RECENT RESULTS FROM THE SAN JACINTO - TIZATE GEOTHERMAL FIELD, NICARAGUA

Phil WHITE[1]; Jim LAWLESS[1]; Greg USSHER[1]; Alexis SMITH[1]

[1]Sinclair Knight Merz Ltd, PO Box 9086, Newmarket, Auckland, email: pwhite@skm.co.nz

SUMMARY The San Jacinto geothermal field is located on the eastern side of the active Telica volcanic complex in northwestern Nicaragua. The geothermal field is underlain mainly by andesites and basaltic andesites, comprising a mixture of lavas, pyroclastic and epiclastic deposits that are locally cut by dioritic intrusives. Thermal features comprise fumaroles/mud pools in the San Jacinto village and fumaroles and weak seasonal warm springs in the Tizate area to the north.

Permeability and fluid flow within the San Jacinto geothermal system are strongly influenced by the distribution of permeable faults and impermeable dioritic intrusives. Recently completed deviated wells targeting faults have encountered high temperatures (over 300°C in one well) and very good permeability in two wells, which are both highly productive, giving 23 MWe (SJ6-2) and 16MWe (SJ9-1).

1. INTRODUCTION

The San Jacinto geothermal field is located in northwestern Nicaragua, on the eastern side of the Telica volcanic complex (Figure 1). It is being developed for geothermal power generation by Polaris Energy Nicaragua S.A., a subsidiary of Polaris Geothermal Inc, which is listed on the Toronto Stock Exchange.

New data presented here from recent drilling and mapping activities means that the location of the upflow zone and the controls on permeability within the geothermal system are better defined.

2. GEOLOGICAL SETTING

Volcanism in Nicaragua results from subduction of the Cocos plate along the Middle America Trench. The rate of subduction of the Cocos plate is amongst the fastest in the world at 8 cm/yr (Weinberg, 1992) and there is a comparatively steep angle of subduction of 60° (Gill, 1982). This angle has increased since the Pliocene, resulting in westward migration of the volcanic front (Weinberg, 1992). The high angle of subduction favours the formation of many small shallow intrusives (Sillitoe and Thompson, 1998), consistent with the many small but clustered Quaternary volcanic centres in Nicaragua, and means that there are many potential heat sources for geothermal fields.

In northwestern Nicaragua, the Quaternary volcanic centres are so closely spaced that they form a semi-continuous range, the Marrabios Range of volcanoes, which extends from San Cristobal to Momotombo (Figure 1). The Telica volcanic complex and the San Jacinto geothermal field are located near the centre of this range. In common with most of the other volcanic complexes in the Marrabios Range, the Telica volcanic complex comprises an active andesite volcano (Telica) at the northwest end, with increasingly older volcanic centres to the southeast, within which the geothermal field is located.

3. EXPLORATION HISTORY

The first geoscientific studies of the area were conducted by McBirney in 1953 (McBirney & Williams, 1965), who drilled three shallow wells to a maximum depth of 86 m. The third of these wells encountered a fracture at a depth of approximately 60 m and produced steam, though the well was uncased and abandoned.

Exploration continued from the 1960s, including geological, geochemical and geophysical surveys, and the drilling of additional shallow temperature gradient wells. This indicated that a high temperature (250 to 300°C) resource existed in the San Jacinto-Tizate area, with a potential resource area of 6 km^2, and a potential considered to be around 100 MWe.

In 1992, DAL SpA (DAL) concluded that the upflow for the field was probably located in the area of Tizate in the north, with an outflow southward to San Jacinto. Seven deep vertical wells were drilled between 1993 and 1995 by Intergeoterm, S.A., a joint venture between the Nicaraguan electricity company ENEL (77%) and Burgazgeoterm (23%), a subsidiary of Gazprom of Russia. One of these wells (SJ4) was a good producer, two (SJ5, SJ6) were moderate producers, and one was a good reinjection well, while one outside the field (SJ2) was cold and two were impermeable (SJ3, SJ7).

