2-D potential field modeling across the Hawtmi and Wiahatya faults in search of geothermal resources within the Umatilla Indian Reservation

Grober, Benjamin L.[1] & Palmer, Zachary A.[1]

[1]U.S. Geological Survey, 345 Middlefield Rd, MS 989, Menlo Park, CA 94025, United States

Abstract

The Bureau of Indian Affairs offered a grant to investigate the potential for geothermal resources on the Umatilla Indian Reservation. The resources could potentially be used for power and heat production to make the reservation energy independent. The USGS and AltaRock partnered together to conduct a primary investigation which included potential field and other surveys, such as: gravity, aeromagnetic, LiDAR, magnetotellurics, and paleomagnetics. These surveys primary purpose is to be used to constrain 2-D potential field models. The geology of this region is dominated by the Columbia River Basalts and extensive faulting and folding. Active faulting is the primary method by which hydrothermal fluids reach the surface. Using the post processed gravity and magnetic data, 2-D models were created from two profiles lines placed across major faults in the region. The models allowed for accurate depictions of geologic units and structures in the subsurface. The models are limited in that they are non-unique and require additional surveys to further constrain them.

Introduction

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) are seeking to become energy self-sufficient. If sufficient geothermal resources are found, the energy could be used for heat and power production. To this end, the Bureau of Indian Affairs offered a grant to assess the possible geothermal resources located on the Umatilla Indian Reservation. The USGS partnered with AltaRock Energy and CTUIR to begin conducting data collection in the region. The geology of the region is dominated by basaltic lava flows and pervasive faulting. Multiple geophysical methods were used to collect data in the region, including: gravity, aeromagnetic, magnetotelluric, LiDAR, and paleomagnetic. Hand samples were also collected and rock properties measured to constrain the potential field models. This report will focus on the use of Geosoft's Oasis montaj to grid and model the collected data, and the creation and interpretation of a 2-D potential-field model created using the GM-SYS extension.

Geology and Structure

The Umatilla Indian Reservation sits on 172,000 acres of land. It is situated in Northeast Oregon on both sides of the Columbia River, between the Blue Mountain Uplift and the Columbia River Basin. The study area is 1,926 square kilometers including and surrounding the reservation. The geology of the region is dominated by the Miocene age Columbia River Basalt, overlaying Cretaceous bedrock. The main formations of the Columbia River Basalt are the Imnaha, Picture George Basalt, Grande Ronde, Wanapum, and Saddle Mountai (Tolan et. al.,1989). The main formations of the study area are the Grande Ronde and the Wanapum. The Grande Ronde formation is Lower to Middle Miocene in age. It consists of 110+ eruptions, amounting to over 150,000 km^3 of basalt. There are both normal and reverse polarity flows present (Reidel and Tolan, 2013). The Wanapum is middle Miocene in age, and it conformably overlies the Grande Ronde. It is an olivine and plagioclase rich basalt and basaltic andesite that are normally polarized. The Wanapum is on average 120 meters thick and covers a volume of 10,800 km^3 (Swanson et. al, 1979). Overlying the Frenchman Springs member of the Wanapum is the Dalles Group McKay Formation. The McKay formation consists of a basalt conglomerate, a partially carbonate-cemented basalt gravel and interbedded tuffaceous sand and silt (Farooqui et. al., 1981). The McKay formation is between 2 and 72 meters thick. Quaternary sediments overlay much of the Western half of the study area.

Wide scale faulting is pervasive throughout the study area. The main fault zones in the region are the Wiahatya, Hawtmi, and Thorn Hollow. The Wiahatya is an Eastern trending fault, and the Hawtmi and Thorn Hollow are both Northeastern trending. The area is also known to have plentiful dike swarms. The largest of these dike swarms is the Chief Joseph Dike Swarm, which covers much of the surrounding area. The region is also home to many folds, but these are less prevalent than the faults. The extensive faulting has allowed hot, geothermal fluids to rise through the cracks to the surface. This has resulted in several hot springs existing in and around the reservation. The wells within the reservation also show elevated temperatures. It is this extensive faulting, combined with the existence of several hotsprings, which provides the basis for the belief of the potential geothermal applications of the region.

Surveys and Methods

Many different types of surveys were used to collect data for this study. For the gravity survey, a gravimeter was used to measure the relative gravity at different stations. Those relative gravity measurements were then converted into absolute gravity measurements. In total, over 1300 stations were taken. Each station was driven to, and then measured by placing the gravimeter on the ground and leveling it. Two measurements were taken at each station, and the terrain correction was calculated. Rock samples were also collected at stations with nearby outcrops to be used for further density and susceptibility measurements. Stations were chosen based on their accessibility and nearby faults. More stations were placed around structures such as faults. The results of the gravity survey could be used to find gravitational anomalies that might indicate underground structures.

