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Low-cost Software for 3D Geothermal Data Visualization and Model Construction

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ABSTRACT

Integrated 3D visualization of complex, multi-component geoscience datasets can be quite useful to geothermal exploration efforts by allowing geoscientists to see and interpret geo-spatial relationships in their proper 3D context. Advanced software tools with 3D geoscience capabilities have been used in the oil & gas and mineral exploration sectors for decades, but these software tools can be quite costly. Early-stage geothermal exploration programs already face significant development barriers related to the high upfront cost of drilling and high exploration risk. Expensive 3D software tools can be yet another barrier for early-stage, geothermal projects that run on shoestring exploration budgets. In the initial stages of exploration at a geothermal prospect, a helpful software tool requires two features: 1) the ability to visualize many types of imported geoscience data (e.g. point locations, geologic maps, cross-sections, 3D surfaces, wellpaths, block models) and 2) a method to construct geoscience interpretations based upon the various 3D datasets (e.g. draw lines, build fault surfaces and 3D geologic contacts). For over 3 years, the author has been using a low-cost (< US$1,000) 3D design software, called Rhino3D, for the purposes of 3D geothermal data visualization and model construction. This software has been used successfully to: a) build and visualize high-resolution digital elevation models, b) build 3D geothermal wellfields annotated with multi-parameter downhole data along 3D wellpaths, c) construct 3D geologic models from 2D geologic cross-sections and well data, d) visualize geophysical data and models as colored points, cross-sections, or 3D block models (e.g. gravity, magnetic, resistivity models), and e) visualize the results of 3D reservoir models (i.e. temperature and permeability) in the context of the 3D static geologic model. This paper provides several examples of the use of the low-cost software Rhino3D for geothermal exploration.

1. INTRODUCTION

The purpose of this paper is to share with the geothermal community the author's experience using a low-cost software package, called Rhino3D (www.rhino3d.com), for 3D visualization of geoscience data and construction of 3D geoscience models. Over the last ten years, a large number of 3D software packages have been available to geothermal explorationists (see Witter and Melosh, 2018 for some examples). Apart from visualizing data in three dimensions, attractive features of a geothermal exploration software package might include the following features: import/export a wide variety of file types, build fault surfaces and geologic horizons in 3D, plot well data, perform 3D geophysical inversion modelling, connect seamlessly to reservoir modelling software, easy to learn/use, and have licensing fees that are affordable. Some software packages that are technologically advanced and have extensive capabilities also come with an elevated price tag. In other cases, some low-cost or free software packages are missing key capabilities which tend to negate the value of the product's low cost. For over 3 years, the author has built complex 3D geoscience models with Rhino3D software, found it to be a remarkably capable 3D modelling tool while at the same time very cost competitive. The remainder of this paper provides a description of Rhino3D software, discusses the use of Rhino3D in geothermal exploration, and presents a variety of example images of 3D geoscience models built with Rhino3D.

2. SOFTWARE DESCRIPTION

It would be quite normal to think that complex, 3D geoscience visualization and model construction for geothermal resource exploration would require a fit-for-purpose, geoscience-specific software tool. Rhino3D, however, is not a geoscience-specific software. Instead, it is a generic, versatile, 3D design software used in a wide variety of applications including realistic three-dimensional rendering of: buildings, automobiles, boats, jewelry, and many other products. The generic nature and versatility of Rhino3D is what makes it able to perform many of the 3D tasks (e.g. visualizing data, building surfaces, etc.) that are useful to a geothermal explorer. In short, Rhino3D is primarily a 3D surface modelling tool that utilizes the NURBS (Non-uniform rational basis spline) mathematical model to depict lines and surfaces in 3D space. However, it is also capable of generating surfaces using wireframe (or faceted) meshes. As a generic 3D drawing software, just about anything can be constructed in Rhino3D and then rendered in a visually appealing 3D environment.

2.1 Software Cost

Many geoscience-specific software tools are also industry-specific (e.g. 3D mining software or 3D oil & gas software) which means the number of customers is relatively small. A small customer base usually means software licensing fees must be high to cover the cost of software development. Generic 3D software packages, like Rhino3D, can reach a much wider base of customers because they are versatile and used in many different sectors. A large customer base can then result in much lower software licensing fees. For example, a permanent single-site commercial license for Rhino3D software costs US$995 with no annual maintenance fees (ever). This compares with geoscience-specific software licensing fees which can range from several thousand dollars to tens of thousands of dollars (and in some cases >US$100,000) with annual maintenance fees of hundreds to thousands of dollars per year.

