

Preliminary Conceptual Model of the Domo San Pedro Geothermal Field - Western Sector of Trans-Mexican Volcanic Belt, Nayarit, Mexico

Violeta Mirthala Reyes-Orozco, David Avalos-Tapia, Julio García-Tirado, Esteban Rodríguez-Pineda and Fernando Ocampo-Aguilar

vreyeso@gdragon.com.mx

reyvil1_11@hotmail.com

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ABSTRACT

The surface exploration of the Domo de San Pedro geothermal field located in Nayarit, Mexico indicates that the permeability of the reservoir is controlled by regional and local tectonic structures. The emplacement of the San Pedro dacitic domes is related along a NW-SE direction and this is limited mainly by the NE-SW normal faulting. The conductive structures of the fluid have a NW-SE and E-W trend, with possible suspicion the N-S normal faulting. These conditions are hosting the geothermal fluid of high enthalpy in the granitic-granodioritic complex of the Jalisco Block, associated with a propylitic alteration and confined by a clay cap which alters the andesites of the Miocene.

1. INTRODUCTION

The Domo de San Pedro geothermal field is located, in the state of Nayarit, in the central western Mexico. This geothermal project is situated 5 km from the municipality of San Pedro Lagunillas as shown in Fig. 1., about 60 km south-east from the town of Tepic, in the western state of Nayarit. The Domo de San Pedro is the first private company in geothermal generation in Mexico, developed and operated by Grupo Dragon. Nine wells have been drilled in the field and currently has an installed capacity of 35.5 MW. It is composed of two backpressure units of 5 MW each and one condensing flash power plant of 25.5 MW.

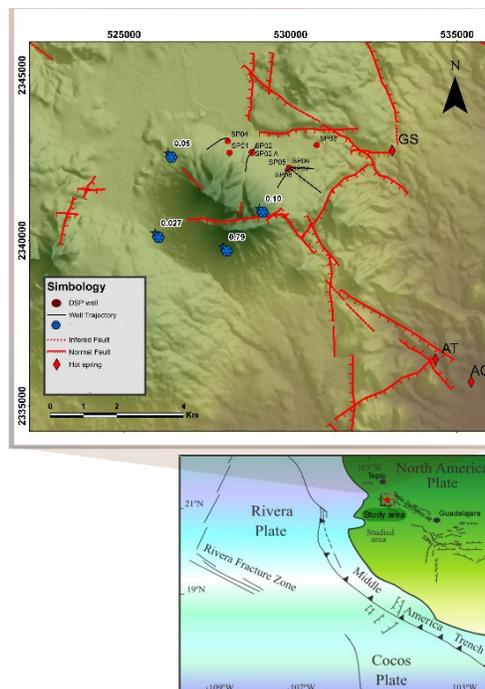


Figure 1: Location of Domo de San Pedro, Nayarit, Mexico.

2. LITHOLOGY AND HYDROTHERMAL ALTERATION

In the Doms de San Pedro geothermal field, four different formations were recognized according to their stratigraphic position, age, and composition with the help of cuttings from the drilled wells. This is made up of the (i) most recent volcanic deposits of dacitic and rhyolitic flows (0.6 -0.1 Ma), including pumicite, glass, and fluidal rhyolite. The San Pedro Pleistocene dacitic formation is present with dacitic colluvium and dacites. (ii) Underlying andesites and dacites of the Pliocene (4.93.8 Ma) and lay over on the (iii) andesitic lavas of the Miocene (13-8 Ma). This unit seems to be the clay cap of the geothermal reservoir. (iv) And the regional basement is the granodiorite and diorite from the Cretaceous to the Late Paleocene (75-56 Ma). This granitic complex is associated with the reservoir of the geothermal system due to secondary permeability related to the faulting.

In the Doms de San Pedro geothermal field, there is an argillic zone (clay layer) over a propylitic zone (high temperature deposit > 240 ° C). The epidote is a common mineral that is indicative of the propylitic zone. However, the epidote occurs more deeply than the 240 ° C isotherm. This difference in the typical mineral set can potentially be explained by the presence of a boiling zone in wells SP06 to SP08, which would cause calcite to be favored by above the epidote and a hydrothermal deposit with an alkaline tendency.

