

## Geomodelling with Minecraft: Geophysics Meets Video Games

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### ABSTRACT

*Large synthetic 3D models are used to test geophysical processing and inversion algorithms as a proof of concept before being employed on real data sets. However, building three-dimensional geologic models is often a time-consuming and expensive undertaking. We instead used the video game Minecraft, with open source modifications to add rules for realistic geology, to procedurally generate three-dimensional worlds that mimic real world structures. We also use open source Minecraft world editors to build our own realistic 3D models in an efficient manner. By assigning different physical properties to each unique rock unit, and taking advantage of the regular geometry of the Minecraft world, we create geophysical datasets from these geologic models suitable for testing processing and inversion algorithms. The method has the potential for extension to geomodelling for integrated geophysical interpretations.*

### INTRODUCTION

Three-dimensional model building remains a difficult task. Often, tools are insufficient for the task at hand, or difficult to use. Fortunately, the video game industry has excelled at creating 3D environments that are easy to interact with. One of these video games, Minecraft, is uniquely suited for geological model building, especially for the purpose of testing algorithms and for teaching purposes.

Minecraft is a procedurally generated video game. Given a random number it generates an endless world filled with mountains, valleys, rivers, oceans, deserts, and everything in between. As the name would suggest, the purpose of the game is to mine resources and then craft those resources into more complex structures. The world itself is built out of a uniform 1 metre grid of blocks; considering that most 3D geophysics algorithms discretize the earth into blocks, translating anything created with Minecraft into a geophysical model is straightforward.

Minecraft has been used to as outreach and teaching tools for geology by several organizations. The British Geological Survey (BGS) created a three-dimensional model of Great Britain at 1:25 scale, consisting of over 88 billion voxels (British Geological Survey, 2015). They included topography and extended the surface geology vertically downward as a first pass at creating something for anyone to explore. Since then, they have also published Minecraft models of Glasgow, West Thurrock, York, and Ingleborough with full 3D realistic geology (British Geological Survey, 2015). All of these models are freely available from the BGS website. M. O'Leary, a glaciologist at Swansea University, published a 3D model of Antarctica in 2015 (O'Leary, 2015). The model contains ice and bedrock terrain at a 1:1 000 scale for the entire continent using data from the British Antarctic Surveys Bedmap-2 project. This model is also freely available on his website.

We can use Minecraft to generate geology of its own by employing additional modifications to the rules defining the world. We use the modification Realistic Terrain Generation (RTG); to curb the games exaggerated and fantasy like terrain generation rules. The normal version of Minecraft only has a few geologic rock units: sandstone and a generalized stone. BetterGeo, developed by the Geologic Survey of Sweden (SGU; Geologic Survey of Sweden, 2015), adds multiple types of sedimentary, metamorphic, and igneous rocks to the game, along with geologic rules about how the rocks can be found in the subsurface.

Developers have created many free external programs to build and modify Minecraft models, which are essentially 3D paint programs. These are relatively easy to use, as the programs define pre-set 3D brushes. We can use these tools to build up our own geology, instead of using Minecraft to generate it for us. They also allow exporting selections of the Minecraft world to be shared with others online in a Named Binary Tag (NBT) formatted file. Each material has its own unique identification number, which then allows us to import the NBT file into programs and assign geophysical properties to each block for subsequent simulation.

These geophysical models are good tools to use for testing algorithms. When real-world data has such a high financial and time cost, it is difficult to test new survey parameters, processing techniques, and inversion algorithms. These Minecraft geology modelling techniques allow us to quickly generate realistic geologic models with corresponding geophysical properties, with a practically unlimited spatial extent.

These tools can also be used as powerful teaching exercises for geophysics courses, enabling a wide variety of synthetic case studies. Students can move beyond simple test models to larger, more realistic data sets, allowing them to develop their interpretation skills earlier.

