CSAMT Geophysical Exploration in the Vicinity of the IMMSA Mine at Taxco

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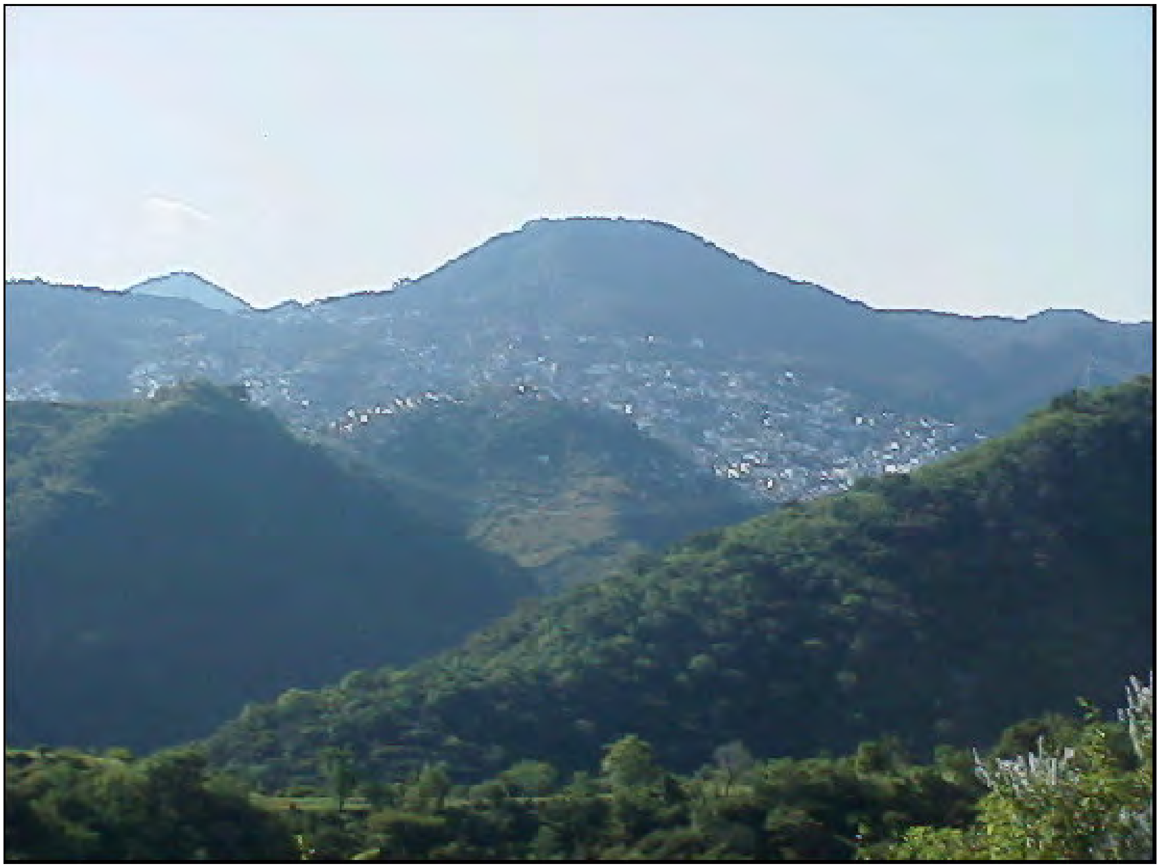

Figure 1. Taxco de Alarcon

A conductive CSAMT feature observed on the Sur de Guerrero Grid, near the town of Taxco in Guerrero, Mexico, was later confirmed as a discovery by this year's IMMSA drilling campaign. This feature is now called the Manto Esperanza Veija Vein. This paper compares the geology identified by IMMSA drilling with the CSAMT results modeled by Zonge International (Zonge).

Geologic information from the IMMSA drilling completed in 2000 and 2001 were provided by Sergio Garza Blackaller, Chief Exploration Geologist at Unidad Taxco, IMMSA's Taxco mine unit. Permission to show these drilling results was provided by Engineer Julian Chavira Quintana, IMMSA Director, and Engineer Oscar Lopez Pineda, the Taxco Manager.

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Sur de Guerrero CSAMT Survey

Sixty-five line kilometers of CSAMT data was collected south of the town of Taxco, Mexico in April through June 1999. The survey area can be seen in the foreground of Figure 1, and the town of Taxco in the distance. The terrain in the Taxco Mining District can be extremely steep, consisting of heavily vegetated mountains, cliffs, and deep canyons. In this situation, line preparation is crucial to the success of any electrical survey. For CSAMT surveys, the basic requirements are clear lines and walking access for the backpack CSAMT equipment. For the work at Sur de Guerrero, Zonge used two CSAMT systems with a single remote transmitter dipole. Burros were used to haul equipment and supplies along survey lines extending as much as 3000 meters. Up to five people were required to support each CSAMT system.

The Sur de Guerrero CSAMT Grid is located southeast of Taxco de Alarcon. It is the easternmost and largest of four CSAMT grids completed by Zonge in the Taxco Mining District (Figures 2a and 2b). Elevations on the Sur de Guerrero Grid range from 1400 to 1700 meters. An electric power substation is located near Line 3. Seven electric power lines radiate from this substation. One power line extends to the northeast crossing Lines 1 and 2. Other power lines extend northwest towards Taxco and south along the western edge of the Grid. Power lines may create severe problems collecting electromagnetic field data. Collecting data on the Sur de Guerrero Grid was a challenge.

The city of Taxco de Alarcon and the Taxco Mining District are located in the State of Guerrero, Mexico. Silver and zinc are important products of this state. Historically silver has been produced in this mining district dating back to the year 1534.

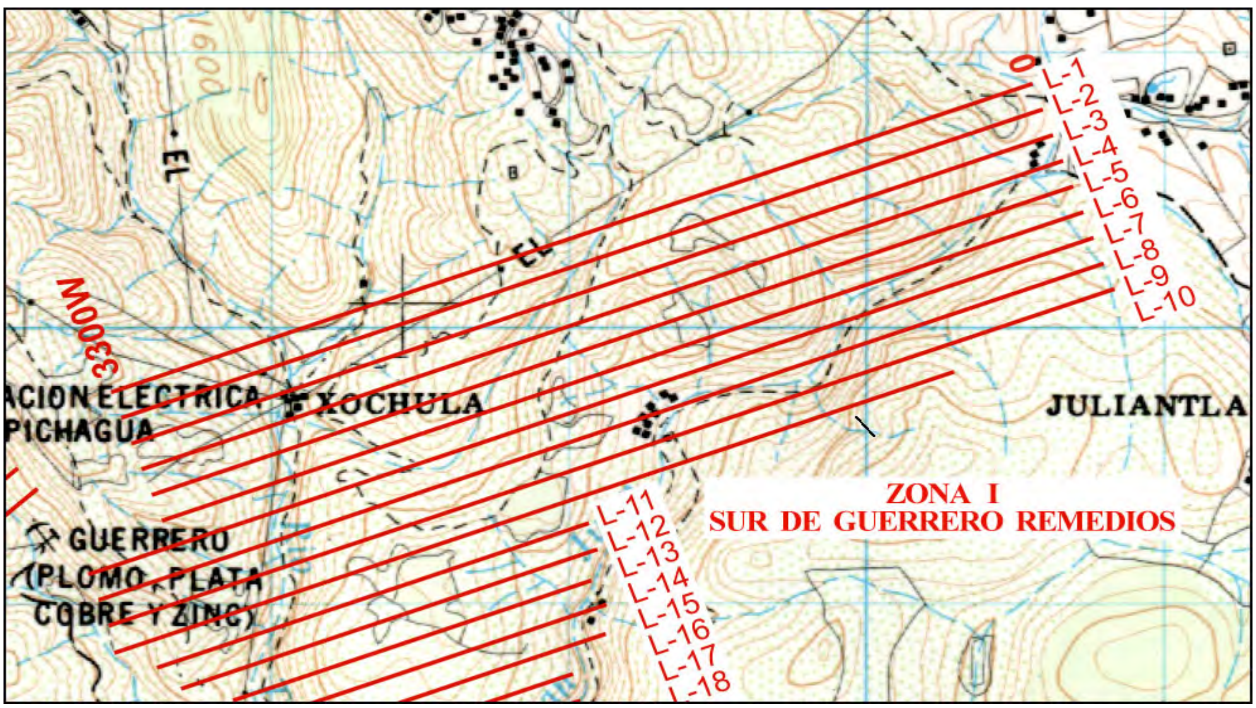

Figure 2a. Northeast trending CSAMT lines from the Sur de Guerrero Grid. The area of interest discussed in this paper includes Lines 1 through 10. Topographic contour interval is 20 meters.

