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3D and 4D Modeling of Ignimbrite Eruptions

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3D and 4D Modeling of Ignimbrite Eruptions

by

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Abstract

The need to model the Yellowstone magma chamber and other possible sites for ignimbrite eruption has been accelerated by the development of the areas surrounding the volcanoes. Early detection of eruptions is the most important aspect when trying to reduce casualties from an eruption. The magma chamber at Yellowstone has been mapped previously using Seismic data and other methods, but more information is needed to predict the next eruptive event.

Through the use of previous research by Dr. de Silva and Dr. Gosnold, it is possible to create a representative model for the magma chamber. The model is created using a combination of ARC, Surfer, and Voxler. Using these programs and pre-existing geothermal data, the relation between the brittle-ductile zone and the magma chamber can be modelled. Through this relatively new method, it will hopefully be possible to put a timetable on the next major eruptive event.

Introduction

In the last 2.1 million years, the Yellowstone volcanic field has produced two of the largest recorded eruptive events on Earth. The last major eruptive event took place 640,000 years ago and projected more than 1000 km^3 of rhyolitic magma onto the surrounding area. During this event the caldera that is evident at Yellowstone National Park was form, and is heavily monitored by members of the scientific community to warn against possible earthquakes and eruptive events. In the event of a modern Yellowstone eruption, the majority of the country would be affected by the large amount of volcanic material ejected either from the ejected lava in the vicinity of the volcano or the large amounts of ash that would blanket the surrounding states. Eruptions are acts of God and cannot be averted or controlled. The most important factor in limiting the damage caused by an eruptive event is warning the population in advance of an eruptive event, so they may reach a safe distance from the epic center of the event. The ability to predict the next eruptive event from Yellowstone can mean life or death for millions of people residing in the area of the volcano.

Hypothesis and Null Hypothesis

Hypothesis: Through the use of 4D and 3D modeling software the next eruption of the Yellowstone caldera system can be predicted.

Null Hypothesis: An accurate prediction for the next Yellowstone eruption will not be possible through the use of 4D and 3D modeling.

Previous Research

Research on the Yellowstone magma chamber is extensive and has been ongoing for many decades. Dr. Shanaka L. de Silva and Dr. William D. Gosnold published the paper titled “Episodic construction of Batholiths: Insights from the spatiotemporal development of an ignimbrite flare-up” which describes in detail the method used to produce the necessary calculations to produce the models. Dr. de Silva and Dr. Gosnold used this method in respect to the Andes volcanic system (De Silva, et. al., 2007). Dr. Jamie Farrell from the University of Utah was able to model the magma chamber through the use of collected seismic data from the Yellowstone seismic network. The resulting model was tomographically imaged three-dimensional P wave velocities. At the end of his study, he determined that the magma reservoir was 2.5 times larger than the previous tomographic determination. Dr. Farrell estimated that the magma chamber is 90 km in length and 5-17 km deep. He also found that the chamber extends 15 km northeast of the caldera (Farrell, et. al, 2014).

Uplift in the Yellowstone is also heavily studied to observe possible indicators of an upcoming eruption. Dr. Robert Smith used twelve global positioning systems located throughout the park and the European Space Agency’s Envisat satellite to measure the uplift of the crust. According to compiled data, between 2004 and 2006 the floor of the caldera rose as 2.8 inches per year, and a total of 7 inches over the 30 month period. The previous fastest rate of rise was 0.8 inches a year, which was recorded between 1976 and 1985. According to Dr. Smith, uplift is still occurring but at a reduced rate. He theorized that the uplift was caused by a horizontal slab, roughly 463 square miles, being injected into the magma chamber.