The most shallow argillic zone is found in the recent rhyolites where clay is observed in thin section. Clay is also highly developed in the underlying pyroclastics of the Pliocene. On the other hand, in the andesites of the Miocene is the largest alteration by argillitization in the rock found with an average thickness of 500 m, where it is present in illite-smectite and illite, as well as hematization and silicification. It is considered that the argillic alteration works as the clay cap of our reservoir, limiting the deposit stored in the granite and granodiorite of the BJ, as well as in the contacts with the diorite. As support of the petrography, the presence of clays with the Methylene Blue test made from wells SP05, SP06, SP07 and SP08 is evidenced.

The propylitic alteration associated with high temperature geothermal deposits is related and is abundant in fault zones that tectonically affect the granite complex, as well as in the dykes emplaced in this faulting, in the northern region of the San Pedro Domes. In the northeastern zone, it is associated with lithological contact with diorite with intense hydrothermal alteration, exclusively in the area of wells SP05, SP06, SP07 and SP08. Since in the northern zone the diorite is without any alteration, being able to observe its original structure.

In general, the analysis of thin sections of the Domo de San Pedro geothermal field shows hydrothermal alteration patterns mainly of argillic and propylitic alteration, as well as the presence of alkaline alteration (SP05-SP08) in the field discharge. The mineralogy of the high temperature geothermal field can be divided into the main hydrothermal mineral zones with increasing depth: argillic, propylitic and propylitic / high temperature potassium. The zones of phyllic alteration can also be found in the propylitic zone, particularly near the structures.

3. REGIONAL GEOLOGY

The San Pedro volcanic system is a WNW-ESE striking extensional basin, with volcanic and subvolcanic bodies emplaced since late Miocene until at least since the Pliocene. These are located along the boundary between two different basement blocks. These are the batholith of the Jalisco Block (JB) to the south, and the Sierra Madre Occidental (SMO) silicic volcanic province to the north. The San Pedro domes are part of a large silicic volcanic complex, where the most activity occurred in the last 1 my. The most recent volcanism is represented by NNW-SSE alignments of several silicic domes and mono-genetic cinder cones (northern and middle chain) with northern WNW-ESE alignment of monogenetic volcanoes. The region of San Pedro is located inside the Compostela graben and center of a structural depression caused by a cross between N-S, NE-SW, NW-SE and E-W faults. This is a complex asymmetrical depression developed during Late Miocene and Pliocene time with vertical displacement exceeding 2 km.

A local-regional geological-structural study was made starting from the observation of the correlation with gravimetric guidelines and the topography of the study area. Previously, there was only one study to recognize the fault in the outcrops of the granodioritic basement of the Jalisco Block. The theory was corroborated that not all the Miocene and Pliocene faulting had been buried by younger magmatic pulses, updating the conceptual model of the San Pedro Domo field and defining the structures that tectonically affect the reservoir, based on the geophysical information, geochemistry and well data.

Ferrari et al (1994) conducted an extensive structural field work campaign over the western part of the Trans-Mexican Volcanic Belt (TMVB). Objectives of this structural campaign is to give clarity to plate tectonic, fault kinematics along with a geologic unit reconnaissance in order to establish the tectonic evolution. It has been documented that the western sector of the TMVB, holds more total deformation than other sectors (i.e. central and eastern sectors) (Pasquarè et al, 1986).

Results of Ferrari in (1994) related to the northern side of Jalisco block mainly consist in: (a) No major strike-slip faulting has been occurring along Tepic-Zacoalco graben (TZG) since late Miocene. This lateral movement is a result of the incipient tectonic separation of Baja California along the west coast and is considered to be mainly dextral. (b) the boundary of the TZG consists in various extensional structures related to different geodynamic events. (c) the neotectonic activity is weak, mainly north-south extensional.

Consequent studies (Ferrari & Rosas-Elguera, 1999; Ferrari et al, 2003) confirmed the geodynamic setting proposed in Ferrari (1994). Field studies found that the right lateral component is only present in middle Miocene rocks as major extensional and lateral displacement is no longer recorded on rocks younger than Miocene. Minor deformation component “ σ_3 ” was determined via inversion of fault data analysis, resulting in a NE-SW trend. As for the whole Tepic-Zacoalco boundary, a set of time-differing extensional structures were identified and properly linked with their period development; main stages comprise the Baja California Gulf opening and the lateral response associated to this movement. Subducting plate roll-back granted new types of volcanism and intra-arc extension. This intra-arc period is considered to be the last one and the current one, eventhought with less deformation intensity; “ σ_3 ” for this last period, reported to be NNE-SSW, thus generating nearly E-W faults.

