Magnetotelluric Phase Tensor Applications to Geothermal Assessment in New Zealand and New Mexico

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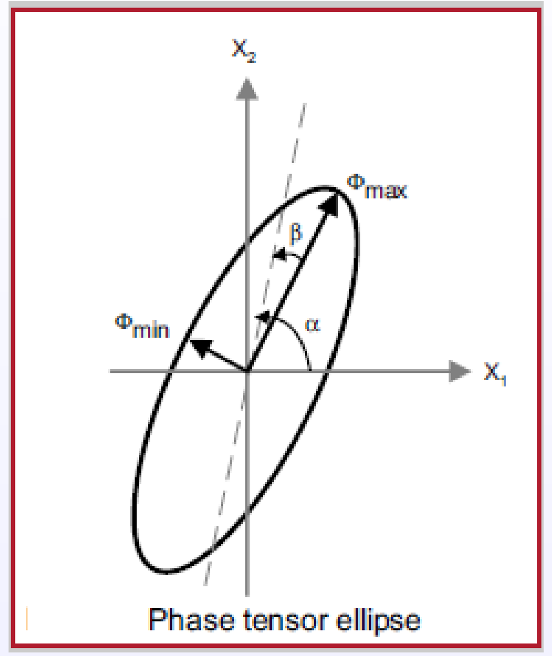
1. The Magnetotelluric (MT) Phase Tensor



The real MT phase tensor is defined by

$$\Phi = X^{-1} Y$$

where **X** and **Y** are the real and imaginary parts of the conventional, complex MT impedance. Features of the 2 x 2 **Φ** matrix include:

1) It's free of distortion from near-surface inhomogeneities after the galvanic response is frequency independent and produces "static offsets" in MT soundings.

2) It has diagonal only elements which are equal for 1-D and unequal for 2-D geoelectric structures.

3) It's asymmetric (has nonzero skew angle β, Figure 1) for 3-D structures.

4) The dimensionality and directionality of background geoelectric structures can be determined.

Figure1. The phase tensor is usually visualized by applying it to a family of spatially rotating, unit length, radial vectors (the unit circle). In plan view this produces circles for 1-D and ellipses for 2-D and 3-D geoelectric structures. Semi-axes of the ellipses are in the MT TE (transverse electric) and TM (transverse magnetic) directions for 2-D geoelectric structures.

2. Phase Tensor Applied to Geothermal Fluid Reinjection Monitoring

- Repeat MT measurements were made in 2010, 2011, and 2012 prior to planned 2013 reinjection of spent geothermal fluids at the southern margin of the Wairakei geothermal field in New Zealand.
- The study applies feature 1. above that phase tensor remains unchanged despite variable noise or surficial changes.