To gain the appropriate background knowledge to preform and understand the contained research, involved finding past research on the modeling of the Yellowstone magma chamber, crustal deformation, mantle upwelling, the Yellowstone volcano itself, and the computing programs used to generate the models and graphs. With regards to crustal deformation and mantle upwelling, papers by Mian Liu and Youging Yang were used to gain an understanding of crustal deformation and upwelling and how it pertains to the relationship between brittle ductile zone and the magma chamber (Liu, et. al, 1998). The final part of information that had to be explored was the geological modelling software, ARC. "Performance Improvements for a Large-Scale Geological Simulation" (Apostal, et al, 2014) provided the necessary background information on the program. The various factors that the program uses to generate the models is described in great detail in the paper. With a topic this diverse and heavily researched it is likely that some information was missed during the information gathering process. The afore mentioned papers should provide an adequate background to perform the necessary research.

Methods

A 3D representation of the Yellowstone magma chamber can be achieved through the use of Excel, ARC, Surfer, and Voxler. Firstly, an excel spreadsheet was created that could be used for the initial model in ARC. The spreadsheet was created using 20 slices, each showing convection and flow throughout the model. During this step, there was the need to find incorrect data in the spreadsheet because it was producing irregularities in the model, which can be seen in Figure 1**.** After the incorrect data was removed from the spreadsheet, the accurate spreadsheet was ran through ARC, which is a program that uses thermal conductivity, thermal diffusivity, degrees C, Node spacing, heat flow, and heat capacity to create a representative model of the assigned data (Apostal, et al, 2014). ARC then produces surfer grid files of the twenty files that must be properly formatted to be used in Voxler. To start this process first the ARC output files had to be imported into Surfer and converted to .dat files. Then it was necessary to define the slice location for each imported file, which is accomplished by having the initial slice have a value of 0 and each following slice having a value that is 5,000 greater than the last slice. To complete the conversion all of the new .dat files are combined into one large .dat file that is used by Voxler. The complete .dat file can then be imported into Voxler and the process of generating the model can be started. The majority of the work within Voxler is mainly setting parameters and other adjustments within the network and property management. Once all the necessary adjustments are made the model can be created. These methods are fairly straight forward and can be used to model a variety of geologic occurrences.

Results

Through the methods mentioned earlier, 2D and 3D representation of the Yellowstone magma chamber were created in Surfer and Voxler, respectively. The models can be seen in Figure 2, Figure 3, and Figure 4. These initial models show that an isotherm at 50 degrees Celsius deforms over the magma chamber, which indicates a change in lithological strength in the overlying crust. Unfortunately, due to time constraints and lack of the appropriate data, it was not possible to model the relation between the Brittle-Ductile transition zone and the magma chamber as originally planned. To accurately answer the hypothesis proposed in this paper, further research needs to be completed. The created models serve as a good starting point for further research, but first the appropriate data must be collected to generate a more in-depth model from the current one. From that model it will be possible to model when the BTDZ will be close enough to the surface to cause a mechanical failure of the crust above the magma chamber. With that information, the next eruption of the Yellowstone caldera system can be approximated.

Discussion

The produced model unfortunately is not comparable to Farrell's 3D model. This is because he used compiled seismic data to create his model, and the model discussed in this paper was created using thermal data. His model and the Voxler model is shown in Figure 5 and Figure 6 for comparison. The Voxler model is also just a general representation of the magma chamber and more data is needed to create a more complete model. The modelling software is fairly new, but it does represent the possibilities for modeling ignimbrite eruptions. Future research will elaborate on the methods described within, and hopefully be able to produce a model that shows the relation between the magma chamber and the brittle ductile transition zone. With that model it will be possible to accomplish the hypothesis mentioned before. Until then a timetable for the collapse of the Yellowstone caldera cannot be approximated.

Conclusions

Ignimbrite eruptions, like Yellowstone, can pose great danger to the surrounding area, and must be constantly monitored to increase the amount of time available to issue an evacuation warning. Through the use of new technologies, like Surfer and Voxler, it soon will be possible to predict an approximate time for the next eruptive event, and increase the amount of time to prepare for such eruptive events tenfold. The model that was created for this paper is a good first step toward accomplishing that goal, and as more data is collected for the Yellowstone Caldera system, it will become easier to produce accurate models of the underlying magma chamber. With these models it will become easier to predict when the caldera will collapse, due to the loss of mechanical strength of the crust over the chamber. This area of study needs to be more thoroughly research to reach its full potential, but it will be well worth it is completed.

