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Gradients of Resistivity Profiles Display Fault Systems

Fidel Cedillo-Rodríguez and Mario Benhumea

fedelecedillo@hotmail.com

mariobenhumealeon@gmail.com

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ABSTRACT

The analysis and interpretation of the final models of the resistivity profiles, demonstrate that changes in the resistivity gradient in geothermal fields or areas with thermal manifestations, show us the presence or absence of geological faults (horsts and grabens) and regional fractures structural represented by structural lineament of volcanic structures. Also, these gradients identify conducts of volcanic arcs, corresponding to possible semicircular faults which possibly relate to caldera collapses. And most importantly: identify systems of "hidden faults" covered by successive deposits of lava and pyroclasts. Moreover, resistivities are influenced by the rock type, porosity, permeability, saturation of fresh water or brine, temperature, primary and secondary mineralogy, metallic and non-metallic minerals, altimetry and presence of seawater.

1. INTRODUCTION:

In the 1970s and 1980s, in areas with thermal manifestations at Los Humeros-Derrumbadas and Los Azufres in the states of Puebla-Veracruz and Michoacan, the Federal Electricity Commission (CFE) carried out regional geoelectric studies using the method of Vertical Electrical Sounding (VES) with AB/2=2000 and AB/2=4000m. For the studies the CFE used a Schlumberger device.

2. DISCUSSION

For the hypothesis proposed here, have more sustenance and technologic and scientific rigor that the "distribution of resistivity and sudden changes of inclination, shown in vertical sections, is caused by a normal fault system" that form geological structures of graben and horsts. These aspects are analyzed from papers presented at the World Geothermal Congress 2015, held in Australia.

2.1 Los Humeros Geothermal Field, México

In Figure 1, we observe the regional section NS, 30 km of length that crosses the caldera Los Humeros (CLH) and the caldera Los Potreros (CLP), and xalapazco Maztaloya, a little caldera, with a collapse of 2 km, and a 50°C steam manifestation in the west wall. For Los Humeros, Figure 1 shows an electroestratrigrafic section and Figure 2 shows an "apparent iso-resistivity section". In the first, observe failures in the lateral resistivities. Note that the failures caused by the collapse of the xalapazco Maztaloya are not marked in the apparent iso-resistivity section (SIRA).

Note especially the resistivity changes on both sides of the CLH; the apparent resistivity rises inland, showing greater inclination in structural faults under the collapse of the CLP. It is also known that for the central part of the SIRA, the resistivity distribution is almost semi-horizontal, suddenly changing to the vertical. This appears as a strong gradient (almost vertical) of apparent iso-resistivities.

The slope change is interpreted to be due to fault planes that act as paths for hydrothermal flow at high temperatures (>100°C). By this reasoning, the graben caused by the collapse of the caldera of Maztaloya (CCM), apparent resistivities of 20 to 1000 ohm-m, are closer to the surface.

In Figure 2, we present the SIRA 46-46' where a resistive low of 10 ohm-m is observed. Flanked by iso-resistivity verticals of 20 and 30 ohm-m. It is noted how of the vertical, tend to the horizontal, this indicates the presence of "hidden faults", covered by the "seal layer" of the electrostratigrafic section of the geothermal reservoir. The "seal layer" is represented by the electrostrata of 2 to 9 ohm-meter. From a geological point of view, this minimum resistivity is represented by a graben. Geothermal production wells are located in this resistive low which have excellent vapor production. This is unlike well H-26, which is located in an area of high resistivity.

2.2 Los Azufres Geothermal Field, México

In order to sustain and demonstrate that changes in slope of the iso-resistivity distribution along sections of SIRA indicate fault systems, the SIRA III-III' section was analyzed (Cedillo-Rodriguez, 2012). Figure 3 shows the distribution of apparent iso-resistivity curves of 5 to 3000ohm-m and sharp changes in iso-resistivity.

It is important to note that the surface of Los Azufres Geothermal Field (CGLA) has a predominantly E-W fault system. Along the traces of the fault system thermal manifestations arise. Photogeology may confuse the escarpment with the spine of the failure. (Figure 4).

Figure 3A shows the E-W faults, drawn along the SIRA III-III' effectively between the SEVs C-7 and M-6. SeVs, slope changes of iso-resistivities are presented, proving the existence of faults. Among the SEVs 11002 and E-4, the faults drawn dip to the S. Therefore, considering the strong gradients of iso-resistivity, the faults mentioned, must dip to the N, as shown in Figure 3C.

To highlight the significant magnitude of the analysis of distributions of the SIRA, verified and demonstrate the existence of the failures identified by the geoelectric methods, present the petrographic-structural correlation, NS, of 11 geothermal wells (Figure 4), considering the horizontal lithological contacts of the rhyolites (R) and andesites (A). Figure 5 shows a graben between wells AZ-25 and AZ-47, but between the lithologic contacts between wells AZ1A and AZ-47 an inverse fault is observed. Also, among AZ- wells AZ-24 36, another inverse fault is observed.

Considering what described above, which is confused by photogeology as fault scarp (Laguna Verde and San Alejo faults), the slope or ridge. The analysis of the slopes of iso-resistivities show that the fault front or real scarp fault and dip, corresponds to a normal fault and, in Figure 6 Section I-I, result that the alleged faults Laguna Verde and San Alejo, correspond to the spines, with the true scarp being, the faults Laguna Larga A and San Alejo Bis. Finally considered inverse faults correspond to "tilted normal faults" presenting Section I-I, a tilted fault system dipping to the north.

3. SECOND DISCUSSION

With the primary objective to check and prove that the hypothesis that the vertical distribution of resistivity models gradient, presented in resistivity profiles of magnetotelluric (MT) surveys, correspond to fault systems, next we analyze and reinterpret the following studies.

3.1 Bacon-Manito, Southern Luzon, Philippines

Figure 7 presents the location of MT stations, resistivity profiles, regional structures and thermal areas at the Bacon-Manito field in the Philippines. Figure 8, shows the SW-NE resistivity profile passing through the Magaho, Tikolob and Kayabon volcanoes, and crosses the regional structural guidelines. Also shown are two minimum resistivities of 9 to 6 ohm-m, covered by semihorizontal lines of 33 to 50 ohm-m. This is known as the central profile, where slope changes combine to form a dome flanked by the minimum resistivity, which is considered to be due to the cap clay, caused by the discharge of geothermal fluids through fault planes of the hidden faults. From a geological point of view, the graben, which is formed by the guidelines WNWESE, is recommended for well construction area.