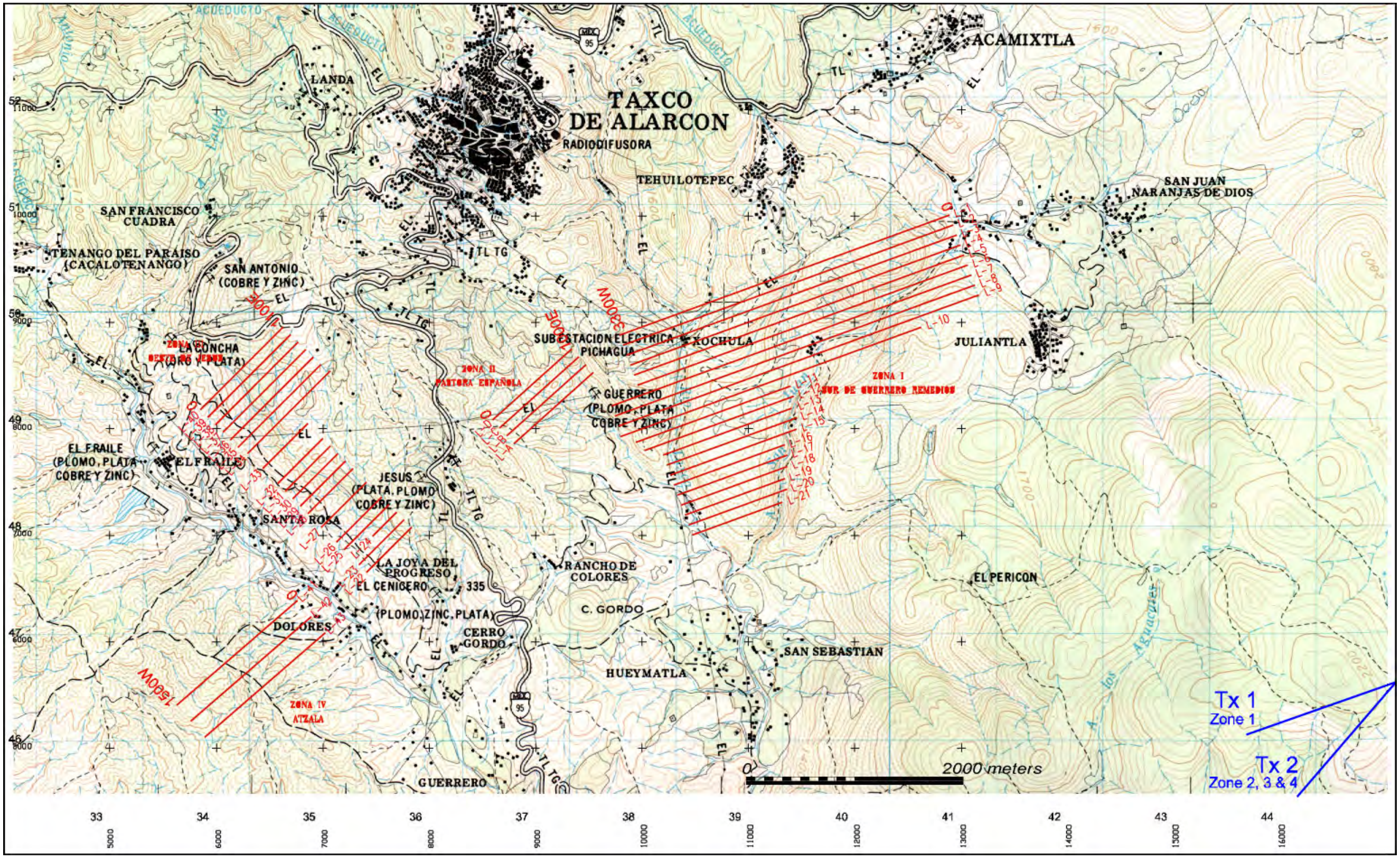

Figure 2b. Zonge CSAMT survey grids near Taxco de Alarcon. The survey lines are shown in orange. Transmitter locations are shown in blue. Regional topography is shown as well with contour interval 20 meters.

CSAMT for the Geologist

CSAMT refers to **C**ontrolled **S**ource **A**udio-frequency **M**agneto-**T**elluric. CSAMT is a frequency based electromagnetic sounding technique that uses a remote synchronous signal source. The electromagnetic signal is generated by a grounded dipole. Electric and magnetic field measurements are made at the grid and results are used to calculate resistivities.

Resistivity values relate to geology, and both resistive and conductive rocks are identified with this method. Values are determined by rock porosity, pore fluids and the presence of metallic sulfides. An anomalous conductive feature is observed on the modeled CSAMT data from the Zonge survey that is associated with metallic luster, pyrite-like mineralization. In contrast, the resistive rock is likely to be fresh un-mineralized limestone or schist, both of which are found in the grid area.

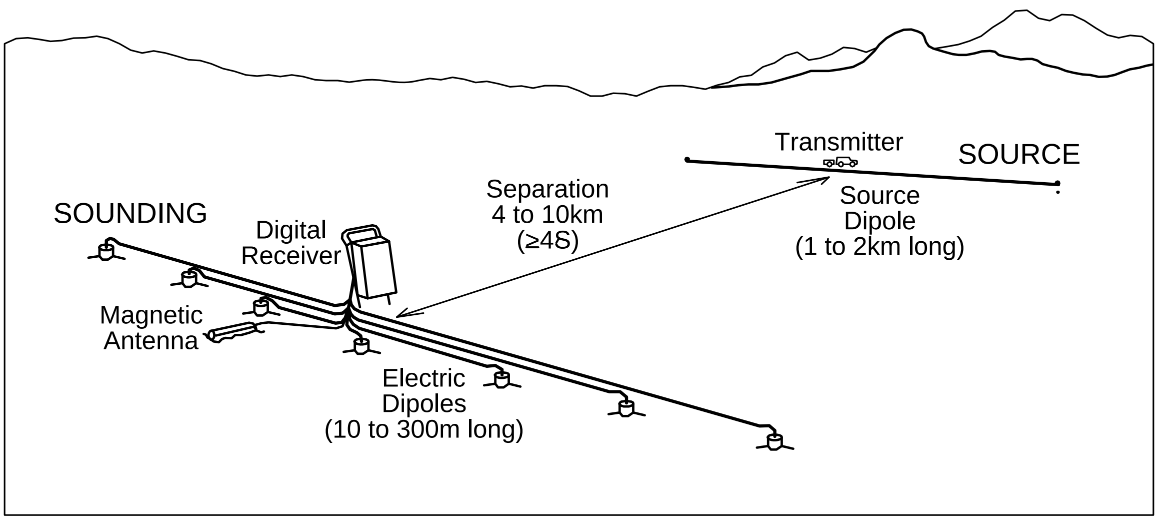

Figure 3. A typical CSAMT field setup.

Survey arrays with up to seven 25-meter dipoles were used to collect scalar electric field data at Sur de Guerrero. Six electric field dipoles are pictured in Figure 3. With seven 25-meter dipoles, each setup acquires data along a distance of 175 meters. Data were collected for twelve binary frequencies ranging from 4 Hz to 8192 Hz. The controlled source transmitter dipole was located 4 to 5 kilometers from the Sur de Guerrero Grid (Figure 2.) In total, 21 CSAMT survey lines were collected on this grid. This paper focuses on data from Lines 1 to 10 only, concentrating on an area of successful drilling by IMMSA.

An example of raw CSAMT data are shown in the form of pseudo-sections in Figure 4. Apparent Resistivities (called Cagniard Resistivities for CSAMT) are based on electric and magnetic field magnitudes. Impedance Phase is related to the change in Apparent Resistivity with respect to frequency. Stations numbers, which correspond to the along-line distance from one end, are plotted along the top axes. Frequencies are plotted on the vertical axes, increasing in the “up” direction. A frequency of 8192 Hz, for example, represents the shallowest depth imaged by modeling the data; 4 Hz represents the deepest depth imaged. Field sections (pseudo-sections) are difficult to visualize. Today, thanks to rapid and robust inversion techniques, these data are inverted to modeled depth sections in order to facilitate interpretation.