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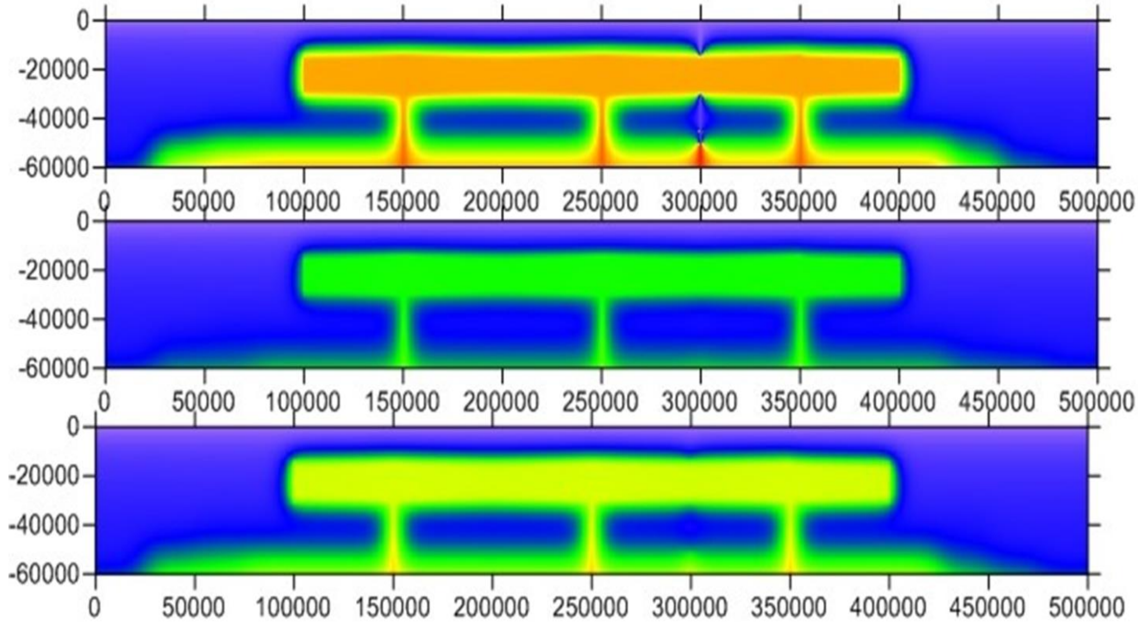

Figure 1. Beginning ARC output showing errors at 300,000m. All units are in meters.