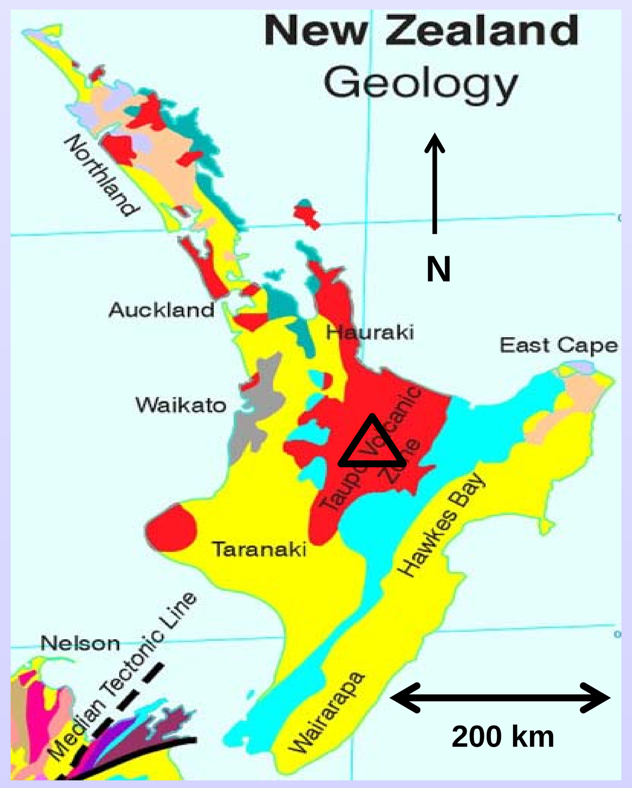
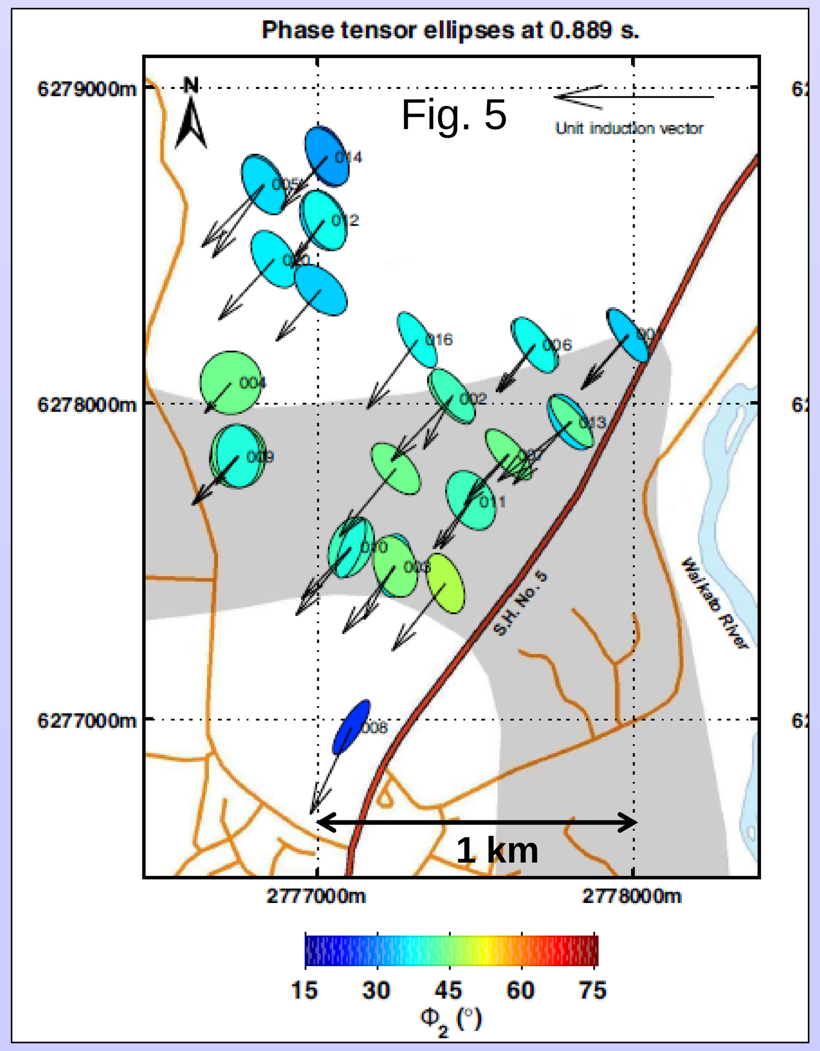
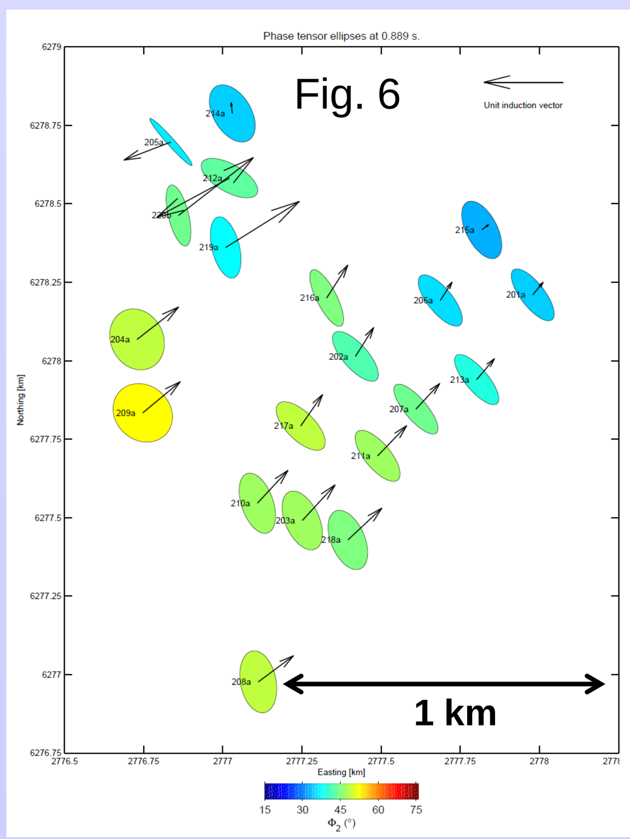


Figure 2. Location, △ of Wairakei geothermal area in the Taupo Volcanic Zone, New Zealand.