4. LOCAL GEOLOGY

The region of San Pedro is located inside the Compostela graben and center of a structural depression caused by a cross between N-S, NE-SW, NW-SE and E-W faults. This is a complex asymmetrical depression developed during Late Miocene and Pliocene time with vertical displacement exceeding 2 km.

The Compostela graben is formed by two NW137°SE Compostela Fault and NW319°SE Pedernales Fault being normal faults which border a 10 km wide depression. This NW-SE faulting is of great importance because it is regional fault and is formed in the area by a structural train of the faults that emerge, they seem to be part of the same fault. These faults are mentioned as Compostela, San Pedro, Corral Falso, Casa Blanca and Atarjea. The Compostela Fault is outcrop in the northwestern region and is interrupted by faulting N-S and NE-SW to be buried below the Domes of San Pedro, and emerging again to SE flank. In the southeastern portion it is conformed for Corral Falso, Casa Blanca and Atarjea Faults, this last means of discharge of the reservoir, by the springs Agua Tibia and Agua Caliente.

To the SE of the prospect, the rhyolitic and dacitic domes are clearly located along a NW-SE direction. Therefore, the distribution of these domes is indicative of an environment limited to an extensional regime NE-SW. In addition, the location of the springs is restricted to a discharge with EW orientation related mainly to the Guasimas Fault and thermal springs to the SE of the field conducted in NW-SE faulting, suggesting that hydrothermal fluids may be draining along EW structures. Northeast of the geothermal field and south-east in NW-SE structures, without evidence that the NE-SW faulting serves as a means of transport.

Middle Miocene N-S faults reactivated during the Pliocene and NE-SW work as a reservoir boundary, the eastern flank of the domes is limited by the NE-SW fault system with a dip south-east toward Agua Caliente and Agua Tibia springs.

The N-S faults of the middle Miocene reactivated during the Pliocene, and the NE-SW function as the boundary of the reservoir. The east flank of the domes is limited by a fault NE-SW with dip to the southeast in the direction of the springs Agua Caliente and Agua Tibia, this fault is Los Lobos Fault. The western flank of san Pedro domes is limited mainly by a system of N-S faults with a dip to the east, which disappear to the center of the graben.

To the SE of the prospect, the rhyolitic and dacitic domes are clearly emplaced along a NW-SE direction. Therefore, the layout of these domes is indicative of an environment constrained by an NE-SW extensive regime. Additionally, the location of the Agua Caliente and Agua Tibia thermal features to the SE of the field, suggests that the hydrothermal fluids might be drained along extensive structures as the San Pedro, Corral Falso, Atarjea, and Casa Blanca faults.

Faults with orientations E-W are also present and are very frequent, considering a secondary system derived from the dominant regime of extensional stress NW-SE Pliocene. These faults become relevant because they are observed crossing the northern flank of the Domes of San Pedro as part of the same system, formed on the surface by the Fallas Ocotes, Avalos and Guásimas. Likewise, in the geophysical analysis, it is identified by gravimetry (Boguer residual with Gaussian high pass filter and Euler deconvolution), magnetotelluric profiles (AA profile, geophysics report) and passive seismic that this system is a deep faulting in a range of 2.5 km and most likely it is affecting the reservoir rock. Another E-W fault is found cutting the Domes of San Pedro in its central part is the Falla Cerro Grande. This E-W fault is significant and is also inferred by gravimetry, however, it is not clear from the geophysical analysis whether this fault is shallow or is also deep.