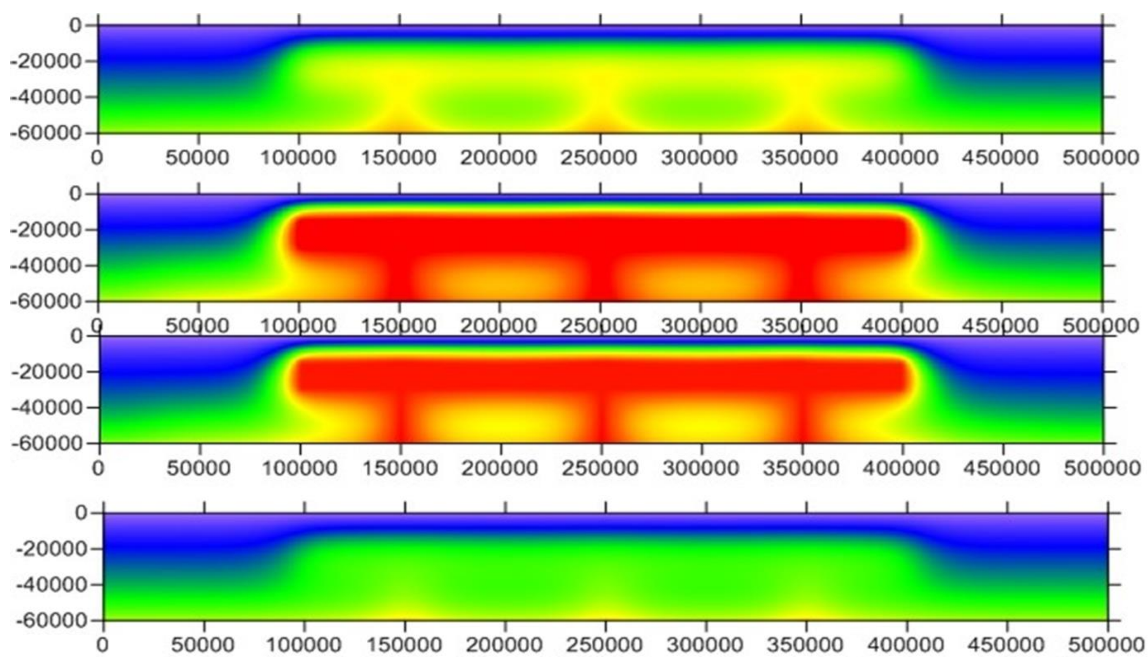

Figure 2. Finalized ARC output, ready to be converted for use in Voxler.