The concession was acquired by Polaris Energy Nicaragua S.A., who in 2005 completed MT surveys and connected four of the existing wells to two 5MWe back pressure units. At the time of writing Polaris has just completed drilling three new production wells and one reinjection well, plus a workover of one of the existing wells (SJ6-1) as part of a planned expansion to 72MWe using condensing steam turbines to replace the back pressure units.

4. THERMAL ACTIVITY

Thermal features comprise steam heated mud pools and fumaroles above the outflow in San Jacinto village and fumaroles and weak seasonal warm springs close to the upflow in the El Tizate area to the north. Although the system is located on the eastern slopes of Telica, there are no thermal features to the north or east of El Tizate, despite the land surface being almost 100m lower in elevation less than 2 km to the east. Rather, the outflow appears to be southwards to San Jacinto, where the surface elevation is similar to that at Tizate.

5. GEOLOGY

The surface geology of San Jacinto largely comprises products from the surrounding volcanic centres of Telica, Santa Clara and Rota, which overlie a suite of older volcanic and epiclastic rocks that are locally intruded by porphyritic diorites. Similarly, wells have largely encountered extrusive volcanic rocks (lavas and tuffs) and related breccias, mainly of andesitic composition, with some intercalated volcanogenic sediments and intrusive diorites. There are not any large differences in lithology between wells, but neither are there any beds that can be correlated across the field (Figure 2). Formation image logging from 600 to 1150mMD in SJ6-2 indicates steeply dipping and tightly folded rocks at depth. Thus it is difficult to predict the detailed geology ahead of drilling, which makes well targeting and well casing design more complex.

Faults and fractures provide both vertical and lateral flow pathways. Regional tectonics predict that primary compression in the 030° direction will produce northwest-trending strike-slip faults and associated north-south normal faults (Weinberg, 1992). Of these, it was considered that the steeply dipping, north-striking normal faults are more likely to be permeable than the east-west structures (Unocal, 1998) and this appears to be borne out by recent drilling results.

Two main sets of faults have been mapped at San Jacinto. One set strikes approximately east-west while the other set strikes within 30° of north. A single fault may be responsible for much of the permeability within the main productive reservoir. The SJ8 Fault was recognised after well SJ8-1 blew out and was abandoned after it encountered an unexpected hot permeable zone at 150m. This fault, oriented at 005° and dipping 80° east, correlates with surface steam vents and altered ground alongside the SJ8 wellpad, and intersects the main permeable zones in wells SJ4-1 and SJ5-1 in addition to SJ8-1, but passes east of wells SJ3-1 and SJ6-1, which have lower permeability. The extrapolated plane of this fault was then used successfully to target permeability in SJ9-1 and SJ6-2. Further south, it may be offset by one of the east-west faults, as it was not found in SJ9-2. This fault does not appear to be controlling the main upflow of hot fluid at depth, as that lies further to the east.

6. ALTERATION

Five alteration assemblages have been identified in the San Jacinto wells, although only three of these are common (Figure 2). With increasing depth from surface, these are:

1. **Argillic**: smectite and interlayered clays (chlorite-smectite and illite-smectite) are accompanied by zeolites (clinoptilolite, chabazite, epistilbite/heulandite, stilbite/mordenite), quartz, pyrite, iron oxides, calcite and chlorite, with rare opal and cristobalite. The zeolites are more or less zoned according to their temperature ranges in the shallower sections.
2. **Mixed argillic-propylitic**: epidote is typically encountered at a depth of about 400-600m, before illite replaces interlayered clays, meaning that instead of a purely phyllic zone, there is a zone of mixed argillic and propylitic minerals.
3. **Propylitic**: epidote is accompanied by minerals such as illite, laumontite, wairakite, adularia, prehnite, quartz, chlorite, calcite and pyrite.
4. **High temperature propylitic**: rare amphibole, indicative of higher temperatures, occurs at depth in SJ9-2.
5. **Contact metamorphic**: minor biotite, amphibole and garnet were observed adjacent to diorite in SJ10-1.

