Spatial Analysis of Gravity Data in the California, Nevada, and Utah (US)

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Abstract. The geological condition of western North America is very complex because of the encounter of three major plates namely North America, Juan de Fuca, and Pacific Plate. The process of Juan de Fuca subduction and Pacific transform against North America plate created many mountains and produced Great Basin that we can see extending across California, Nevada, and Utah. The varied natural condition causes the varied value of gravity anomaly distribution. Using Topex free-air anomaly analyzed with second vertical derivative (SVD), we can analyze the fracture structures that occur in the Great Basin. The results show that the maximal SVD anomaly value is higher than the minimal SVD anomaly value at the western and eastern border of Great Basin. This explains that the two of Great Basin border are normal faults with trend direction NW-SE in the western boundary and NE-SW trending in the eastern boundary. This research result corresponds with the high seismicity data along the fault. Through this research, we can know that topex free-air anomaly data can be used to determine the type and trend of fault on a regional scale.

1. Introduction
Subduction of Farallon plate begun in the Mesozoic era had dominated the geological history of western North America [1]. At the late of Mesozoic, the Farallon plate subducting the North America plate moved upward to form a horizontal slab beneath North American Plate [2]. About 30 million years ago, end of the Farallon plate produced triple junction in western California and divided the Farallon plate into two parts, namely Juan de Fuca in the north, and Cocos in the south [3]. Relic of the Farallon plate is moving down towards the North America plate until now, but a drastic decrease in slope occurred to a depth of 400 km. It was caused by the presence of the plume about 17 million years ago [4, 5]. The occurrence of this plume produced upwelling of the asthenosphere, thinning of the lithosphere, extending zone and normal fault in the western North America to form Great Basin and Range that extended throughout Nevada to Utah [6].

The Gorda plate is the southernmost part of the Juan de Fuca plate system, which subducts the North America plate towards N 50°E – N 55° E [7]. The encounter of 3 plates between the Gorda, Pacific, and North America plate greatly affected the geological condition of the western North America region. This encounter was referred to as Mendocino Triple Junction (MTJ) where the Pacific plate that moved to the northwest pushes the Gorda Plate. The area with high seismic is located in the San Andreas Fault which marks the boundary of the Pacific-North America plate [8]. The change in the movement of the Pacific plate from the azimuth N60°W to the N37°W caused an extension.
between the Sierra Nevada and the Colorado Plateau. This was related to the stretching of the Basin and Range areas [9]. Basin and Range’s eco region spans an area of 343,169 km², mostly in Nevada (65.4%), Utah (25.1%) and the rest are scattered in several other states [10].

The varied natural appearance is highly correlated with its gravity value. In this research, we used secondary data obtained from http://topex.ucsd.edu/cgi-bin_data.cgi to analyze spatially the region of western North America. The accuracy of topex data always increases significantly through GPS to get a more precise orbit point [11]. Our research area map can be seen in Figure 1.

![Geological map of California, Nevada, and Utah.](image)

Figure 1. Geological map of California, Nevada, and Utah. Generally, surface appearance in the California is dominated by igneous rocks in the Sierra Nevada and sedimentary rocks in the Great Valley. Nevada and Utah are dominated by sedimentary and metamorphic rocks throughout the Basin and Range region [12, 13, 14].

2. Method

In this research, Topex free-air anomaly data that were used to map faults in the Great Basin area were obtained via http://topex.ucsd.edu/cgi-bin/get_data.cgi. The free-air data were better used to delineate deeper basin than shallow dip [15]. The coordinates of this research area were 112°W-127°W and 37°N-42°N. To separate residual and regional anomalies, there were several frequently used methods such as Continuation, Moving Average, Polynomial, Griffin, and visual methods. We used upward continuation to separate residual and regional anomalies up to 50km. This method applied the Blakely equation [16].

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

(1)

\(U (x, y, z_0 - \Delta z)\) is the potential value in the continuation result field, \(\Delta z\) is the value of upward, and \(U(x', y', z_0)\) is the potential value in the observation field. After doing upward continuation, regional anomaly data were analyzed using Second Vertical Derivative (SVD) to see the fracture structure. SVD is a method that can be used to see the effect of gravitational gradient on mapping [17].

By analyzing the maximum and minimum values of SVD, we can determine the type of fault occurring at that location [18]. With the equation :
For normal faults:
\[
\left(\frac{\partial^2 \Delta g}{\partial x^2}\right)_{\text{max}} \geq \left| \left(\frac{\partial^2 \Delta g}{\partial x^2}\right)_{\text{min}} \right|
\]  
(2)

For reverse faults:
\[
\left(\frac{\partial^2 \Delta g}{\partial x^2}\right)_{\text{max}} \leq \left| \left(\frac{\partial^2 \Delta g}{\partial x^2}\right)_{\text{min}} \right|
\]  
(3)

With \(\frac{\partial^2 \Delta g}{\partial x^2}\) is the second vertical derivative of \(\Delta g\), and \(\Delta g\) is the value of gravity anomaly.

3. Results and Discussion

Based on free-air anomaly data from Topex, the gravity response anomaly results in the range of -160mGal/\(\theta^2\) to 280mGal/\(\theta^2\), as shown in Figure 2.

![Figure 2](image)

**Figure 2.** Map of free-air gravity anomaly distribution in California, Nevada, and Utah. High anomaly values are marked with red color and low anomaly values are marked with blue to purple color. The black line is the boundary of the three countries.

![Figure 3](image)

**Figure 3.** Mapping of SVD analysis results in overlay with seismicity data. Red color describes the high anomaly response and blue color illustrates the low anomaly response. A, B, C, D, E, F, and G slices are made along the area that is assumed a fault because having a high anomaly contrast.

Figure 2 shows the gravity anomaly response caused by the variation of rock density in the research area. The high anomalies associated with Cascadia volcanic arc and the Sierra Nevada mountains located in California and the western rocky mountains in Utah. In the Nevada state, we can see that
there are repetitive high-low anomalies. These are related to the Great Basin area along Nevada country. After doing upward continuation to eliminate local anomalies, we used SVD analysis with results in Figure 3.

The SVD anomaly contour that is shown in Figure 3 shows the anomaly values between -250 to 400mGal/θ². The white color on the map illustrates the zero anomaly value that correlates with the lineament of fault. This corresponds with another study that in the eastern Great Basin there is a Wasatch fault that extends along 370km and has 6 large segments such as Brigham City Segment, Weber Segment, Salt Lake City Segment, Provo Segment, Neph Segment, and Levan Segment [19]. In the western Great Basin bordering on the Sierra Nevada mountains, there is Sierra Nevada Fault [20]. The cross-section pattern on SVD anomaly map in figure 3 is made of curves can be seen in Figure 4.

Figure 4. A, B, C, and D slices illustrate the SVD values at the western Great Basin boundary while E, F, and G Slices represent the eastern Great Basin boundary. A black line extending on the zero Y-axis signifies the high and low anomaly boundary of the SVD anomaly contour pattern.

From figure 4, we can see that from all slices, both of western and eastern frontier of Great Basin indicate that the maximum value of SVD is higher than the minimum value of SVD. Based on equation (2) and (3), we can know that the fault on the western and eastern Great Basin is a normal fault.

4. Conclusion
Through this research, we can conclude that topex free-air data can be analyzed using SVD analysis for regional coverage area. With SVD analysis we can also get the direction of the fault lineament. It can be seen from the lineament of normal fault in the western Great Basin with NW-SE trending and in the eastern Great Basin with NE-SW trending.

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