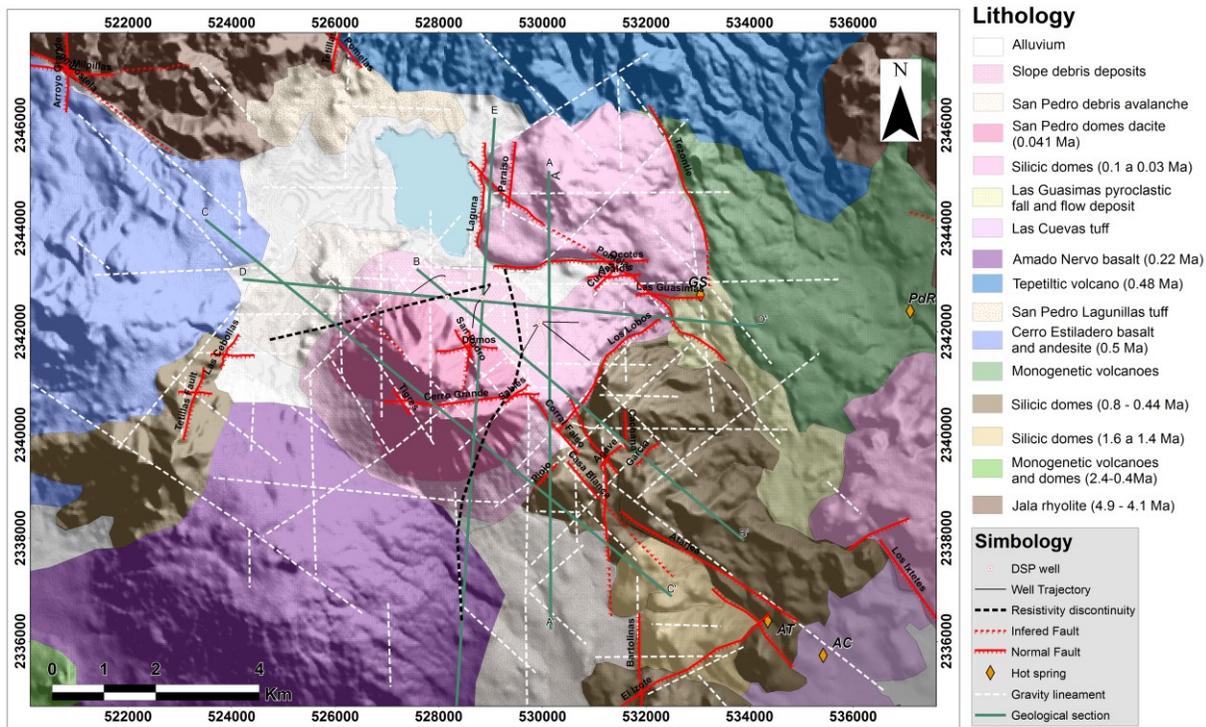


Figure 2. Structural and geological map of the study area with inferred faults based on the previous gravimetry and resistivity discontinuity.

5. GEOPHYSICS

5.1 MICROSEISMIC

During a period of 6 months, a seismicity register was made through a network of 5 digital seismographs installed in the vicinity of the DSP. Registered microsisms were induced as a result of the injection in well SP03, having earthquakes with an average of 1.3 ° in magnitude of coda at depths of the order of 2.5 km and with injection averages of 150 m³ / h. The focal mechanisms of these earthquakes; that is, the orientations of the structures in which the earthquakes are occurring correspond to faults with orientations predominantly Northeast-Southeast and North-South.

5.2 GRAVIMETRIC EXPLORATION

Gauss filter was used on the residual bouguer anomaly data in order to identify slim structures. Two wide range anomalies can be seen in gauss filter map in NW and SE area; these anomalies might delineate the underground structure of the area as a possible response for elevated crystalline blocks that comprise the basements.

In the Euler deconvolution map for DSP, a alignment of deep source faults can be seen under the San Pedro Domes. This orientations correlate to main graben fault structure that might continue from Compostela fault in northwest, to the DSP towards the southeast; in addition, a strong lineation can be proposed in the east sector of DSP, with a NE-SW trend that links with structural limits seen in other filtered maps.

