Journal of Physics: Conference Series

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To cite this article: Y K Lubis *et al* 2018 *J. Phys.: Conf. Ser.* **1011** 012035

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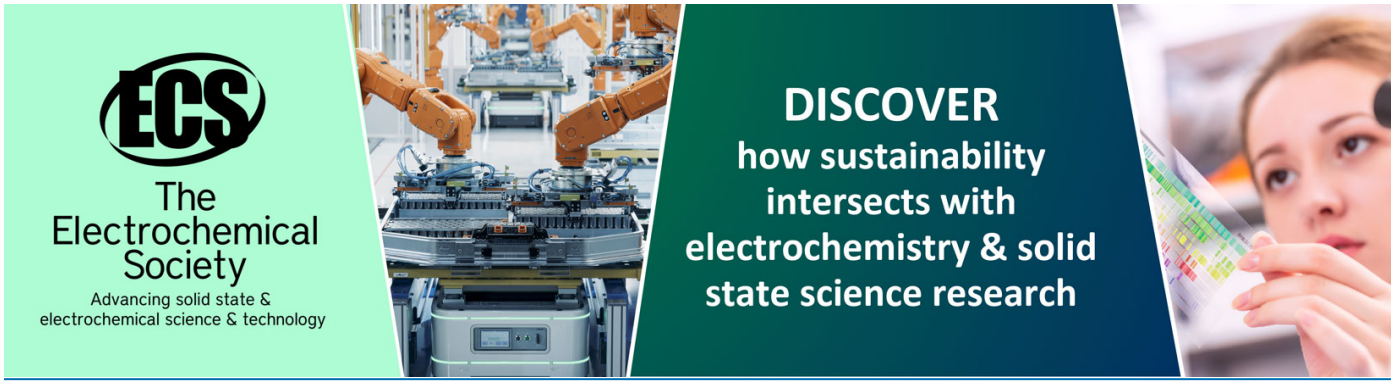

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IOP Conf. Series: Journal of Physics: Conf. Series **1011** (2018) 012035 doi:10.1088/1742-6596/1011/1/012035

MT2D Inversion to Image the Gorda Plate Subduction Zone

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Abstract. The magnetotelluric method is applicable for studying complicated geological structures because the subsurface electrical properties are strongly influenced by the electric and magnetic fields. This research located in the Gorda subduction zone beneath the North American continental plate. Magnetotelluric 2D inversion was used to image the variation of subsurface resistivity although the phase tensor analysis shows that the majority of dimensionality data is 3D. 19 MT sites were acquired from EarthScope/USArray Project. Wepresent the image of MT 2D inversion to exhibit conductivity distribution from the middle crust to uppermost asthenosphere at a depth of 120 kilometers. Based on the inversion, the overall data misfit value is 3.89. The Gorda plate subduction appears as a high resistive zone beneath the California. Local conductive features are found in the middle crust downward Klamath Mountain, Bonneville Lake, and below the eastern of Utah. Furthermore, mid-crustal is characterized by moderately resistive. Below the extensional Basin and Range province was related to highly resistive. The middle crust to the uppermost asthenosphere becomes moderately resistive. We conclude that the electrical parameters and the dimensionality of datain the shallow depth(about 22.319 km) beneath the North American platein accordance with surface geological features.

1. Introduction

The Gorda plate is a southernmost microplate of the Juan de Fuca plate system. The Gorda plate covers about 45,000 km^2 as estimated by Chaytor [1]. The western frontier of the Gorda plate is the Gorda Ridge, and the south frontier is the Mendocino Fracture Zone. Both of them restrict the Gorda plate from the Pacific plate. The half-spreading rates of the Gorda Ridge are 27.5 mm/yr near the Blanco Fracture Zone on the north and 14.0 mm/yr to the south near Mendocino Fracture Zone since 2 Ma [2]. Moreover, the relative movement rate of the North American plate is about 58 mm/yr, and it contrasts to the Pacific plate [3].The Gorda plate moves relatively to the east and subducts the North American plate since late Mesozoic and early Tertiary[4].