Petrographic studies reveal disequilibrium mineral assemblages in all of the wells examined to date, with the coexistence of epidote with interlayered illite-smectite being one of the most obvious signs. This indicates that reservoir conditions have fluctuated over time.

The relatively low calcite content compared with the common presence of zeolites is consistent with low gas in the deep fluids, while the general absence of minerals such as alunite indicates that acid fluids are restricted in their distribution, if they occur at all in this part of the system. Most of the secondary minerals reflect near-neutral pH conditions.

There does not appear to be a close correlation between alteration assemblages and current subsurface temperatures. Typically the first appearance of epidote approximates the 260°C temperature contour, though in some wells epidote occurs where temperatures are lower. So the distribution of alteration mineralogy does not accurately represent current reservoir conditions.

7. GEOCHEMISTRY

San Jacinto is a liquid-dominated reservoir with outflows of steam and water to surface thermal areas. The deep reservoir has been sampled from production wells, and is a slightly alkaline, medium salinity, sodium chloride water. The chemistry for the El Tizate wells is quite uniform, with calculated reservoir chloride concentrations falling in a range of 1,800 to 2,400 ppm. The original gas content of the deep reservoir was about 0.1 wt% based on discharge data from well SJ4-1. This has fallen to 0.04 wt% currently. The higher gas content in the SJ5-1 discharge (0.2 wt%) is considered to result from excess steam providing additional gas. Chemistry from the recently drilled wells SJ6-2, SJ9-1 and SJ9-2 is consistent with earlier wells. Longer discharge times are required to establish any chemical trends. The chemistry does not provide any particular problems for development, and the low gas content means that carbon credits provide a significant income stream.

8. GEOPHYSICS

The MT surveys revealed an extensive conductive layer with resistivity ranging from less than 2 Ωm to about 5 Ωm. This conductive layer broadly domes upwards across most of the concession area and is thick on the flanks of the volcanic complex, particularly to the north (Figure 3). From experience with most other high temperature hydrothermal systems, this conductive layer probably represents the clay “cap” that lies above the high temperature reservoir. Within the survey area, two main doming structures were observed. In the eastern sector there is a doming of the cap coincident with the El Tizate thermal area and the present production wells. The shallow extension of the domed conductor south from El Tizate to San Jacinto corresponds with the known geothermal outflow in this direction. The deeper structure indicated by the base of conductor extending to the SSE of El Tizate, may indicate an extension of the high temperature reservoir at depth, along the NNW-SSE oriented fault structures that have been postulated here.

A second larger doming structure is seen in the western sector of the concession and this is associated with fumaroles and steam heated features in the north. This western feature is targeted for future development.

The thickening of the conductor to the north and east of El Tizate indicates the limits of the reservoir in these directions, although the reservoir could be wider at depth. The high elevation of the base of conductor near well SJ7-1 could be reflecting the relatively young intrusive encountered in this well, rather than hydrothermal alteration. The resistivity needs to be interpreted in light of the indications that some of the alteration is relict and does not reflect current conditions. Accordingly, it is possible that the MT anomaly is locally larger than the active geothermal system, but also that in some places the deep reservoir may be broader than indicated by the simple doming of the clay cap. Therefore, estimates of reservoir capacity based on the area outlined by MT data alone have greater uncertainty in directions that are not constrained by well temperatures.

9. PERMEABILITY

The wells drilled to date have encountered a wide range of permeabilities. SJ7-1 drilled through several hundred metres of diorite, and had very low permeability. Most other wells have low permeability over most of their depth, but a few wells have moderate to very high permeability over a short interval or intervals. In particular, most of the recent wells that targeted north-south faults encountered very good permeability at about the predicted depth. This was not due to just a single structure however, since in SJ6-2 for example, major permeability close to the predicted fault intersection at about 900m was accompanied by at least three other zones of minor permeability between 1300 and 1900mMD.

