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Spatial Gravity Analysis of the Cascadia Subduction Zone using Satellite Data

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Abstract. Cascadia Subduction Zone is a subduction zone elongated about 1000 km length. The remnants of Farallon plate subduct the North American plate and form this subduction area. One of Farallon plate remnants, i.e. Juan de Fuca plate, subducts dominantly the North American plate. We focused on the observation of three states, i.e. Oregon, Idaho, and Wyoming. This research aims to determine the direction, the shape, and the initial coordinates of subduction in our study area. We obtained free air corrected gravity data from TOPEX. Then we visualized data to get contour map and found that Cascadia Subduction Zone has direction from west to east that can be proofed by increasing of gravity anomaly. The gravity anomaly ranges from -140 mGals until 320 mGals. We applied upward continuation and got the result that the subduction is elongated from north to south. Initial coordinate detail of subduction shown by SVD result. The subduction starts from coordinate 46.811° Northern Hemisphere and Longitude of 123.436° into 41.260° Northern Hemisphere and longitude of -123.204°. This coordinate appropriate with the result of magnetotelluric research that shows a high resistivity. We can conclude that from gravity satellite data, we can visualize the contour map then take several steps to get details information of subduction.

1. Introduction

A geological condition in Northern American plate, particularly in the Northwestern United States shows complex geological features. This complexity was started on 150 Ma resulted in the Farallon plate subduction. It shaped the Pacific Northwest and affected its upper mantle and crust [1]. The convergence between the subduction zone of the North American west coast and the East Pacific Rise caused a fragmentation of Farallon plate [2,3]. Since Oligocene era, Farallon plate was divided into Juan de Fuca plate, Cocos plate, Nazca plate, and several microplates [4].

Juan de Fuca plate is an oceanic plate that subducts the Northern American plate along the Cascadia Subduction Zone. The subduction of the Juan de Fuca Plate towards Northern America plate had 50° of dipping, ~ 400 km of depth, and ~75 km of thickness [5]. This subduction moves 30-45 mm/year [6]. Cascadia Subduction Zone that elongated about 1000 km can be included as a vulnerable area and has a high possibility of earthquakes [7]. One of the influencing factors of seismic activities is the geometry of subduction slab [8]. Oceanic plates usually brought chemical and physical bound water into subduction zones [9]. The result of this subduction emerges some geological features in the Northwestern United States, i.e. Oregon, Idaho, and Wyoming.



Previous research studied about the model of lithospheric structure because of Juan de Fuca Plate's influence towards the Cascadia Subduction [10]. This gravity inverse study used a density-depth relation in the subducted slab and oceanic asthenosphere beneath Vancouver Island and Oregon. The result showed that the down going slab is steeper beneath Oregon than beneath Vancouver Island.

In this research, we used secondary data. We analyzed the Cascadia Subduction Zone in the Northwestern United States spatially. The spatial analysis involves several factors, i.e. direction, shape, and the initial coordinate of Cascadia Subduction Zone in our study area.

2. The Data Sets and Methods

In geophysics, the spatial analysis can be used for many applications. Spatial analysis is the previous step before modeling. Modeling of gravity anomaly data aimed to estimate the geometry, depth, and densities of an object [11]. In this research, we used gravity secondary data from http://topex.ucsd.edu/cgi-bin/get_data.cgi in free-air corrected format data with ± 1.25 km in space. These data were a satellite data based which is already resulted in free air anomaly map [12]. The longitude-latitude coordinate taken was 40° to 48° Northern Hemisphere and -126° until -103° . Our research focus is in the Cascadia Subduction Zone, particularly subduction from Juan de Fuca plate towards North America plate through Oregon, Idaho, and Wyoming.

The next step was creating a contour map. We separated the regional and residual anomaly used upward continuation. We used 230.000 m of upward continuation. Upward continuation will eliminate the local anomaly gravity data in our contour map. The principle of this separation used low pass filter to get the low frequency. In this upward continuation step, we used equation (1) [13]:

$$U(x, y, z_0 - \Delta z) = \frac{\Delta z}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{U(x, y, z_0)}{\left[(x - x')^2 + (y - y')^2 + (\Delta z)^2 \right]^{\frac{3}{2}}} dx' dy' \quad (1)$$

The general problem in the interpretation of anomaly map is that it is hard to handle the effect of shallow structure from the deeper-seated ones. The result of removal regional field effect is the indeterminate and non-unique set of residuals. Second Vertical Derivative (SVD) can be used to determine the shallow and deeper structures [14]. SVD is often used to enhance the structures of localized near-surface [15].