Figure 3. Brine transport pipe system.

Figure 4. GNS scientist Stewart Bennie oversees MT test by Brian Castro, Becky Hollingshaus, and Collin Wilson (r to l).





Figures 5 and 6. Maps of phase tensor ellipses from April and August 2010 (Figure 5) and April 2012 (Figure 6) at 0.889 s period. Ellipse fill color is geometric mean of Φ_{max} and Φ_{min} (Figure 1). Period bands and site locations where phase tensor results are highly repeatable are considered potentially valuable for monitoring future brine reinjection .

3. Phase Tensor Applied to Geothermal Modeling (Inversion)

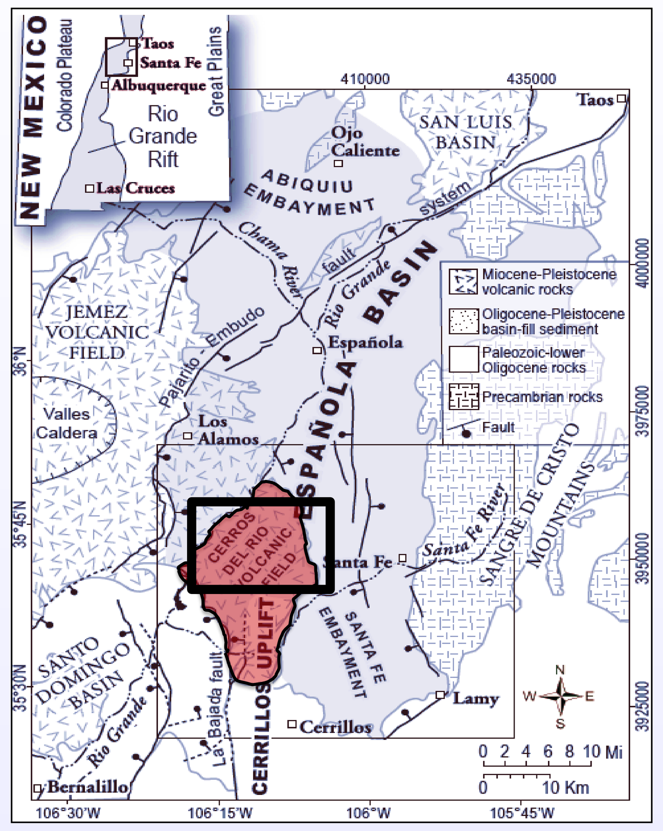


Figure 7.Geothermal study area in Cerros del Rio volcanic field of the central Rio Grande rift, New Mexico.

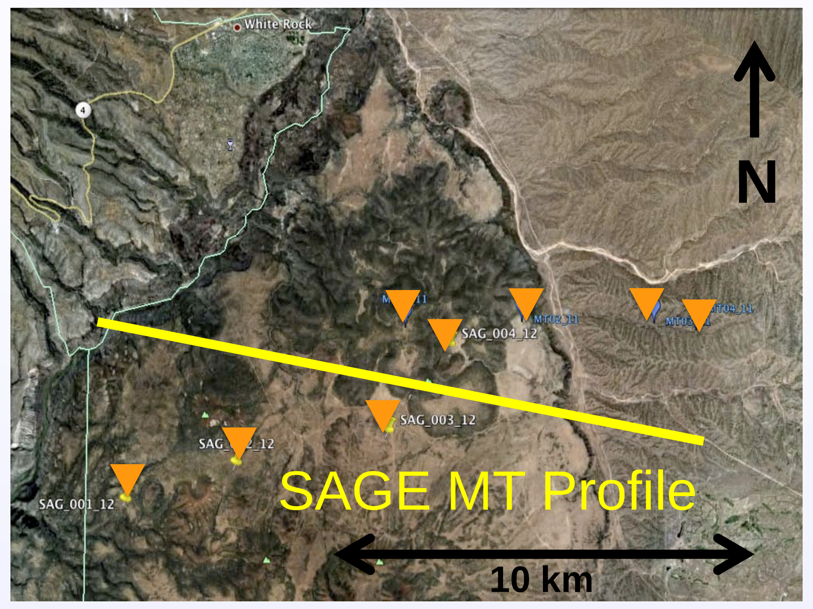


Figure 8. MT sites and modeling profile in SAGE (Summer of Applied Geophysical Experience)study area.