2.2 Geoscience Application of Rhino3D

The author is aware of only three published examples of the use of Rhino3D in geoscience applications: Neumann et al. (2006) built a 3D engineering geology model for the city of Magdeburg, Germany, Tonini et al. (2008) used the software to build a 3D model to analyze the geological implications of different train tunnel alignments in central Italy, and Dzik et al. (2017) describe the use of Rhino3D and other software to enable 3D modelling of complex geometries in the mining industry. In 2016, the author was in search of a more affordable alternative to costly geoscience-specific software to use for 3D geothermal data visualization and modelling. Since that time, the author has used Rhino3D to: a) build and visualize high-resolution digital elevation models, b) build 3D geothermal wellfields annotated with multi-parameter downhole data along 3D wellpaths, c) construct 3D geologic models from 2D geologic cross-sections and well data, d) visualize geophysical data and models as colored points, cross-sections, or 3D block models (e.g. gravity, magnetic, resistivity models), e) visualize subsurface hydraulic connections in 3D from tracer test data, and f) visualize the results of 3D reservoir models (i.e. temperature and permeability) in the context of the 3D static geologic model. Once uploaded and/or constructed in Rhino3D, all of these geoscience datasets can then be co-interpreted in the same 3D environment to better understand subsurface relationships of the geothermal system, all for a very low cost.

It should be emphasized here that Rhino3D is a generic (not geoscience-oriented) 3D software tool. So, for example, Rhino3D cannot perform 3D geophysical inversion modelling or 3D numerical reservoir modelling. These geoscience-specific tasks must be done outside of Rhino3D, However, the results can be imported and then visualized in Rhino3D.

2.3 Data Georeferencing

The ability to analyze your 3D geoscience data in the same 3D spatial context is important. Some geoscience-specific software platforms can take different geoscience datasets that are in different coordinate systems/datums and re-project them so that the data are properly georeferenced. As a generic software, Rhino3D does not do that. All geoscience data needs to be georeferenced prior to import into Rhino3D. One particular software which is very useful for georeferencing geoscience data is the open source (free) software QGIS. Once data are properly georeferenced and imported into Rhino3D, the exact georeferenced location of any point in the Rhino3D model space can easily be ascertained. Rhino3D works best with X, Y (horizontal) data in a UTM coordinate system (i.e. in units of meters) so that the Z (vertical) coordinate can be in the same units (i.e. meters).

2.4 Import/Export

Due to the generic nature of Rhino3D software, it does not import/export proprietary, geoscience-specific file formats. Instead, Rhino3D employs much more common, generic formats for importing and exporting data. To import and export geoscience data into Rhino3D, the author generally uses the following:

- For points, lines, and polygons: .dxf, .csv, .txt, .xyz files
- For surfaces: .dxf
- For images: .jpg, .png, .tif

In practice, the author has found that importing and exporting generic geoscience file formats (and avoiding proprietary, geoscience-software-specific file formats) sidesteps many import/export headaches.

GIS shapefiles are a very common file format in geoscience. These can easily be imported into Rhino3D by first converting them to .dxf prior to import. The open source (free) software QGIS can be used to make this .shp to .dxf file conversion.

3D topography is usually imported into Rhino3D as a .dxf file (of a 3D surface) or as a .txt file of points and then re-built as a 3D surface within Rhino3D software. Other pre-existing 3D geologic surfaces (built in other software platforms) can be imported in a similar fashion.

Geologic maps can be imported into Rhino3D as an image and then draped on 3D topography (provided the geologic map is georeferenced in the same way as the topography and X, Y corner points of the geologic map are known). Similarly, geologic cross-sections of any orientation can also be imported into Rhino3D as images, provide X, Y, Z corner points of the cross-section are known.

3D wellpaths are imported into Rhino3D as a string of points along the wellpath (derived from deviation survey well logs) and these sets of points are then connected by a line in Rhino3D.

Block models, such as 3D geophysical models or 3D reservoir models, can be visualized in Rhino3D as colored point clouds. Each point in the point cloud represents the center of a cell in the block model. And the color of the point represents the value of whatever is depicted in the block model (e.g. resistivity in a 3D MT model or temperature/permeability in a 3D reservoir model). A short Python script is used to control the import of the block model data and the coloring of the points. After import, the points in the point cloud can be increased in size to fill the cell size in the block model. In practice, this can work quite well for visualizing large point clouds that represent the data in block models. For example, the author has found that Rhino3D has no difficulty visualizing a point cloud with > 2 million points. Visualization of block models in Rhino3D works best if the block model consists of cells that have the same or similar size.

When it comes to exporting 3D geologic surfaces, such as fault planes or geologic horizons, that have been built in Rhino3D, the author has found that exporting them either as a 3D surface (.dxf) or a series of points that represent the surface (.txt) is the most effective approach since both formats are easily uploadable into most any other software platform.