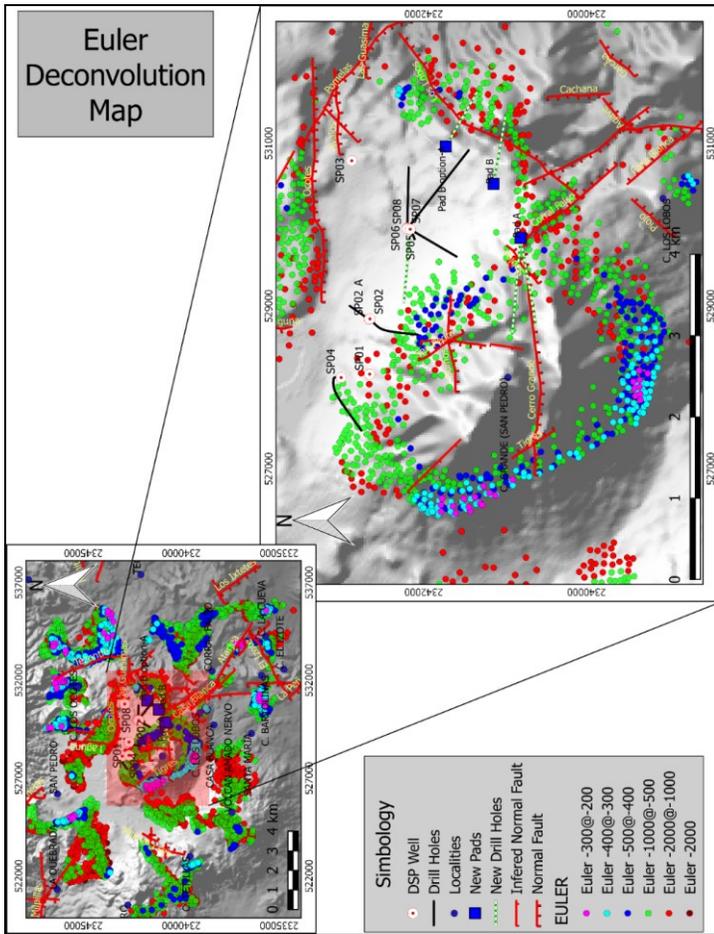


Figure 3: Euler Deconvolution Map.

5.3 MAGNETOTELURIC PROSPECTION

The magnetotelluric data information was compiled and reinterpreted by the WestJEC company based in Fukuoka, Japan. And using different considerations for data inversion (such as noise elimination and data preprocessing, among others) developed 2 profiles and maps of electrical resistivity from 100 m to 3,000 m depth from the inversion of magnetotelluric data at different depths. Two zones of discontinuity in the resistivity were identified from the maps and profiles developed. The first one with N-S orientation east of the San Pedro Dome and the second with slightly E-W orientation to the north and central sector of the Domes of San Pedro. Magnetotelluric data used by GEOTEM was taken from a previous campaign conducted by MombaRiga Geoscience, since nearly 65 magnetotelluric stations were established. Gravimetric information generated through the GEOTEM field campaign and ZONGE data addition, can be considered as a qualitative interpretation; this allowed the identification of geological structures or prominent domains linked to density contrast over the study area. Nevertheless, to generate a quantitative interpretation of gravimetric data, a bi-dimensional gravimetric model was performed, using the 2D (TE-MT) inversion of geoelectrical model from the magnetotelluric information available through MombaRiga field campaign. This process, along with the available lithological information, allowed the restriction of unit thickness and lateral continuity to provide the optimal density consignment.

Four profiles named “A, B, C and D” with different orientations, were generated across the San Pedro Domes geothermal field taking in consideration that, several amounts of magnetotelluric stations where available, and that underground complexity is present so that comprehensibility needs to be achieved.

This profile A is north-south oriented and located in the eastern sector of DSP. It uses a restriction model of 4 kilometres (1400 to -2600 m.a.s.l.) (Figure 4). The bouguer residual filter shows a low amplitude anomaly from the 0 km reference to the 7 km point; from this point, anomaly begins to recover high values, associated to an elevated crystalline block.

Another anomaly can be detected from 1 km to 2.5 km reference; it could be associated to intense fracturing and probably fluid circulation. Strong red colours or low resistivities are inferred to be the seal cap of the geothermal reservoir, as hydrothermal fluid alter the host rock and produces clay minerals that are conductive. In Figure 2, the integration of gravimetric, electrical and geological information for profile A are presented.

