Vector IP (VIP)
A Reconnaissance Approach

Introduction: During the past two decades the costs of most electrical geophysical surveys have decreased substantially, due to the implementation of digital receivers with multiple input channels. The costs of data processing, modeling and the generation of color sections and maps have also decreased considerably with dramatic improvements in low cost personal computers along with the latest relatively high-speed color plotters. The net result of improvements in digital data collection and processing has been a reduction in the cost-per-station by a factor of 10 or more for some methods in the face of increased daily costs for providing geophysical services.

One problem has been how to apply advances in collecting IP to approaches more suitable for reconnaissance coverage. Here there are two factors at play: first has been the use of data-intense IP procedures required for imaging results, and second has been the time required to stack and average IP data. Commonly used IP arrays, such as dipole-dipole and pole-dipole, are regularly used to collect data sets for depth imaging. While these digital images provide detailed features difficult to imagine twenty years ago, these data-intense procedures are not suitable for reconnaissance program budgets. Production time “bottlenecks”, due to the fixed amount of time required to gather reliable frequency domain IP data at 0.125 Hz (equivalent in time to 8 seconds/cycle for time-domain IP), have been somewhat relieved by using multiple channel receivers such as the Zonge GDP-32^{II}. Increased productivity, made possible through use of multiple channel instrumentation, has helped control cost increases for IP and Resistivity surveys in recent years. On a cost-per-station basis, adjusted costs for dipole-dipole IP surveys may have actually decreased. In discussing reconnaissance applications, the real problems are logistical and the inability to effectively use multiple channel receivers where data are collected at widely separated stations.

One approach providing cost effective IP coverage for today’s reconnaissance IP surveys is based on the Reconnaissance IP technique (otherwise referred to as RIP) developed by Kennecott Exploration in the 1970’s. This approach is able to cover large survey areas quickly with minimal logistical support. Zonge has taken RIP into the digital age with Vector array IP (VIP). Using harmonic tools, complex resistivity data collected in the VIP mode are presented as vector array IP. With multiple transmitter sites, this VIP data can be converted to Tensor array IP (TIP). The GDP-32^{II} receiver, combined with a 10 or 30 kilowatt GGT-series transmitter, provide a highly advanced geophysical system capable of measuring IP for these reconnaissance type surveys.

In the following discussion, we will look at the original Kennecott "Wagon Wheel" vector system and follow its development and modification to the present day. We will present a few model results for surveys over one and two polarizable bodies using both vector and tensor setups. Then we will present vector IP field results from the North Silver Bell porphyry copper deposit and from a prospect in Chile, and tensor IP results over a prospect in Arizona.

The Basic VIP Setup: Kennecott began using the “Wagon Wheel” reconnaissance IP array around 1971. The original development was based on a model to detect a polarizable body (typically a porphyry copper deposit) one mile on a side, buried 1000 ft below the surface with a 4000 ft depth extent, and occurring within a one-mile radius of the transmitter bipole. The transmitter bipole was about 2000 ft long and the perpendicular receiver dipoles were 500 ft long and oriented in an "L" shape as shown in Figure 1. Logistically, the L-shape array is easier to manage in the field than a crossed array. Both IP and resistivity are measured in this survey.

The IP data were plotted along the spokes of the wheel and it was originally assumed that the appropriate plot point for the IP response was at the midpoint between the center of the transmitter bipole and the receiver location. Field results have shown that VIP data should be referenced from the location of the receiver site.

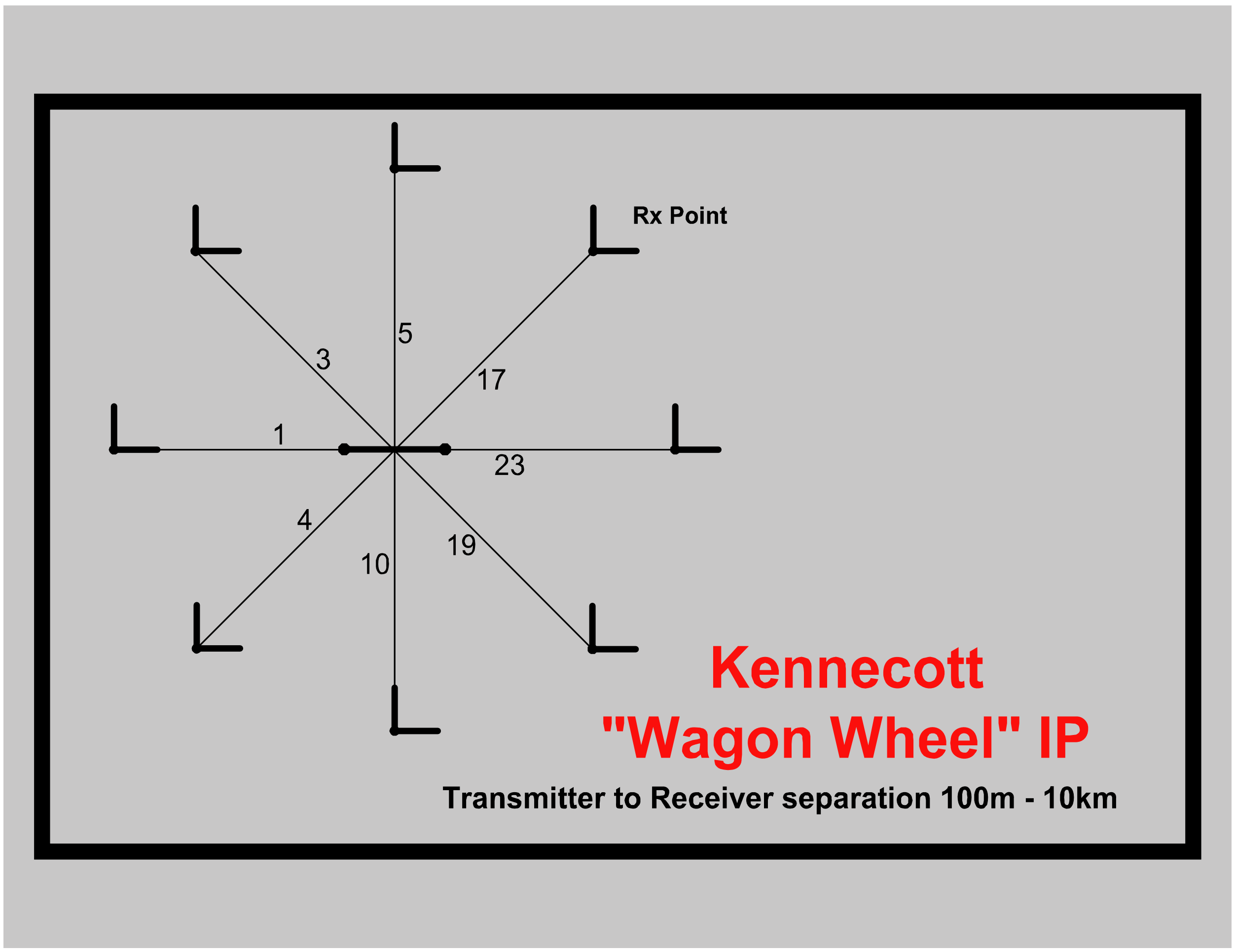

Figure 1: “WagonWheel” VIP

At a later date, a modification to the "Wagon Wheel" array was found to provide useful coverage over an extended area. This variation is more properly called the "Checker Board" array, as shown on Figure 2. As an example, with the one-kilometer grid as shown, a perpendicular pair of receiver dipoles (the "L" shaped vector array) are positioned on alternating one kilometer squares. The plot points for resistivity and IP for this array would be located at each receiver site. With this checkerboard pattern, all receiver sites are located within 3 kilometers of each transmitter electrode setup. In this example, twenty vector IP sites are collected with one transmitter electrode setup that covers a 5 x 7 km area.