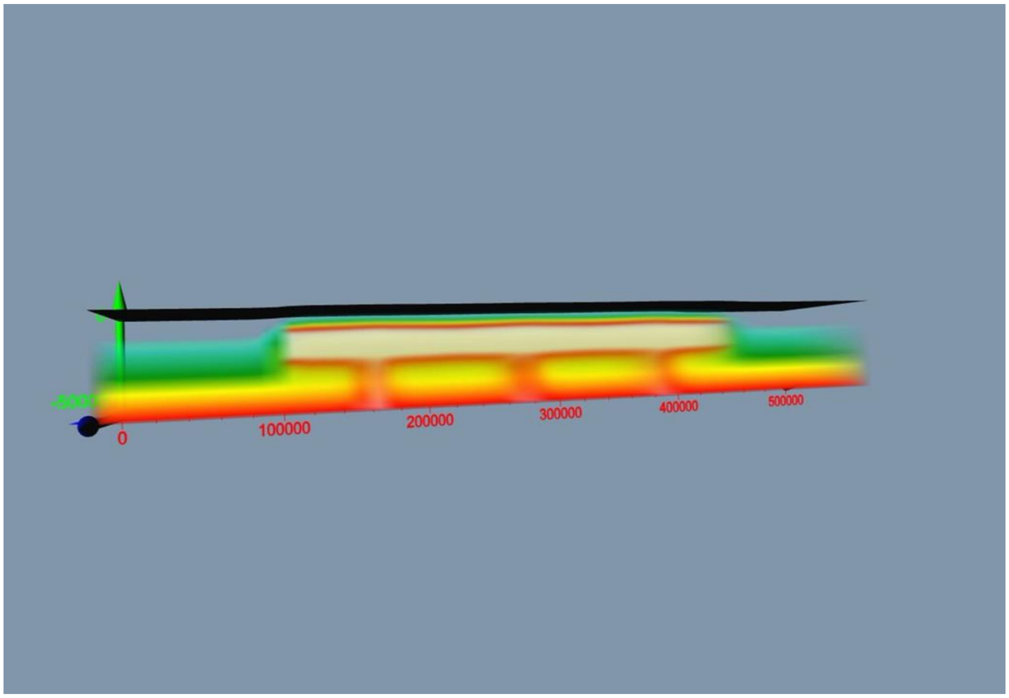

Figure 3. Voxler Image of the Yellowstone Magma Chamber. Isotherm @ 50 degrees C

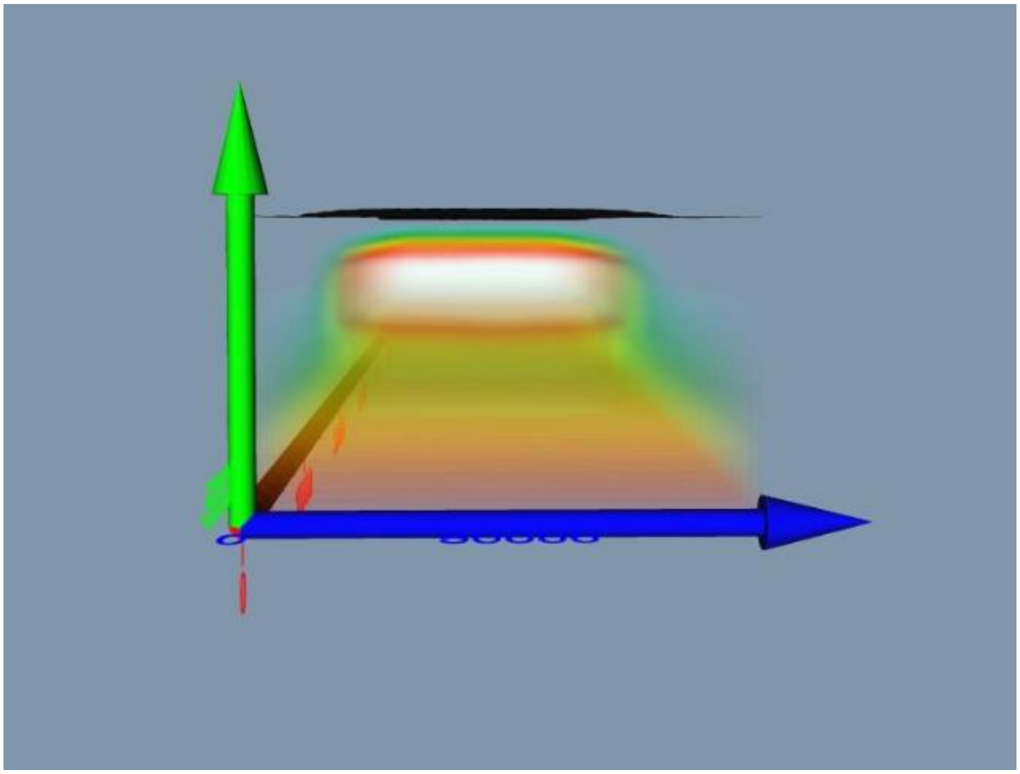

Figure 4. Model of the chamber showing deformation of the isotherm above the chamber