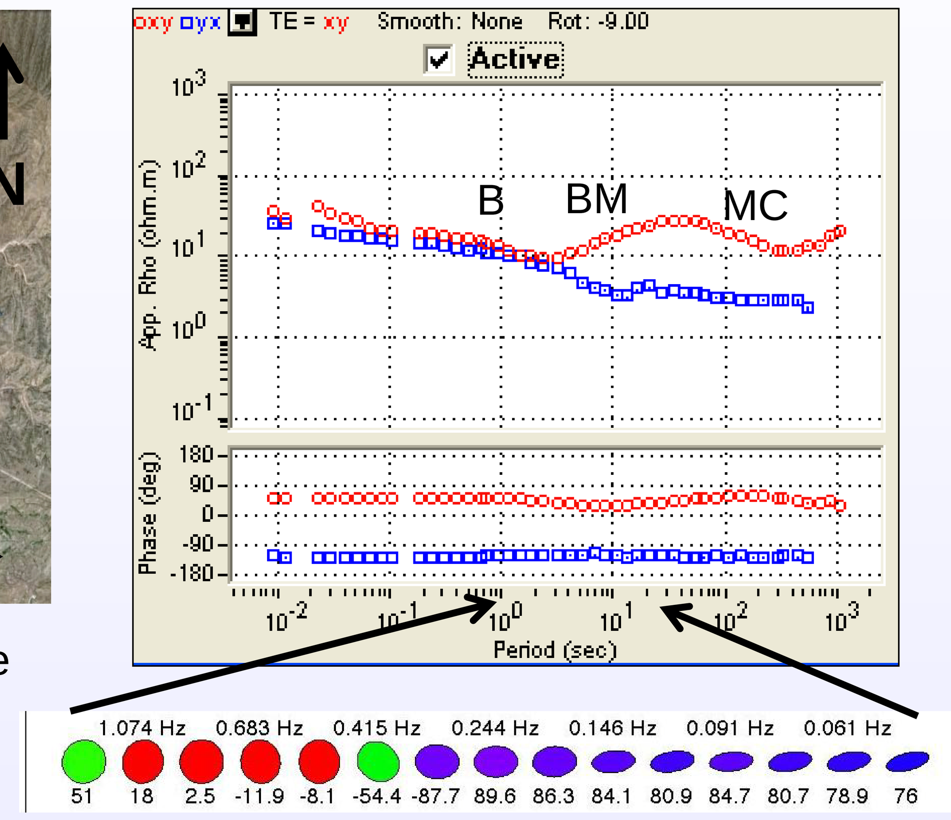
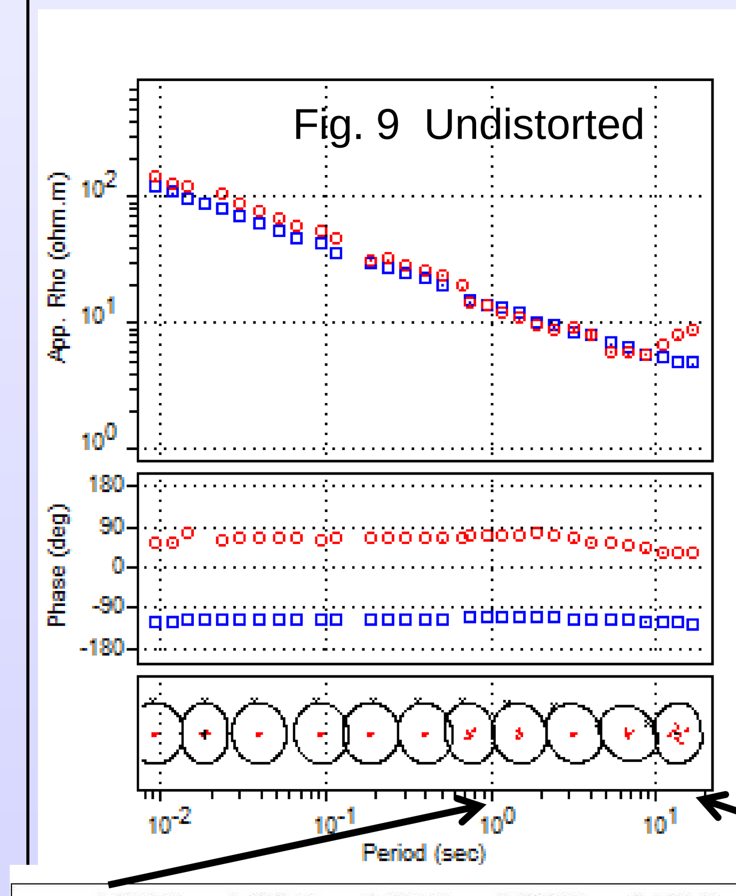
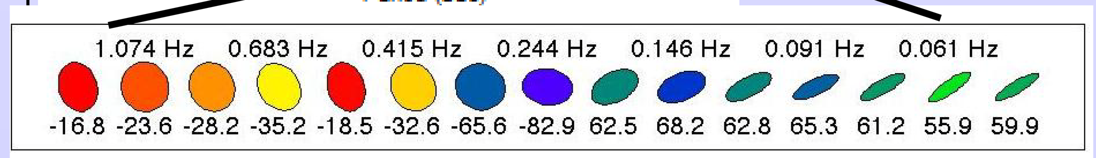


