Resistivity Image from 2D Inversion of Magnetotelluric Data in the Northern Cascadia Subduction Zone (United States)

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Abstract. Cascadia Subduction Zone (CSZ) lies between Pacific margin and North America plate. The purpose of this research is to identify the CSZ along Oregon, Idaho, Wyoming from conductivity (\(\sigma\)) contrast in the subsurface by using the magnetotelluric (MT) method. MT is an electromagnetic method that use frequency between \(10^{-4}\) Hz and \(10^4\) Hz. We obtained the MT data from the EarthScope USArray in the form of EDI-File (five components of the electromagnetic field). We analyzed the MT data using phase tensor and modeled the data using 2D inversion. From the phase tensor analysis, the 3D data dominated the eastern regions. Global data misfit is 6,88, where WYI18 (close to Yellowstone) contributes misfit of 29,3. This means that the model response does not fit the data, which implies the data is not fully 2D. The 2D inversion results are found high resistivity anomalies (more than 500 ohm.m) at shallow depth beneath Oregon and Wyoming, which corespond to high density anomalies. This high resistivity anomalies might correspond to the north American plate. Thus, it can be concluded that 2D inversion model can be used for most 3D MT data to illustrate the resistivity distribution in the Cascadia Subduction Zone.

1. Introduction

The north western America has more active tectonic than the eastern regions that tend to be more stable [1]. One of the most complex geological structures in North America is the Cascadia Zone [2]. In Cascadia, there is a subduction between the Juan de Fuca (JdF) and the Northern plate [3]. The slab thickness is 75 km that subducts the North American plate with a dip 50\(^{\circ}\) and a rate of 32-44 mm/year [3]. This subduction beneath the North America plate occured in the early Cenozoic [4]. This subduction process is certainly related to the fact of the emergence of the Cascadia Volcanic Arc in the Oregon. Meanwhile, Idaho is surrounded by more varied rock. The emergence of a geological feature found in Idaho such as Columbia river basalt and Snack River Plain [5]. In the North eastern Wyoming revealed the dominance of oldest rock.

In the previous research, it had been shown that the 1D and 3D model of resistivity distribution due to JdF plate subduction using magnetotelluric method [1,6]. In addition, the density anomaly over the research area had been studied using gravity methods [2]. Both of the previous studies results show similarity responses, i.e high resistivity and high-density anomaly beneath the JdF plate subduction area. In the measured MT of the eastern Cascadia detected a very low resistivity to the south [6].
Reviews of the Magnetotelluric (MT) method are provided in some papers and electromagnetic books [7,8]. Magnetotelluric method used natural electromagnetic signals to reveal resistivity distribution in the subsurface [8]. The penetration depth of MT soundings depend on the period and the resistivity [7]. The magnetic field and electric field that are transmitted in the XYZ direction resulted in Ex, Ey, Hx, Hy, Hz components [9].

In this study, we focus on identifying the Cascadia Subduction Zone along Oregon, Idaho, Wyoming from resistivity (ρ) contrast in the subsurface. We used phase tensor method to analyze the MT data. And then, we performed 2D inversion to found out. If the 2D inversion could not resolve fully 3D data, but resolve 1D or 2D data. We also hypotheses that there is an increase in subsurface resistivity throughout the study area beneath the North American plate.

2. The Data Sets and Methods

We downloaded the EDI-file from EarthScope USArray (http://ds.iris.edu/spud). The total stations were 20 points shown in figure 1. At each point of measurements, we needed to insert the coordinates in the website to obtain the data in the form of impedance and frequency (EDI-file). The coordinates in this research are Latitude coordinates from 43,68⁰ to 44,34⁰ and Longitude coordinates from -124,16⁰ to -107,11⁰. Measurement points distance was 70 km for each site from Oregon to Wyoming (figure 1).

![Figure 1](image1.png)

**Figure 1.** Left: Geological map of Oregon, Idaho, Wyoming (United States). The rocks consist of Cenozoic Igneous rock and Cenozoic Sedimentary rock. The MT data are shown by black dots. [10,11,12]. Right: US territory map. The research study is shown by black rectangle [13].