Figure 9 shows the three traits identified by the authors of this article, which correspond to the change in slope of the resistivity, forming convex and concave curves, the first observed below the mountains, Malobago, Tikolob and Cawayan, Bolong. As mentioned previously, sudden changes in slope of the resistivity suggest fault systems related to grabens and horsts. Figure 9 shows "hidden faults" that give rise to three grabens, separated by two horsts. These are precisely the grabens below the Bolong and Cawayan volcanoes, where directional wells were drilled towards the center of the tectonic depression. Hydrothermal fluids may flow up the "hidden faults" and result mineralogical alterations of the surrounding rocks, e.g. resulting in the clay cap suggested by the low resistivity of 6-14 ohm-m.

Among the PB-1 and Pal-5D wells, a hidden fault was drawn, which shows how the temperature of 250°C, is presented more superficial across the fault, to prove the existence of these proposed hidden faults, it is necessary to observe the change in slope of the resistivity between two MT stations. In addition, these hidden grabens, check and demonstrate the presence of the upflow detected (Tugawi, Rigor Jr., Los Baños & Layugan, 2015). Our opinion is that hidden graven beneath the Molobago volcano is another upflow zone.

3.2 Yanaizu-Nishiyama Geothermal Reservoir, Northern Japan

Figure 10 shows the location of the sections A-A' and D-D ', along with the location of MT stations at the Yanaizu-Nishiyama geothermal field. Figure 11 shows the resistivity profiles, the clay cap appears in the low resistivities and the reservoir in high the resistivity, as shown by the data of geothermal wells.

In AA 'profiles with ROT=35, and ROT=0, the distribution of resistivities have different slope changes; still it is possible to trace faults in sudden changes of inclination. Thus, it stands, as initially proposed, that high temperatures occur in the structural low of the faults. The A-A' profile shows a graben formed by hidden faults where directional wells were drilled. The feed zones of those wells may correspond to the hidden faults, which act as flow channels for hydrothermal fluids that altered host rock in the clay cap. Considering the temperature curves and the arrangement of the inclination of the resistivity, was changed the direction of the original temperature curves (Uchida,Takakura, Ueda, Sato & Abe, 2015), reversing the direction.

4. CONCLUSIONS

For planes of normal fault systems with high penetration, rise lavas and pyroclastic material, forming volcanic structures. In the structural low, the main plane of the fault system presents high temperatures. Those high temperatures are, first of all, a result of the flow of lava and piroclastic material and, second, a result of the flow of geothermal fluids. Some of the geothermal fluid flows to the surface, forming thermal manifestations, and elsewhere the hot fluid altered rocks in the system.

Structural high, present lower temperatures, as the fault plane acts as an impermeable barrier to the above fluids. Moreover, fault planes, allowing the infiltration and percolation of meteoric water and surface storage water, recharging the geothermal reservoirs.

Regarding the presence of the planes of "hidden faults" covered by lava and pyroclastic deposits, these "hidden faults" appear in depressions. Precisely at the apex of these planes of faults, there is circulation and laterally discharge of hydrothermal fluids, which alters the adjacent rocks. In some geothermal systems this hydrothermal alteration of rock results in the "seal layer" or cap rock.

In terms of resistivity, several geothermal specialists agree that: lower resistivity (<20 ohm-m) relates to a higher temperature (> 100 ° C). And vice versa, the higher resistivity (>1000 ohm-m) relates to a lower temperature (<30 ° C). That is not final, the dissertation of the papers, disagree with the resistivity versus temperature.