There is some possible correlation of permeability with depth, with permeability in several wells at -400 to -550 mrsl. However, there are also some wells in which there is no permeability in this depth range.

10. TEMPERATURE PROFILES

At shallow depths, the highest temperatures are centred on well SJ4-1, which encountered a highly permeable zone at a depth of about 600m. At greater depth, the highest temperatures measured to date are in well SJ5-1 (289°C) and SJ6-2 (304°C) to the east. The maximum temperature in SJ6-2 is more significant because this well is not as deep as SJ5-1 (1700mVD), and the measurement was after just one month heating. Wells to the west (especially SJ3-1 and SJ6-1) reveal a slight temperature inversion at depth (Figure 4).

11. HYDROGEOLOGICAL MODEL

The geothermal system in the Eastern Sector of the San Jacinto – Tizate concession has an unusual asymmetric form, with the upflow located on the eastern edge (Figure 5) and toward the northern end, rather than in the centre of the field, and with the major outflow not following the regional groundwater trend. The hydrology of this system appears to be strongly influenced by both the orientation of the major permeable structures, and by a continuous band of impermeable diorite along the eastern margin. This band of diorite prevents any cold water recharge from the east, meaning that the main recharge is from the west, where any recharge may have been preheated by the Western Sector system.

The diorite also prevents any hot outflow to the east, explaining the lack of thermal features in that direction. Instead, the outflow is to the south, where it feeds the steam heated thermal features at San Jacinto.

12. PRESENT STATUS

In the recent round of drilling, three wells were completed and one worked over that together provide an additional 40 MWe of steam for the planned expansion, plus a reinjection well, which is already in service. Thus the requirements for Phase 1 drilling are complete, with 75% of the steam required for the full 72MWe development now available at the wellhead. Furthermore, and just as significantly, the particular features of the San Jacinto geothermal system are now better understood, so that we are more confident of targeting hot permeable parts of the reservoir with future production wells.

13. FUTURE DIRECTION

Drilling is due to resume shortly at San Jacinto, to complete drilling for the planned 72MWe development. The priority is now to drill more reinjection wells, although additional production wells are also required. It is planned to drill several injection wells around the northern and eastern margins of the reservoir. Further production wells will then be drilled to the north, east and south of the existing production wells, to expand the proven resource area. The development will comprise three 24MWe modular condensing turbines; when those are installed, the existing 2 x 5MWe back pressure turbines will be decommissioned.

The longer term aim is to drill and develop the Western Sector, which based on the resistivity anomaly is larger and so has more potential than the Eastern Sector, but is as yet undrilled.

14. ACKNOWLEDGEMENTS

The permission of Polaris Energy Nicaragua S.A. to publish this data and the support of both Polaris and SKM to present it are gratefully acknowledged. Allan Clotworthy, Keg Alexander, Mark Harvey, Jacques Charroy, Brian Lovelock and Abbas Azarkish assisted with data analysis and preparation of figures. Ian Bogie contributed to earlier geological reports on which this paper is in part based.

15. REFERENCES

Gill, J.B. 1981. Orogenic andesites and plate tectonics. Springer-Verlag, New York.

McBirney, A.R. and Williams, H. 1965. Volcanic history of Nicaragua. University of California Press, Berkeley, 69p.

Sillitoe, R.H. and Thompson, J.F.H. 1998. Intrusion-related vein gold deposits: types, tectono-magmatic settings and difficulties of distinction from orogenic gold deposits. Resource Geology 48 (4): 237-250.

Unocal, 1998. Structural geology of the El Ñajo – Santa Clara concession, Nicaragua. Technical memorandum No. RT-S&RS 98-2. Prepared by Hickman, R.G. and Stimac, J.A. March 30 1998.

Weinberg, R.F. (1992). Neotectonic development of western Nicaragua. Tectonics 11 (5): 1010-1017.