An aeromagnetic survey was flown over the study area and surrounding region. A plane carrying a magnetometer was flown at a near constant altitude of 200 meters above the surface of the ground. The magnetometer collected high resolution data of the magnetic field. This method is able to detect magnetic anomalies in the subsurface and can be used to infer the existence and location of geologic structures.

A magnetotelluric survey was also conducted. Magnetotellurics uses coils and electrodes to measure the resistivity of the subsurface. It can find conductive and resistant layers and bodies at specific depths. It is useful for finding fluids or hydrothermally altered material in the subsurface. The collected data is still being analyzed, but when it is complete, it will be used to determine the locations of geothermal fluids and subsurface structures.

Core samples were taken from basalt flows in order to conduct paleomagnetic studies on them. The magnetic minerals inside the basalt aligned with Earth's magnetic field when the lava cooled. Using these core samples, and susceptibility measurements taken from the hand samples, the induced magnetic direction can be stripped away revealing the remnant direction; the direction of Earth's magnetic field at the time of the individual flow.

Light Detection and Ranging (LiDAR) is used to map topography. Beams of light are emitted from an aircraft. A sensor on the aircraft then detects the incoming light as it bounces back. The distance from the ground determines the time it takes the light to bounce back. This can then be mapped to give an excellent sense of topography, on the order of centimeters of accuracy. The LiDAR can also be used to view fault scarps, and in combination with potential field techniques, determine fault movement and activity. A LiDAR survey is planned for the study area, but has not yet been completed.

When collecting rock hand samples from the field, the magnetic susceptibility of the outcrop was measured. For each hand sample, the magnetic susceptibility and the densities were measured. The density was measured by first measuring the mass of each sample. The masses were measured in air, under water, and in air while saturated with water. Using these three measurements, the densities were able to be calculated. These density and susceptibility measurements were used to determine the properties on the units in the model.

Process and Modeling

The gravity and aeromagnetic data were processed using standard methods. Once they were processed, they were imported into Oasis montaj, along with a geologic map of the region. The datasets were gridded and used as the basis for the models. Two profile lines were chosen within the study area to make 2-D models. The profile lines are located perpendicular to major faults in the region, and they're location was chosen to attempt to model interesting structures, as seen in figure 1. Profile 1 (figure 2) crosses the Hawtmi fault zone, and Profile 2 (figure 3) crosses the Waihatya fault zone. Both models contain bedrock with a deep crustal wedge. The wedge was added to adjust the gravity to the correct general trend. The units present in the model are the Grande Ronde, Wanapum, McKay Formation, and Quaternary sediment. There is one reverse polarity flow present in the Grande Ronde in the model. This type of model can be used to determine geologic structure beneath the surface. The models use a forward modeling method. The blocks are adjusted separately until they match the measured potential field values. By adjusting the model to match the gravity and magnetic data, geologic units and structures (such as: faults, dikes, and reverse polarity flows) can be inferred beneath the surface without any direct measurement. This type of model has its limitations. The model is non-unique, and has an infinite number of possible solutions. Careful consideration must be taken to make sure the model remains geologically sound.

The two models created contain multiple faults and dikes that were not mapped on the geologic map. There are some discrepancies between the measured magnetic data and the modeled magnetic data, but the measured and modeled gravity data seem to fit much better. The magnetic data anomalies could be caused by additional faults or geologic bodies beneath the surface. The gravity and magnetic data are very good constraints for the models; however, the rock properties used were an average, so variations within the unit are not taken into account. Further constraints will be added with the addition of the magnetotelluric and LiDAR data.

