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Research Article

Two-dimensional Regional Scale Resistivity Model of Western Part of United States of America based on Magnetotelluric Data

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Abstract: The North American continent has complex geological phenomena. Especially, in the western part of the continent are the Cascadian subduction zone (CSZ) and volcanic arc chain. Some hypotheses of the CSZ associated with volcanism commonly correspond with the low resistive anomalies. Here, 21 very low frequencies of the MT data from the USArray along Oregon to Wyoming were used to image the resistivity distribution below western part of America continent. The spacing between the measurement sites was 70 km. The two-dimensional (2D) inversion results of the MT data displayed some subduction slab approximately until the depth of 50 km. The CSZ corresponds to moderate resistive anomaly of 64 Ωm to 256 Ωm, and the Wyoming Craton was imaged as the resister that identified as stable archean lithosphere. The 2D MT inversion resulted in similar resistivity distribution with 3D MT inversion results for some depth. From this study, it can be concluded that the CSZ zone can be depicted in the western part and Wyoming Craton in the eastern part of study area.

Keywords: 2D inversion, 2D model, MT data

1. INTRODUCTION

The unique geological condition in the North America continent is the result of convergence between oceanic plate and North America plate. The result of the convergence is the establishment of Cascadian Subduction Zone (CSZ) which is formed in 30 Ma [1]. The CSZ is elongated from Vancouver to California and divided into three main plate from north to south: Explorer, Juan de Fuca, and Gorda. This study is focused in Juan de Fuca plate which subduct beneath the North America continent.

The subduction performs the formation of volcanic arc and dilates with north-south orientation. Juan de Fuca plate moves (30 to 40) mm yr^{-1} with (30 to 50) km thickness [2]. The acquisition points are perpendicular to the CSZ direction and located along Oregon, Idaho and Wyoming districts.

Previous studies imaged the CSZ based on P-wave and S-wave velocity values [3]. Tomography study used 1 883 earthquakes from 350 permanent stations. The result showed that a high-velocity value is located in the CSZ and a low-velocity value is located around volcanic arc. Another study about resistivity mapping shows that the interfacial boundary between Juan de Fuca plate and North American plate is like a thin conductor caused by the presence of fluid [4].

In order to understand the resistivity variation of the subsurface, a 2D inversion of magnetotelluric data using a non linier conjugate gradient was performed. An MT is suitable for imaging geological targets until hundreds of meters. The 2D MT inversion was analyzed and then the 2D model with the 3D model were compared. The CSZ corresponds to resistive zone and volcanic arc correlates with conductive zone due to expected fluid content.

2. THE DATA SETS AND METHODS

Fig. 1 represents the location of the study area around CSZ zone. The red dots (check in symbol) show the location of the recording stations. Here, long period magnetotelluric data from the US Array (10^{-1} s to 10^{-4} s) were used. The total

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stations were 21 points with 70 km spacing. The stations are along the western to central part of the North American continent (Oregon to Wyoming). The data were collected with a sampling rate of 1 Hz, using fluxgate magnetometer and non-polarizable lead-lead chloride electrodes, with 3 wk minimum recording [5].

The data dimensionality were analyzed using polar diagram and phase tensor. The data analysis reveal that most of the data are 3D as shown in Fig. 2. However, in this study, the 2D inversion was used though, to find out whether the CSZ still can be imaged because of resource limitation in 3D inversion software and to show how reliable the result.

Initial model is a homogenous half space model. Resistivity distribution in the 2D inversion uses a finite difference method, where the distribution is imaged by block (mesh). The model parameters used in this study are weight function, error floor, and smoothing operator. The weight function used in this study is 1.2 in vertical and horizontal direction while the error floor threshold at 50 % for error rho and 5 % for error phase. One of the important parameter is smoothing operator ($\boldsymbol{\tau}$). The smoothing operator is determined using L-curve analysis with the amount result is 5. The inversion is done with 100 iterations. The 2D inversion uses NLGC (Non-Linier Gradient Conjugate) algorithm [7]. The inverse problem could be written in Equation (1):

$$d = F(m) + e\,, \tag{1}$$

where d is a data vector, e is an error vector and F is a forward modeling function. The forward modeling function basically is differential equations derived from Maxwel equation for TE polarization (Equation 2) and TM polarization (Equation 3).