3. Results and Discussion

Oregon, Idaho, and Wyoming are three states located in the Northwestern United States. For prior information, the rock arrangement in Oregon is dominated by young rocks. Idaho has the most varied rock types and unit ages. Wyoming has the oldest rock age than Oregon and Idaho. So we have a prior hypothesis that Wyoming is the state that has the longest distance from the Juan de Fuca subduction zone boundary.

We got topography and gravity data from TOPEX. We used topography data to know the space line of gravity data. From gravity data downloaded, we got the anomaly gravity response in the observational area. The difference color of contour map shows the difference value of gravity anomaly. The highest value of gravity anomaly showed by dark red color whereas the lowest showed by black color. It ranged from -140 mGals until 320 mGals as shown in Figure 1. As we know, one mGals is equal to 1 cm/s^2 .

The initial area of subduction zone showed by a specific increase of gravity anomaly. Further, we can confirm it by upward continuation step. There are weak zones around the subduction that dominated by purple color. These weak zones have a high possibility of earthquakes and hazards around Cascadia Subduction Zone.

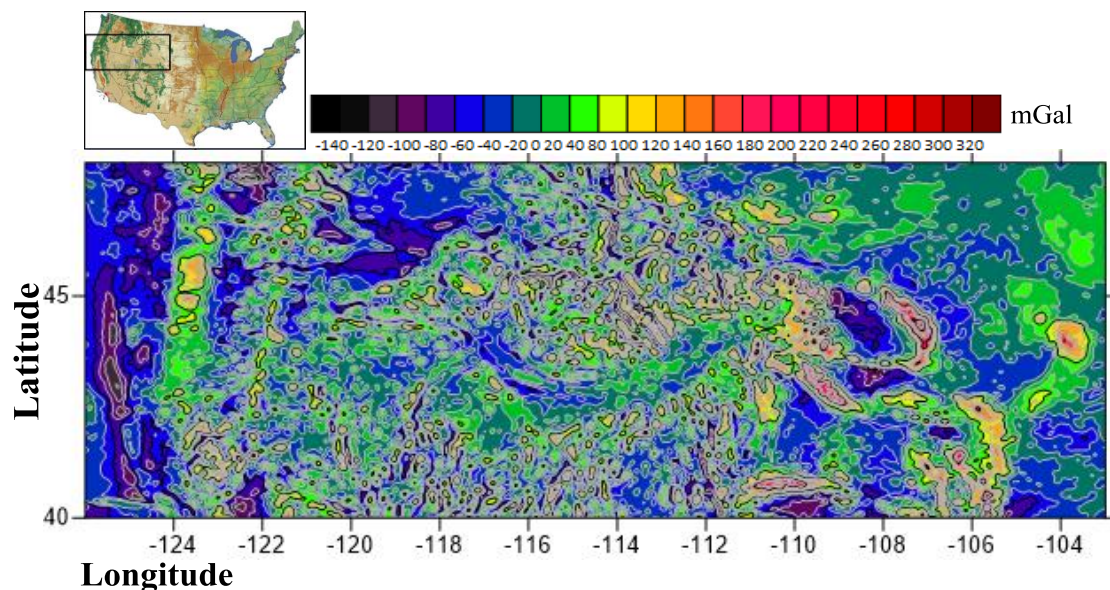


Figure 1. The picture shows gravity anomaly of the study area. The map shows gravity anomaly in the coordinate 40° until 48° and -126° until -103° . In the west area, the dominant color of the map is dark purple. This color indicates low gravity anomaly. In the east area the red color that indicates high anomaly gravity. These value can be associated with the geological features, i.e. Yellowstone plume. Inset: American continent (Source: [16]).

