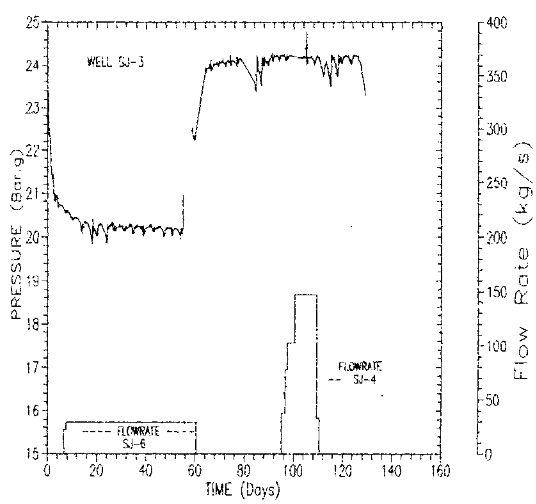

Figure 6: Pressure response of well SJ-3

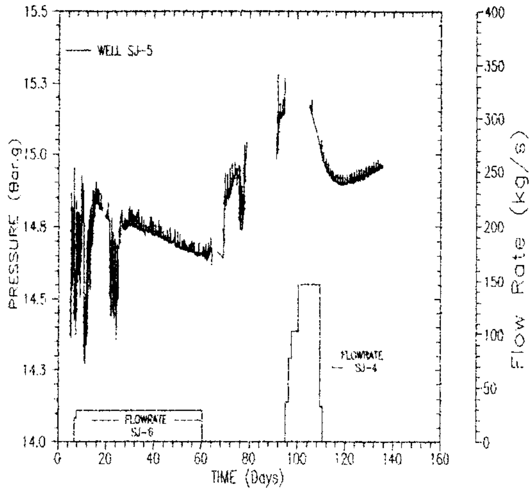

Figure 7: Pressure response of well SJ-5

CONCEPTUAL MODEL

Figure 8 shows a conceptual model of the San Jacinto-Tizate Geothermal Area, this model is based on the geohysical, geologycal, hydrological survey, and the reservoir evaluation done so far.

Belonging to one structure (San Jacinto Graben), San Jacinto and Tizate areas of San Jacinto-Tizate geothermal field, looks like rather independent areas, at least until the depth of 2000 meters. The thermal characteristics of upflow are very different, 190°C in San Jacinto and 290°C in Tizate.

A comun caprock exist at San Jacinto-Tizate geothermal field, with thickness of 300-400 meters. It consistes of strongly alterated rocks of different age and different primary lithology.

At the Tizate area we found that the up flow zones is located close to the SJ-4 and SJ-5, then the fluid flowes to the south-east, where the next drilling will take place in the near future.

CONCLUSION

At the San Jacinto area, two permeable levels were found. The shallow reservoir, at the depth of 350-680 meters, and the deep reservoir, with depth of 880-1080 meters. Both of them consist of pliocen quaternary volcanic rocks. According to the low temperature (180-190°C), San Jacinto reservoirs are not productive, but may be used for reinjection.

At Tizate area two reservoirs, hydraulic connected, were found. The shallow reservoir (Pliocen-Quaternary volcanic rocks) at depth of 550-1200 meters, and the deep reservoir (Oligocene ? - Miocene volcanic - sedimentary rocks) at the depth of more than 1600 meters. Both of them are water dominated reservoirs. From the geochemestry we know that the up flow zone is close to SJ-4 and SJ-5. Some cooler fluid is flowing throughout the reservoir along regional fault NW-SE.

Two phase conditions exist at the upper part of the shallow reservoir. The production tests show the commercial interest of both reservoir of Tizate area. Until now the wells can supply steam for 21 MWe.

REFERENCES

Bjornsson, G., Bodvarsson, G., 1987: " A multifeedzone wellbore simulator", Geothermal Resources Council, Transactions, 11, 503-507.

Earlougher R.C., 1977: "Advanced in Well Test Analysis, Monograph ph Series, Society of Petroleum Engineers of AIME, Dallas (1977).