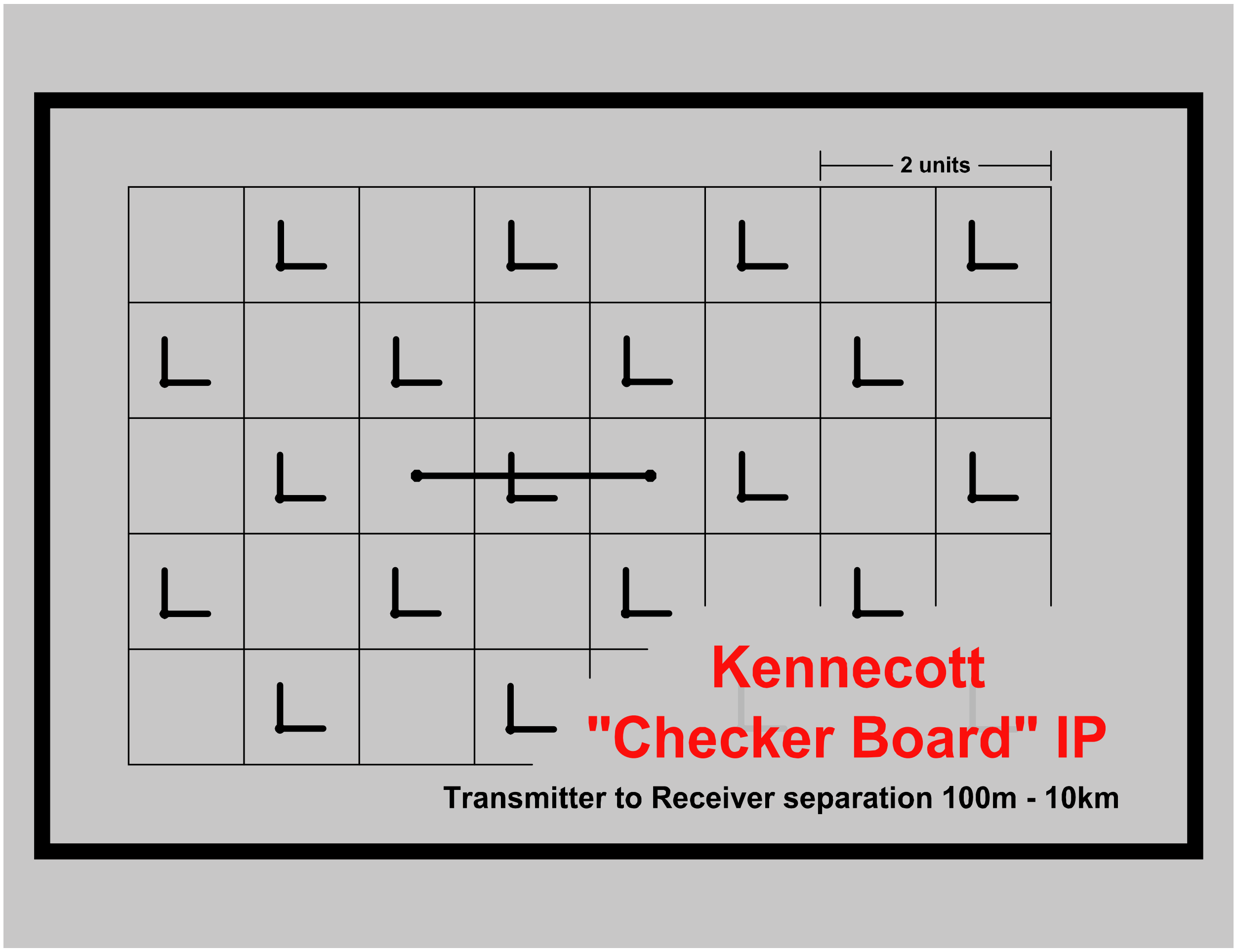

Figure 2: "Checker Board" VIP

Variations of the "Checker Board" array can increase or decrease the density at which VIP data are collected. The "L" shaped receiver array can be rotated to improve signal levels produced by the bipole electric field. The length and orientation of the transmitting bipole can be varied to suit specific situations. Zonge typically uses an array similar to Figure 2, where a 4000 foot-long transmitter bipole is placed off to the side of an area to be surveyed. Orthogonal receiver arrays are used with 500-foot dipoles to measure Ex and Ey (electric field components) at selected locations within the prospect area.

Receiver / Transmitter separations up to 5 miles have been used with the VIP receiver array oriented so that neither Ex or Ey has a null response (see Figure 3). The depth of investigation for this logistical plan is expected to extend well past 1000 feet. Coordinates of each site are obtained with a GPS receiver for accurate calculation of apparent resistivities. Critical to the success of the VIP technique is the ability to determine the actual vector IP ground response from measurements collected at each receiver site.

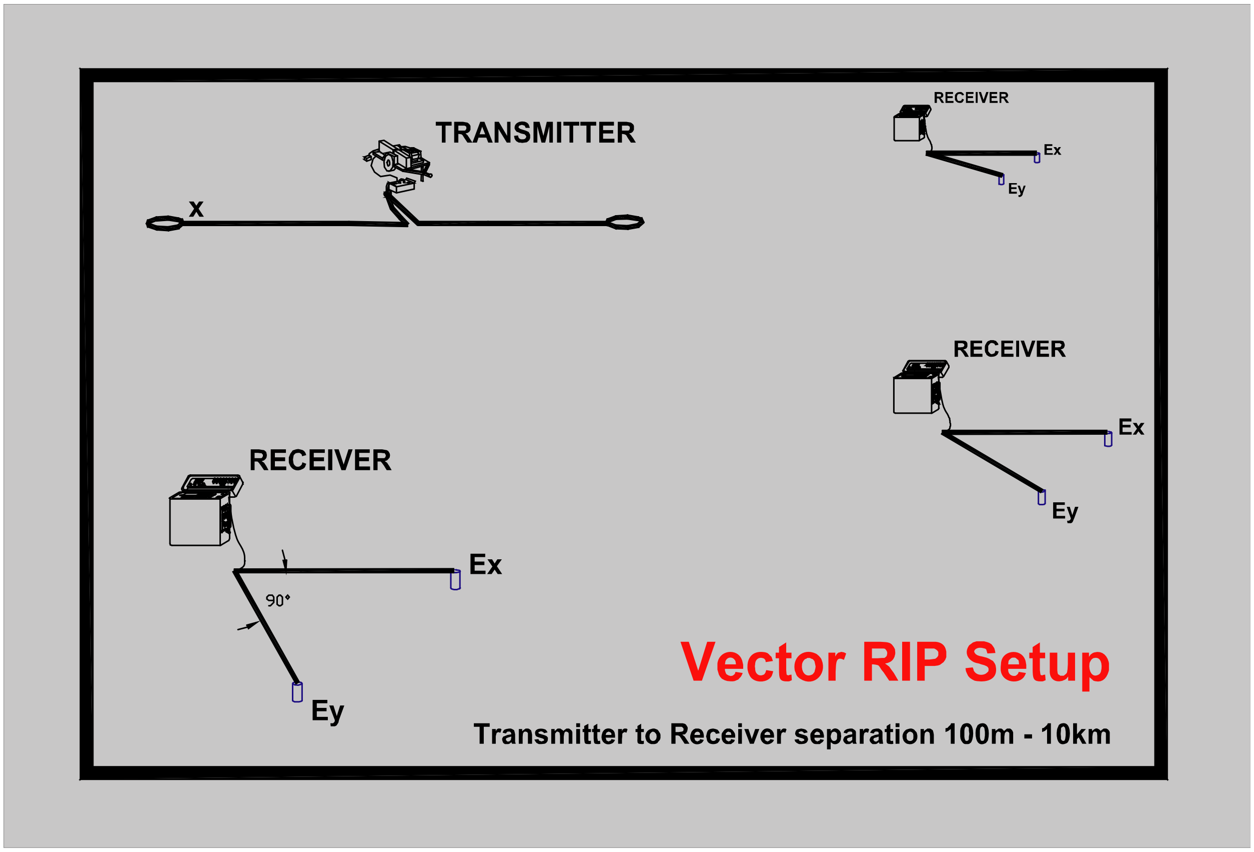

Figure 3: Standard VIP Setup

Because of the large separations between receiver and transmitter, wire-to-wire electromagnetic (EM) coupling is present. Some form of EM decoupling is necessary to determine the actual IP ground response. For frequency-domain IP, Zonge uses the 3-frequency extrapolation method, or so-called 3-point decoupling method, which works well in most instances. The three frequencies are derived from the harmonics of a single frequency square wave, e.g., 0.125 Hz and the 3rd and 5th harmonics at 0.375 and 0.625 Hz. Evaluation of IP data collected at higher frequencies is more problematic because EM coupling is proportional to frequency: the higher the frequency, the more intensely EM coupling influences IP results.

Tensor TIP Data: Tensor TIP data requires the use of two orthogonal transmitter dipoles (see Figure 4). The tensor approach provides a more complete "volumetric" description of the distribution and character of ground IP and resistivity. Tensor TIP measurements require a second transmitter dipole. Conceptually, this is the same as running a VIP survey twice, each time with a different transmitter orientation.