The subduction of the Gorda plate, as a part of the largest of Juan de Fuca plate system, beneath the North America plate formed several geological features such as the Klamath Mountain, the Cascadia Range, the Central Basin and Range, and the Wasatch fault. Furthermore, the unit of individual rock of the North American plate generally is younger to the eastward [4].The geological structures denote the variation of the subsurface physical properties namely resistivity, density, seismicity, susceptibility, etc. These parameters are commonly employed to identify the subsurface structure includingto

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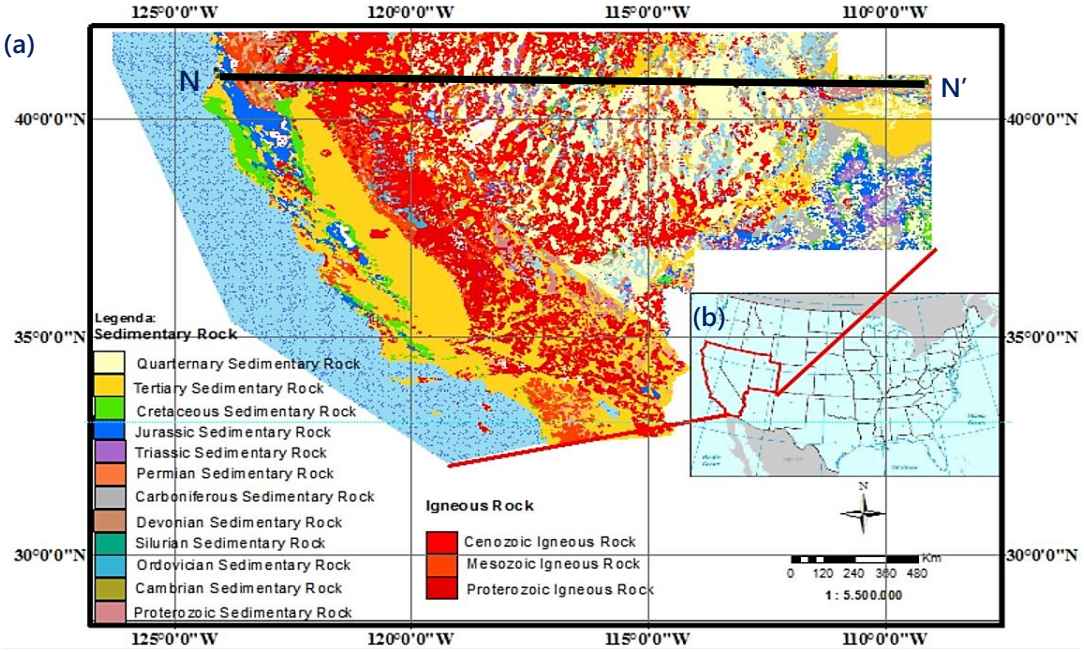
imagethesubductionzone.The Central Basin and Range (CBR) showed a high resistivity value as a result of thermal releasing and basaltic hydrating [9]. The contrast resistivity around CBR is a representation of the upper crust resistivity value [8].The study area is located in the western North American plate (Figure 1). This research aims to delineate the Gorda plate subduction zone beneath the North American plate using 2D inversion magnetotelluric data. Magnetotelluric is a geophysical method that usenatural electromagnetic wavesto describe the subsurface resistivity distribution [10][11].This method informs the subsurface resistivity structure by simultaneous measuring of an electrical field and magnetic field components [12]. In this study, we also analyze the dimensionality



of magnetotelluricdata by using phase tensor analysis.

Figure 1: (a)TheSurface Geology Map of California, Nevada, and Utah shows the distribution of lithologies. A bold line green N-N' with black dots denote MT sites that extend ~1300 kilometers [5, 6, 7]. (b) Inset: The North American Map (Modified from USGS Geology Map, 2017)[8]

2. Materials and Methods

This research employs the magnetotelluric method. We have taken 19 MT sites as data. These data were acquired from the openaccess datafrom National Science Foundation in Earth Scope USArray Project [13]. The site spacing is 70 kilometers and the range frequency used is 10^{-1} – 10^{-4} Hz. These MT sites elongated about 1300 kilometers from Redwood Park of California to Brown Park of Utah. These data consist of the coordinate, the impedance, and the frequency of the MT sites.