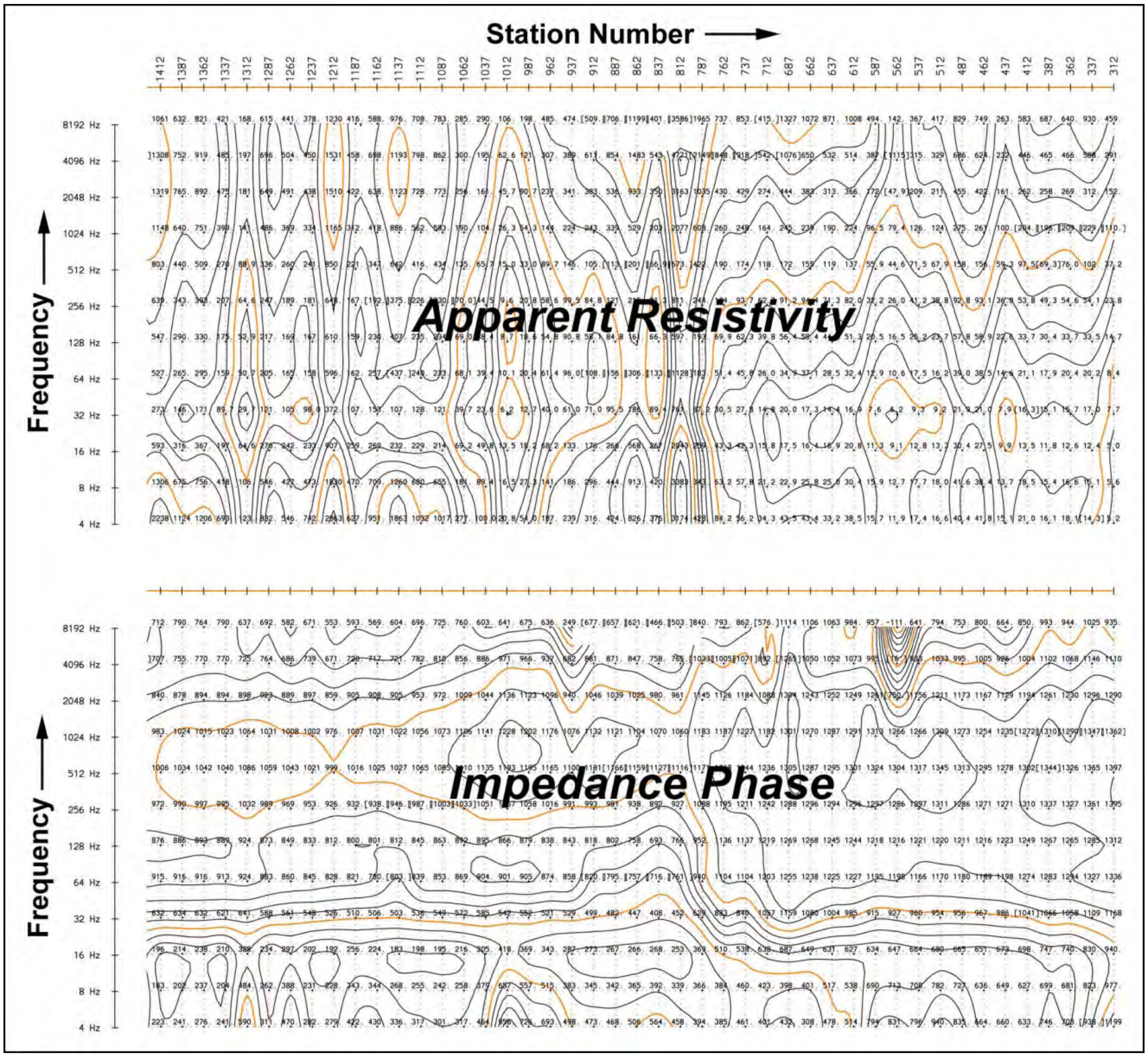

Figure 4. CSAMT Pseudo-sections.

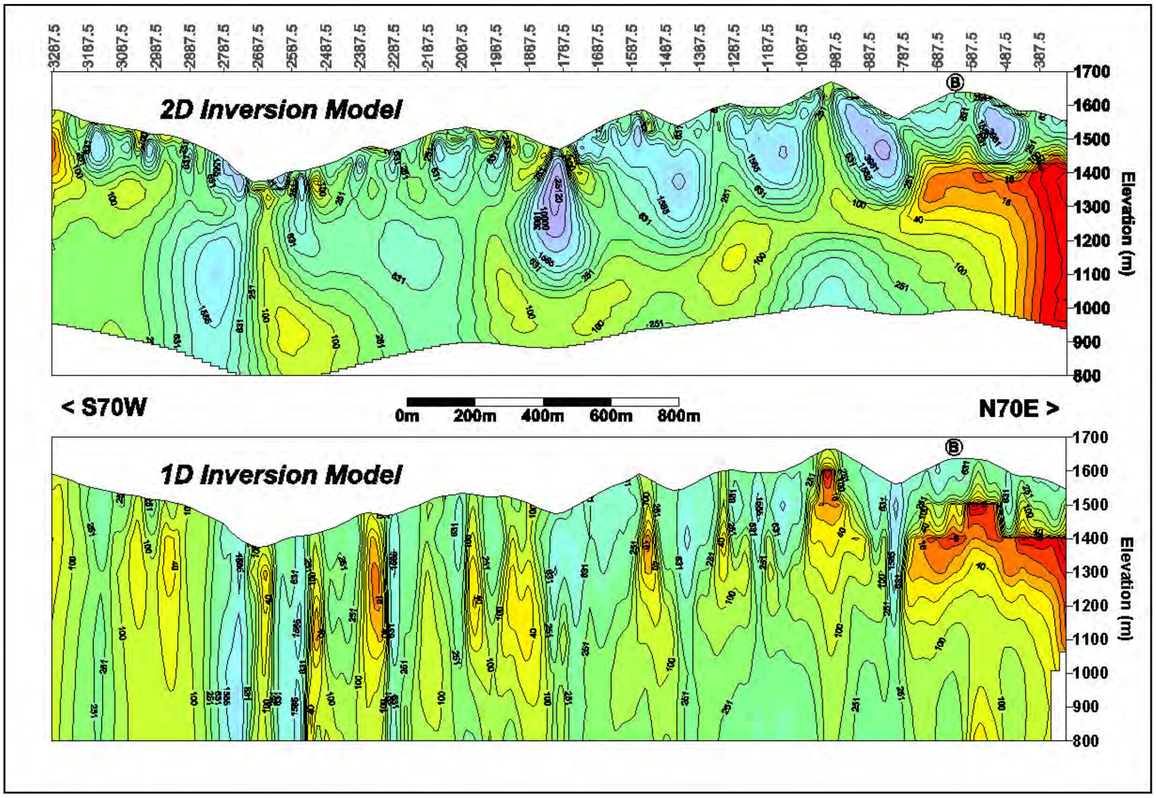

Figure 5. Line 2- Comparison of 1-D and 2-D inversion models.

Figure 5 shows some 1-D and 2-D inversion models of Line 2. The 1-D and 2-D descriptions refer to assumptions used in the modeled inversion of CSAMT field data. 1-D modeling is based on single stations where geology is assumed layered. 2-D modeling is based on multiple stations and assumes that high-angle contacts and "edges" define geology. Compared to field data, modeled resistivity and depth results are easier to understand and are related more directly to geology.

The 1-D inversion enhances thin high-angle features found at the surface. Deeper layered horizons are imaged best with the 2-D inversion. The 2-D inversion corrects modeled resistivities for topography. This is not possible with the 1-D inversion.

The "Red" shading identifies conductive geology. Resistive geology is identified by the "Blue" shading. The colors, grading from "Red" to "Blue", identify the range of resistivities observed on the modeled section. The modeled results for Line 2, as well as Lines 1 and 4, will be discussed in this paper.

Geology for the Geophysicist

A comprehensive study of the surface geology at Sur de Guerrero was made by Fowler in 1948 (Figure 6). The Zonge 1999 CSAMT survey grids completed at Taxco are shown on the figure as well. The Sur de Guerrero Grid is located east of the known vein groups (shown in dark green) that have provided much of the silver produced at Taxco during the last 60 years. Here, ore grade mineralization has been associated with a manto-like deposit.