$$H_y = -\frac{1}{i\omega\mu_0}\frac{\partial E_x}{\partial z} \tag{2}$$

$$E_y = \rho\frac{\partial H_x}{\partial z} \tag{3}$$

The NLCG inversion aim to minimize the value of objective function which is the smaller value of misfit result the appropriate model. The objective function could be written as:

$$\Phi(m,\tau) = \Phi_d + \tau\Phi_m \tag{4}$$

Where $\boldsymbol{\tau}$ is regularization parameter from misfit between observed data and calculated data (Φ_d) to roughness model (Φ_m).

3. RESULTS AND DISCUSSION

Fig. 3 shows the results of the 2D inversion with overall rms error is 4.7 %. This is caused by the misfit error each sites vary from 0.7 % to 18.8 %. The great value of misfit is caused by the 3D data characteristic. There are two resistivity structures, indicated by red and blue colors. The red color represents conductor while blue color indicates resistor. There are many explanations for the regions with high conductivity, including free aqueous fluid, partial melt, and mantle upwelling zone.

The high conductive area below the Cascadia Volcanic Arc (CVA) in Fig. 2 indicates partial melt in the crust. This zone is the result of the Juan de Fuca subduction plate. High conductive anomaly is also found at the MT sites of ORH04 – ORH05 named as Back Arc Conductor (BAC). The BAC anomaly correlates with the upwelling astenopheric corner flow caused by the subduction [8]. The low resistive anomaly (1 to 100) Ωm in the Snake River Plain (SRP) zone indicates the presence of sub-moho layer and uppermost mantle flow [9]. The eastern conductive anomaly in Cheyenne Belt (CB) is resulted in because of metamorphose and presence of graphite and sulfides minerals [10].

Besides, a high resistive zone in the eastern part of the study area was found. A high resistive value in this zone correlates with the stable archean lithosphere, i.e. Wyoming Craton (WYC) [11]. This WYC anomaly is present along Montana to Wyoming states. This resistive area beneath the MT sites of MTH15, MTH16, WYYS1 and WYYS3 could be caused by the volcanic rocks. Below the MT sites of WYYS1 and WYYS3, there is a high conductive anomaly that is interpreted as Yellowstone plumes head (YPH). This YPH zone is marked by brown dash line that reaches the earth surface.

The 2D model inversion result show not quite similar result with the 3D inversion model. The comparison of those two models show in Fig. 4. The 3D model shows distinctively Juan de Fuca slab with high resistivity value but in 2D model the Juan de Fuca is not shown clearly. The Back Arc Conductor (BAC) beneath Oregon district is found in 3D model and 2D model as well but the high resistivity value (R1) at depth 100 km to 200 km along Oregon – Idaho which is shown in 3D model unable to identified in 2D model. Based on

Fig. 1. Acquisition point of MT data map. Red dots show measured points of MT data. The acquisition starts from Oregon to Wyoming districts (west to east).