Figure 1 shows the differences of gravity anomaly that illustrated by different color scales. High gravity anomaly lies dominantly in the east. Our hypothesis is the gravity anomaly increased from west to east. This fact can be attributed to the direction of Juan de Fuca plate subduction towards North American plate. Juan de Fuca subduction stretched from west to east, particularly in our observation is from Oregon to Wyoming. The highest gravity anomaly lies around the coordinate -110° BB because there are geothermal areas of Yellowstone.

After we got the gravity anomaly map, we used upward continuation to separate the regional and residual gravity anomaly. In this case, we took the regional gravity anomaly because the study area is large. Upward continuation process was done by software with several limits (i.e. 13.000 m, 20.000 m, 30.000 m, 40.000 m, 50.000 m, 60.000 m, 70.000 m, 80.000 m, 90.000 m, 100.000 m, 200.000 m, and 230.000 m). From the visualization of several limits of upward continuation, we finally decided to used 230.000 m. The reason for this decision is because the regional anomaly looks clearest in height 230.000 m than another limitation (Figure 2).

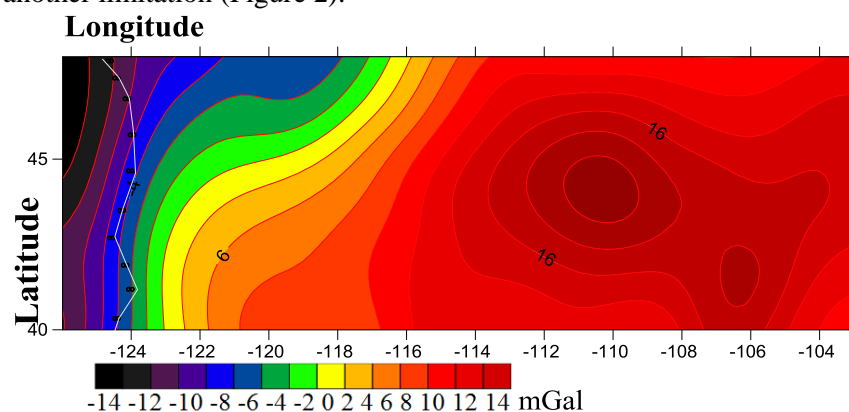


Figure 2. Gravity anomaly map of 230.000 m upward continuation. The gravity anomaly increased from black into red. The gravity anomaly value increased from west to east. It means that our early hypothesis is true. The white line shows the coastline.

Figure 2 shows the difference of gravity anomaly regionally. The result of upward continuation step confirmed our hypothesis before. There is an increase of gravity anomaly from west to east that can be correlated with the Juan de Fuca oceanic plate subduction towards North American plate. In the study area, i.e. Oregon, Idaho, and Wyoming, there is an increase of gravity anomaly too. Further, we can use SVD (Second Vertical Derivative) to know the initial coordinates of the subduction zone in the gravity anomaly map from 230.000 m of upward continuation. Gravity anomaly map after SVD process is shown in Figure 3.