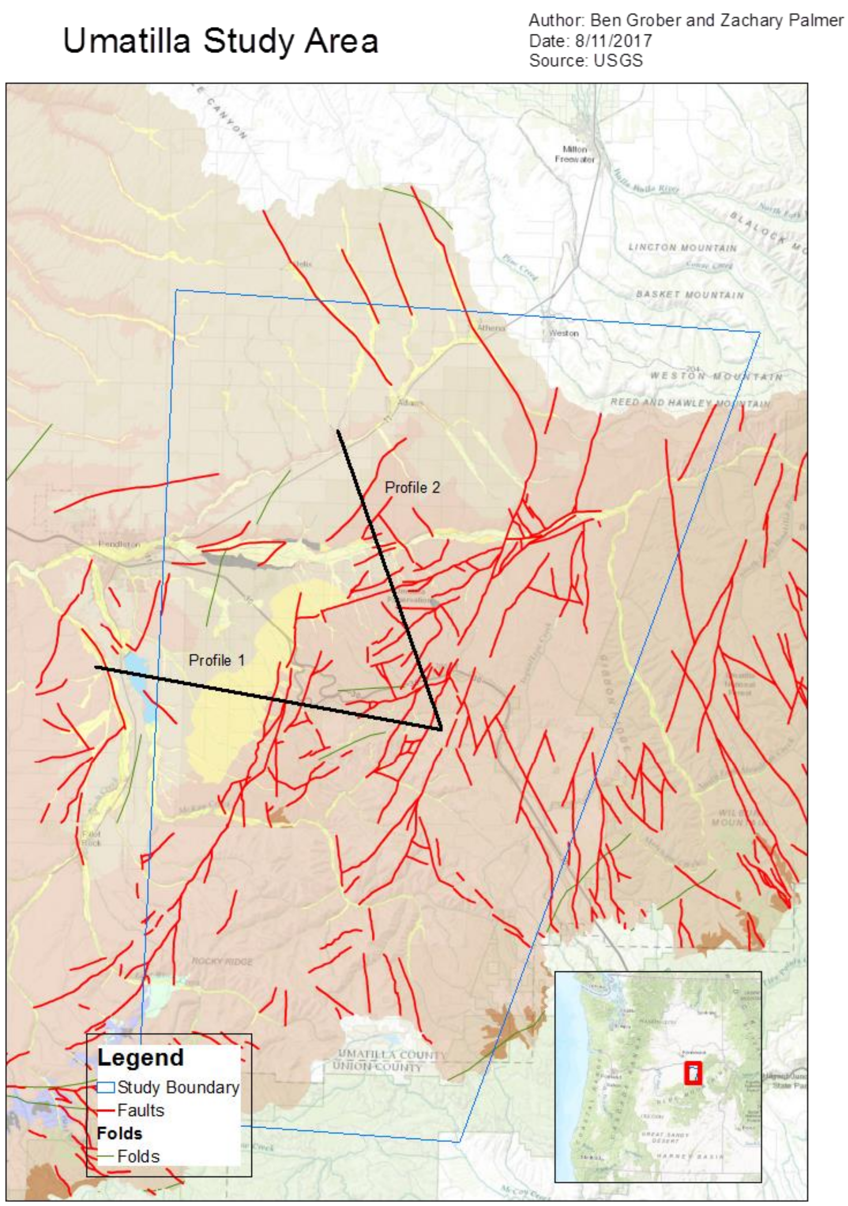

Figure 1. Displays study area and profile lines.