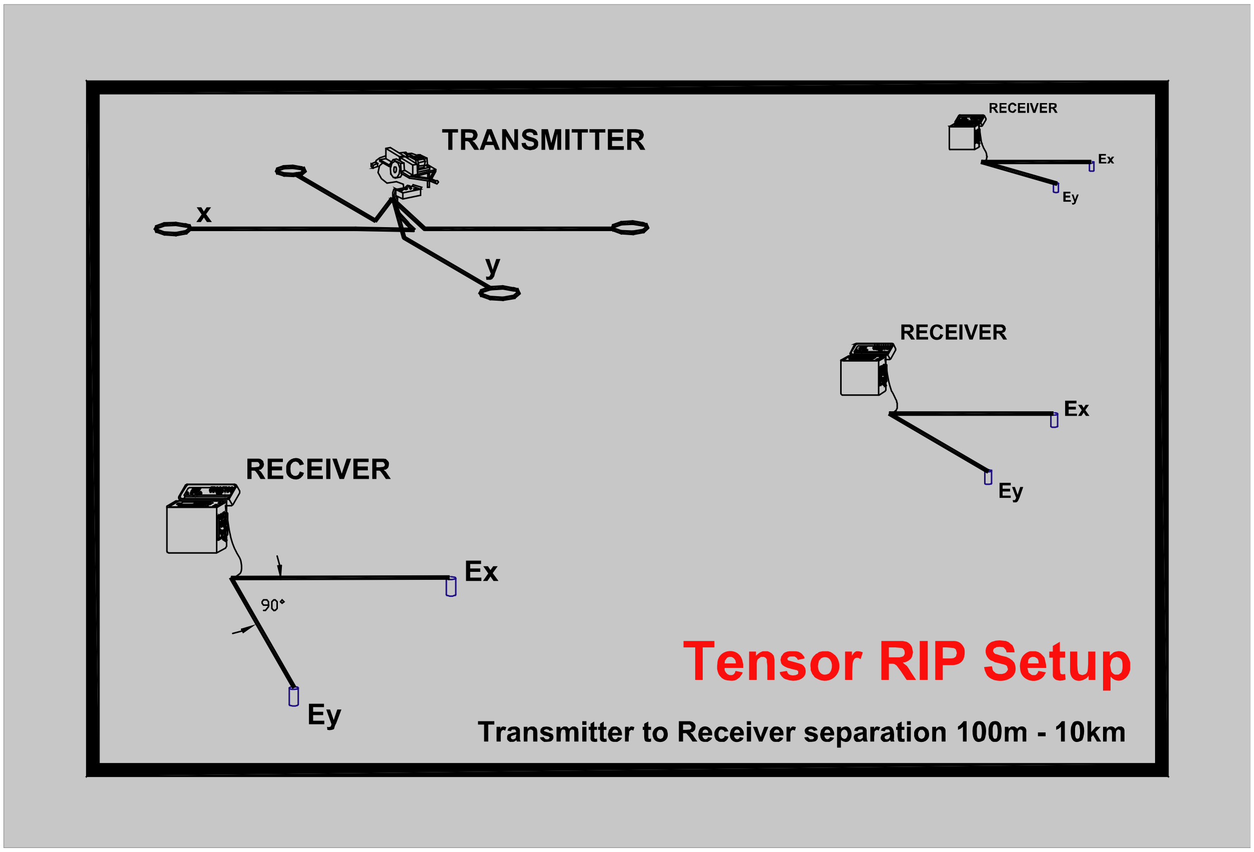

Figure 4: Tensor TIP Setup

One critical step in the conduct of any VIP or TIP survey is transmitter placement. The transmitter should never be placed over a strong IP source or important geologic contact. It is important that one VIP measurement be made at the center of the transmitter (shown on Figure 2) to check for an IP response. An IP responder under the transmitter will characterize the entire survey area as an IP source. This may mask the location of any particular IP source at depth. The same can be said if the transmitter is place directly on top of a resistivity "high" or "low". Proper transmitter placement avoids these "extremes". When "extreme" values are detected by VIP data collected at the bipole, often the source can be avoided by shifting the transmitter bipole as little as half a length.

The utility of the VIP technique for reconnaissance surveys comes where one is looking for large porphyry-like bodies under covered areas such as valleys. The VIP technique is most cost-effective when used to detect anomalous IP sources that can be later detailed with higher resolution (and more expensive) coverage with depth control, such as dipole-dipole IP. While tensor TIP provides more complete information useful in evaluating IP sources, production time is increased since two separate VIP data sets are required to produce TIP results. This adds to the production cost. Operating in the reconnaissance mode, often nothing is gained by collecting TIP data, especially if the purpose of the VIP survey is simply to detect anomalous IP sources at low cost. This is demonstrated in the Arizona Case History.

The Coincident-Loop Option: To provide basic depth control with VIP or TIP coverage, it is relatively easy to include an in-loop type transient EM (TEM) sounding with the vector array used at the receiver site. To complete TEM soundings at each receiver site, the field crew only needs to pull out two additional lengths of wire from the "L" array to form a square (see Figure 5). If each length is comprised of two wires bundled together, minimal effort is required to setup a coincident loop array. With the small ZMG-30 battery powered TEM transmitter and GDP-32^{II} receiver, coincident loop TEM measurements can be made at each site with little inconvenience. The TEM sounding provides a resistivity-versus-depth sounding at each VIP station. This resistivity depth control can be useful in evaluating IP results.

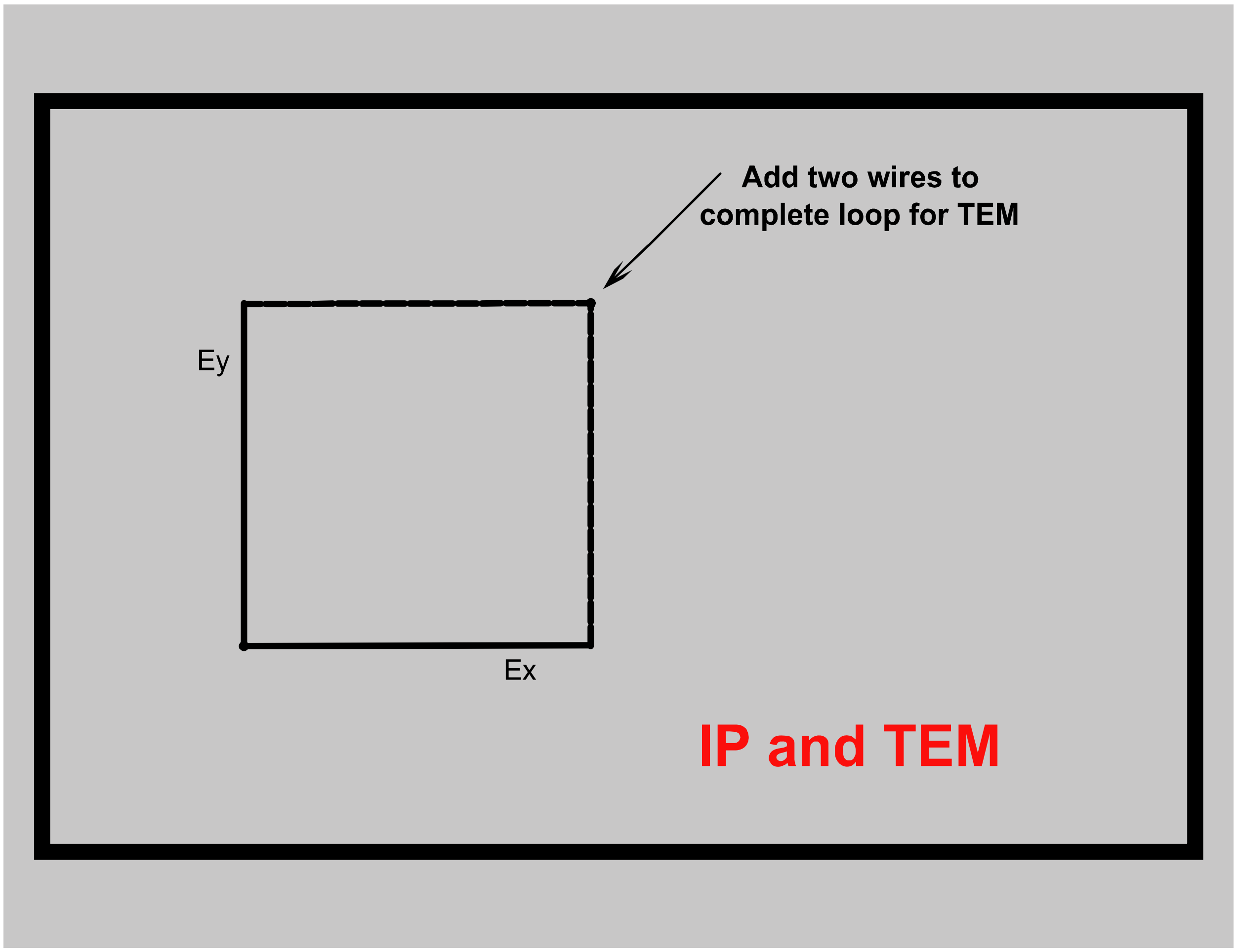

Figure 5: Coincident Loop TEM Setup

Tensor TIP & Vector VIP Comparisons, Arizona Case History: This TIP survey completed in Arizona provides a comparison of standard VIP, tensor TIP and Coincident-Loop TEM soundings. Tensor TIP results shown in Figures 6 and 7 define an anomalous IP response and plan-view resistivities. For this particular project, TEM resistivity-versus-depth soundings were important in evaluating the significance of the IP source. The IP feature was drilled based on these data. Although drilling did not find economic mineralization, drilling results are useful in evaluating the effectiveness of the IP survey.