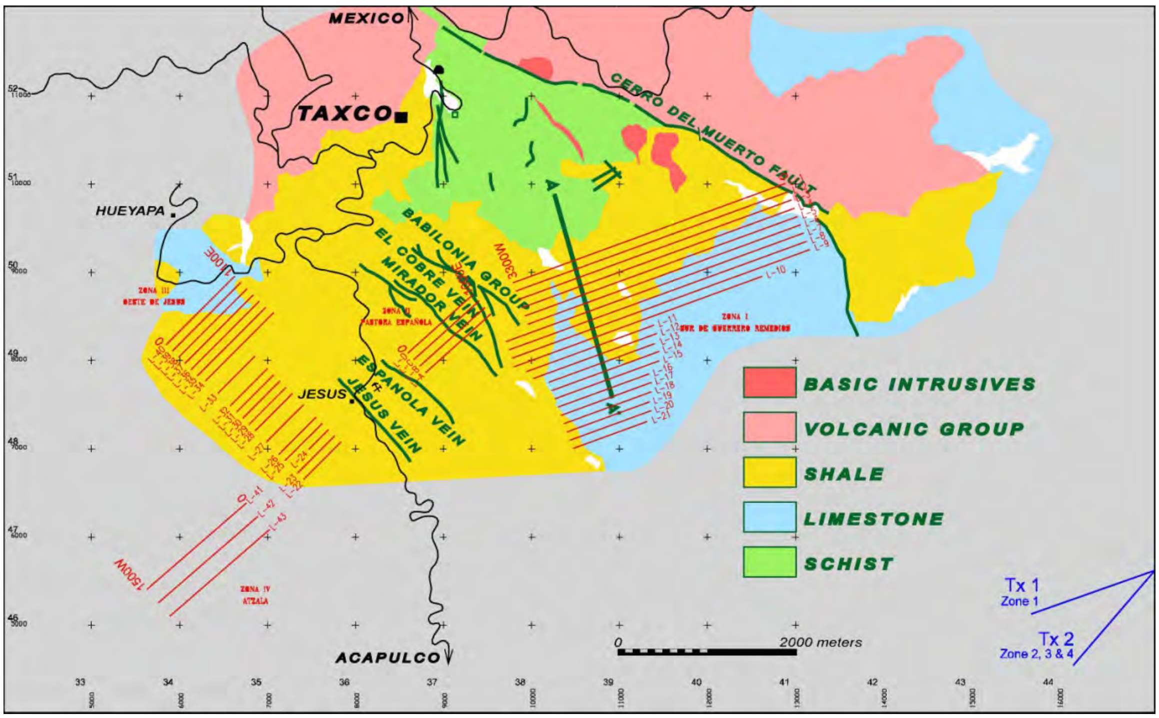

Figure 6. Taxco area surface geology (after M. G. Fowler, 1948).

The green shading identifies surface schist; yellow identifies Upper Cretaceous Shale, and blue identifies Lower Cretaceous Limestone. The dark red indicates basic intrusive rock. It is in the vicinity of the projection of this basic intrusive rock onto the Sur de Guerrero Grid that the Manto Esperanza Vieja Vein is located. Recent evaluations of drill hole logs from Line 4 suggest that Esperanza Vieja Vein may be a VMS (Volcanic Massive Sulfide) deposit.

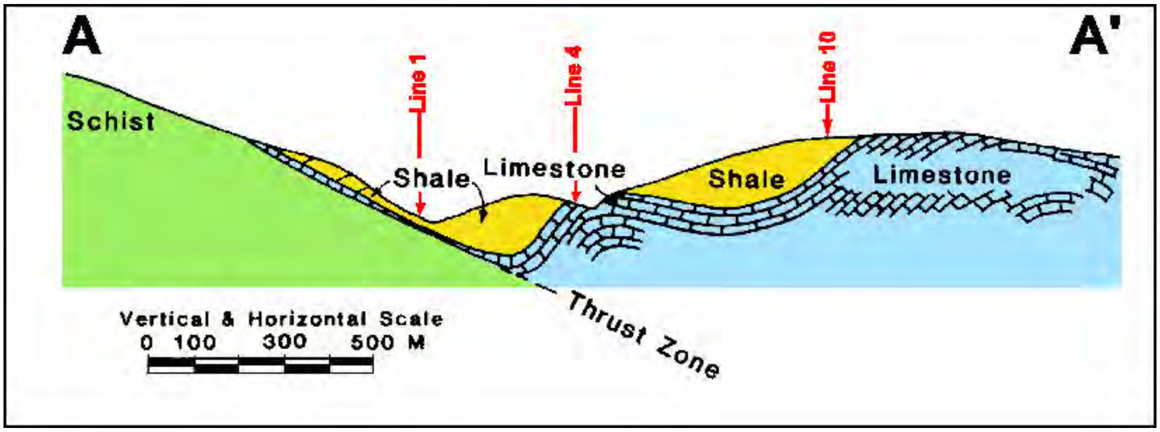

Figure 7. Geologic cross-section A-A' (after G. P. Salas, 1991).

The geologic cross-section **A – A',** Figure 7, shows details relating to the upper shale and lower limestone groups mapped by Salas (1991). The Manto Esperanza Viejo Vein is located northeast of **A– A'**.

The strike of **A – A'** is to the northwest, Figure 6; northwest is to the left on Figure 7. The limestone, colored blue, is clearly wedged between the basal schist and surface shale northwest of the Line 4 intercept. The Manto Esperanza Vieja Vein is located 1500 meters northeast of **A – A'** (into the page on Figure 7) within a thicker section of limestone. Figure 8 is a geologic cross section based on recent drilling results, centered on Drill Pad **B,** along CSAMT Line 1. It reveals similar details to the theoretical cross section, Figure 7 above.

The background geologic information presented in this talk are from work published years ago. It is interesting how well these early studies agree with today's CSAMT investigations. CSAMT extends the understanding of the geology to depth.

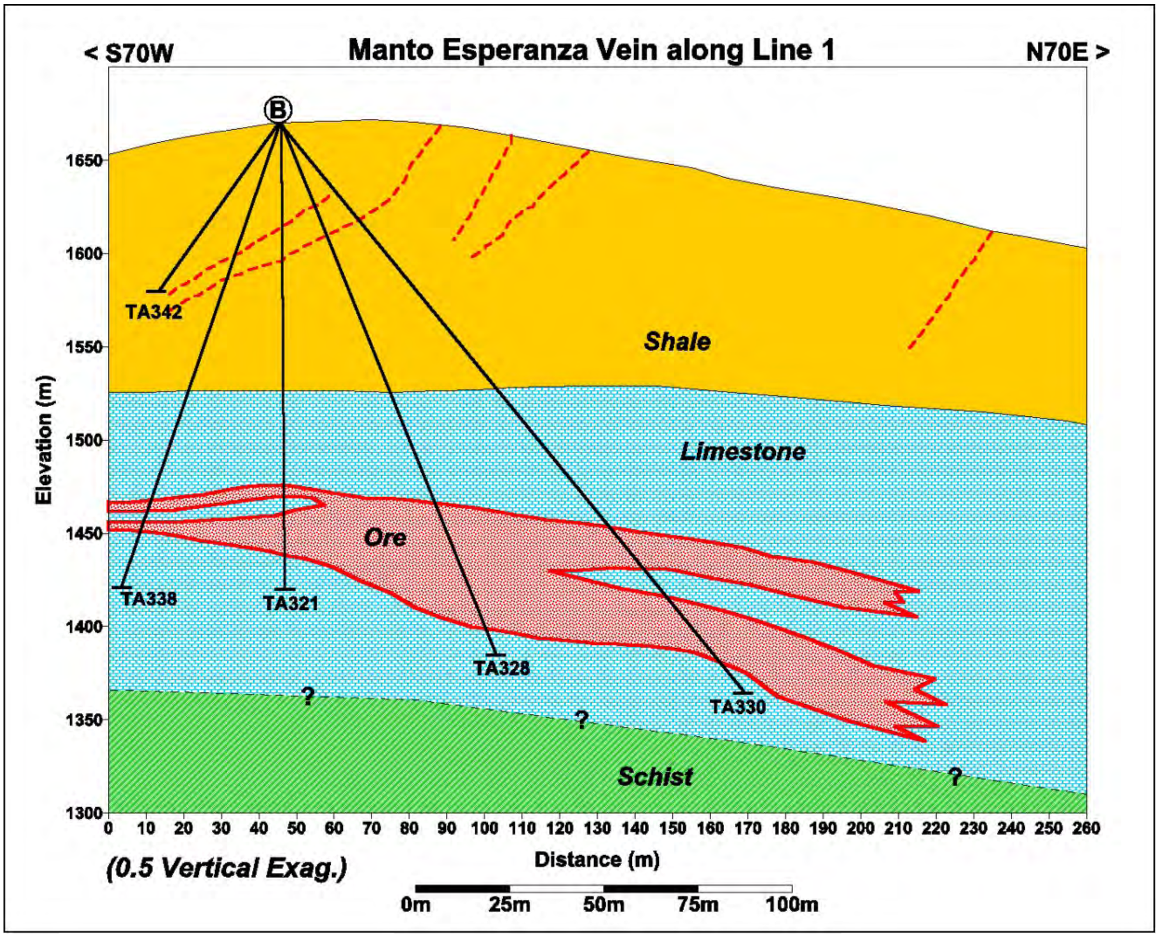

Figure 8.
Geologic cross-section along Line 1 showing ore-discovery drillholes.