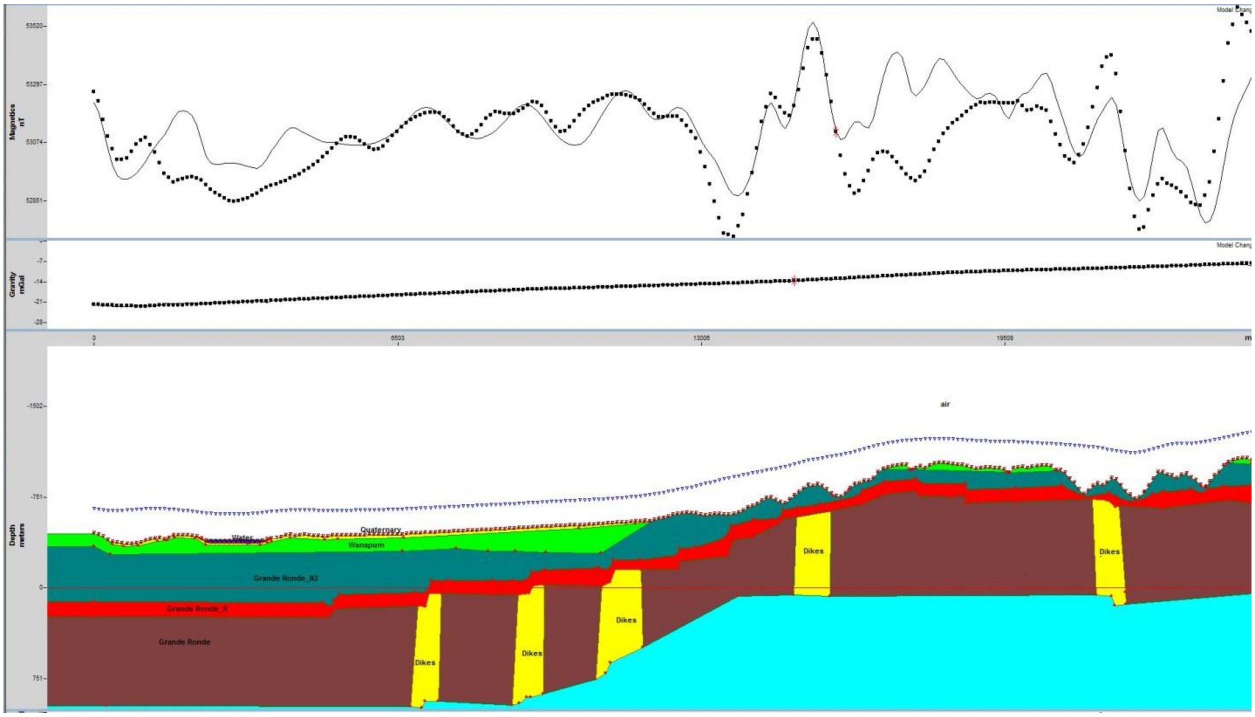

Figure 2. Profile 1 2-D potential field model displaying magnetics and gravity data and geologic interpretations.

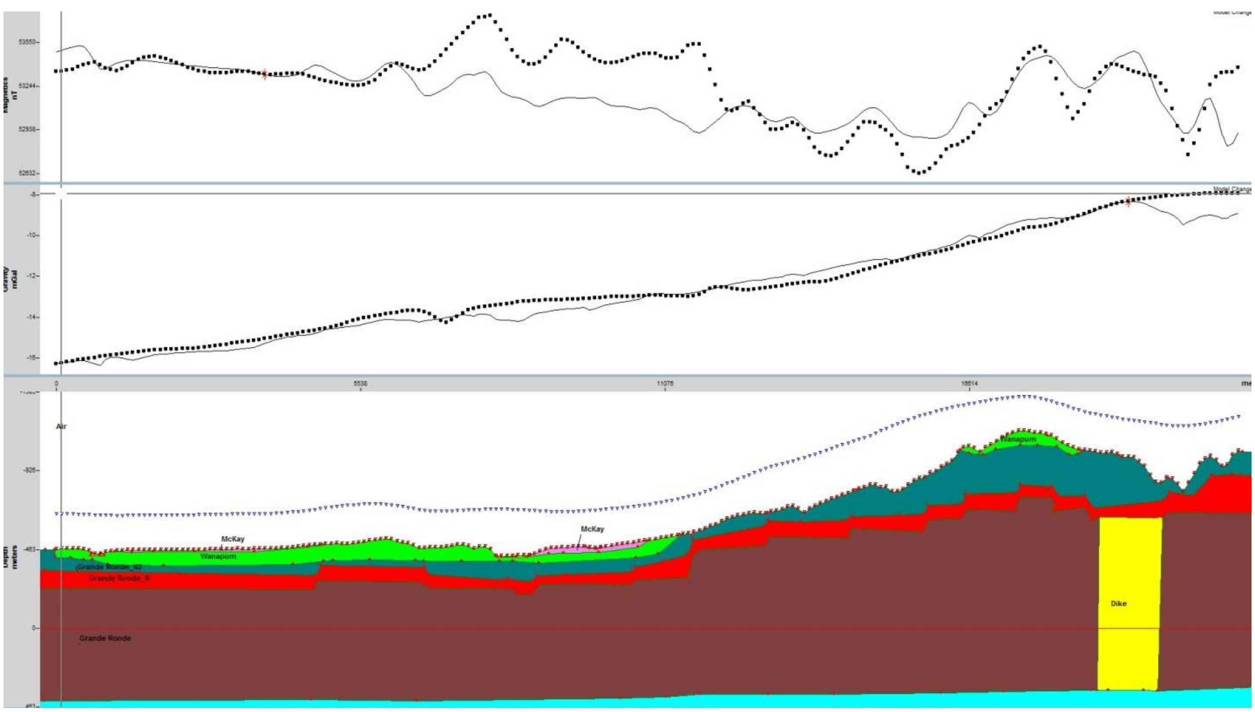

Figure 3. Profile 2 2-D potential field model displaying magnetic and gravity data and geologic interpretations.

Conclusion

With the surveys of gravity, aeromagnetic, and magnetotelluric, along with the collection of paleomagnetic cores and rock hand samples, 2-D models were able to be created across major fault zones within the Umatilla Indian Reservation. The models suggest the existence of multiple faults and dikes that are not currently mapped. The addition of data from the magnetotellurics and LiDAR surveys will allow for better constraint of the models. Caution should be exercised when using the models, as their limitations allow for other equally valid interpretations. Further changes to the models are required to better fit the observed data.

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