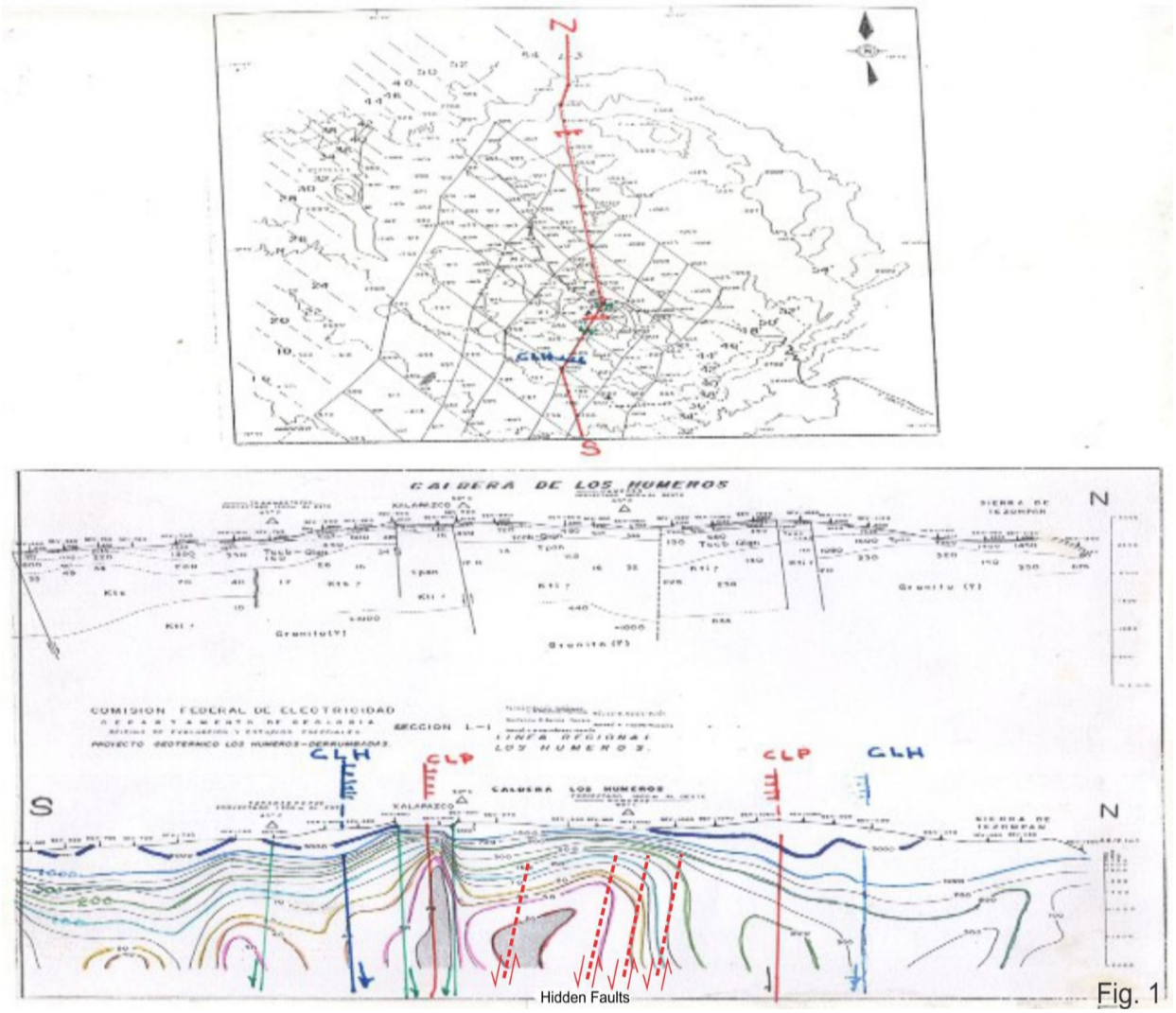

Figure 1: Geologic section NS of Los Humeros Geothermal Field (modified from (Cedillo-Rodriguez, 2012)).

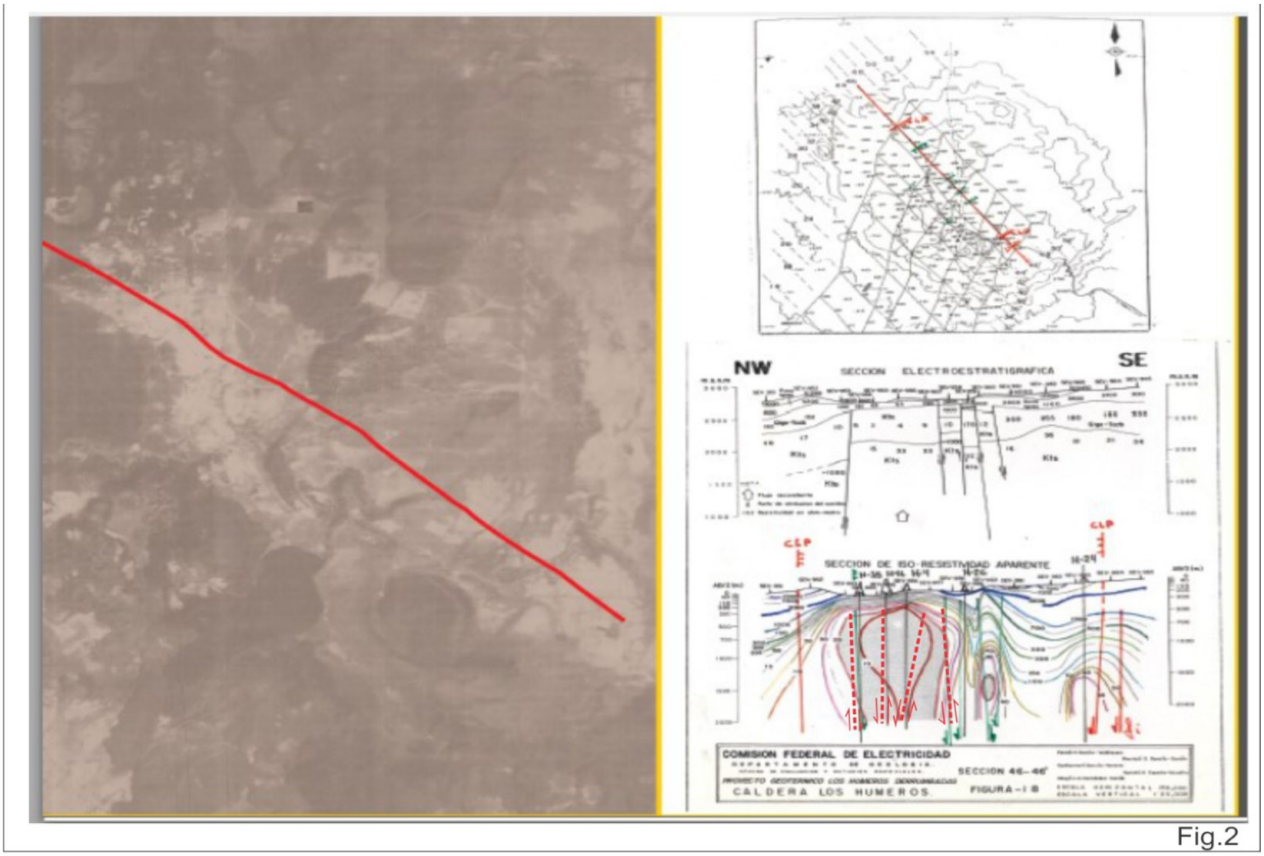

Figure 2: SIRA 46-46'of Los Humeros Geothermal Field (modified from (Cedillo-Rodriguez, 2012)).