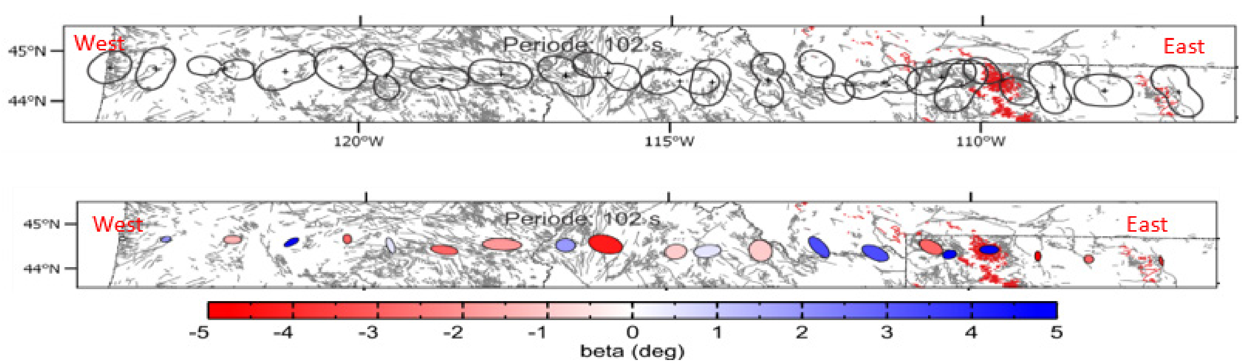

Fig. 2. The dimensionality analysis using polar diagram (up) and phase tensor (down). Based on polar diagram analysis data with 3D dimensionality shaped like peanut shell, 2D data shaped like ellipse and 1D data shown as circle. While the characteristic data from phase tensor analysis, 3D data shown as ellipse ($\beta > -3^o$ atau $\beta > 3^o$), 2D data shown as ellipse ($-3^o < \beta < 3^o$), and 1D data shaped like circle [6].

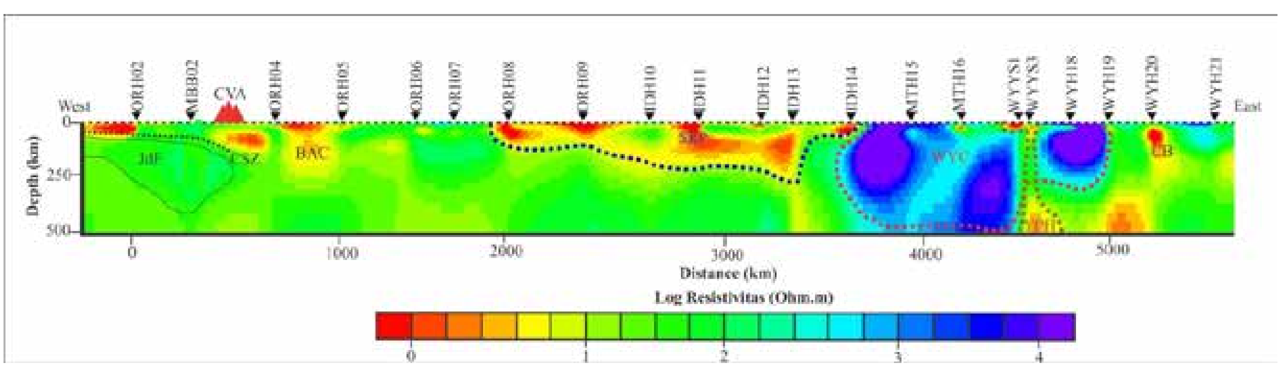

Fig. 3. The cross-section of the resistivity model from west to east along North American continent (Oregon to Wyoming). Black dash line shows the subduction zone of the Cascadian Subduction Zone (CSZ). Below the CSZ, the solid black line interpreted as Juan de Fuca slab (JdF). Red triangle represents Cascadia Volcanic Arc (CVA). BAC is Back Arc Conductor. Blue dash line shows the SRP (Snake River Plain) zone. Red color marks as the highest resistivity value interpreted as the WYC (Wyoming Craton). The brown dash line indicates as the YPH (Yellowstone Plumes Head). The YPH is located in the middle of WYC. CB is Cheyenne Belt where the conductive area is presented.