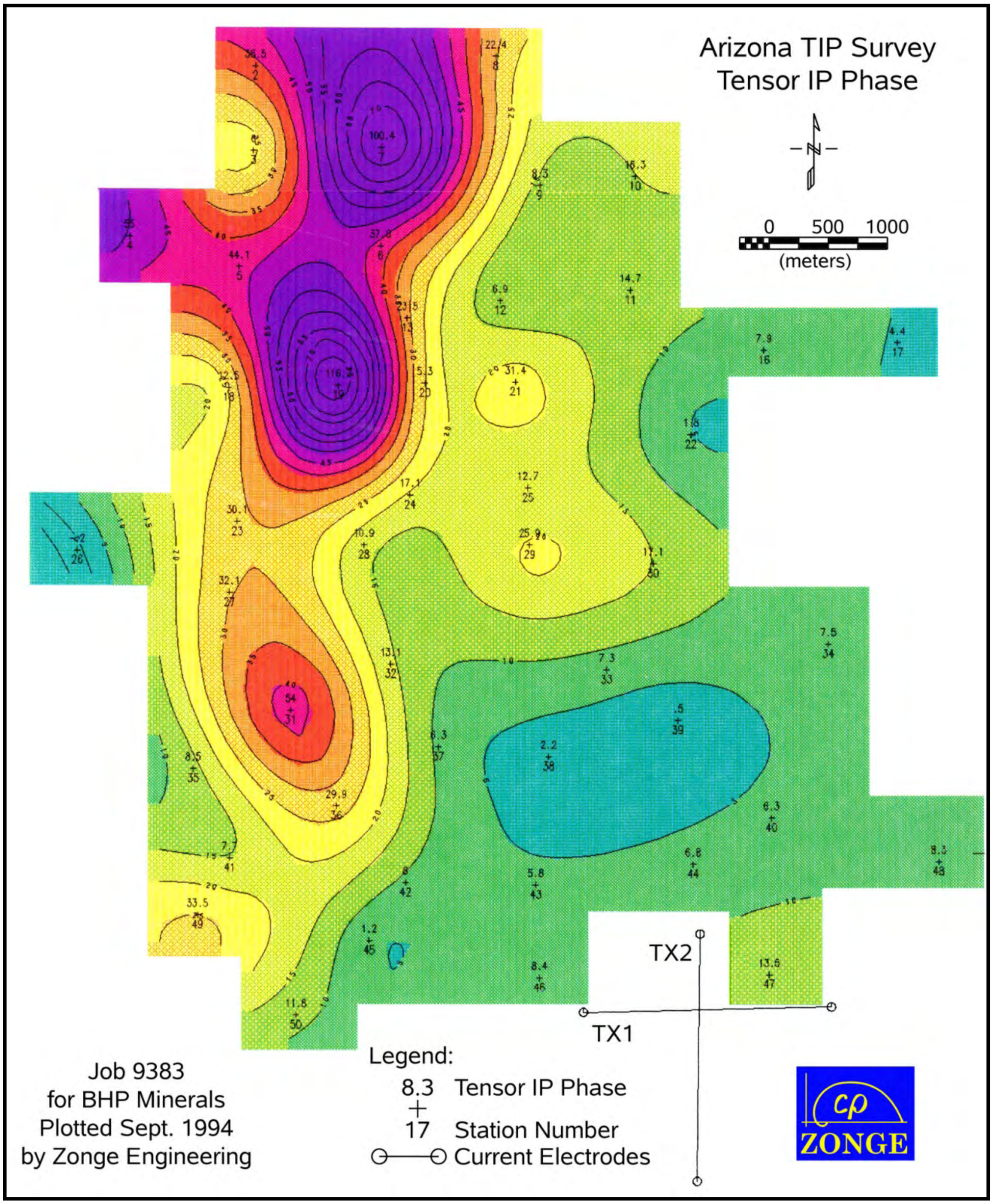

Figure 6: Tensor TIP "IP" (TX1 & TX2)

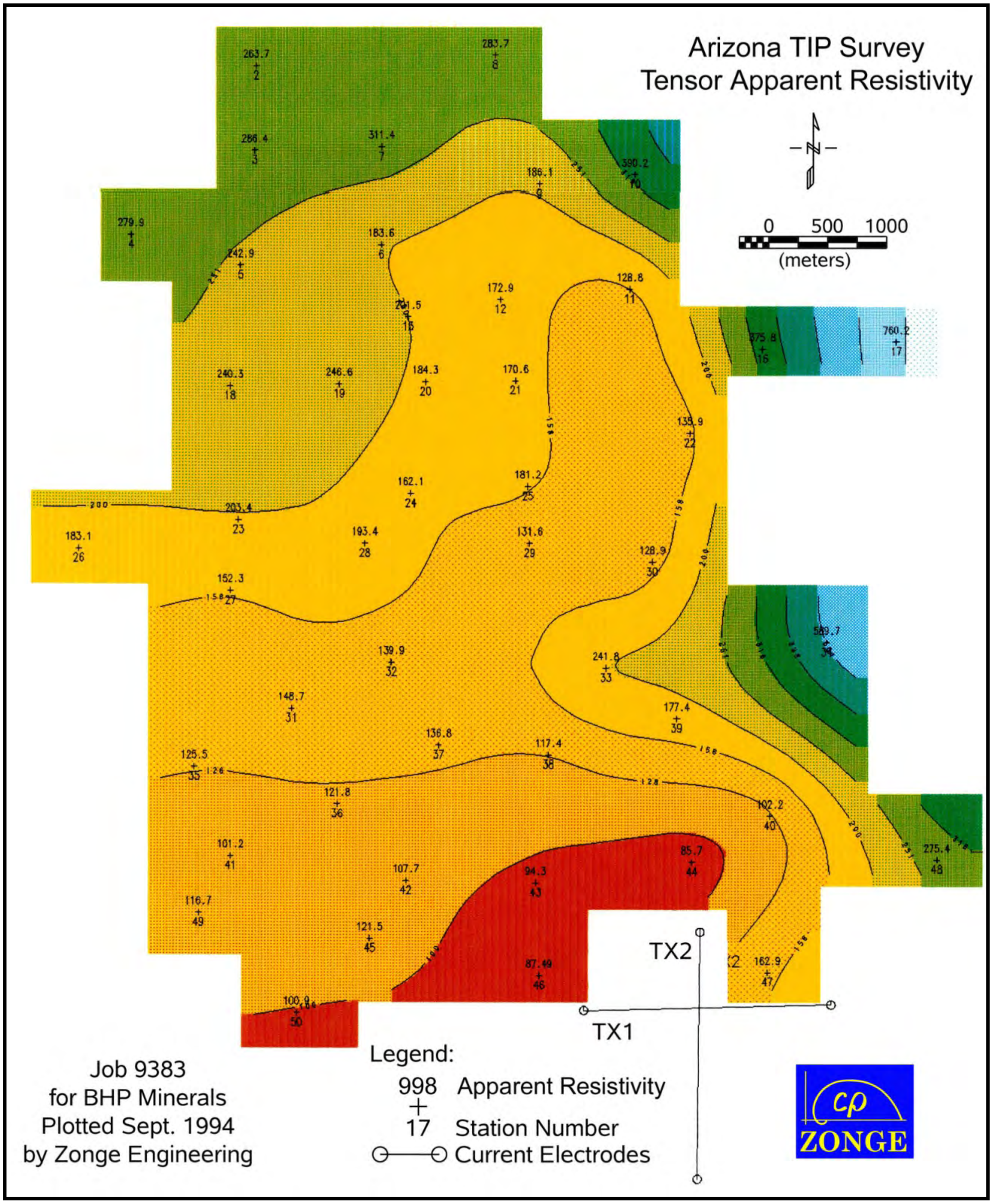

Figure 7: Tensor TIP "Resistivity" (TX1 & TX2)

Orientations of the two transmitter bipoles used for this Tensor TIP survey (TX1 and TX2) are shown on Figures 6 and 7. Figure 8 shows Arizona Case History geophysical profiles for IP and Resistivity taken through the two drill holes sited on the anomalous IP response. Notice that the clay alteration above the rhyolite is thought to be the source of the IP response identified in the TIP survey. TEM resistivities correlate with the rhyolite plug identified in the drilling program.

Interpretation of the initial survey results suggested that the IP source should be associated with resistive geology (rather than more conductive near-surface alluvial fill, a much less interesting target). Here the real problem was not being able to distinguish between an IP response associated with metallic luster sulfides (a porphyry target) and IP from the clay associated with the weathered rhyolite. This identification is beyond the capability of either VIP-type or TEM surveys.