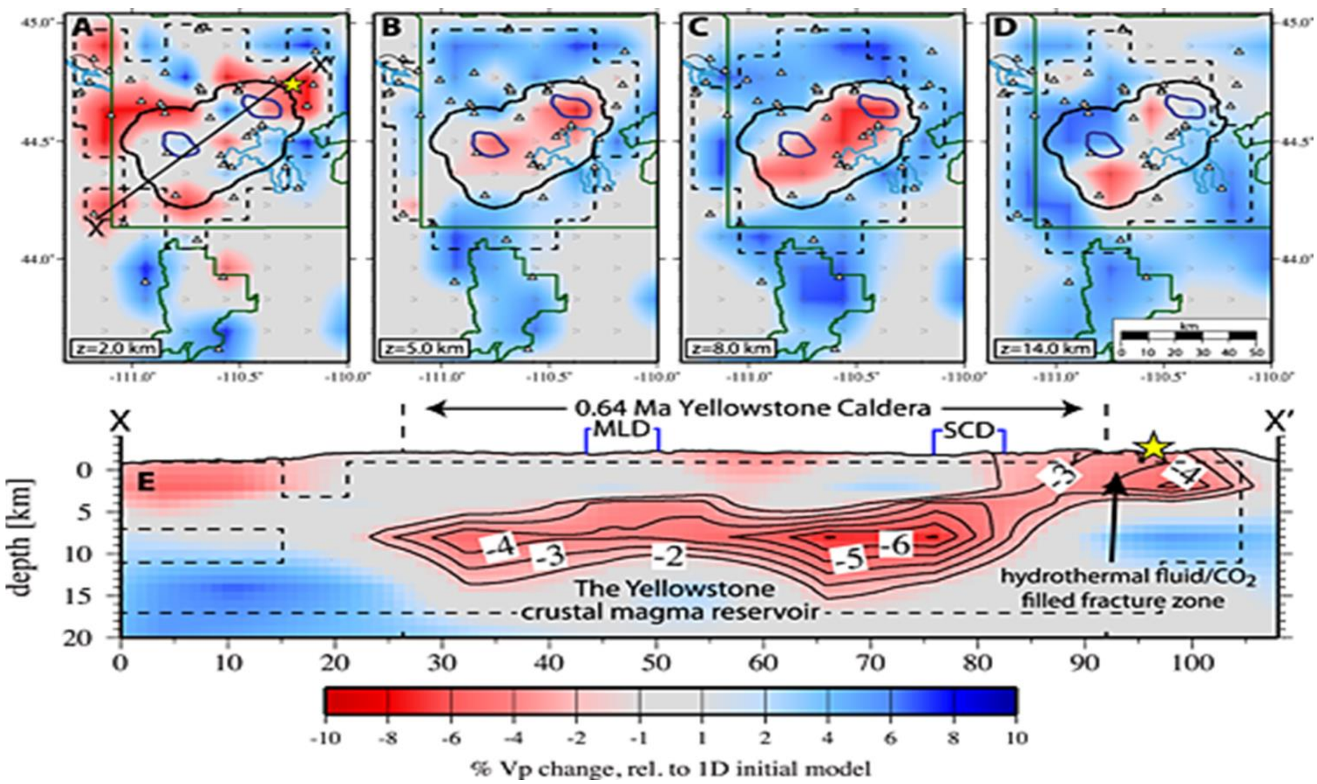

Figure 5. 3D model of the Yellowstone Magma Chamber created through the use of Seismicity Data (Farrell, et. al., 2013)

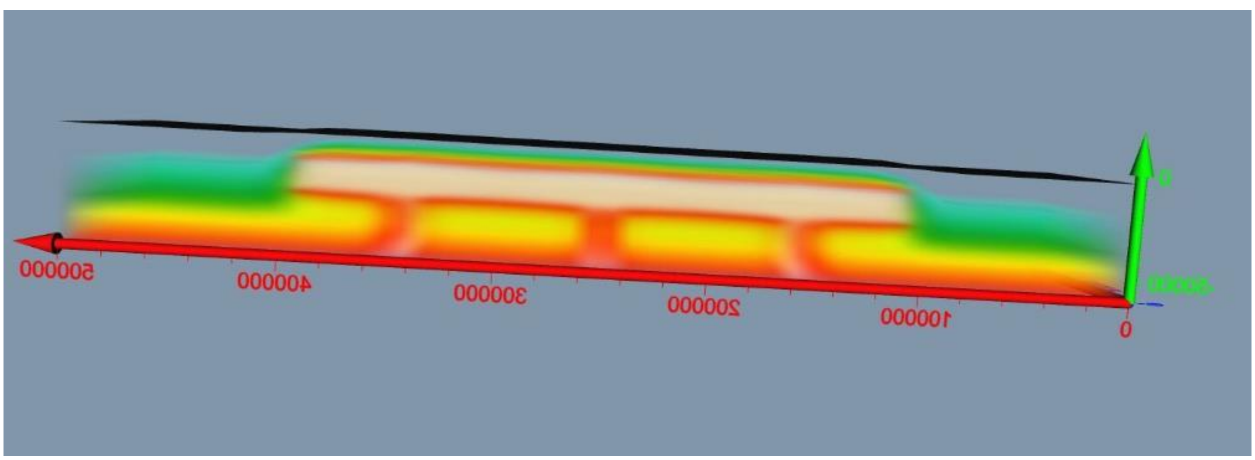

Figure 6. Backside of model. Used for comparison with Farrell's 3D model.