Ore from the Manto Esperanza Vieja Vein is located within the limestone host along a 65 meter intercept. This manto system is flat lying, and several lens shaped zones are identified at depths of 200 meters. Based on diamond drilling completed to date by IMMSA, ore reserves of over 4 million tons are identified with typical grades of 40 grams per ton of silver, 0.2% lead and 7% zinc.

Note that several high-angle veinlets, generally with higher silver values, are identified in the vicinity of Drill Pad **B** (Figure 8). Such features are better seen on the 1-D modeled sections. The conductive ore horizon at 200 meters is best seen on the 2-D modeled sections.

Drilling Discovers Ore

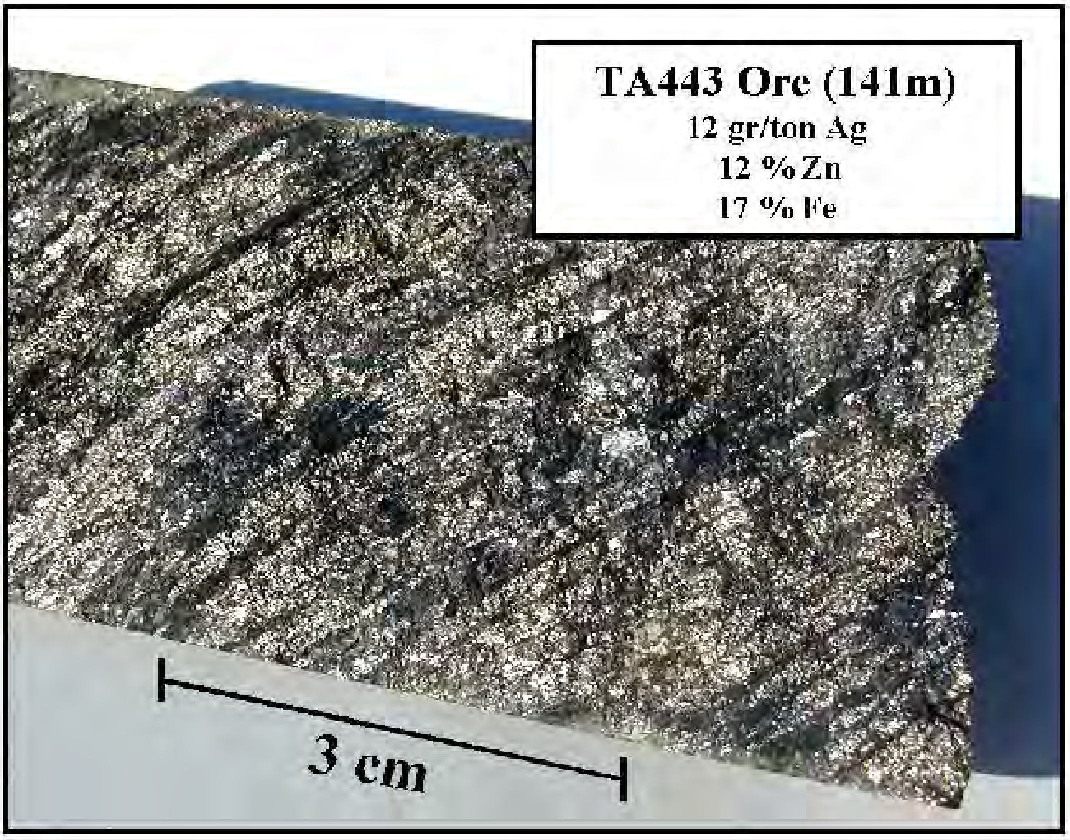

Figure 9. Taxco drillhole TA443 ore core.

The core sample shown in Figure 9 is identified as silver-zinc replacement ore from a 12 meter intercept at a depth of 140 meters on drill hole TA-443. TA-443 is located near Line 4 on Drill Pad **C**. The principal mineralization is identified as pyrite, pyrrhotite and sphalerite. Pyrite and pyrrhotite are very conductive. This makes this sample highly conductive even though this drill core is zinc-rich. Elsewhere in the ore zone, along very thin laminates, up to 500 grams per ton silver has been identified.

Figures 10 and 11 are the 1-D and 2-D modeled plan-view sections at topographically draped depths of 100 and 200 meters. Both sets of models clearly identify the conductive zone associated with ore (dashed circled area on Figures 10 and 11).

The 1-D modeled images are dominated by high-angle near-surface contacts. 1-D modeled depths are not particularly accurate and features at depth appear distorted. The 1-D modeled inversion assumes that geology is layered at each station and modeled resistivities are not corrected for topography. Therefore resistivities can be expected to be exaggerated in these 1-D modeled plan-view sections.

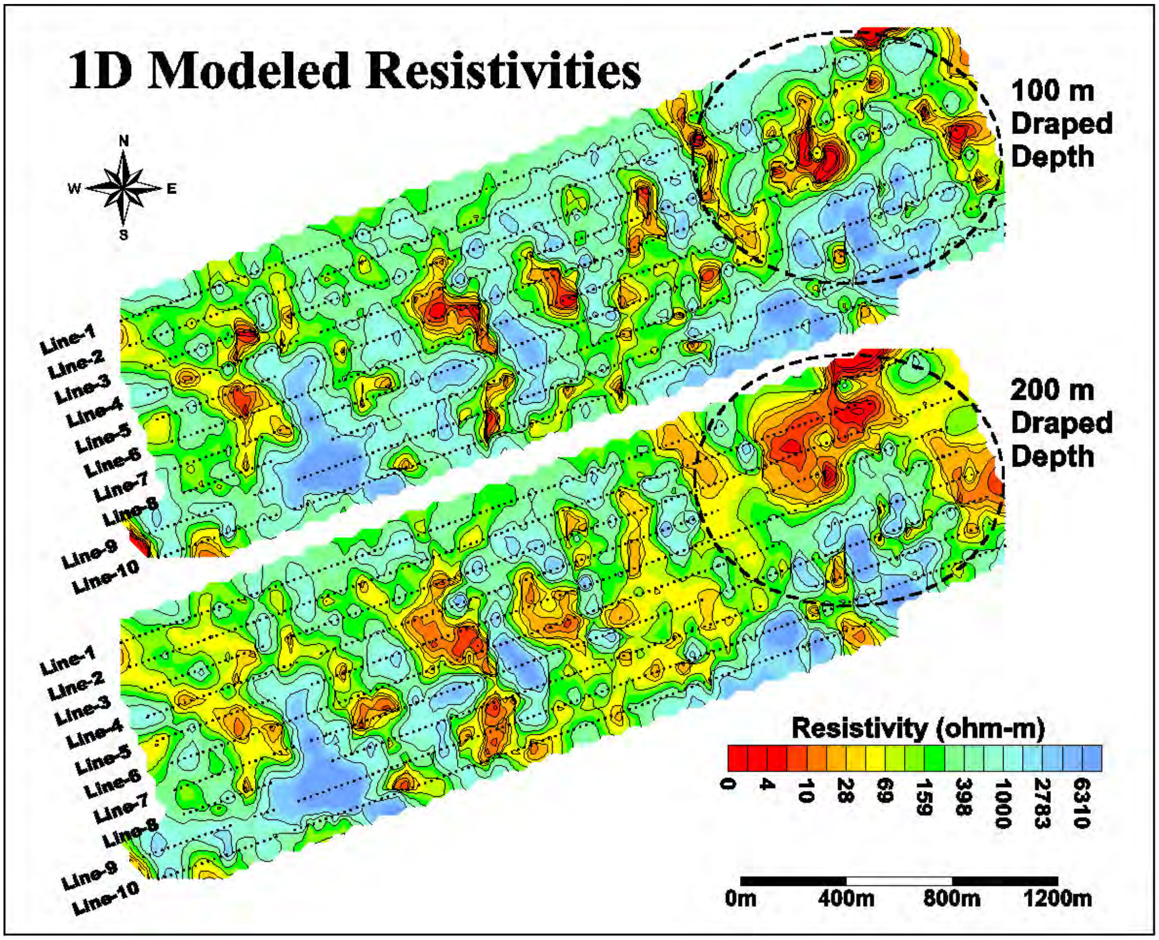

Figure 10.
1D modeled resistivities at draped depths of 100 m and 200 m.