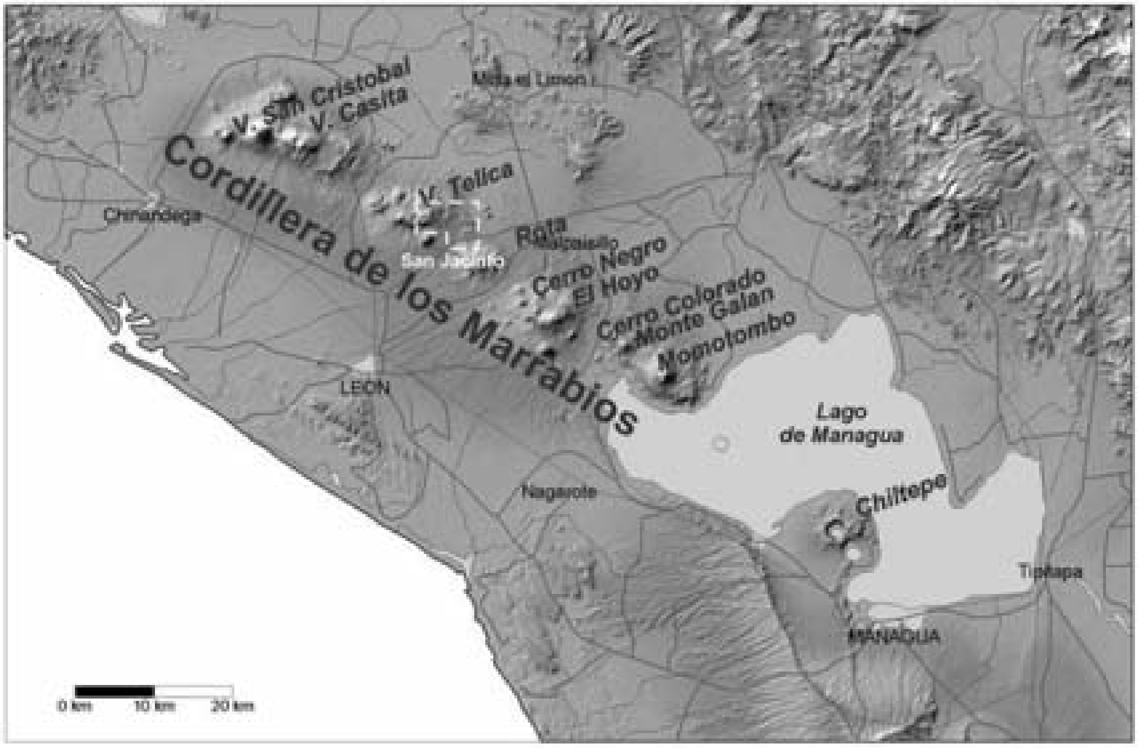

Figure 1: Location of San Jacinto – Tizate geothermal concession in Nicaragua.