Giggenbach, W.F.: "Graphical Techniques for the Evaluation of Water/Rock Equilibration Conditions by Use of Na, K, Mg, and Ca-contents of Discharge Waters". Proc., of the 8th New Zeland Workshop, p.37 -43. University of Auckland, 1986

Grant, M. A: "Broadlands Geothermal Field, Interference test at BR13, 19 and 23". Applied Mathematics Division, DSIR, New Zealand, report No. 98 (July, 1980).

INTERGEOTERM, 1994: "Geologycal and technical report of well SJ-1". INTERGEOTERM report, May 1994 (in Spanish).

INTERGEOTERM, 1995: "Results of the multi-well interference test at the Tizate area". INTERGEOTERM report, October 1995 (in Spanish).

INTERGEOTERM, 1995: "Results of exploration at the San Jacinto-Tizate Geothermal Field". INTERGEOTERM report, July 1995 (in Spanish).

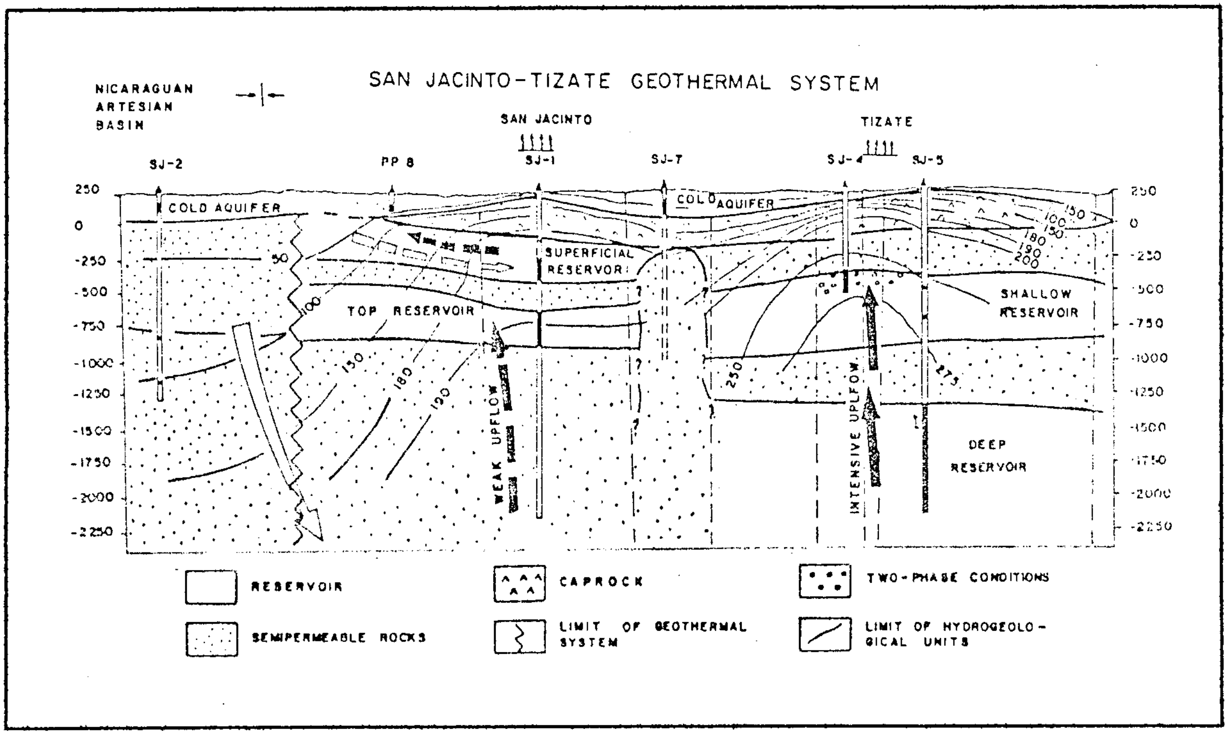

Figure 8: Conceptual Model of the San Jacinto-Tizate Geothermal Area.