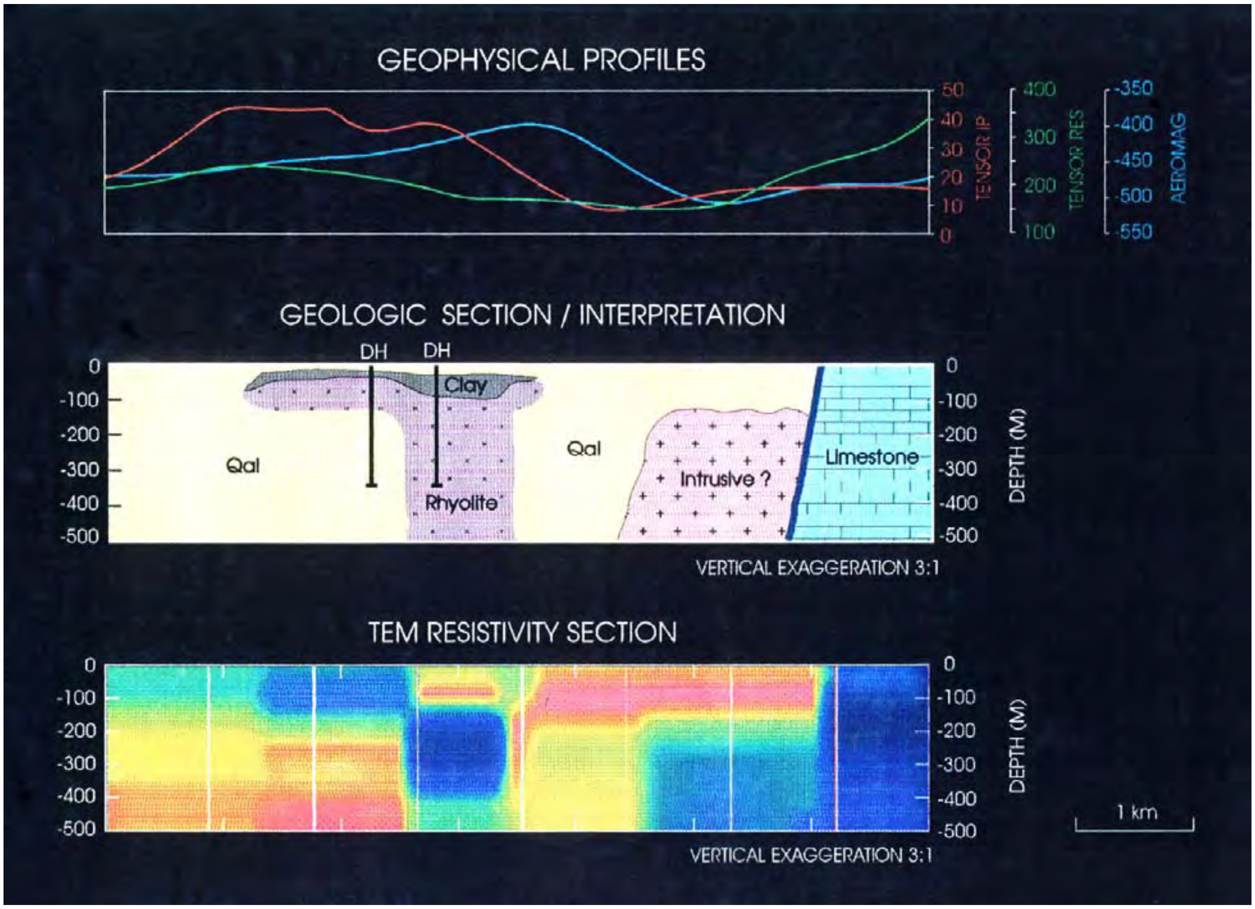

Figure 8: Geophysical Profiles, Arizona Case History

Figures 9 and 10 show the standard VIP 'IP' phase plots for TX1 and TX2. The purpose of showing these two plots is to emphasize that either TX1 or TX2 would have identified an anomalous IP source. What is not clear is whether the IP results from TX1 or TX2 would have provided the same accuracy in locating the first drill hole. Generally the rule for reconnaissance VIP coverage is: All VIP targets should be verified by more detailed complementary surveys before drilling! This may not have changed the outcome of this Arizona case history, but elsewhere this rule has proved critical in selecting drill holes, especially for large projects with overlapping VIP survey coverage.

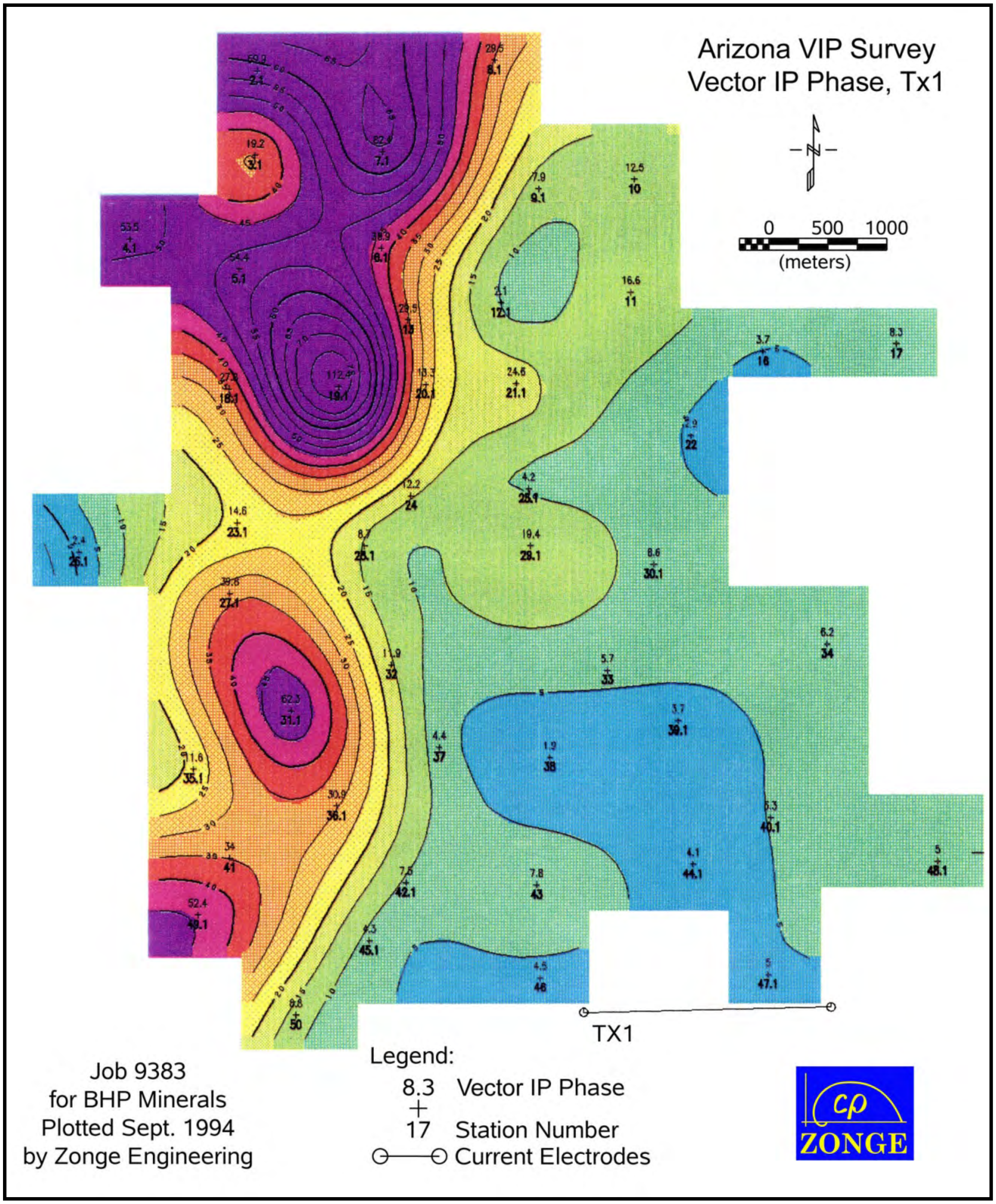

Figure 9: Vector VIP "IP" (TX1)