2.5 Constructing a Model

Many low-cost or free geoscience software platforms are quite good at importing and visualizing many different types of geoscience data. However, the author has found that one important factor setting Rhino3D apart is that, for a very low cost, Rhino3D can not only visualize data in 3D but it also allows for construction of a model from the visualized data. Nothing is worse than being able to visualize all your geoscience data in 3D space in a "Viewer" software but not have the ability to build a 3D interpretation of the data with newly constructed lines and surfaces. As a generic 3D software, Rhino3D has a wide variety of model construction tools to easily build lines and surfaces in 3D. One noteworthy feature of Rhino3D is that the software interface consists of 4 viewports which view the 3D model simultaneously from the top, right side, and front side, as well as a 3D perspective view (Figure 1). These simultaneous points of view are important because it allows the user to always know "where you are" in 3D space as well as control model construction with great precision.

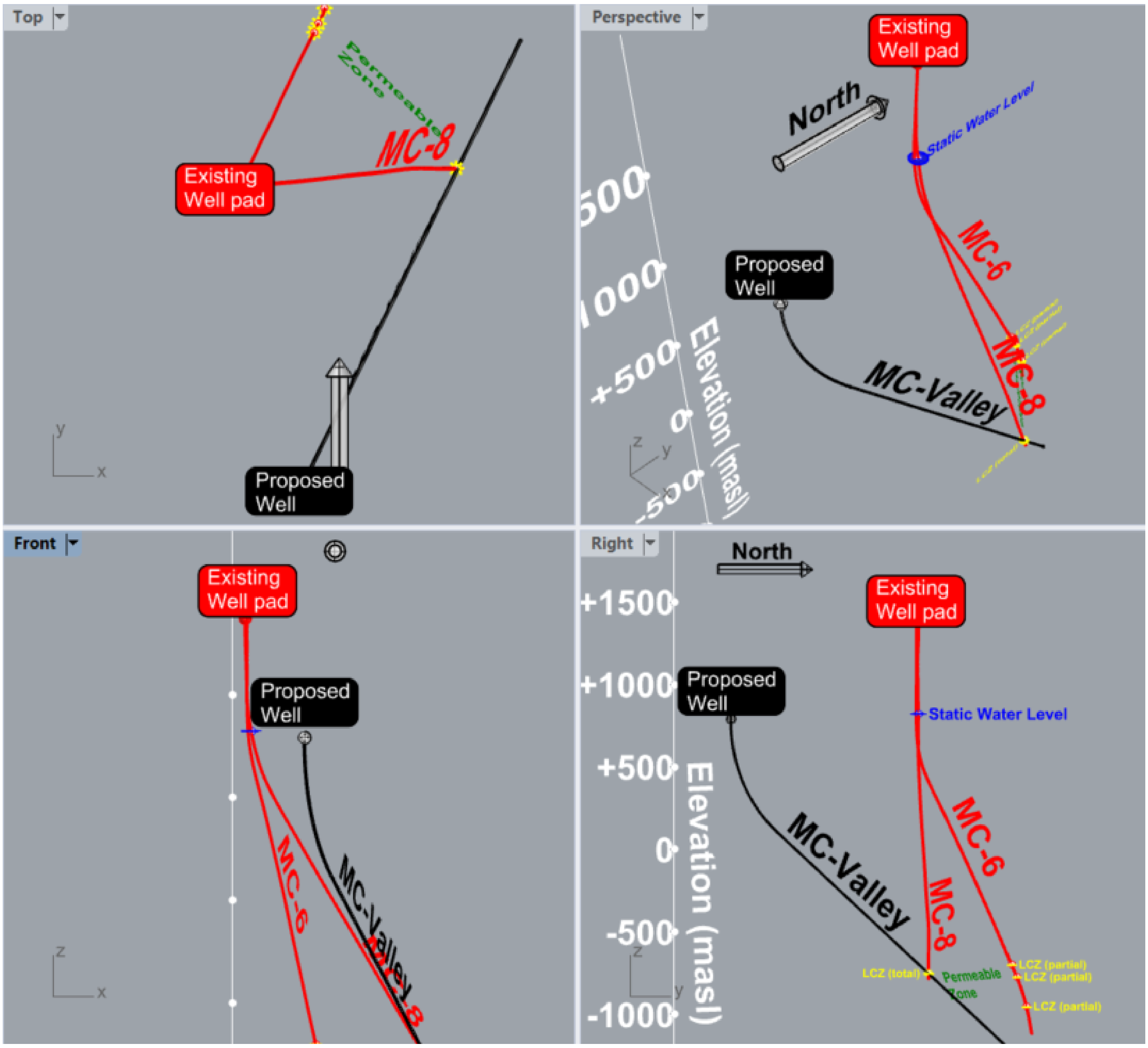


Figure 1: An example of the four viewports in the Rhino3D software interface: Top view, Front side, Right side, and Perspective view. The user is able to simultaneously view the 3D model from all these different views which significantly aids 3D model construction. Shown are selected 3D wellpaths from the South Meager geothermal field in British Columbia, Canada (Geoscience BC, 2019).