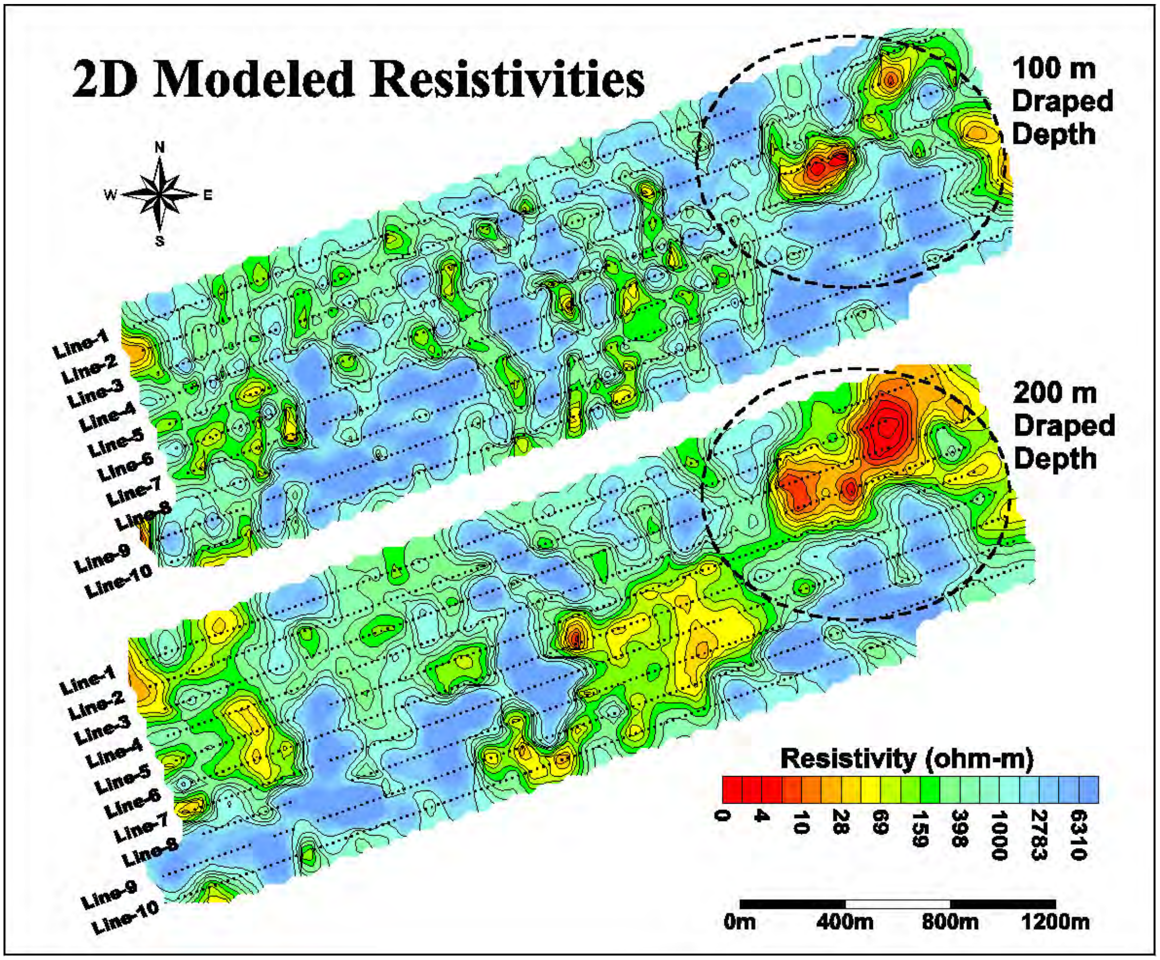

Figure 11.
2D modeled resistivities at draped depths of 100 m and 200 m.

The 2-D modeled images (Figure 11) minimize the influence of near-surface contacts on deeper features. Note that the imaged features are smoother at depth. 2-D models also correct resistivities for topographic effects. This plan-view section clearly identifies deeper conductive and resistive features. The 2-D plan-view plot at a depth of 200 meters clearly identifies the conductive ore.

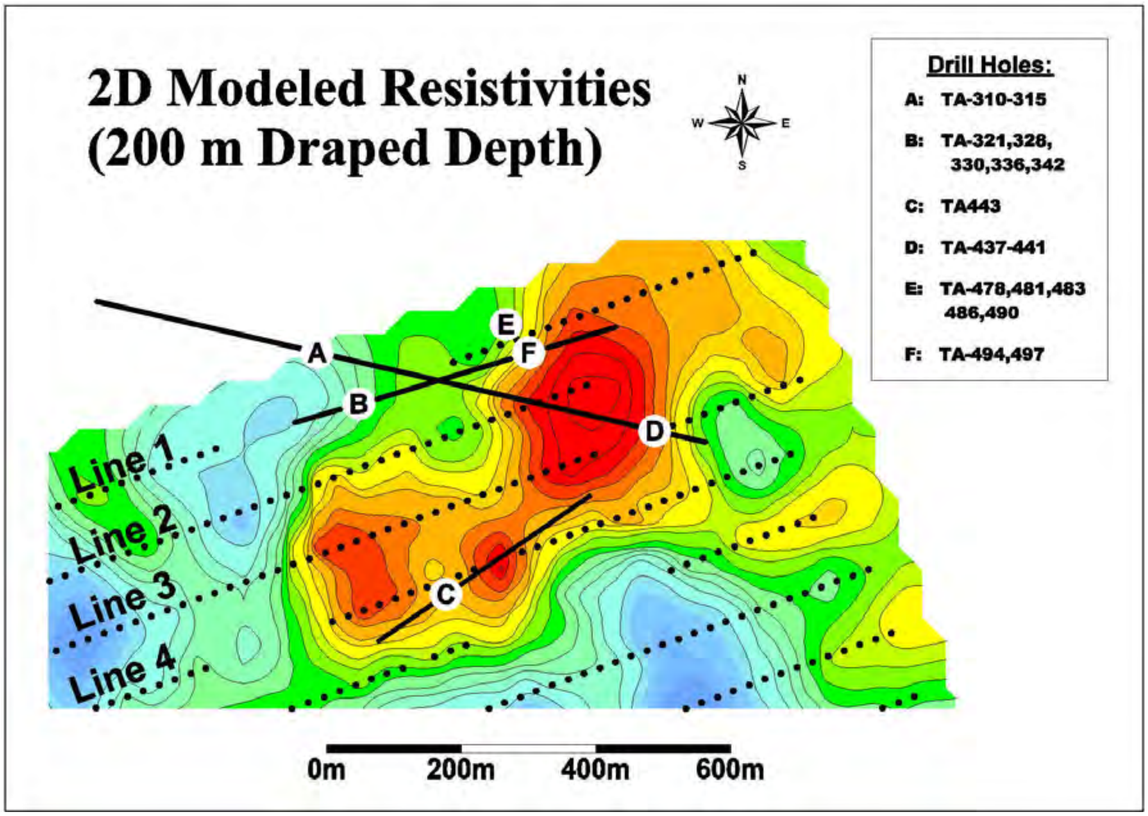

Figure 12. Map showing location of Drill Pad Sites A, B, C, D, E and F; geologic section lines, and the 2-D modeled resistivity anomaly at 200 m depth from Zonge CSAMT data.

Figure 12 is an enlarged section of the previous 2-D plan-view section at a depth of 200 meters. Shown are the locations of Drill Pad Sites **A**, **B**, **C, D, E** and **F** discussed in this report. Several drill holes extend from each pad; listed are the drill holes selected for this case history study. The drill core sample shown in this report comes from a depth of 140 meters on TA-443.

Figure 13 shows geology along Line 1 identified by drill pads **B** and **F**. CSAMT along this section is shown above in Figure 14, with the ore zone projected onto the 2-D vertical depth model. The gap in coverage is private property that was off limits to the Zonge CSAMT crew at the time of the survey. (Discovery hole geology is shown on Figure 8.) Results shown from Drill Pad **F** are from drilling completed in 2001. Drilling results from Drill Pad **E** correlate well with **F**, but the **BF** projection more closely parallels Line 1.

The gap on the Line 1 coverage is unfortunate, but this still makes a great "picture" showing a well-defined anomalous target with ore-grade mineralization. On surveys, often gaps in data coverage are unavoidable. The CSAMT survey crew may encounter cliffs, rivers, or steep canyons, as well as the occasional un-cooperative landowner. While unfortunate, in most situations these short gaps do not compromise interpretation.

Drilling results and the 2-D modeled CSAMT results match extremely well and define an anomalous zone. CSAMT clearly extends the conductive zone identified by drilling. CSAMT is a volumetric measurement and not defined along a single line as in drilling.