The two-dimensionality of MT data inversion was implemented using WinGlink software. The MT data were inverted applying the nonlinear gradient conjugate.The first step that we didwasmasking process. Subsequently, the homogeneous half-space model was used to createthe initial model in resolution setting of the model. The next process wastodetermineinversion parameters.We selectXY and YX components, error floor 5%,and the weight function for horizontal and vertical orientation. Moreover, we conduct the tau test by plotting rms value until L-curve is formed. Then, the tau value optimum of the tau test (τ) chosen here is $\tau = 10$. The tau value optimum is the most balanced value of the L-curve. Thistau test controls the relative weight and the roughness [14]. Furthermore, the last stage wasthe inversion process to produce a convergent model whichwas indicated by the absence of changes to the model although the iteration is still conducted.

Furthermore, the dimensionality of magnetotelluric data wasconducted using the skew angle value (β), and the ellips shape of tensor phase was done employing tensor phase analysis [15]. This analysis results the characteristic of data. The circle shape with skewness value (β)distributed within $-3^0 > \beta > 3^0$indicated1D character. The ellips shape signified 2D character when skewness value (β) range is -3^0 up to 3^0 or 3D character when skewness value (β) is less than -3^0 or more than 3^0. Mathematically, the formula of tensor phase can be written as follows:

$$\Phi = R^T(\alpha-\beta)\begin{bmatrix}\Phi_{max} & 0\\ 0 & \Phi_{min}\end{bmatrix}R(\alpha+\beta) \quad (1)$$

$$\alpha = \frac{1}{2}\arctan\left(\frac{\Phi_{12}+\Phi_{21}}{\Phi_{11}+\Phi_{22}}\right) \quad (2)$$

$$\beta = \frac{1}{2}\arctan\left(\frac{\Phi_{12}+\Phi_{21}}{\Phi_{11}+\Phi_{22}}\right) \quad (3)$$

R^T is transposed matrix, β is skewness angle, and α is an angle that express the dependency of tensor toward coordinate system. The geoelectrical strike orientation is shown by the remaining of α – β[14].

3. Results and discussion

The result of 2D inversion model of magnetotelluric is shownin Figure 2. The root mean square (rms) value of this model generally is 3.889. This rms value indicates the suitability of the data and the electrical properties model. Then, the phase tensor analysis is given by Figure 3 in period 19.6928 s. The phase tensor model describes the majority of magnetotelluric data character is 3D. The characters of the data dimensionality candescribesthe relevancy of the subsurface resistivity properties with geological structures on surface.

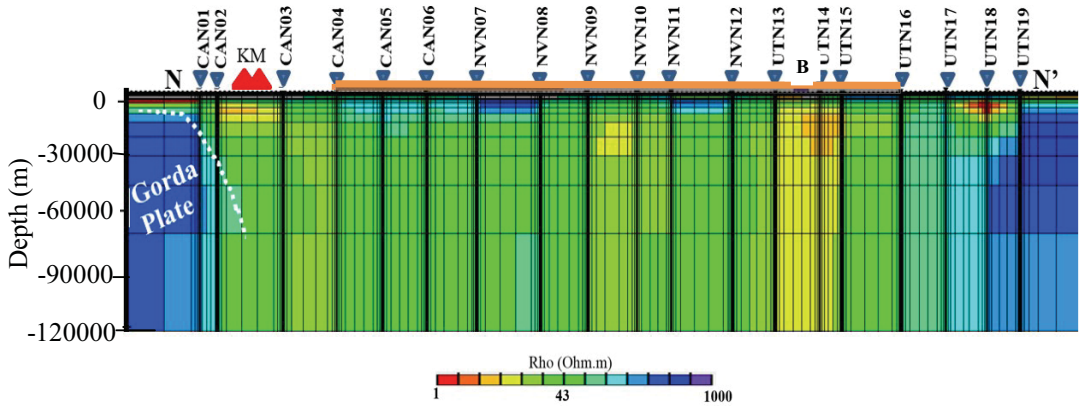
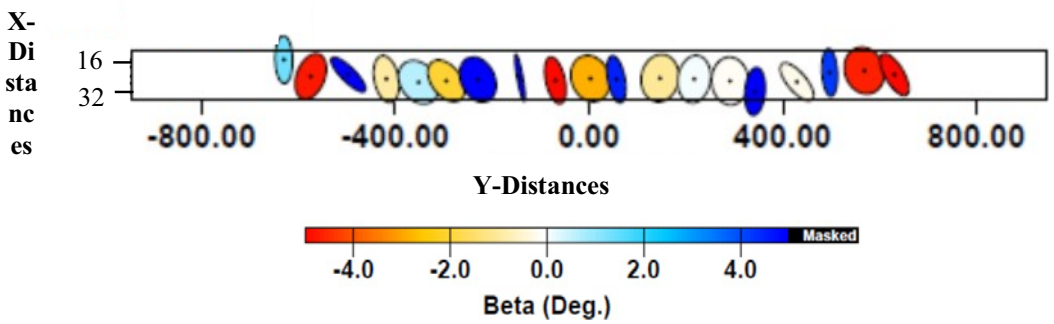