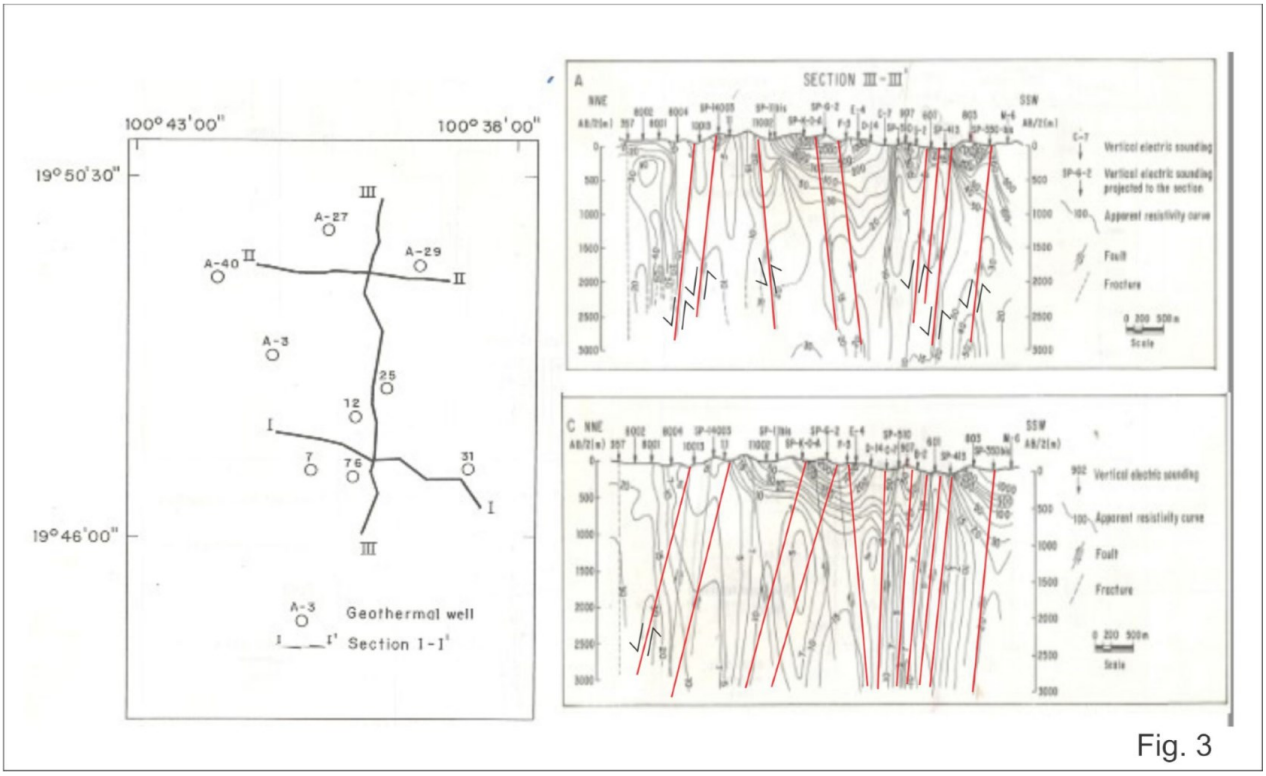

Figure 3: Iso-resistivity section III-III' of Los Azufres Geothermal Field (modified from (Cedillo-Rodriguez, 2012)).

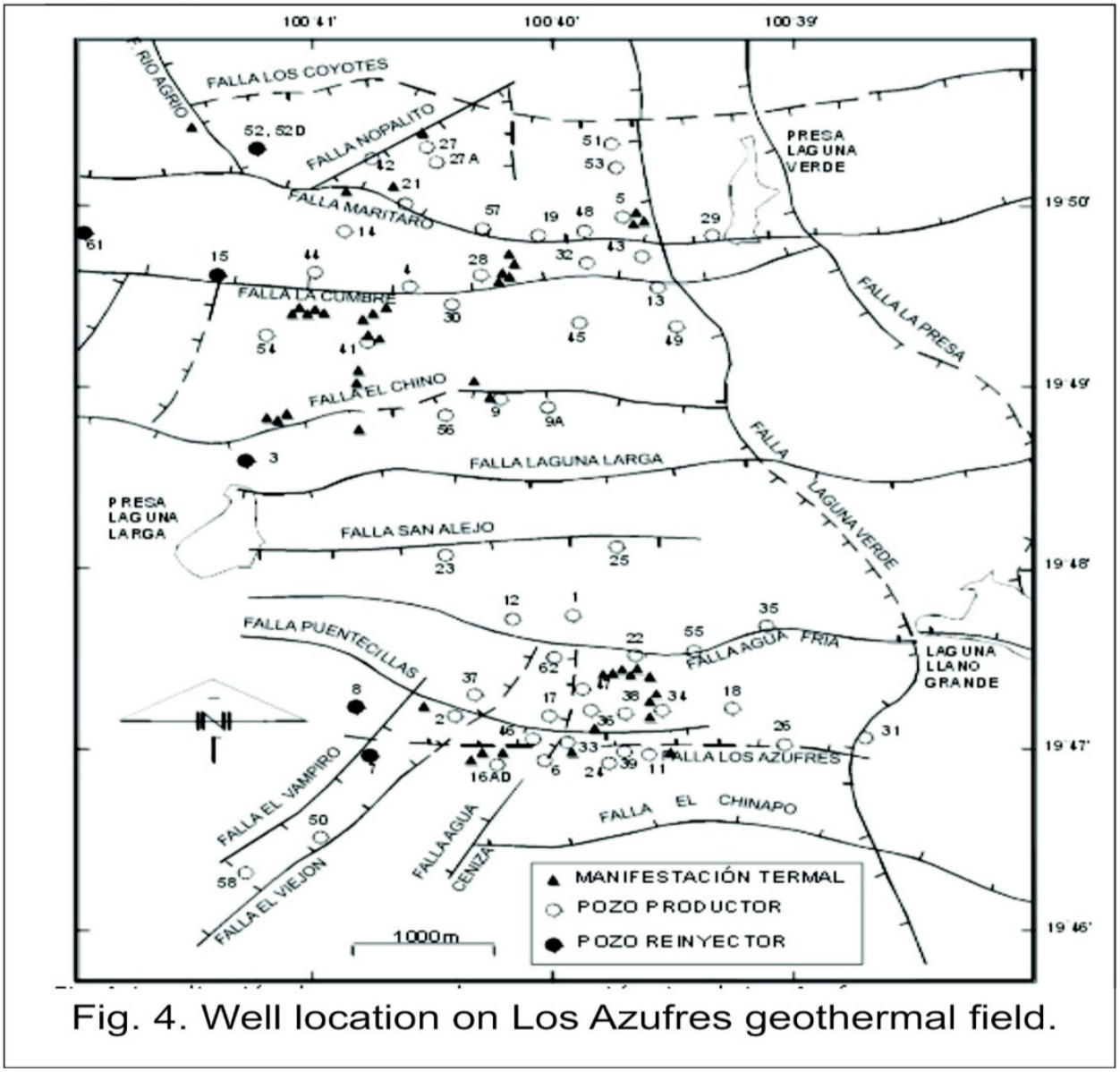

Fig. 4. Well location on Los Azufres geothermal field.

Figure 4: Well locations in the Los Azufres Geothermal Field (Cedillo-Rodriguez, 2012).