2.6 Learning to Use the Software

Rhino3D is the easiest to use and easiest to learn 3D software the author has ever used. Two key factors when learning any new software are: 1) understanding what the software can and can't do and 2) figuring out how to do the things that the software can do. For Rhino3D, the answers to both of these questions can be found either: A) in the free Rhino3D user's guide and tutorial, B) within the software in the form of short videos that explain how to execute a specific software function, or C) on the internet. Thanks to a Rhino3D user base that numbers in the hundreds of thousands, there are countless YouTube videos and discussion forums online which, in many cases, already have an answer to a Rhino3D user question. Whenever the author has a Rhino3D question, a quick search on Google usually returns an instantaneous answer.

3. EXAMPLES

Here, I provide a variety of visual snapshots of 3D geoscience models built in Rhino3D. The aim is to provide examples of specific aspects of models built with Rhino3D to highlight some of the 3D visualization and modelling aspects of the software. Note that when using the software, Clipping Planes can be used to actively "clip away" portions of a 3D model to better view the interior portions of a model.

3.1 Digital Elevation Model with Draped Geology and Cross-Sections

Interpretation of geologic map and cross-section information is an important aspect of geothermal exploration. This can be achieved in a 3D visual environment by draping a geologic map on 3D topography in conjunction with 2D geologic cross-sections that are correctly positioned in 3D space. An example is shown in Figure 2.

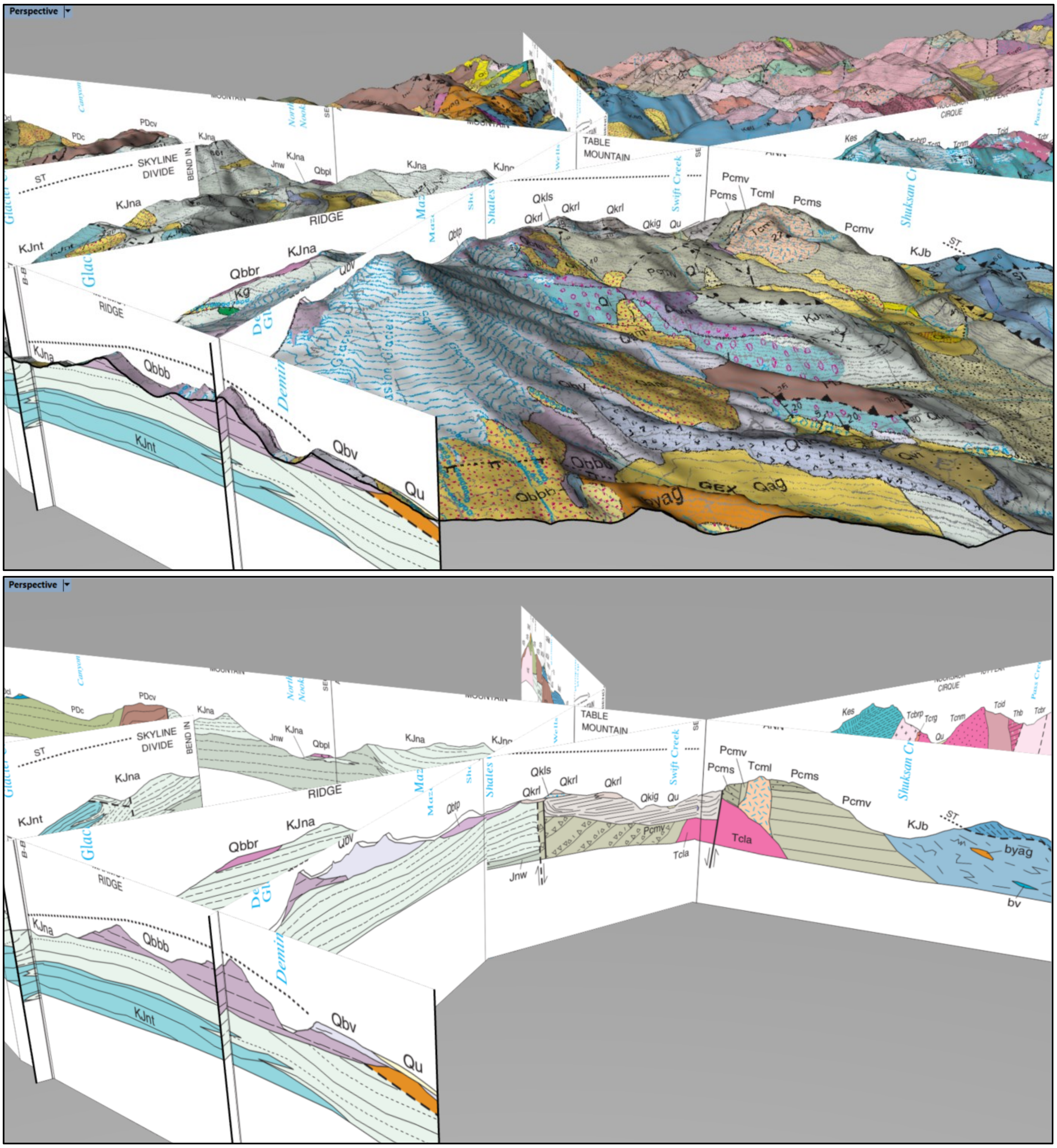


Figure 2: A 3D perspective view looking to the northeast across Mt. Baker volcano in Washington State, USA. The 3D topography is from public domain SRTM data. The geologic map and cross-sections have been manually clipped out of Tabor et al. (2003) and then positioned at exact coordinates in 3D space. Upper panel is the view with topography. Lower panel is the view without topography so the cross-sections can be seen.