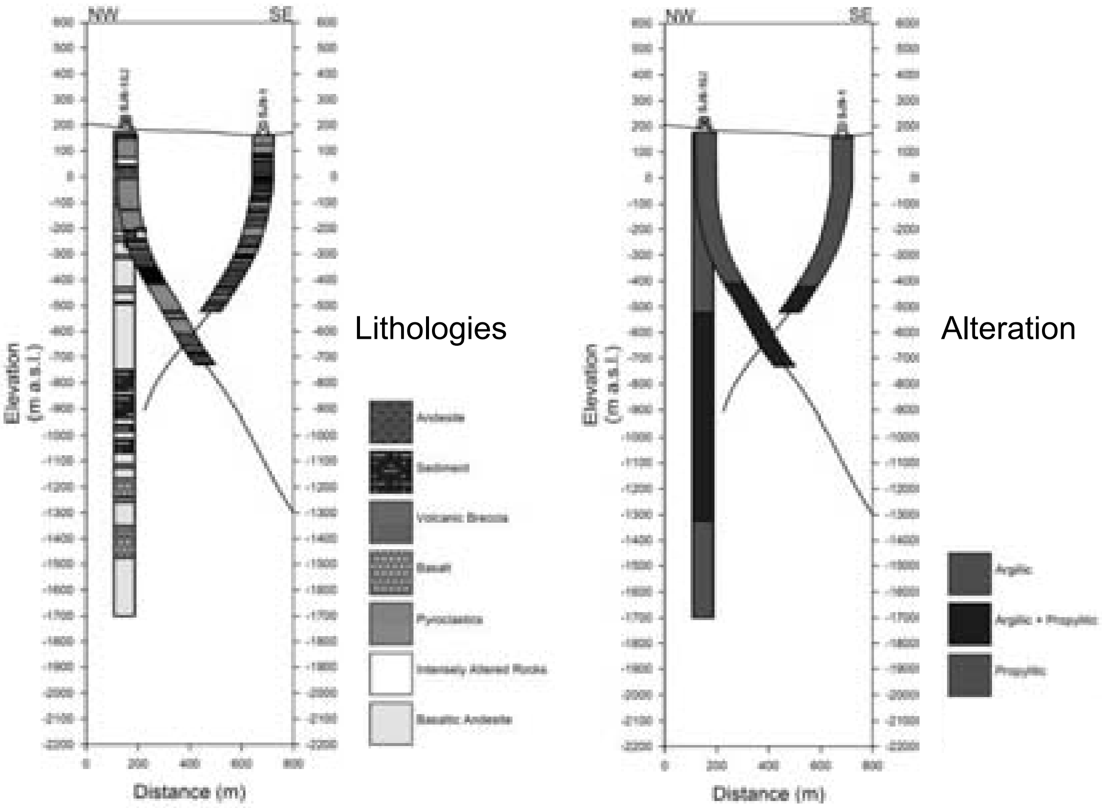

Figure 2: Lithologies and alteration in wells SJ6-1, SJ6-2 and SJ9-1.