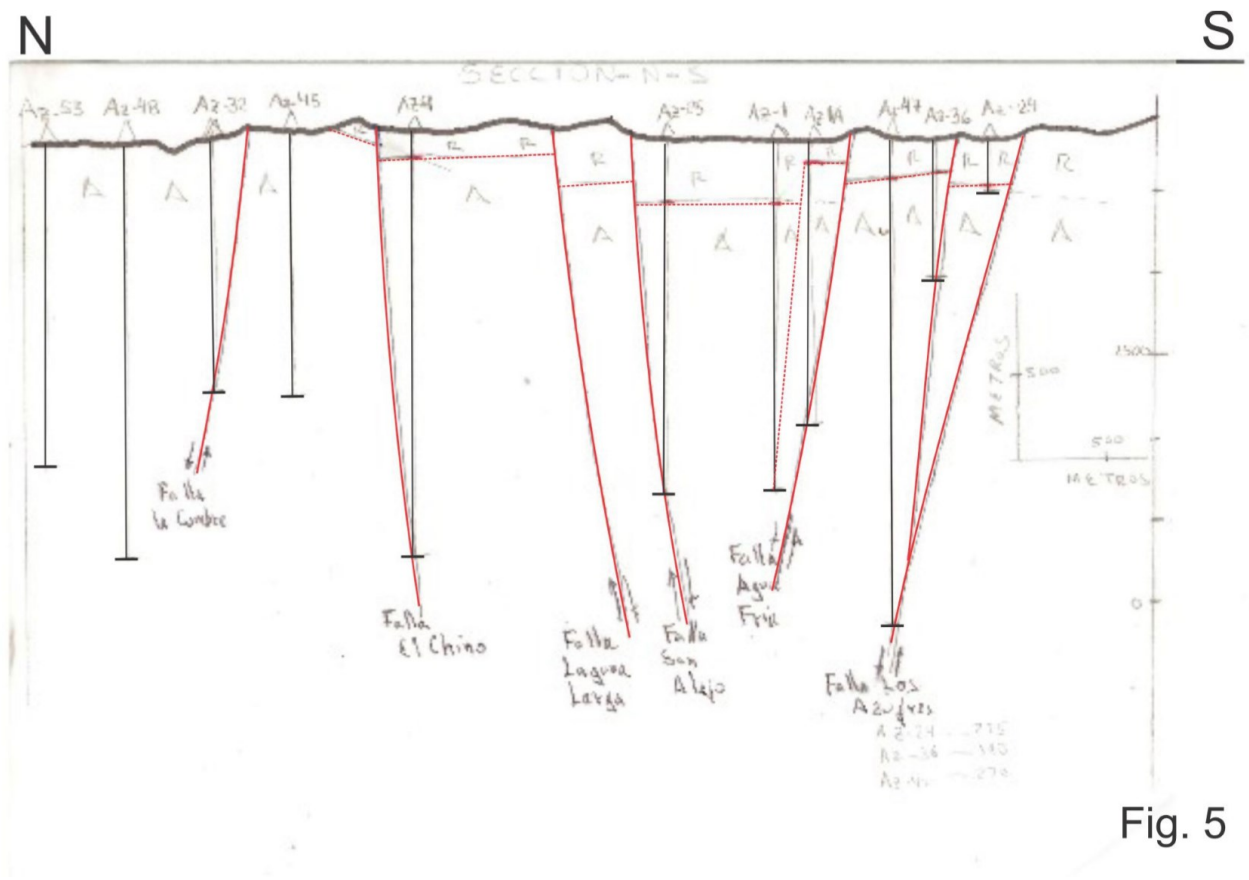

Figure 5: Conceptual idea of the fault structure (graben and horst) in the Los Azufres Geothermal Field (modified from (Cedillo-Rodriguez, 2012)).

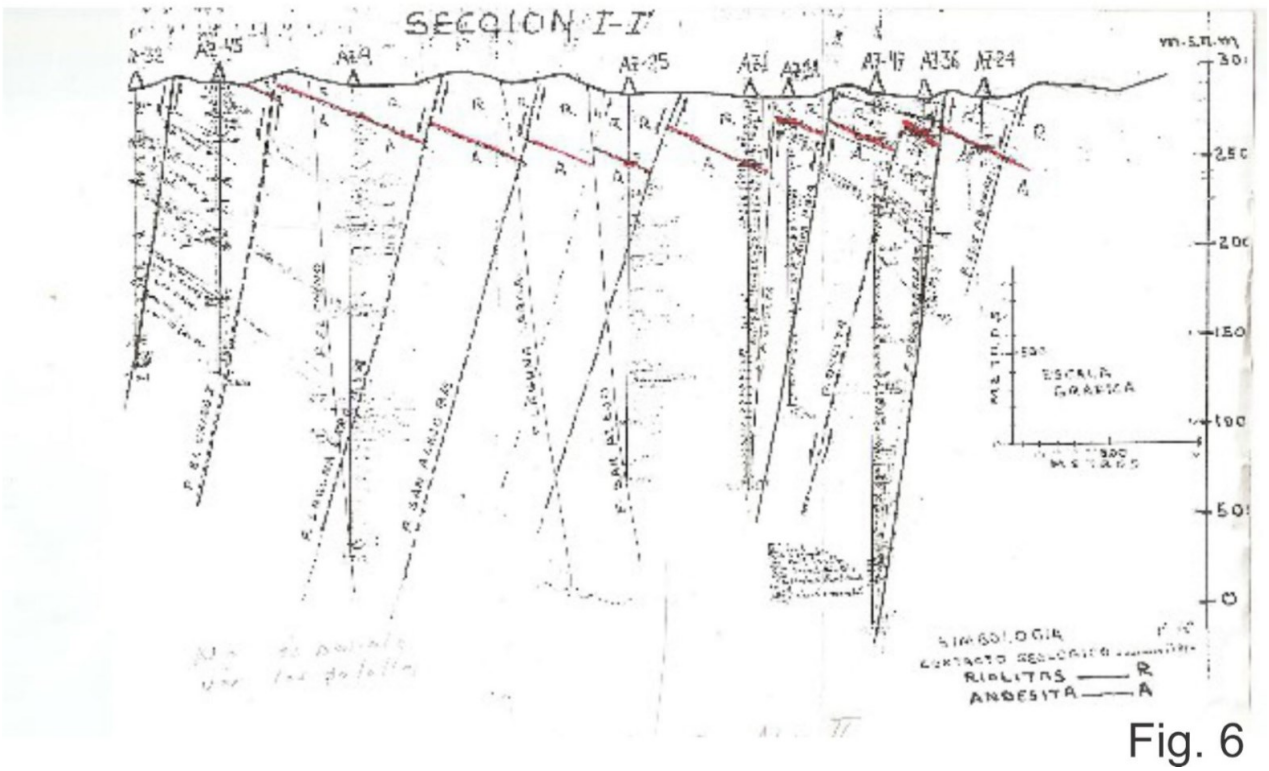

Figure 6: Iso-resistivity section I-I' for the Los Azufres Geothermal Field (modified from (Cedillo-Rodriguez, 2012)).