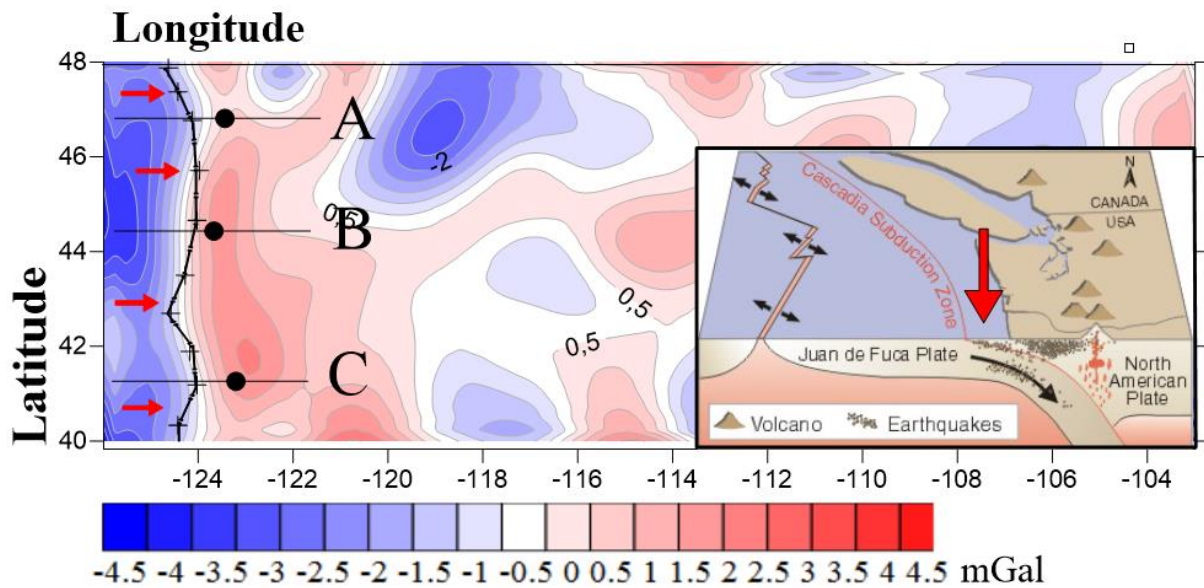


Figure 3. Gravity anomaly map after SVD process. There is contrast color from one area and others. The Juan de Fuca oceanic plate dominated by blue color. It shows a low gravity anomaly. The boundary of Juan de Fuca plate and the North American plate is dominated by white color that shows higher gravity anomaly. The increase of gravity anomaly can be correlated with the beginning of Cascadia Subduction Zone. Line A, B, and C show the position of slice. Black line shows the coastline whereas black dots show the beginning of subduction zone in our slices. Inset: Cascadia Subduction Zone (Source: [17]).

Figure 3 displays increasing gravity anomaly from the west coast to the east, as indicated by blue color (low anomaly) and red color (high anomaly). From the figure, we can conclude that the subduction has an elongated shape from North to South. The details coordinate of beginning subduction zone can be known by slicing the SVD map. We slice in three lines (i.e. line A, line B, and line C). From three slices, we got the graphic as shown in Figure 4.

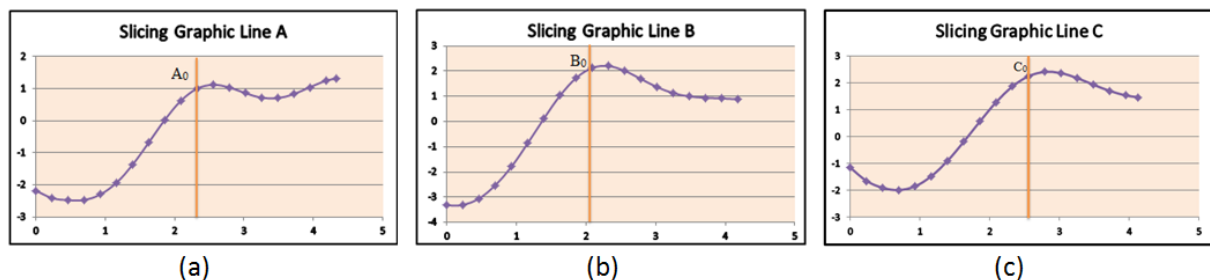


Figure 4 (a, b, c). The picture shows the slicing graphic of SVD anomaly from three lines. There is a similarity from these graphics. Similarity can be shown by the graphics that start with the low value and then increased. The orange line shows the beginning of subduction.

Similarity of three SVD curves can be correlated with the gravity anomaly, which shows the increasing density from Juan de Fuca oceanic plate, the beginning of subduction to the North American Plate. The orange line of each curve in Figure 4 indicates the beginning of subduction from North to South in 46.811° to 41.260° Northern Hemisphere and longitude of -123.436° until -123.204° .

4. Conclusion

Cascadia Subduction Zone formed by the Juan de Fuca oceanic plate subduction towards the North American continental plate. The subduction is elongated from north to south that starts from coordinate 46.811° to 41.260° Northern Hemisphere and longitude of -123.436° into 123.204° in the study area. Cascadia Subduction Zone has the direction from west to east that can be proofed by the increase of gravity anomaly from -140 mGals into 320 mGals.

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