In this abstract, we elaborate on how to use Minecraft to create geologic models, and show experiments using two models. First

we create multiple data sets from a model generated using Minecraft, RTG, and BetterGeo to show the multiple scales of anomalies in the data. Then we create a model using a world editor to test a joint gravity and gravity gradient inversion algorithm, which was first presented in (Capriotti and Li, 2014).

## MINECRAFT

Minecraft is a sandbox style video game. The game world is composed of voxels, with each voxel having a single type of material in it. Starting from an initial seed given to a random number generator, the game procedurally generates a unique world to explore. Once the world is generated, the player mines for materials to craft into other items and build structures.

Terrain, mineral deposits, villages, etc. are created by following a set of rules. The world itself is divided into different biomes such as jungles, deserts, plains and oceans, and the rules that control generating the world depend on the biome. Some simple rules in the basic version of the game (Vanilla) are that certain types of minerals can only exist at certain depths.

Because of these rules, Vanilla Minecraft only attempts to create worlds that superficially appear real, no geologic structures are created and every mineral is found in the same type of material.

### Modifications

The game is sold across multiple platforms, including computers, game consoles, and tablets, and has become the 2nd best-selling video game of all time. Part of this popularity is the accessibility of the game, but also because the developers of the game have allowed for others to develop modifications (colloquially known as 'mods') for the game. We will highlight two of these mods that alter the rules for materials to be generated in Minecraft, allowing for more geologically realistic worlds.

First is the mod RTG. The Vanilla rules for Minecraft tend to create structures that are overly exaggerated, or simply impossible. This mod alters the terrain generation rules to create terrains that are more realistic.

Second is the mod BetterGeo (Geologic Survey of Sweden, 2015) published by the SGU. This mod adds many rock types and soil types to the game, and also gives more realistic rules for them to generate. For example in a plains biome, sedimentary rocks limestone, sandstone, and shale are generated in layers, metamorphic rocks start appearing below these sediments, and igneous rocks form intrusions that can crosscut all of the layers. Structures like kimberlite pipes that contain diamonds are allowed to form in the subsurface.

The BetterGeo mod was started to teach how rock types, minerals, and metals are dependent on the geology. The structures that it generates are generally simpler than the real world counterparts (there are no faults or folds). However, using both of these mods allows us to procedurally generate endless realistic worlds.

## World Editors

A large portion of Minecraft is building elaborate structures, which can then be shared with others. Minecraft world editors are built with this in mind. The programs can open up worlds generated within the game world, and manipulate them like 3D paint programs. More importantly, the most robust editors are open-source and freely available.

These programs also allow for simple ways to build structures in a planned-out manner. To build models we can essentially mimic events that happen in geologic times. For example, you can build up a mountain range and then fill the valley with sediment.

Every material type in Minecraft has a unique block identification number, and these editors also provide tools that allow one to export selections of the world to a file format called NBT. The files contain an ordered list of block ID numbers that describe the selection, enabling others to import the same structure into their Minecraft worlds. For our models we have used the MCedit 2.0 beta 6 program as our world editor, available from [www.mcedit.net](http://www.mcedit.net).

## GEOPHYSICAL MODELLING AND INVERSION

To create geophysical data, we take these geological models defined in the exported selections and translate them into geophysical property models. We start by importing a NBT file and reading in the blocks tag. This tag contains the ordered list of block IDs. We can then use a lookup table to assign different physical properties to each block depending on the material present.

This step enables us to adjust the scales of the model in three different directions. The world itself is represented as a regular geometry of 1 metre cubes, but this is certainly not a requirement. Any rectilinear type geometry can be assigned to the model and preserve the generated structures.

To illustrate this process, we have created two models. One model is generated using Minecraft with the mods BetterGeo and RTG, and the second using a world editor to create basin structures by hand. We then generate multiple types of geophysical data from the models, which are suitable for testing inversion algorithms.