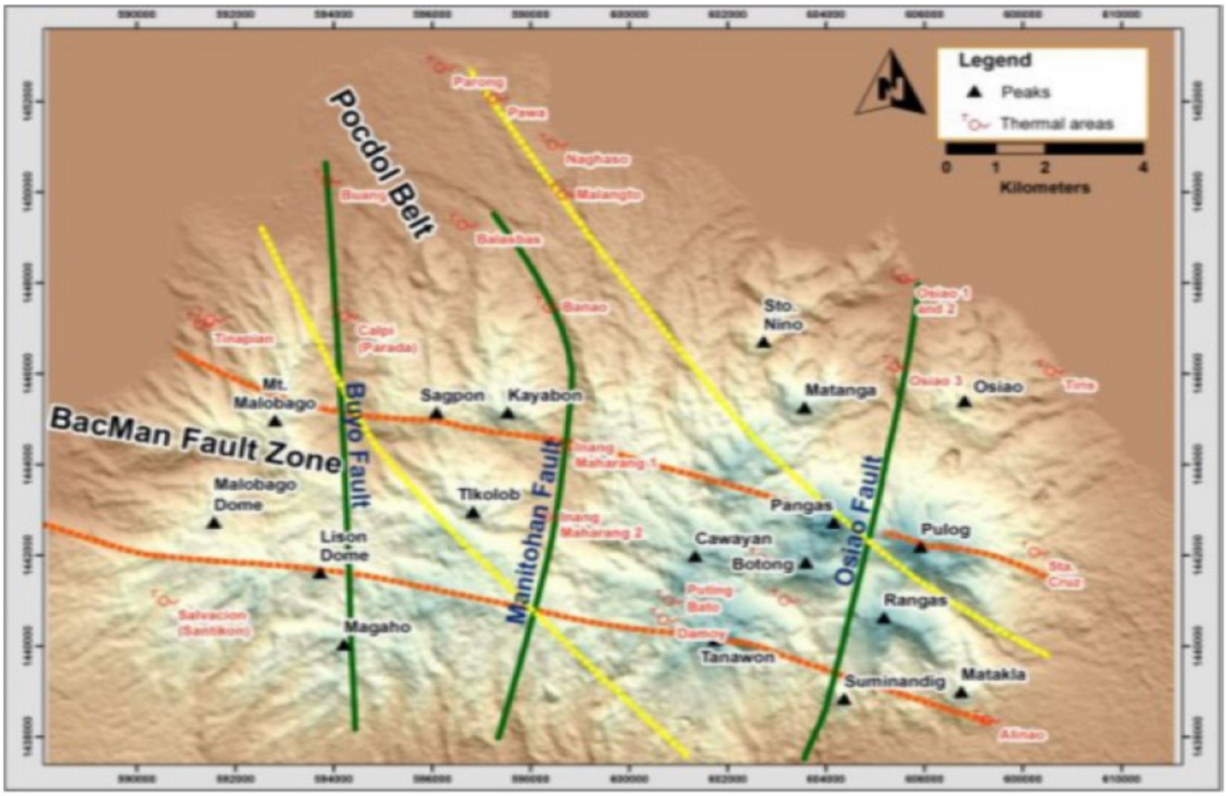

Fig. 7. Location map of Bac-Man MT stations and regional structures. A total of 527 MT stations were occupied in a total area of 188 km2.

Figure 7: Regional structures and locations of magnetotelluric (MT) survey stations at Bacon-Manito. A total of 527 MT stations were used in an area of 188 km^2 (Tugawin, et al., 2015)).