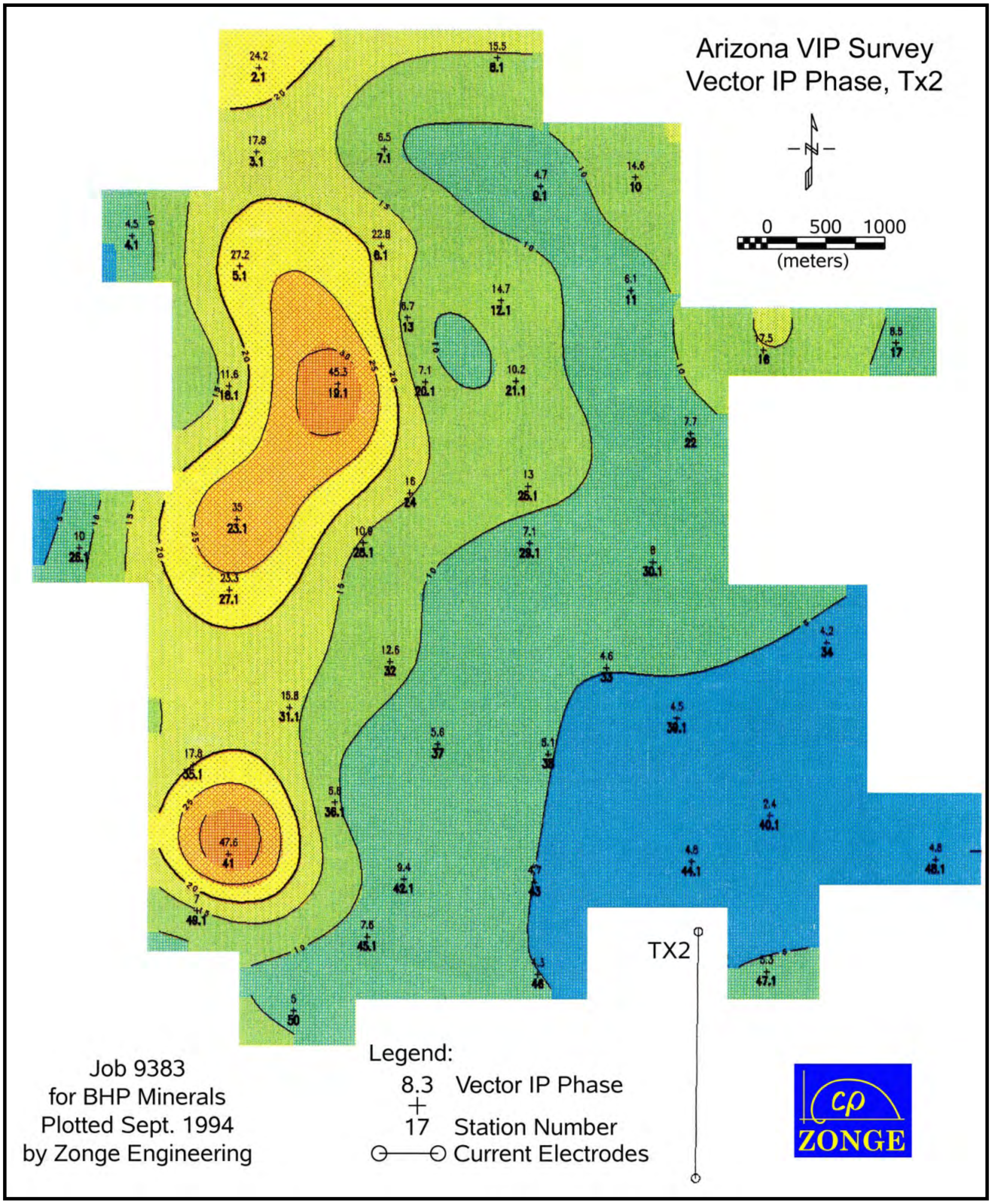

Figure 10: Vector VIP "IP" (TX2)

Tensor TIP Modeling: The following models are included to demonstrate the types of responses expected from vector and tensor processing. For a more complete treatment of this type of modeling see Bibby and Hohmann (Bibby, H.H., and Hohmann, G.W. 1993. Three-dimensional interpretation of multiple-source bipole-dipole resistivity data using the apparent resistivity tensor. *Geophysical Prospecting* 41, 697-723).

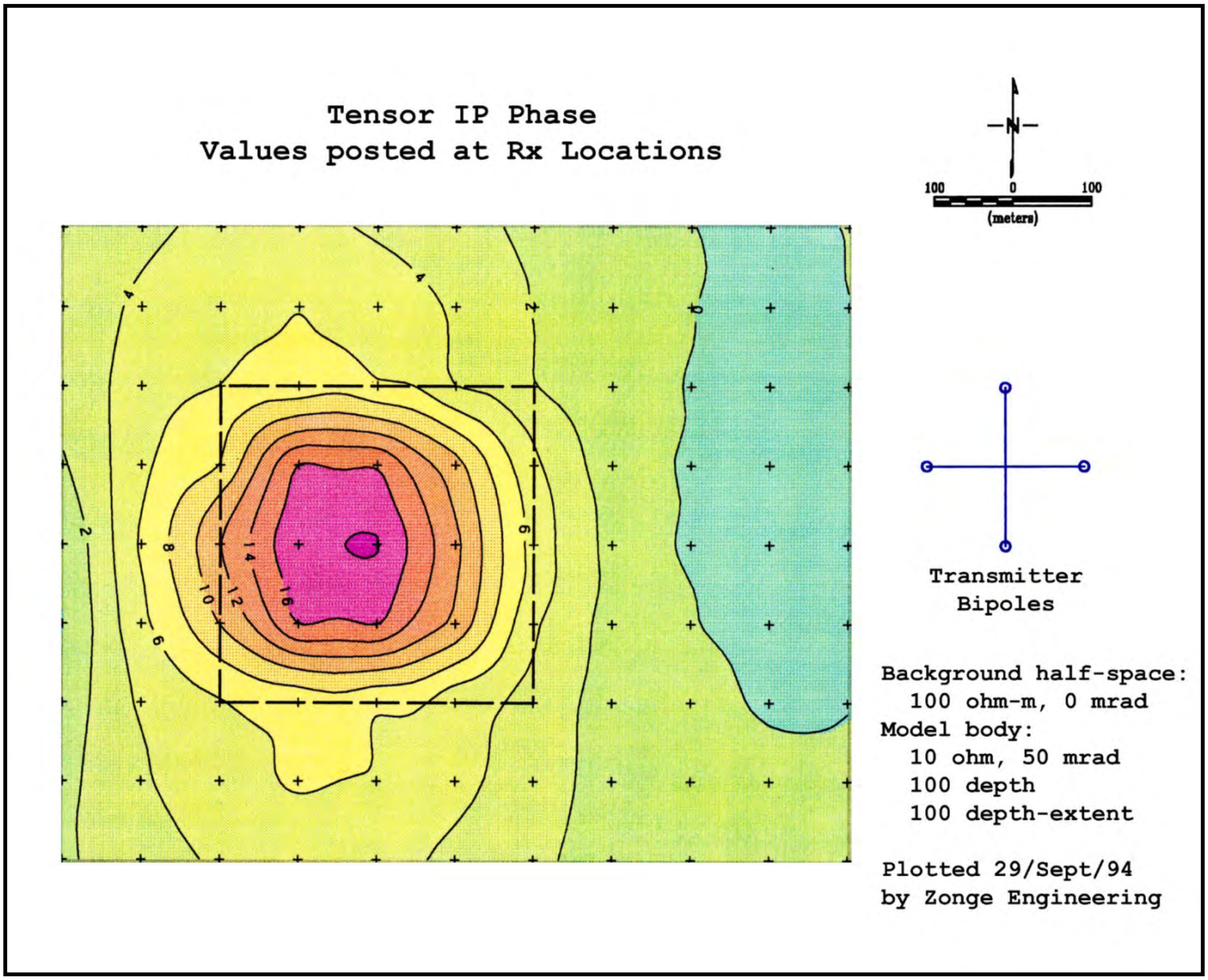

Figure 11: Broadside Tensor TIP Phase Model.