First, we performed the dimensionality data analysis using phase tensor (Φ) [14]. This used to determine the characteristic of data in the research area. This result will reveal the inversion modeling type that corresponds to characteristic data. Data with a 3D character represented by a red or blue ellipse (with a value of β > 3⁰ or β < -3⁰). The 2D character data represented by a white ellipse with β values between 3⁰ and -3⁰. The 1D character data represented by a white circle with the value of β between > -3⁰ and <3⁰ [14]. The phase tensor equation could be written as:

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

(1)

where $X^{-1}$ is the inverse of the X component (the real component), while Y is the imaginary component of the phase tensor.

Then, we performed 2D inversion using NLGC (Non-Linear Gradient Conjugate) [15]. This serves to minimize the residual effects and spatial data of resistivity. The inverse problem could be written as:

$$d = F(m) + e$$

(2)

where $d$ is an observation data, $e$ is an error value, $m$ is calculated data and $F$ is a forward modeling function.
3. Results and Discussion

Figure 2 shows 2D inversion model result after 208 iteration. The red and the blue blocks represent the respectively condition in the subsurface. The RMS value at the last iteration is 6.88. There is a significant contribution of RMS value from the WYI18, which is 29.3. The contribution of a large error value is due to the 3D character data of the WYI18.

![Rho (Ohm.m) with depth and distance](image)

**Figure 2.** Resistivity cross section model along Oregon, Idaho, Wyoming. This model image 2D MT inversion after 208 iteration. Blue color represent the resistive area. ORI03 and WYI18 reveal the high resistivity. The resistivity anomalies are correlates with emerged geology features such as Cascadia Volcanic Arc in Oregon and Yellowstone in Wyoming.

The result of 2D inversion show that the Cascadia Subduction Zone has a high resistivity distribution in the subsurface of Oregon. We found high resistivity (more than 500 ohm.m) at shallow depths of < 20 km and also at 70-120 km depth (beneath ORI03). These results are similar with the previous studies where at a depth of 20-50 km there is a low-velocity anomaly along the western Cascadia boundary [16]. Gravity studies also show an increasing of density anomalies at the depth of JdF plate subduction which is close to high resistivity anomaly beneath ORI03 [2]. Beneath Wyoming, high resistivity anomaly is found near to the surface (about 10 km depth). At WYI17 and WYI 18, below the resistor, there is a conductive anomaly (i.e. < 7 ohm m), which might corresponds to the Yellowstone geothermal area [1].

![Log Period and Beta](image)

**Figure 3.** The Phase Tensor of 20 sites on period of 11.6 s. The ellipse colour represent beta (β) value. This value describes the character of the data. The 3D data is represented as red (β < -3) or blue (β > 3).
The dimensionality analysis results are shown in the period of 11.6360 s and beta variation (\(\beta\)) (see figure 3). The short period corresponds to a shallow depth, which correlates to the geological features in the surface. Additionally, the skew variation shows the data characteristics. The phase tensor over a given period illustrates the lateral changes of the conductivity structure at a depth corresponding to that period. From this analysis, the red phase tensor and blue ellipses are found in the eastern region, which correspond to the 3D character, including MT sites of WYI 18. Although at the short period the data is relatively 2D, but at the long period the data are 3D. As in WYI18 there is a failure of 2D inversion particulary at depths > 50 km, which is indicated by a high RMS error value (i.e 29.3) and orange ellips phase tensor. That is indicates the data at this MT site is 3D.

4. Conclusion
From MT studies in three countries in Northwestern America (Oregon, Idaho, and Wyoming), we found that the high resistivity anomalies in two sites (Oregon and Wyoming). This high resistivity value is more than 500 Ohm.m is seen at shallow depths (< 20 km). In the western regions tend to be more resistive than the east. At the east of the study area, there is a high conductive anomaly that corresponds to Yellowstone geothermal area.

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