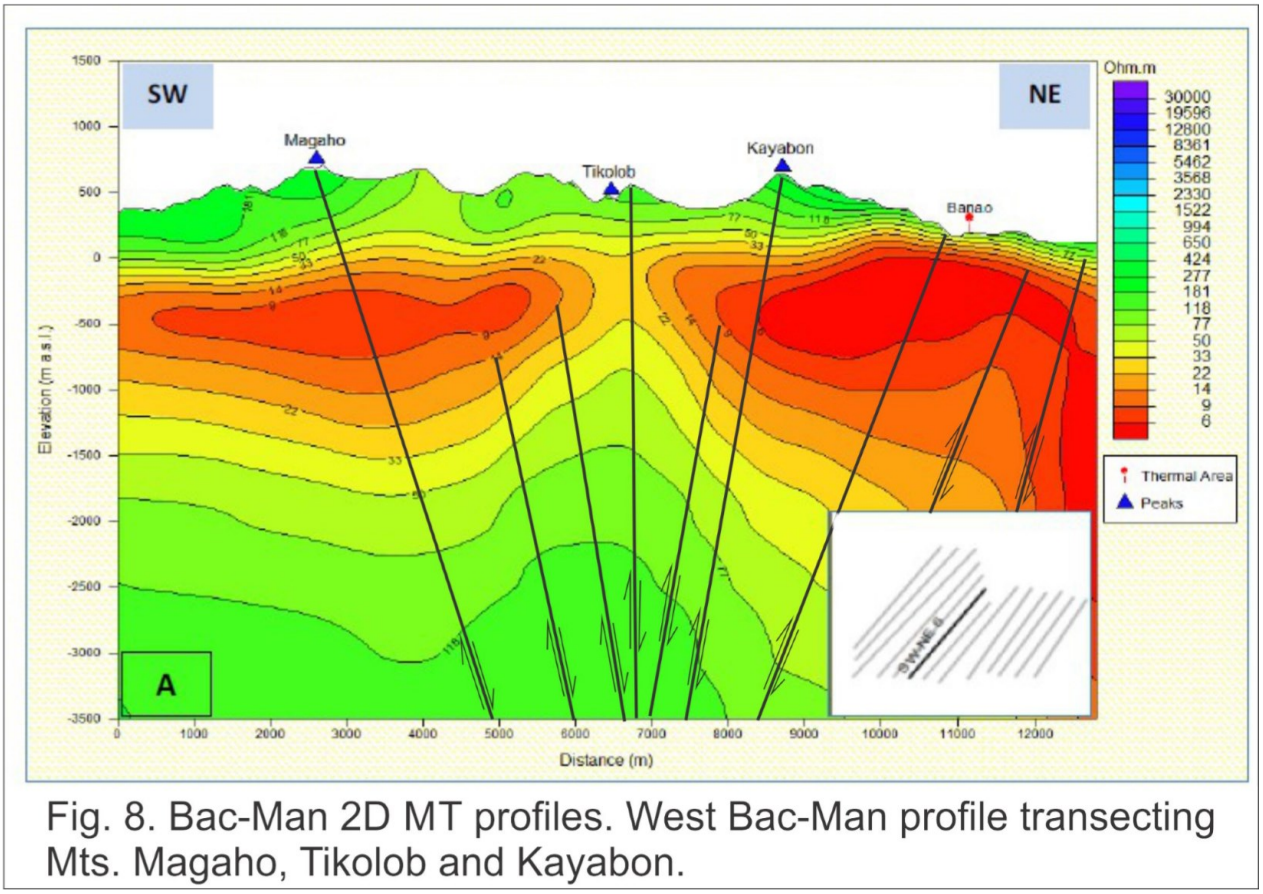

Figure 8: Bacon-Manito 2D MT profiles showing proposed hidden faults (modified from (Tugawin, et al., 2015)).

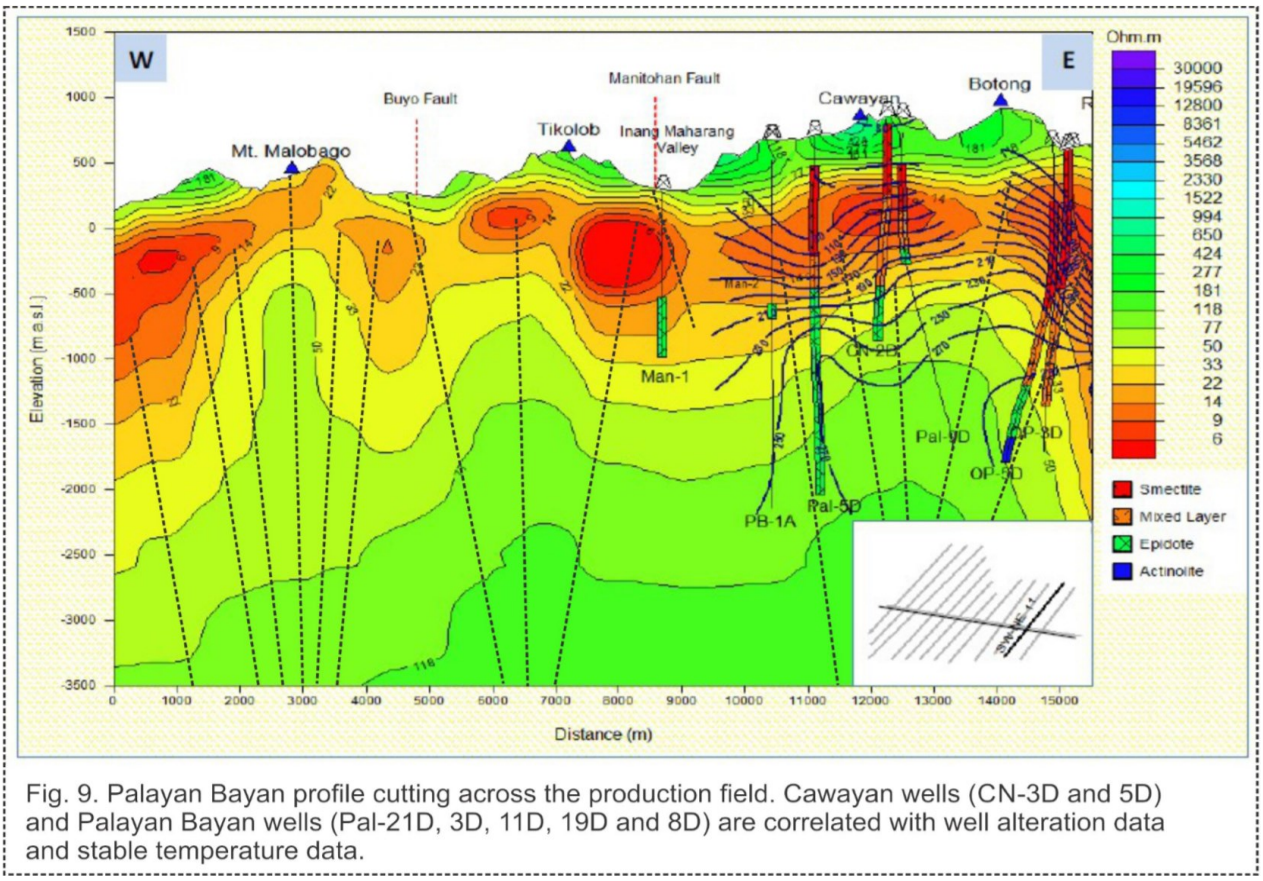

Figure 9: Palayan Bayan profile cutting across the production field showing proposed hidden faults (modified from (Tugawin, et al., 2015)).