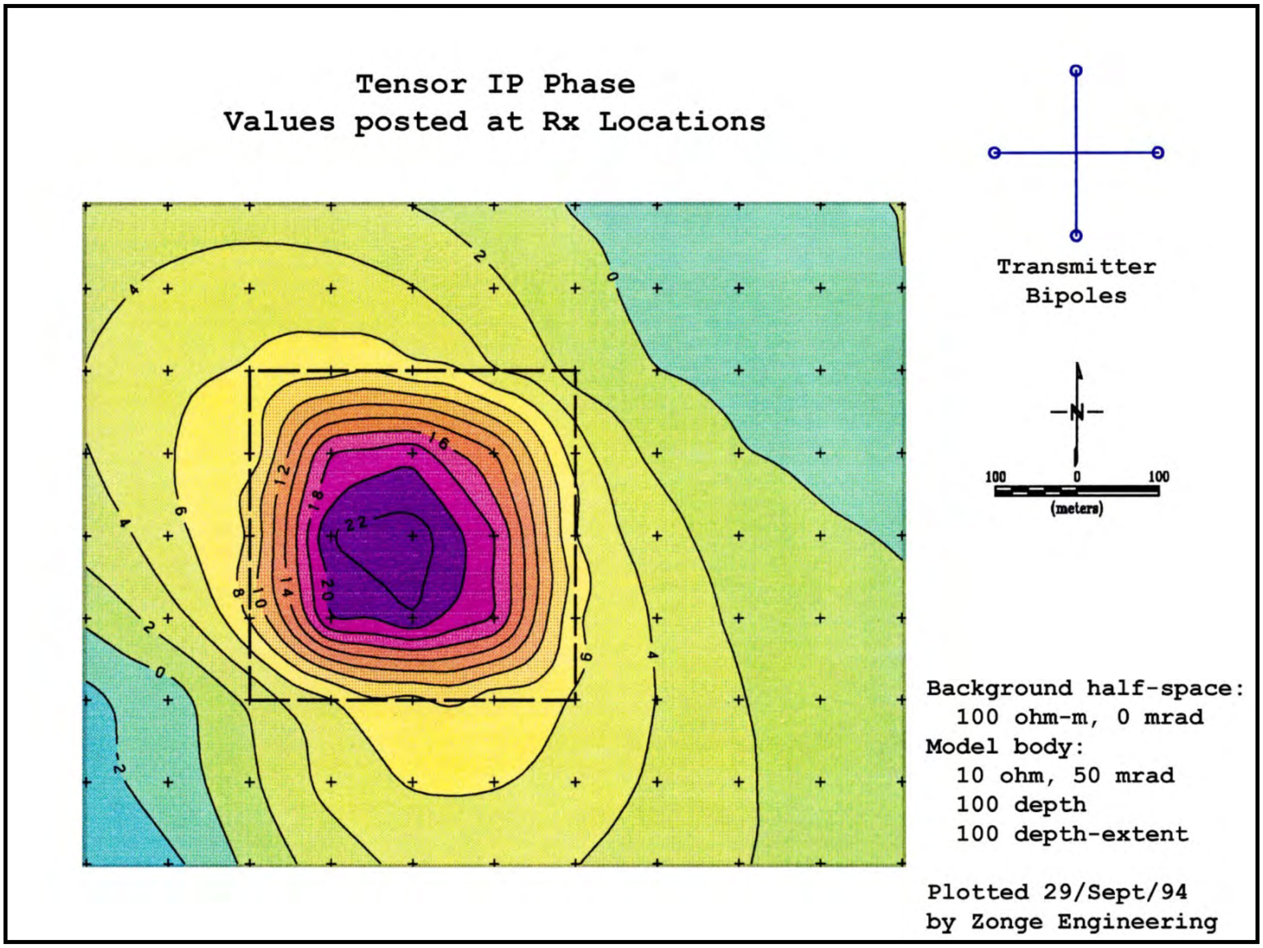

Figure 12: Diagonal Tensor TIP Phase Model

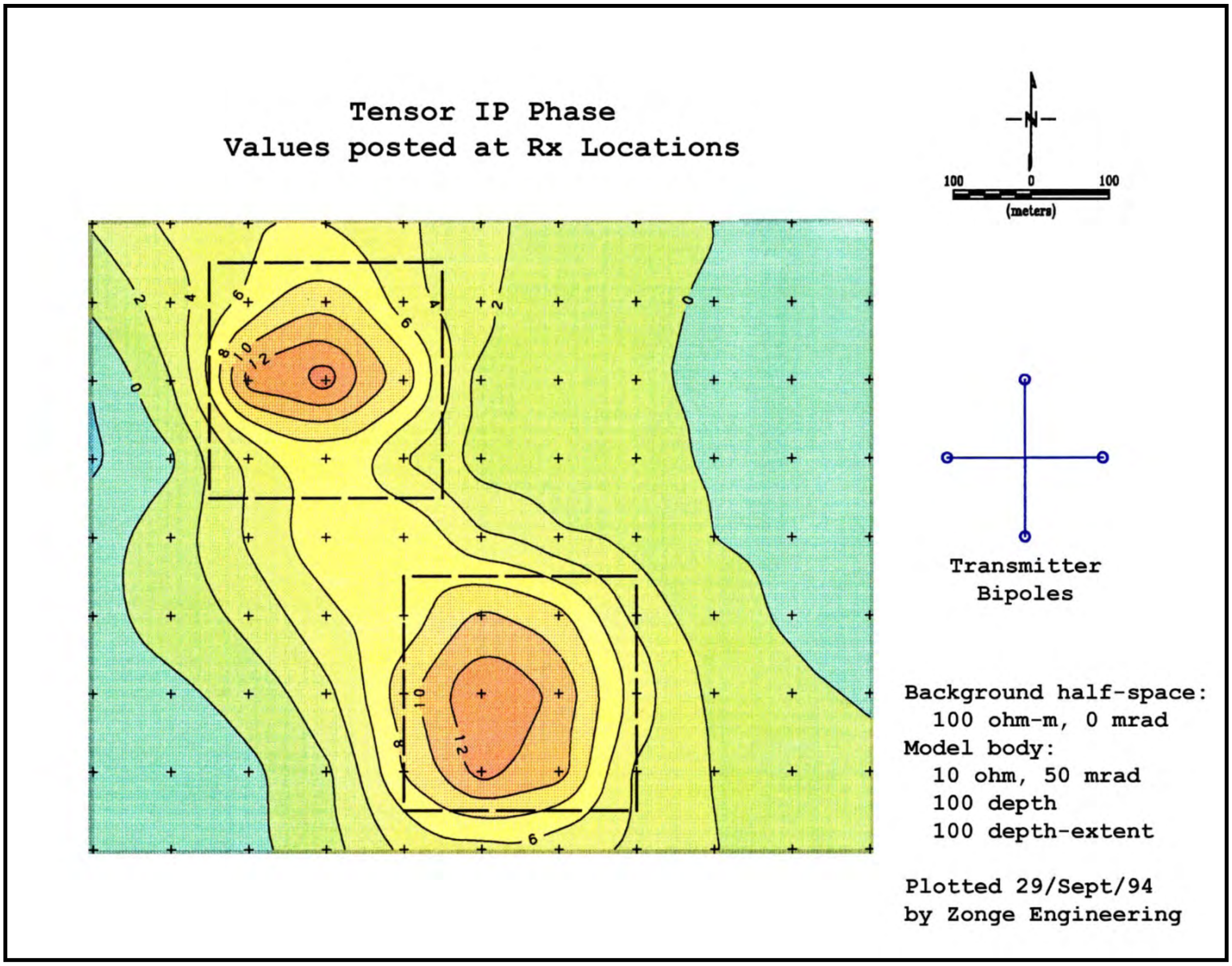

Figure 13: Two Body Tensor TIP Phase Model

Important observations about TIP tensor results can be summarized from these models:

1. The tensor results are invariant with respect to the actual position of the transmitter bipoles (note Figures 11 and 12).
2. To image the anomalous body in the ground, the resistivity and IP data points should be plotted at the receiver location.

There is no question that Tensor IP results provide more complete information than either of the two VIP subsets that form the TIP data set. It is important to realize that for reconnaissance surveys targeting large porphyry-like deposits over large regions, detecting anomalous IP sources and cost effectiveness are both important survey criteria for any exploration program.

Vector VIP Surveys: Following are two examples (see Figures 14 and 15) of Vector IP surveys (one transmitter bipole used) collected in Arizona and Chile. These further demonstrate the utility of using the VIP technique for reconnaissance IP work. While the decision whether to use VIP or TIP must be made on the basis of survey objectives and known geology, in general the simplest approach is generally the most cost effective for reconnaissance work when dealing with exploration dollars.