3.2 Annotated Wellpaths in 3D

Deviated wellpaths are not uncommon in geothermal wellfields and, oftentimes, the wellpaths curve downwards in three dimensions which makes it difficult to depict them properly in profile view. In addition, large amounts of geoscience and well construction data are collected along these 3D wellpaths (e.g. temperature, geophysical logs, casing points, downhole geology & alteration, locations of lost circulation zones, etc.) Subsurface interpretation of geoscience data in 3D wellfields requires knowledge of where everything is located in 3D space (Figure 3).

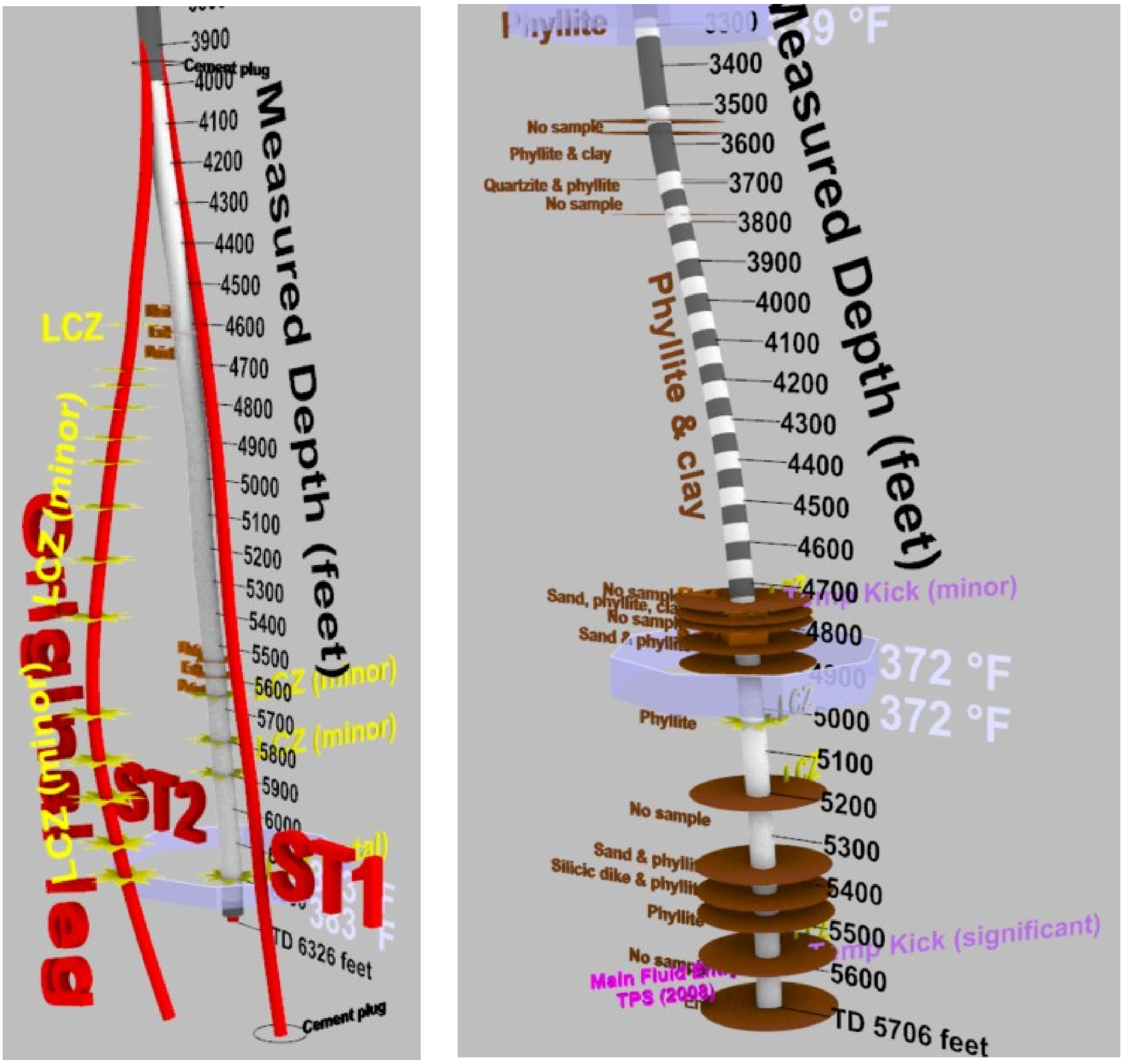


Figure 3: Left panel: Perspective view of a three-legged geothermal well consisting of the Original Leg, sidetrack#1 (ST1) and sidetrack#2 (ST2). The original leg and ST1 are open hole (red), while ST2 has a slotted liner (white). Blank (unslotted) liner is shown in grey. Lost circulation zones have been identified along the well paths (yellow) and the measured depth is shown along ST2 (in feet). A small ~10 foot thick isothermal zone (383 deg F) is also identified near the bottom of ST2 (lavender color). Right panel: A 3D wellpath showing downhole geology (brown), lost circulation zones (yellow), isothermal zones (lavender), and locations of fluid entries from the interpretation of TPS logs (pink). Wellpath is annotated with measured depth (in feet) and shows slotted liner (white) and blank liner (grey). Both wells are from a geothermal field in Nevada, USA.