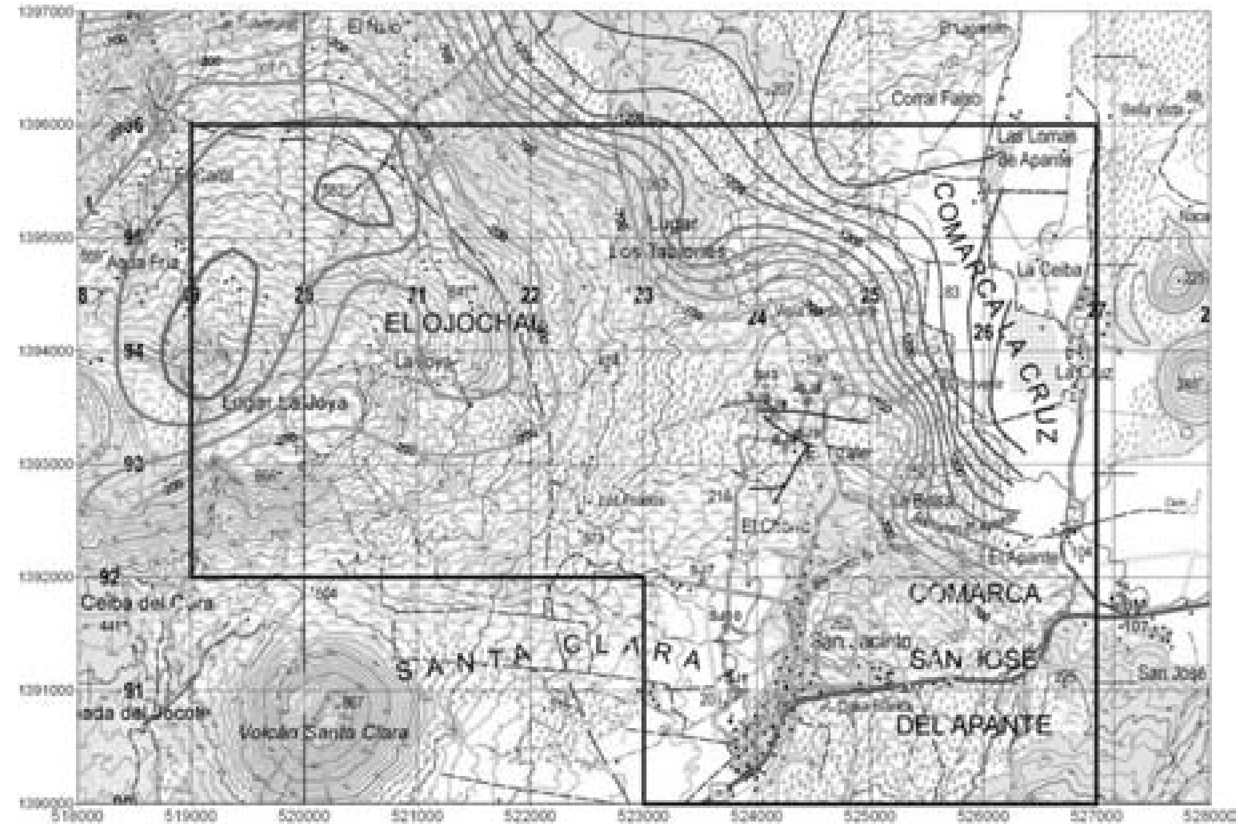

Figure 3: Elevation of the base of the conductive layer from 3D resistivity model (mrsl). Well locations are marked (except SJ2, which is off the map, south of Volcan Santa Clara), including the tracks of deviated wells.