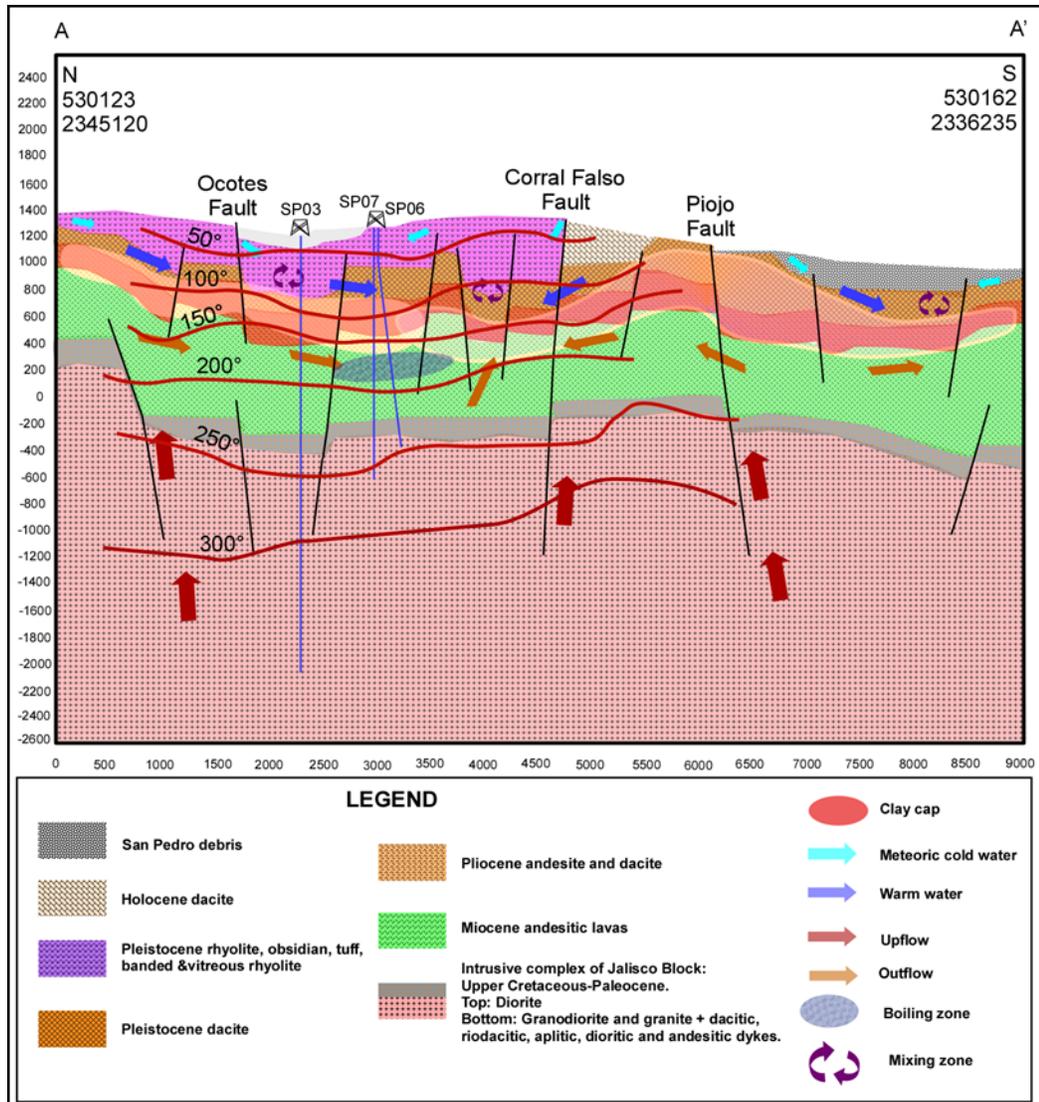


Figure 4: Resistivity result for profile A-A'.

Profile "B" is NW-SE oriented; restriction model is similar to profile A (4 km magnitude) (Figure 5). Low amplitude anomaly in bouguer residual can be inferred in the base of dacitic DSP; from northwest to southeast the anomaly recovers its values as it appraises an elevated block. A 1 km width anomaly is seen from the 2.5 to 3 .5 reference points, possibly linked to intense fracturing and fluid ascent. A low resistivity horizon measured at 800 m depth, acts as the seal cap of geothermal system. Near surface high resistivity values correspond to unaltered rhyolitic, basaltic and dacitic rocks of Quaternary period.