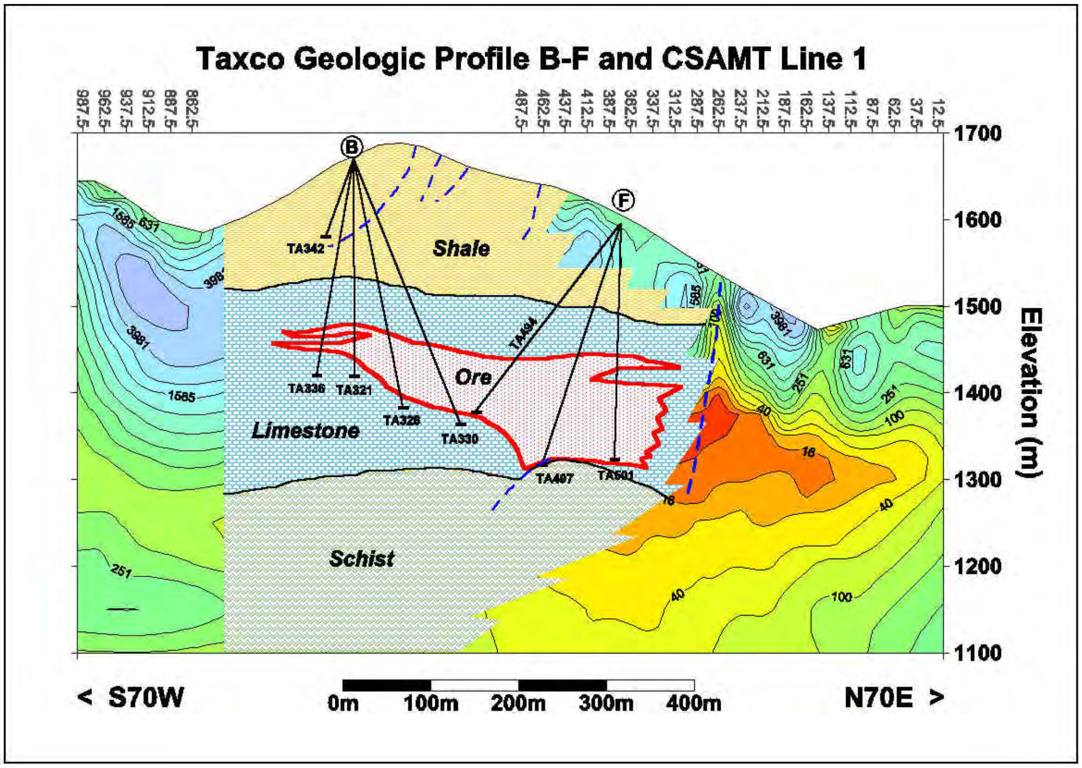

Figure 13. Geology identified by Drill Pads B and F on Taxco Line 1.

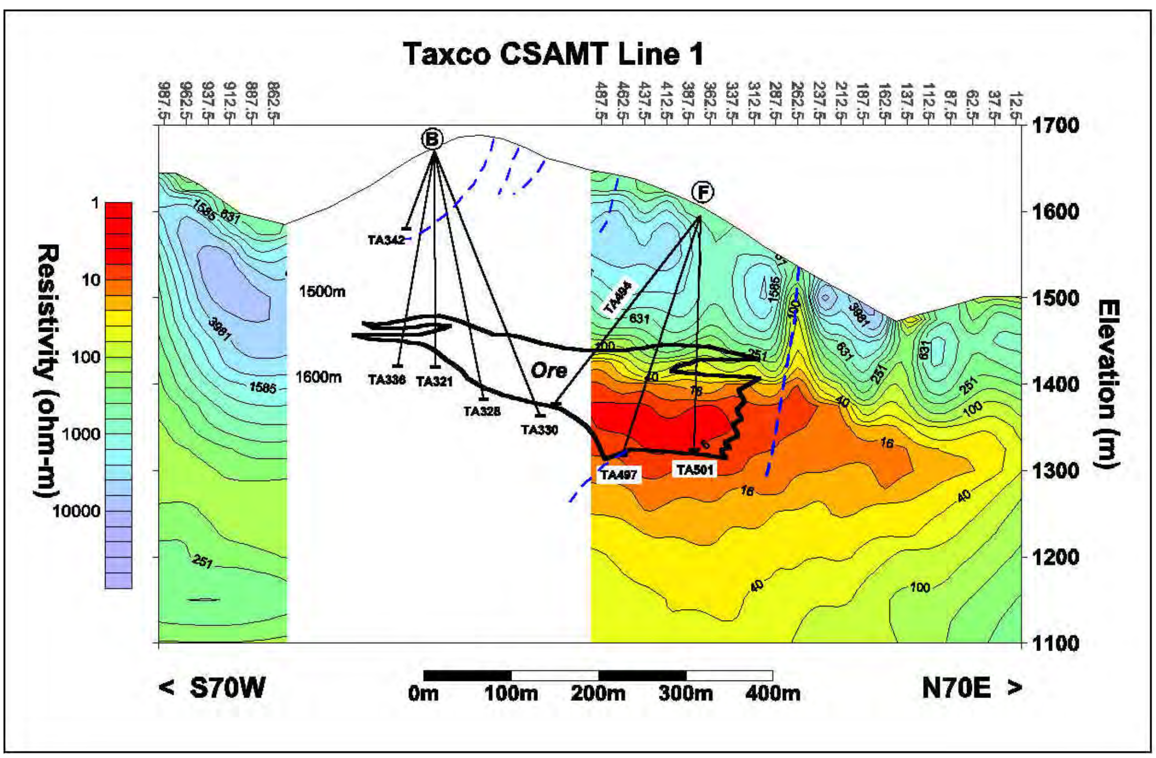

Figure 14. Geology with 2D modeled resistivities along Taxco Line 1.

CSAMT Line 2 is offset 100 meters southeast of Line 1 (Figure 12) where it provides continuous coverage across the Line 1 “gap”. Figure 14 above illustrates the drilling-derived geologic cross-section, as well as the resistivity model on Line 2. The geologic section intersects Line 2 near station 388. Drill Pad **D** provides geologic control close to Line 3. Drill Pads **A, B** and **F** are located towards the northwest closer to Line 1. The geologic cross section crosses Line 2 just southwest of **F**.

The conductive ore horizon is clearly identified by drilling results based on these four drill pads. Other drill holes suggest that the limestone horizon thins towards the west. The comparison of the 1-D and 2-D modeled sections clearly shows a deep conductive zone northeast of station 413. Drilling results indicate that the conductive ore is in direct contact with an extremely resistive basal schist, with evidence of several high-angle veinlets.

The individual 1-D and 2-D modeled conductive cross sections certainly change across Lines 2, 3 and 4. Never-the-less results suggest good line-to-line continuity of a conductive manto-like feature. In this section of the Sur de Guerrero Grid, the survey lines cross several cliffs that suggest structure. The deep conductive response imaged northeast of station 413 may be an artifact produced by high-contrast off-line conductive contacts. Viewing both the 1-D and 2-D modeled sections provide important clues useful in interpretation.