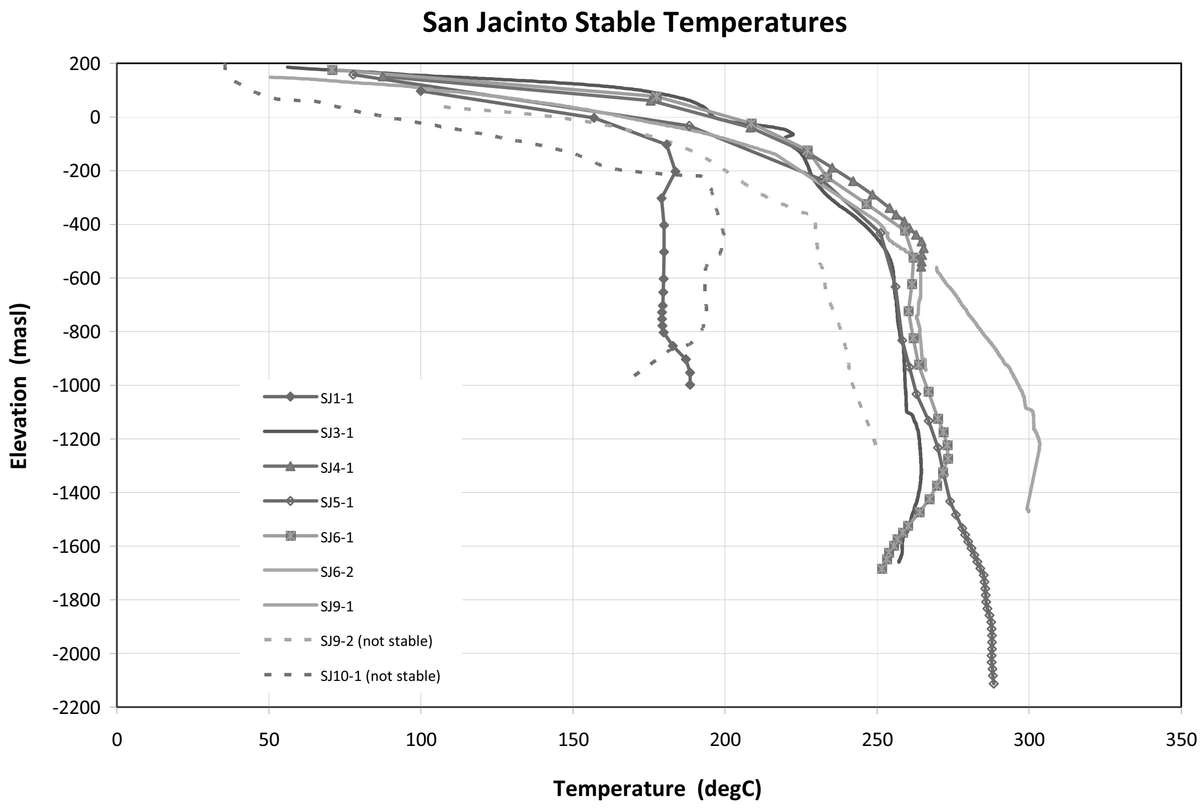

Figure 4: Temperature profiles of completed wells. SJ9-2 and SJ10-1 are included for completeness although they were not fully heated at the time of those surveys.

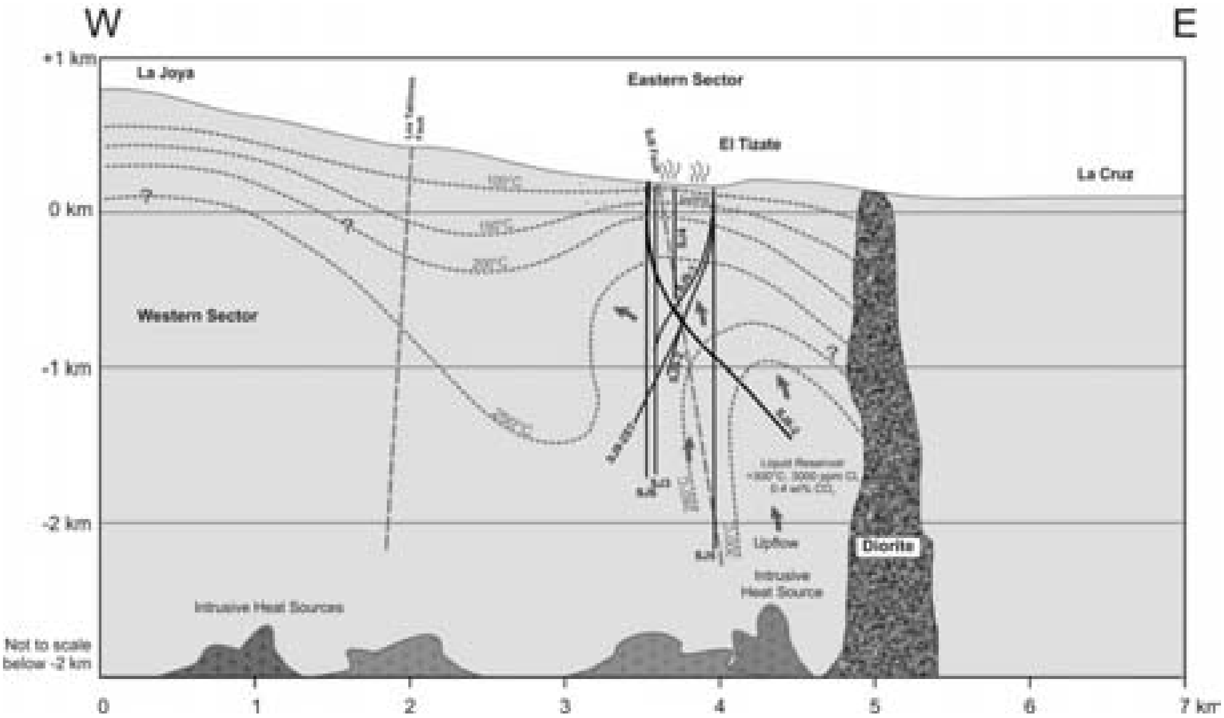

Figure 5: Simplified hydrogeological model of the San Jacinto geothermal system.