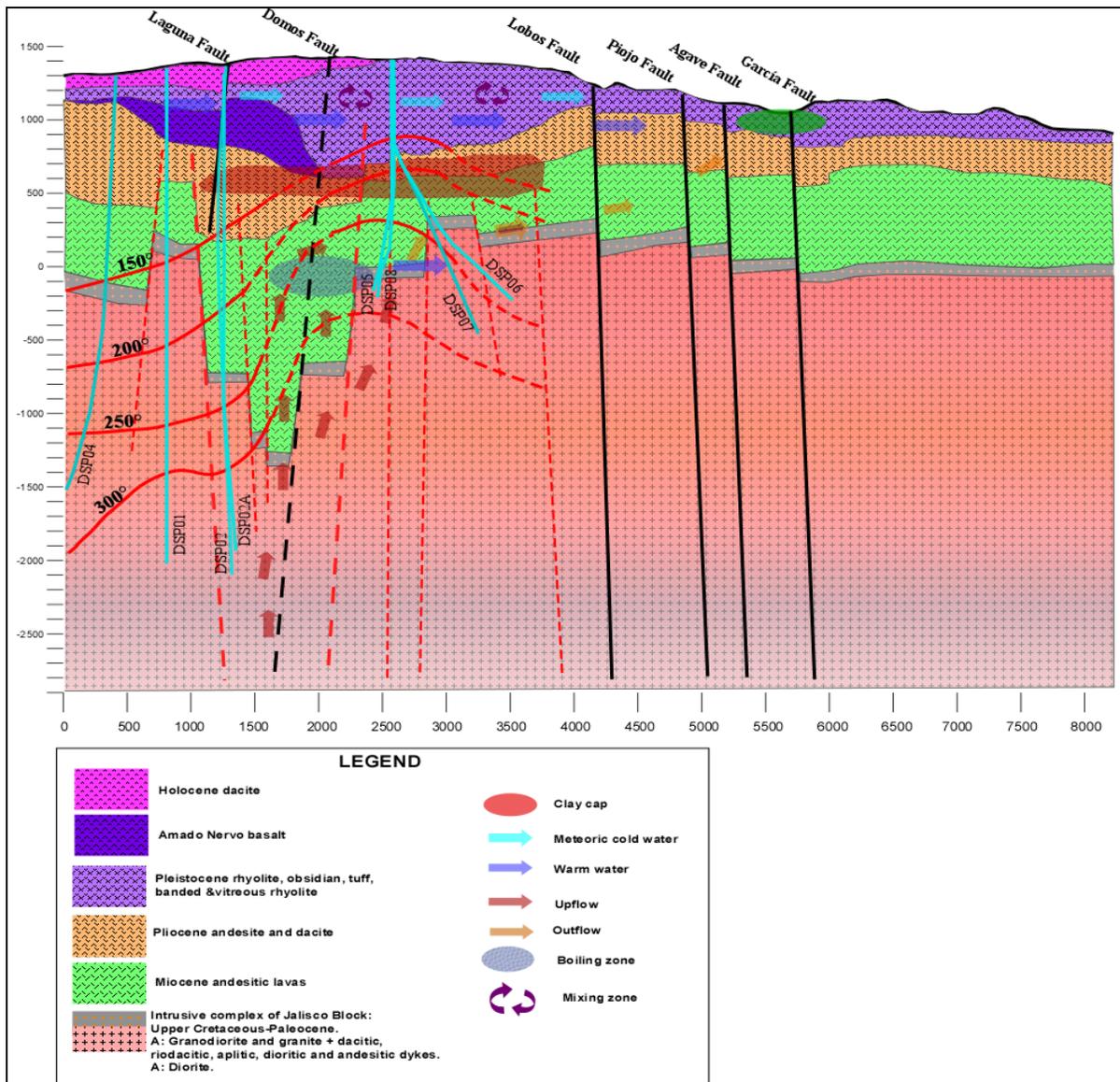


Figure 5: Integrated profile B-B'.

CONCLUSION

Summarizing, the conceptual geothermal model of the Domo de San Pedro geothermal field is limited mainly by the NE-SW faulting, as well as the existence of conductive structures of the fluid, which most likely would be NW-SE and EW faulting and with possible suspicion the NS fault. Hosting the geothermal fluid in the granite-granodiorite complex of the Jalisco Block, which is confined by a layer of clay which alters the andesites of the Miocene and knowing that the permeability zones are associated with the faulting that affected said plutonic rock, where the major propylitic alteration associated with geothermal deposits of high enthalpy is presented. The EW orientation related mainly to the Guasimas fault and thermal springs to the SE of the field conducted in NW-SE faulting, suggest that hydrothermal fluids may be draining along EW structures. To the Northeast of the geothermal field and to the south-east in NW-SE structures, without evidence that the NE-SW faulting serves as a means of transport, if not as a limiter of the geothermal system.

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