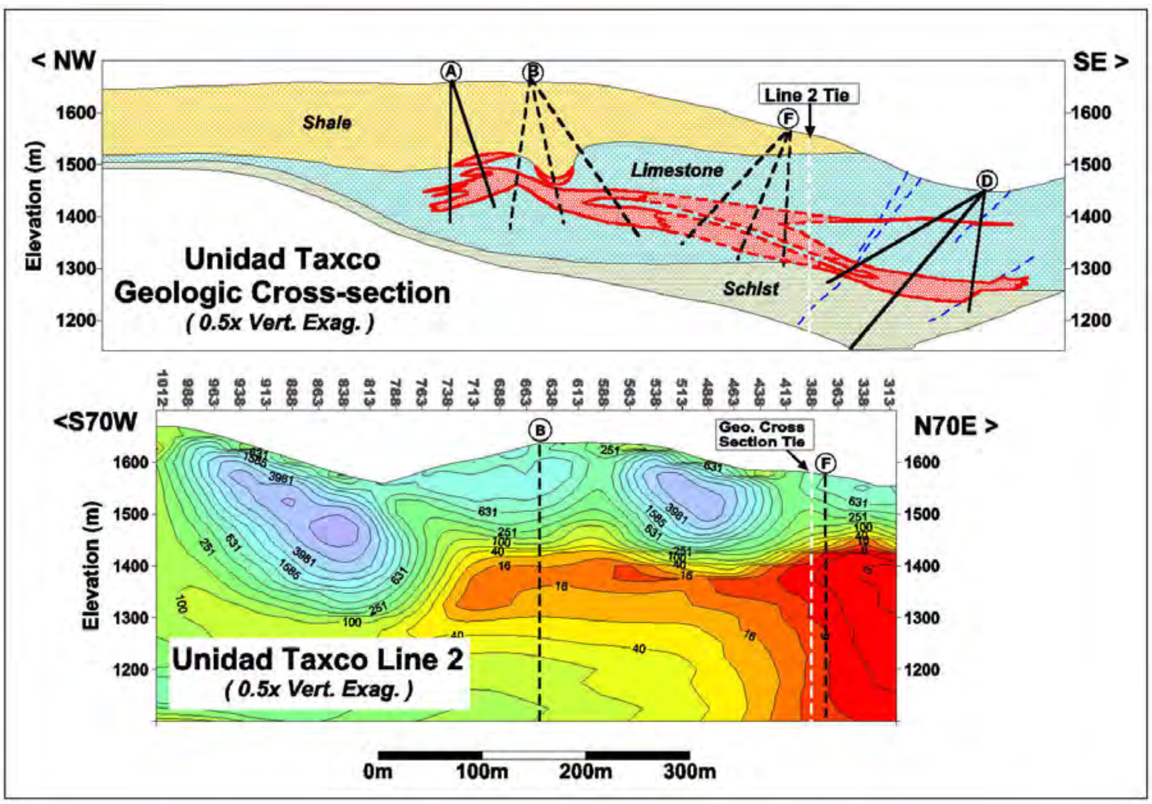

Figure 15. 2D modeled resistivities along Taxco Line 2 and intersecting geologic cross-section.

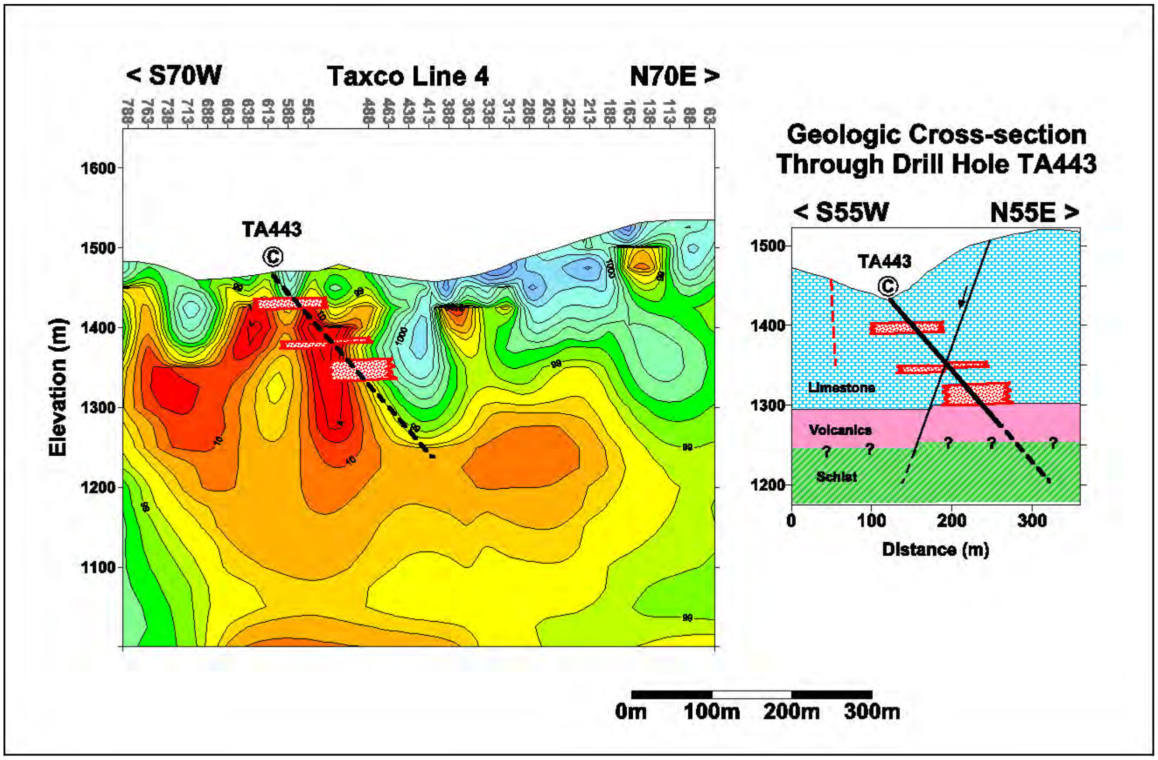

Figure 16. 2D modeled resistivities along Taxco Line 4 and geologic cross-section through drillsite C (TA443 ore discovery).

The actual drill core shown in Figure 9 comes from drill hole TA-443, located on Drill Pad **C** (slightly off Line 4). One significant difference between the geology crossed by Line 2 (Figure 15) and Line 4 (Figure 16) is the presence of basal volcanic rock, rather than the basal schist observed on Lines 2 and 3. The drill core pictured in this report comes from a depth of 140 meters from the ore zone in direct contact with the volcanic rock.

The 2-D plan-view at a depth of 200 meters (Figure 12) clearly shows that Line 4 defines the edge of a much larger conductive horizon.

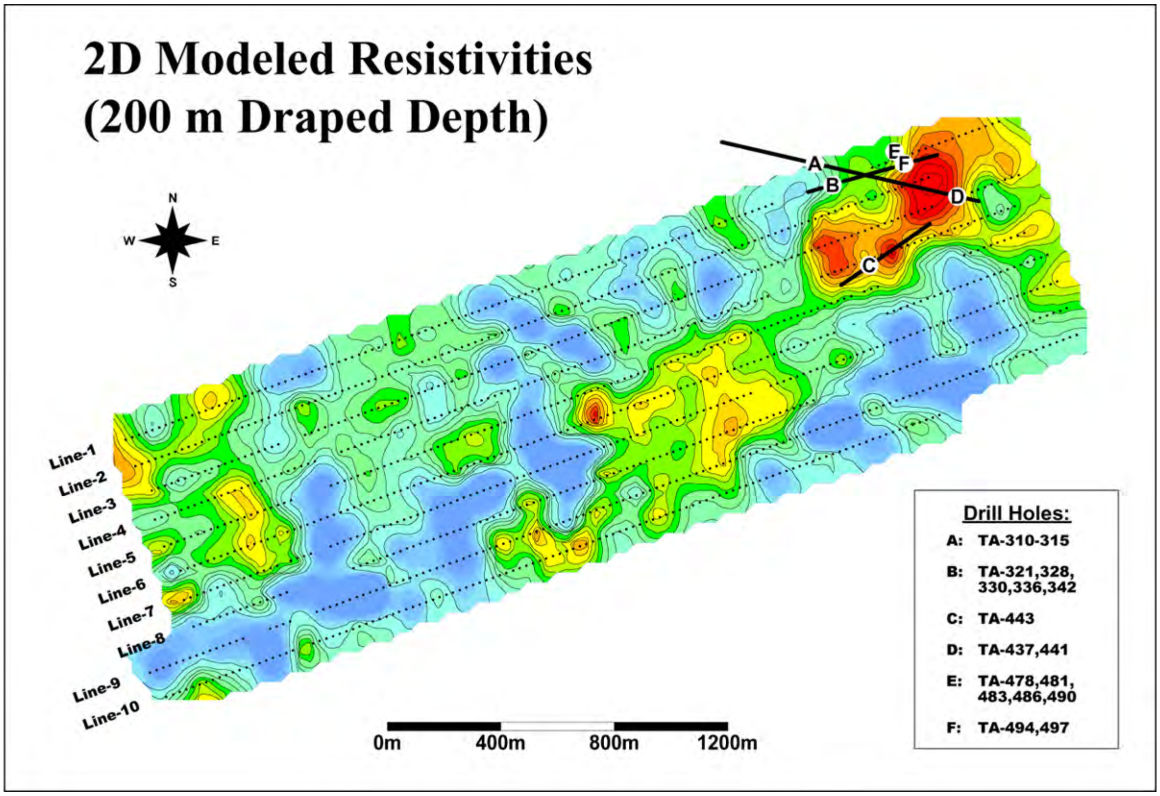

Figure 17. 2D modeled resistivities on northern ten lines of Sur de Guerrero Grid.

Conclusion

The Sur de Guerrero CSAMT survey has defined several minor linear trends. However the horizontal conductive zone occupied by the Manto Esperanza Vieja Vein is clearly defined along a band near depths of 200 meters (Figure 17).

While flat laying conductors could be located using geophysical techniques such TEM (Transient ElectroMagnetic) or IP/Resistivity, none of these applications have the ability to provide this modeled detail in the rough mountainous terrain found at Taxco. At Sur de Guerrero, CSAMT has provided modeled detail useful in geologic mapping, and CSAMT has identified economic ore grade mineralization. These are both important geophysical survey objectives.