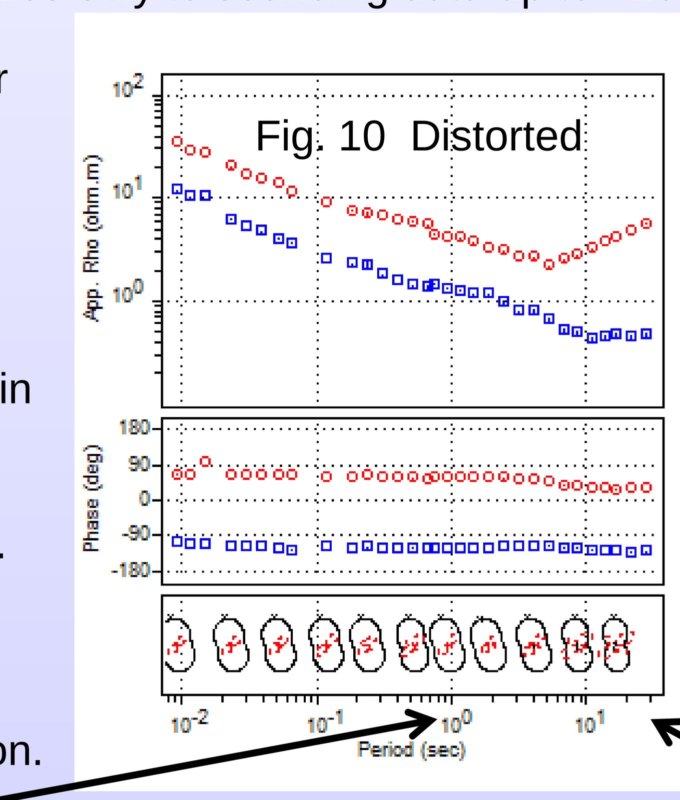
Figure 9. Typical MT sounding curves showing basin, B; basement, BM; and midcrustal conductor, MC. Phase tensor ellipses clearly show 1-D basin and 2-D basement with ~ 85° major ellipse axis. Midcrustal conductor has distinctly different ellipse axes (not shown). This reveals overall 3-D dimensionality, therefore,1-D/2-D modeling applies only to sounding data up to ~10 s period.