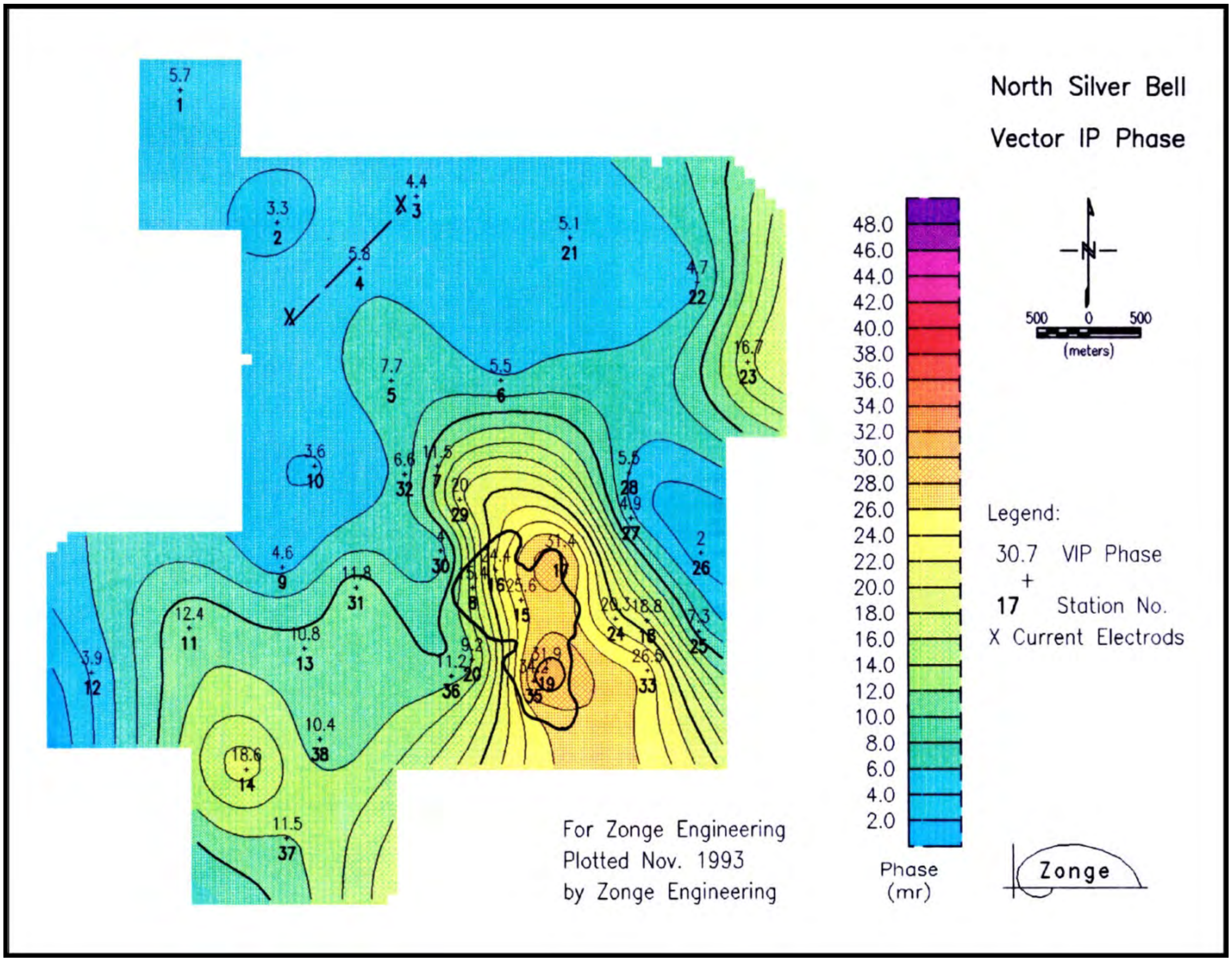

Figure 14: North Silver Bell VIP Survey, IP Phase with Proposed Pit Outline.

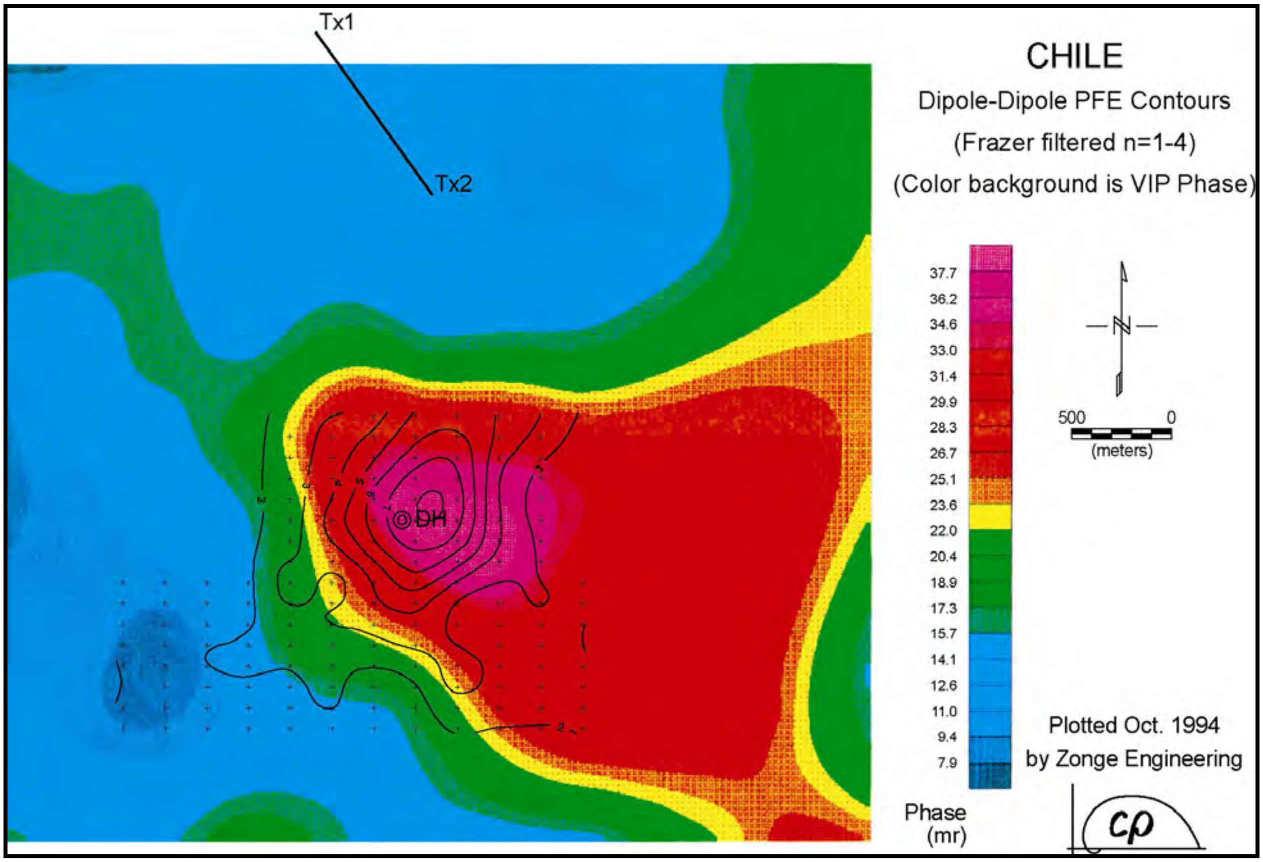

Figure 15: Phelps Dodge VIP Survey, IP Phase over Chilean Prospect.

Drill hole information:

1 - 23 m	oxidized layer
24 - 56 m	andesite, disseminated pyrite 1-2%
57 -100 m	latite, disseminated pyrite
31 m	water table

Conclusions: The reconnaissance VIP method can be used to cover large tracts of ground relatively quickly compared to dipole-dipole and dipole-dipole coverage. While access is always important, the VIP method uses a minimal amount of electric wire/cabling that greatly eases logistics. This may be crucial in projects where survey logistics are limited by ground cover, grid access or terrain. Line clearing requirements are minimal in conducting a VIP survey in comparison with other deep-looking IP techniques.

By suitable placement of transmitter and receiver stations, VIP investigations can usually be expected to locate large IP sources at depths in excess of 1000 feet as demonstrated by forward modeling. Plotting the resistivity and phase values at the receiver location will accurately delineate anomalous features in most cases. While plots of field IP and Resistivity have been shown in this paper, VIP data can also be presented as vector plots of “magnitude” and “phase” showing distribution patterns. “Vector” plots are a reliable tool for evaluating survey results, and the plots themselves will identify resistivity contacts and IP sources. The “vector” magnitude results identify the current distribution associated with the transmitter bipole. The “vector” IP phase results identify the secondary field associated with IP responders (vectors point to the IP source). These plots really support the interpretation of the IP data and are not meant to replace IP or Resistivity plan-view plots.

In covering large areas, multiple data sets of VIP and TIP data can often be used to create a composite plot. This requires repeat control points between setups as different transmitter sites may produce “static-shift” displacement for resistivities.

Once the type and size of a target of interest is determined, either VIP or TIP coverage can be selected and optimally configured for reconnaissance IP coverage. TEM data can be collected with either VIP or TIP logistics to better characterize structure in the survey area.

The VIP-TIP technique has been used with up to an 8-mile separation between the transmitter bipole and receiver array in resistive environments such as Alaska, albeit this was pushing signal levels to the limit. Distances of 4 to 5 miles are more common operating in the more conductive environment of the American Southwest. Our experience has shown that a single receiver crew can acquire between 5 and 12 setups per day, depending upon access, topography, distance between stations, and whether VIP or TIP data are collected. Many VIP-type surveys have been collected on the basis of one station per kilometer grid, with 500 ft receiver dipoles. With the above production parameters, five to twelve square kilometers of reconnaissance coverage can be expected per day under these conditions. Field production can be almost doubled if two GDP-32^{II} receiver crews are collecting data simultaneously.

There is great flexibility in optimizing VIP-type surveys for reconnaissance coverage required for your mining exploration programs.

Note: This technical review is based on a paper presented by Zonge in 1994. Zonge wishes to thank Phelps Dodge and BHP Minerals for permission to present this data.

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