3.3 Geologic Model Construction in 3D

Most geothermal fields contain geology and structure that varies in three dimensions. Thus, construction of a 3D geologic framework is commonly the best way to depict and interpret the geologic and structural complexities of a geothermal field. Usually, 3D geologic models are built from a wide array of geoscience data (e.g. 3D seismic data, well data, geologic maps & cross-sections, etc.) Therefore, it is important to have all the geoscience data within the same 3D environment when building a 3D geologic framework. One of the strong suits of Rhino3D is its ability to model complex surfaces in 3D. As such, Rhino3D is quite useful for constructing geologic horizons and fault surfaces in three dimensions (Figure 4).

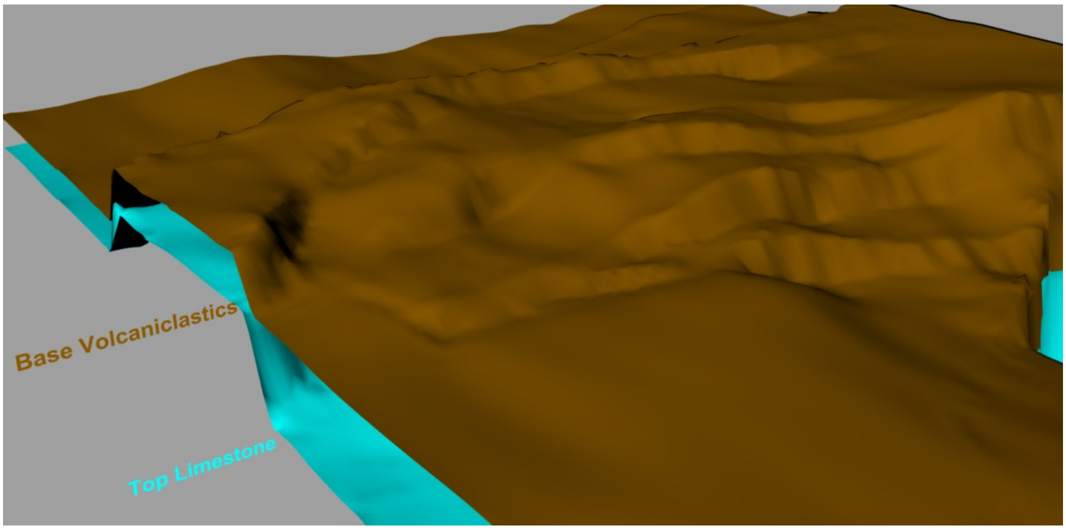
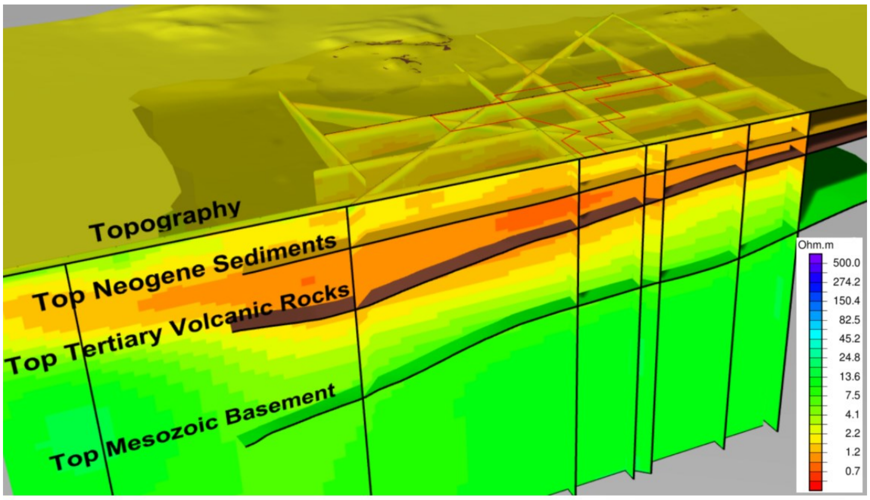


Figure 4: Perspective view of 3D geologic horizons built from 3D seismic data and well data. 3D seismic data was interpreted outside of Rhino3D; however, the 3D geologic surfaces were constructed in Rhino3D. Note the complex, 3D fault offsets visible in the Base of Volcaniclastics horizon (brown). These surfaces are from a geothermal field in the Western USA.