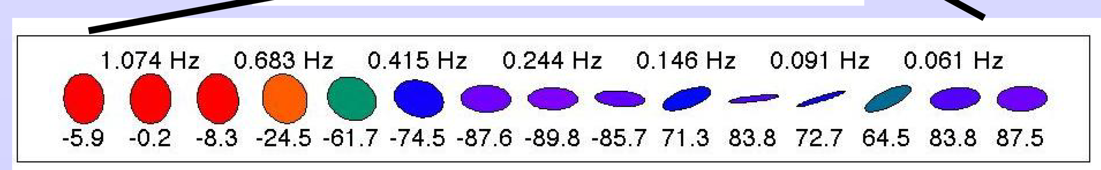


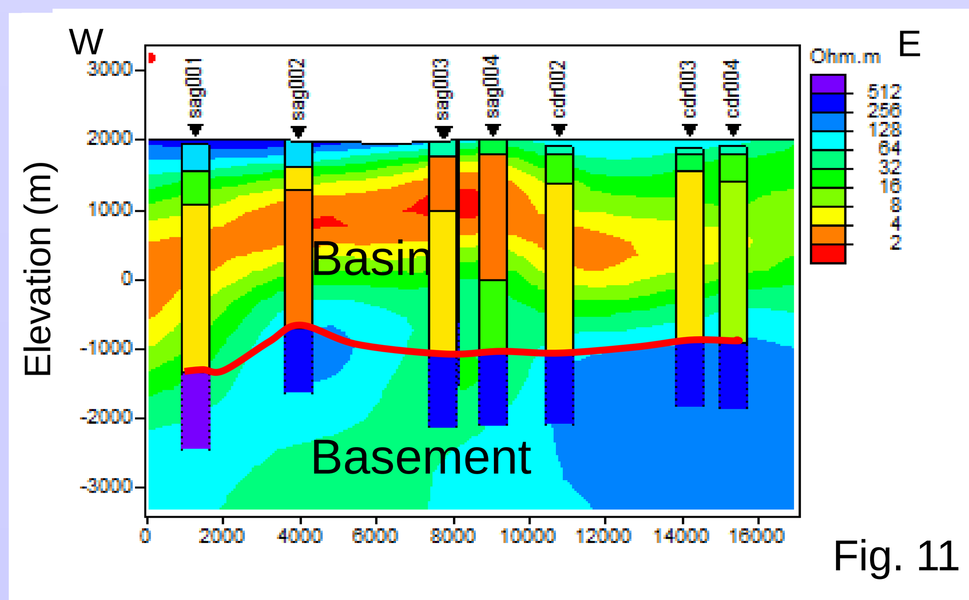


Figures 9 and 10. Using MT sounding data for periods up to ~10 s period isolates 1-D/2-D shallower sections and allows non 3-D modeling. Comparison of tensor ellipses with polar diagrams for an undistorted sounding (Figure 9) and a distorted one (Figure 10) confirms that the phase tensor identifies 1-D in both cases (i.e., circular ellipses), whereas, polar diagrams do not. Phase tensors clearly identified the basement 2-D geoelectric strike.

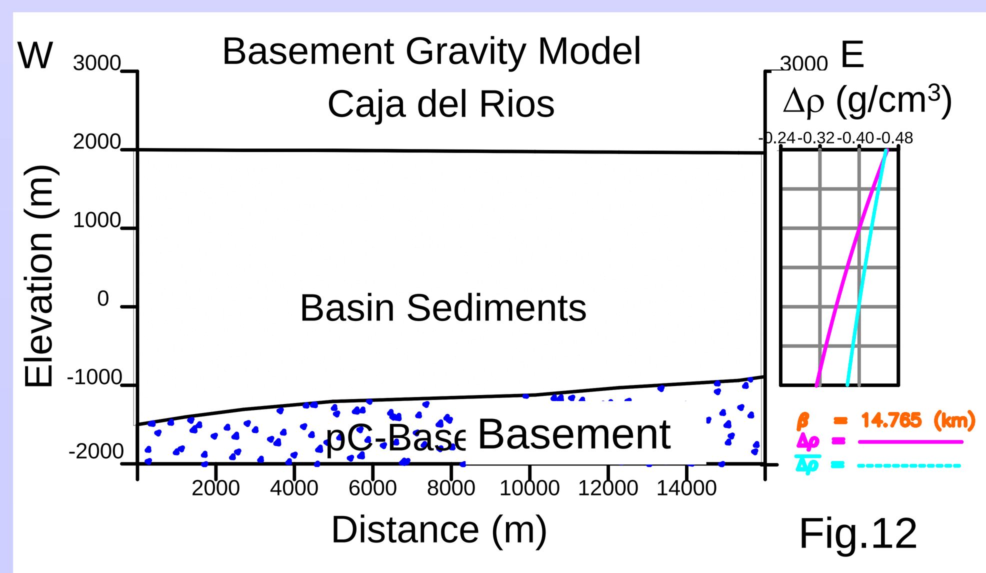
Prior to MT inversions, static offsets were corrected by using: 1) the known geoelectric section above the water table from well logs and dc resistivity soundings and 2) its elevation.







Figures 11 and 12. Resulting geoelectric section from stitched 1-D inversions agrees with gravity density model in the study area. The basement depth is ~ 3 km and thickens on the west by a few 100 m.



4. Conclusions

- MT phase tensor analysis has unique applications in repeat monitoring of fluid injection and dimensionally, directivity analysis prior to inversion modeling. For example, dimensional analysis can reveal if a deeper section, responsible for 3-D structure, can be removed thus allowing valid, shallower,1-D/2-D inversion.