Figure 2:2D resistivity Model of profile N-N'. The Gorda plate subduction is assigned by white dashes and associated to the high resistivity zone. The shallow resistivity values exist below the Klamath Mountain (red triangles) and the Bonneville Lake (BL). The shallow conductivity values are found in the Central Basin and Range province (orange bolt line).

The highest rms value found is 13.237 at UTN18 site in the eastern Utah. The data analysis described at this site was3D character. Moreover, the local conductive anomaly are found in the upper crust (~22 km) underneath this site, but the geological feature on the surface can't be connected. This might be caused by the incompatibility of the 3D data of UTN18 with the 2D inversion magnetotelluric used at shallow depth. Otherwise, the lowest rms value is 1.047 located in Nevada at NVN12 site with 2D character. This site has a low resistivity at shallow/deep depththat relates to the

addition of the widespread extension of Central Basin and Range (CBR) province. CBR is part of a great basin filled with streams flowing into the lakes(e.g Lahontan Lake and Bonneville Lake) or drowning in the valleys [13]. Subsequently,low resistivities(10-100Ωm) in the mid-crustal extend from western Nevada to Western Utah at depths > 20 km. These zones are related to the addition of the widespread extension of the Central Basin Range. Further below the CBR,the low resistivity zones extend to a depth 120 km. These can be explained by magma mobilization from the upper asthenosphere.

Thesubduction zone of the Gorda plate as shown in Figure 2 is characterized by high resistivity (more than 500 Ωm). Thisresistoris continuous from shallow depth to greater depth, and itis interpreted as the body of theGorda plate.Atthe east, the shallow conductorwasfound belowKlamath Mountain (KM)estimatedas a resultof arc magmatism and molten products due to plate subduction[16]. The presence of the melt product is decided as the explanation for the high conductivitiesbeneath fore arc and volcanic arc in the state of California [10]. High conductive crustalalso appears in northeastern Utah that passes the Bonneville Lake. This conductor is associated to fluid content emplaced in shallow depth and magmatism activity from the greater depth (more than



120 km).

Figure 3. The result of Phase Tensor analysis replects the dimensionality of magnetotelluric data in periode 19,6928 s. The 3D characters of data are assigned by the ellips shape with skewness value (β) is less than -3^0 or more than 3^0. The 2D characters of data is showed by the ellips shape with skewness value range is -3^0 up to 3^0. The 1D characters of data has the circle shape and the skewness value is same with 2D character. The dimensionality characters of UTN18 and NVN12 are showed by the red rectangular and the blue rectangular.

3. Conclusion

In summary, the magnetotelluric 2D inversion model has been applied to delineate the subsurface resitivity distribution underneath the western North American plate in the Gorda plate zone. This 2D inversion magnetotelluric model and the characteristic of the short period magnetotelluric data (19s)are correspond to the geological structure on the surface.

4. Acknowledgments

This research has been possible due to the availability of magnetotelluric data from EarthScope USArray Project. The authors are very thankful to the reviewers for their constructive suggestionto improve this paper.

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