3.4 Visualization of Geophysical Models

Geophysical data and models used for geothermal exploration are best interpreted within a 3D geological context. For example, geophysical data collected at the land surface should be interpreted as data draped on 3D topography to ascertain the influence of the topography on the geophysical variations. Similarly, geophysical models can be interpreted either as 3D block models or as horizontal/vertical slices through the 3D block model. Figure 5 shows an MT resistivity model visualized in 3D with Rhino3D.



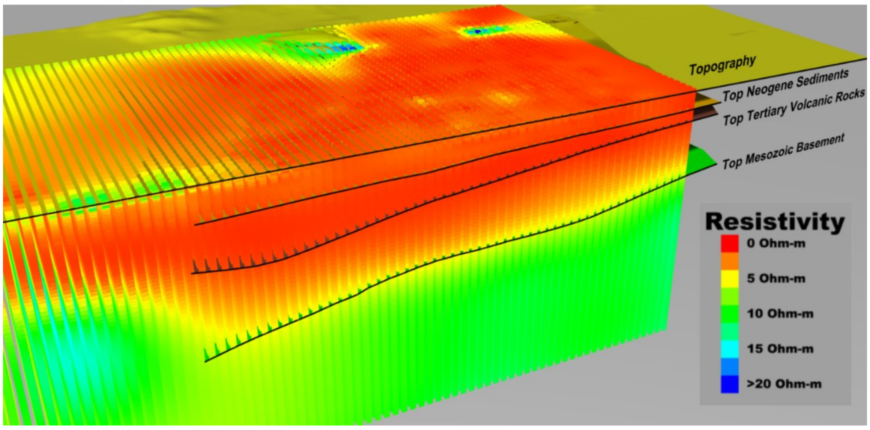


Figure 5: Perspective views of a 3D resistivity model coupled with 3D geologic horizons from the Fallon FORGE project in Nevada, USA (Siler et al, 2016). Upper panel: Cut-away view showing 2D resistivity profiles positioned in 3D space. Lower panel: 3D resistivity model visualized as a colored point cloud. Note: the resistivity color ramps used to plot the MT resistivity models are slightly different for the 2D and 3D cases.

3.5 Visualization of Tracer Test Results in 3D

Tracer tests are a valuable geochemical tool to better understand subsurface connections between injection and production wells. Chemical tracers are injected into injection wells and then over a period of many months, water samples are retrieved from production wells every few days to few weeks. The concentrations of the chemical tracer in these multiple water samples are then analyzed to obtain a graph of tracer concentration vs. time. The magnitude of the tracer's peak concentration and the elapsed time required to reach the peak are both measures of the amount of "connectedness" between injection and production wells. For example, if the peak chemical tracer concentration found in a set of production well samples has a magnitude of hundreds of ppb, and it is reached only a couple days after the tracer was put into the injection well, that could indicate a rather strong subsurface connection between the two wells. Tracer tests can provide valuable information about which well pairs are connected in the subsurface and by how much. However, they provide few specifics about the exact flow path through the subsurface from injection to production well. Interpretation of tracer test results in 3D space, within the context of the 3D geological model, can help infer such flow paths (Figure 6).