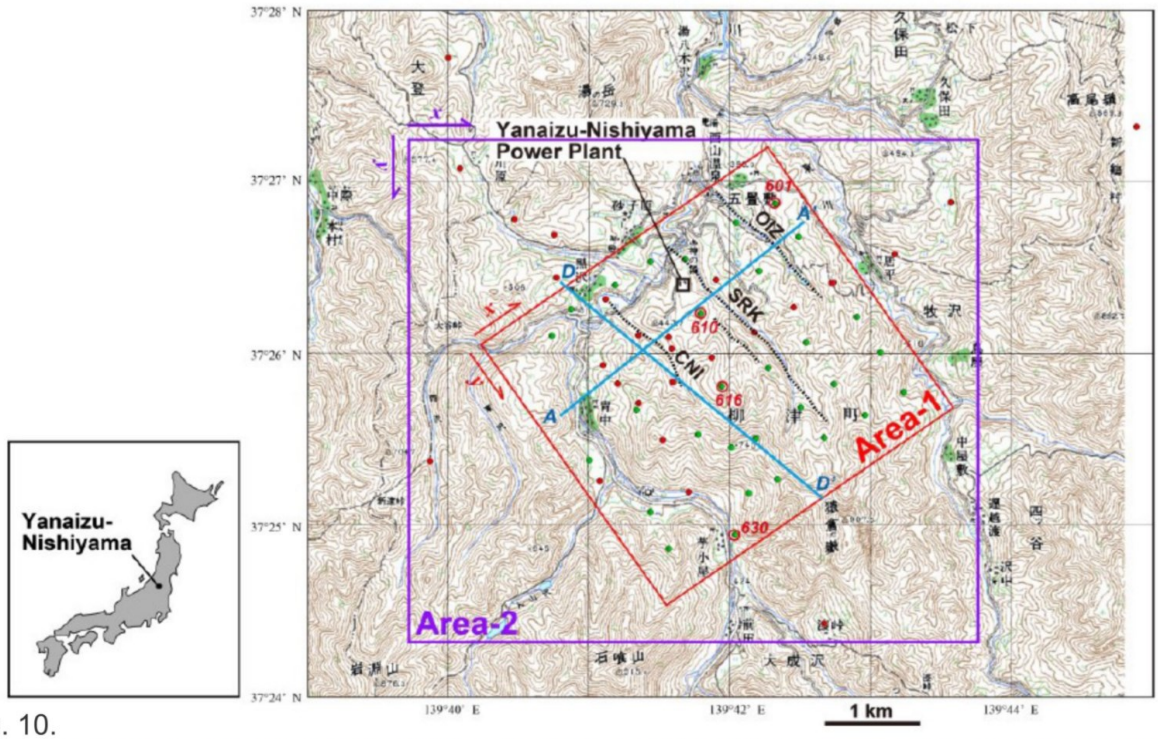

Fig. 10.

MT survey stations at the Yanaizu-Nishiyama geothermal field. Green and red dots are MT stations in 2010 and 2000/2001, respectively. Dashed lines are estimated faults; CNI: Chinoikezawa Fault, SRK: Sarukurazawa Fault, OIZ: Oizawa Fault. Red (Area-1) and purple (Area-2) rectangles are zones for 3D inversion. Cyan lines, AA' and DD', are profiles for comparison between resistivity model and drilling data.

Figure 10: Location of magnetotelluric (MT) survey stations and sections A-A' and D-D ' at the Yanaizu-Nishiyama Geothermal Field (Uchida et al., 2015).

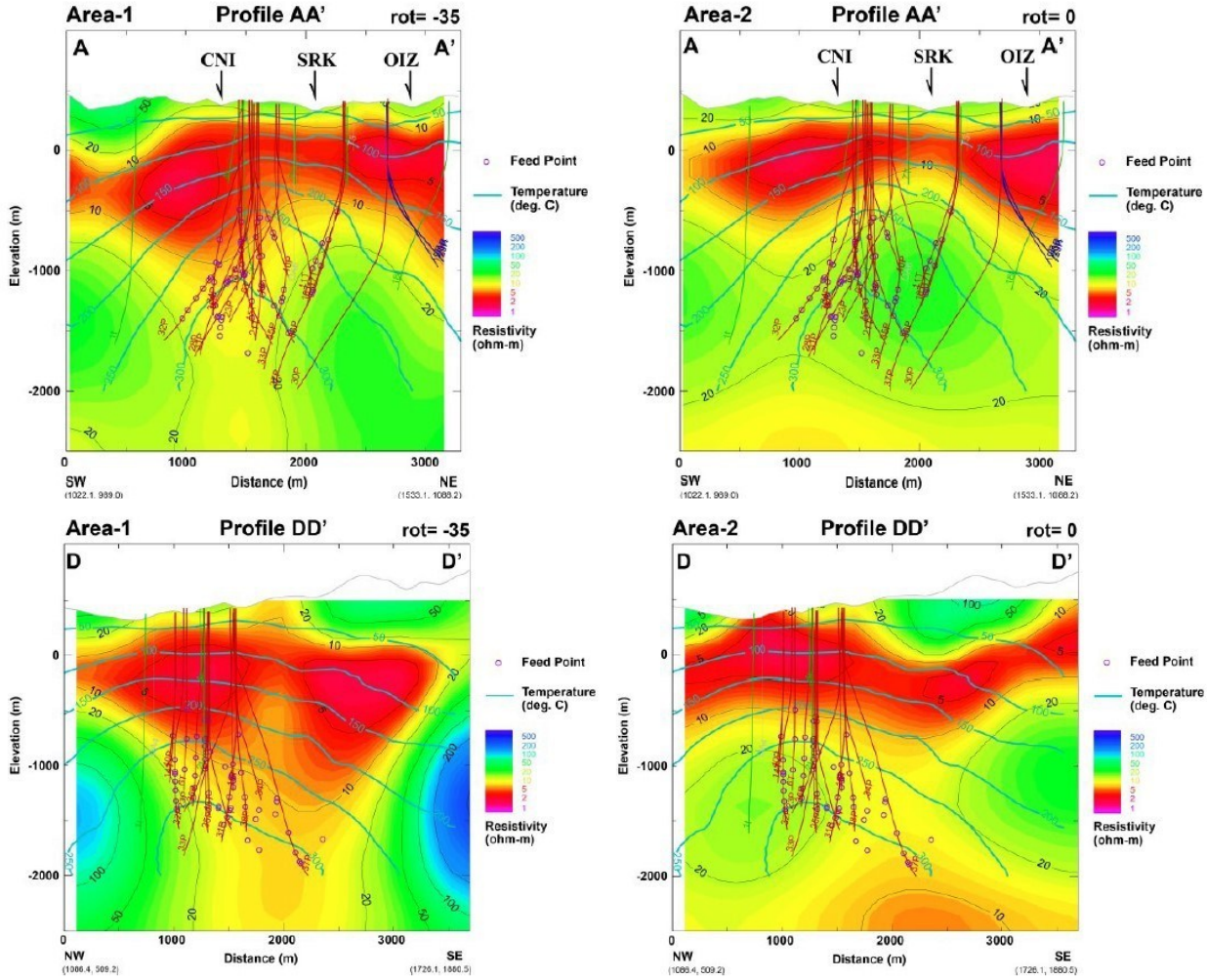

Figure 11: Resistivity distribution profiles with new proposed temperature curves and hidden faults at the Yanaizu-Nishiyama Geothermal Field (modified from (Uchida et al., 2015)).

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