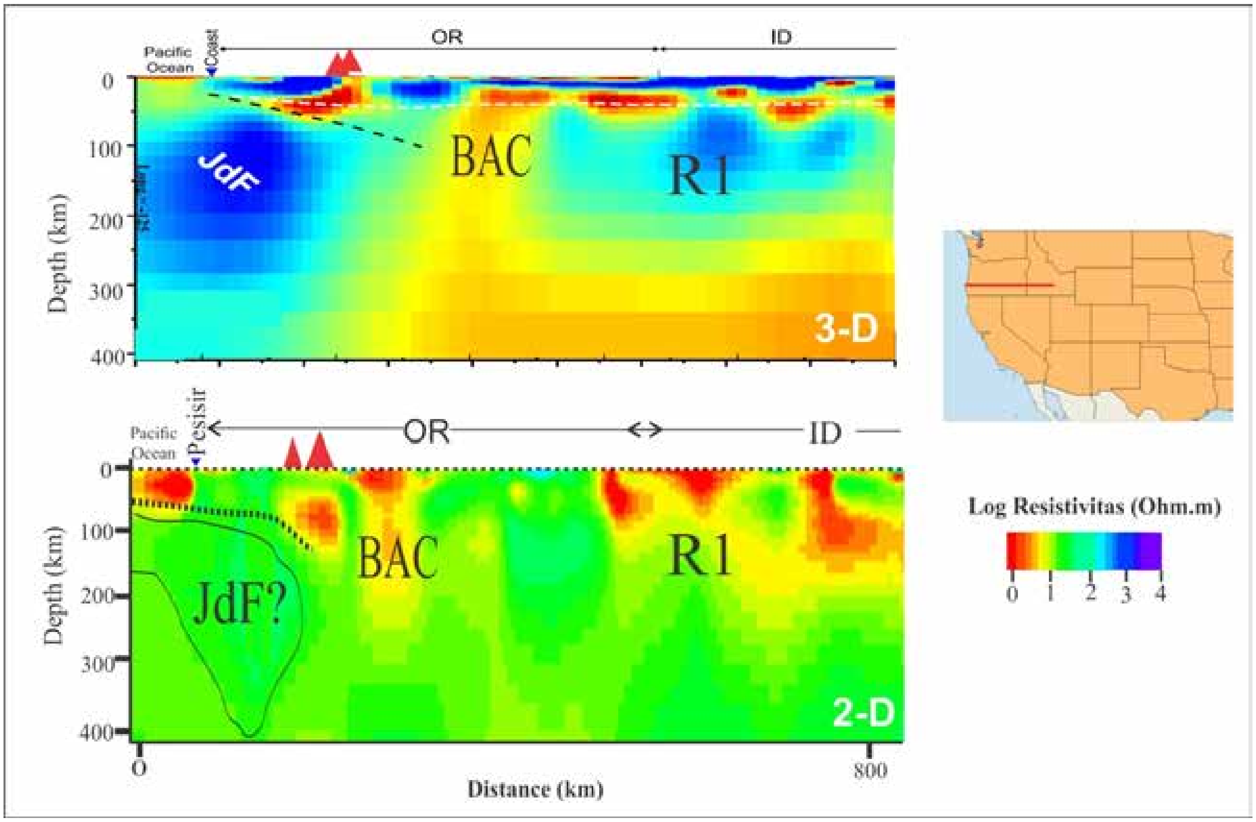

Fig. 4. The comparison between 3D [8] (up) and 2D (down) modeling result. This comparison is only done from west coast Oregon to some sites in Idaho. The red triangle represents Cascadia volcanic arc.

the comparison of the two models show adequate similarities only at near surface depth (0 km to 50 km) for example the Pasific ocean and the magmatism beneath Cascadia volcanic arc. This is caused by the near surface data is still affected by 2D structure but the deeper data (> 50 km) it's become more complicated structure (3D data characteristic) so that will affect the 2D inversion result.

From the 2D inversion model, the Cascadian subduction zone (CSZ) is not clearly imaged because the Juan de Fuca slab that subduct beneath North America continent is not present in 2D model. Nevertheless from the previous study noted that the subduction zone is found at 50 km depth so it can be expected that the CSZ is located at the same depth in the 2D model. The reason is the present of Pacific ocean in 2D and 3D clearly show the interface boundary between low and moderate resistivity zone. Beside that the present of magmatism because of the partial melting of the slab beneath Cascadia volcanic arc also act as major evidence the present of CSZ in the 2D model that elongated from resistivity contrast in the west which increasingly piercing as shown in Fig. 3 (dash lines).

4. CONCLUSIONS

The Cascadia subduction zone (CSZ) is not clearly shown in 2D model but still can be identified at 50 km below the surface. The 2D inversion on 3D charasteristics will give actual result at near surface otherwise at a very deep depht the result should be adjusted with 3D inversion. Based on 2D model the eastern part of the sudy area shows high resistivy zone because the present of Wyomming craton and the near surface shown as conductive zone. Different from the western part, in the east of the study area, the highest conductive area are shown.

5. OUTLOOK

The authors suggest to do 3D inversion around conductive area and identify the regional geology in detail. It will be better if we know the direction of the subduction below the North American continent and the plumes head.

6. ACKNOWLEDGMENTS

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