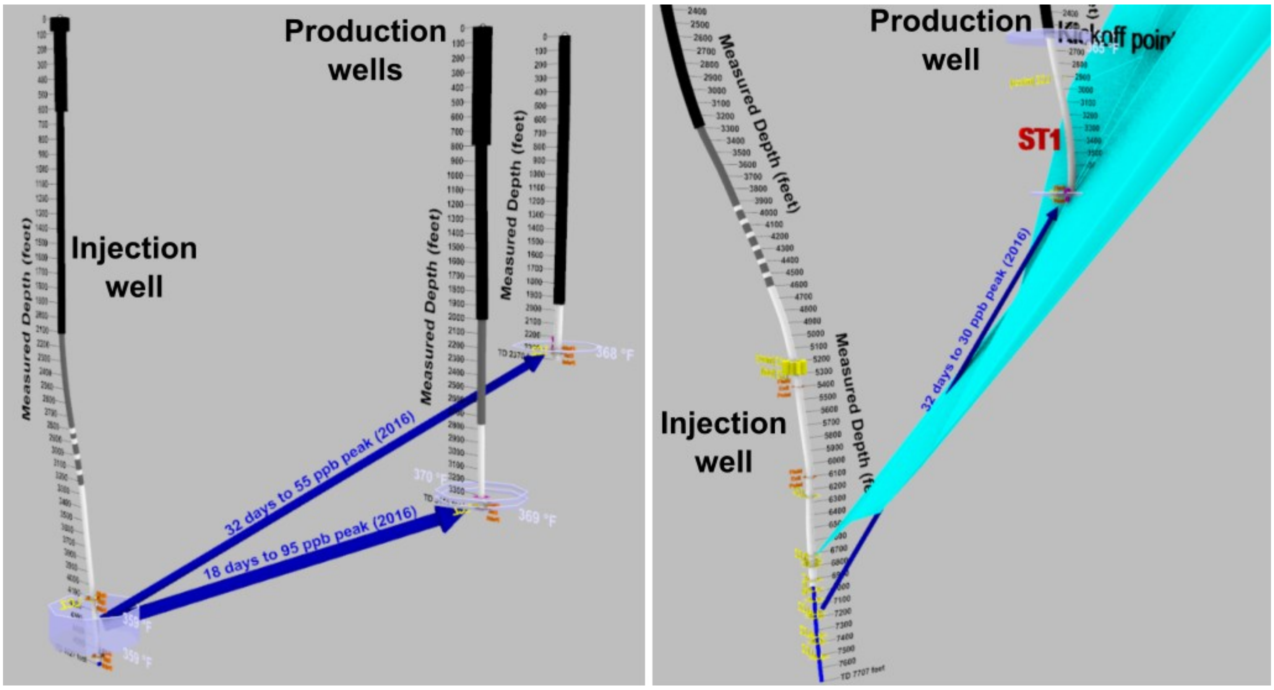


Figure 6: 3D visualization of tracer test results depicting inferred subsurface flow paths. Peak tracer concentration, elapsed time to reach peak, and year of tracer test are all shown (dark blue). Left panel: flow paths between one injection well and two production wells have been inferred by simply connecting the known lost circulation zones in the wells. Right panel: a flow path inferred from tracer test results (dark blue) that follows a 3D fault surface (light blue). Subsurface flow paths need not be straight.

4. ALTERNATIVES

This paper focuses on the low-cost software Rhino3D. However, it is useful to mention here three other software tools, which are free, and may be beneficial to the geothermal exploration community.

First, Geoscience Analyst (www.mirageoscience.com) is a free software which is particularly good at visualizing geoscience data, well data, and especially block models in 3D. The author often uses Geoscience Analyst in conjunction with Rhino3D to visualize block models. The free version of Geoscience Analyst is only for visualizing; the construction of new fault surfaces or geologic horizons is not possible.

Second, for 3D model construction, the reader may want to try the free and open source 3D software called Blender (www.blender.org). Blender is a software extensively used in the visual effects, video, and gaming industry to build virtually anything in 3D. As a generic 3D modelling platform, Blender may be useful as a no-cost tool for visualization and construction of 3D geoscience models for geothermal exploration.

Third, GemPy (www.gempy.org) is an open source, free 3D geological modelling software developed at RWTH Aachen University in Germany (de la Varga, et al., 2019). It is a Python-based software and uses implicit modelling to create complex geological models that include stratigraphical and structural features such as folds, faults and unconformities.

5. CONCLUSIONS

Rhino3D is a low-cost (<US$1,000) and generic 3D visualization and model construction software. The generic nature of the software makes it quite versatile and, therefore, it can be used effectively for the visualization of complex 3D geoscience data encountered in geothermal exploration programs. In addition, the extensive model construction capabilities of Rhino3D enable the

geothermal explorer to build a 3D model interpretation of the geoscience data. Import and export of geoscience data in and out of Rhino3D is most effectively accomplished using common, generic file formats as opposed to proprietary geoscience-specific file formats. Furthermore, data are visualized and models constructed in a georeferenced 3D environment. The author has found Rhino3D to be remarkably easy to learn and use. He has used Rhino3D to build many 3D models for geothermal exploration which have the following features: a) 3D topography draped with geology, b) geothermal wellfields annotated with multi-parameter downhole data along 3D wellpaths, c) 2D geologic cross-sections, d) 3D geologic models consisting of 3D geologic horizons and fault planes, e) 3D block models (e.g. gravity, magnetic, resistivity models), f) tracer test results in 3D, and g) 3D reservoir model results (i.e. temperature and permeability) in the context of the 3D static geologic model. Although Rhino3D may lack some of the advanced features of a geoscience-specific software platform, the author has found Rhino3D to be a powerful software tool for geothermal exploration with a very affordable price tag.

DISCLAIMER

The author is not a Rhino3D salesperson nor a re-seller of the software and he has not received any compensation for writing this paper. The author's motivation for writing this paper is simply to share his experience that Rhino3D has been a useful and low-cost 3D software platform for geothermal resource exploration. The observations expressed in this paper are merely the opinions of the author based upon his experience as a user of Rhino3D.

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