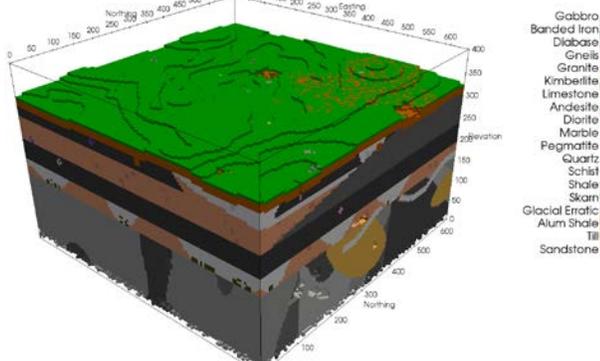
### Procedurally Generated Model

Minecraft procedurally generates the model segment in Figures 1 and 2 with the RTG and BetterGeo mods. The segment is located in a plains biome. We see that there are multiple different rock types located within the section. There are sedimentary rocks such as sandstone, shale, and limestone. There are also metamorphic rocks such as marble and gneiss, and igneous rocks such as gabbro and kimberlite.

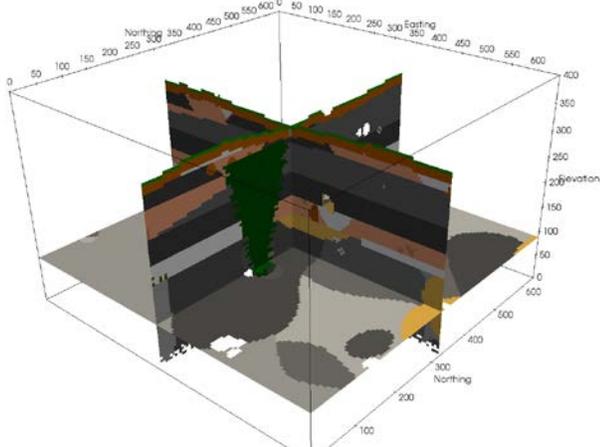
The sedimentary units occur in flat lying layers until half the depth of the section. Some of these units are pinched out within the volume. In the deeper half of the model, metamorphic rocks are present. Igneous rocks can be found throughout the volume

crosscutting other units. All of these rocks have different physical properties that we will use to create geophysical models.

We assign different physical properties (density, magnetic susceptibility, and electrical conductivity) to each unit within this selection and generate gravity (Figure 3), magnetic (Figure 4), and resistivity data (Figure 5) at the surface of the model. All of the data sets are simulated over the same area. The gravity and magnetic surveys are collocated, and the DC resistivity survey is set up as a grid of middle gradient electrodes in the easting-direction.



**Figure 1:** Segment from a world generated by Minecraft with the BetterGeo and RTG mods. The BetterGeo mod has added new rock types to the game world along with rules about how they can appear. The sedimentary layers are flat lying and cover deeper metamorphic and igneous rocks.



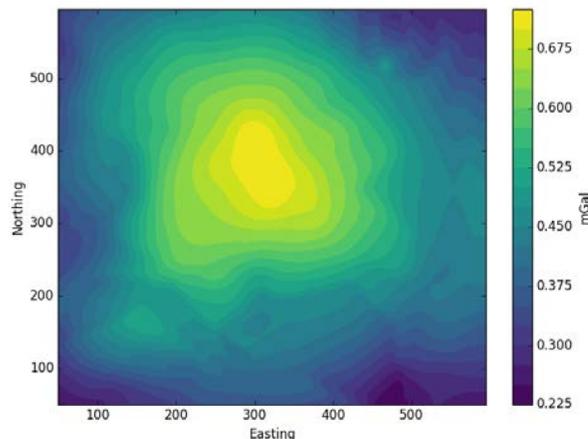
**Figure 2:** Slices through the model in Figure 1. Note how sedimentary layers can become pinched out. We can also see a kimberlite pipe that was generated in green.

The gravity data (Figure 3) show a large, broad, positive anomaly due a deep intrusion of high-density gabbro, but there are also several short wavelength anomalies in the area.

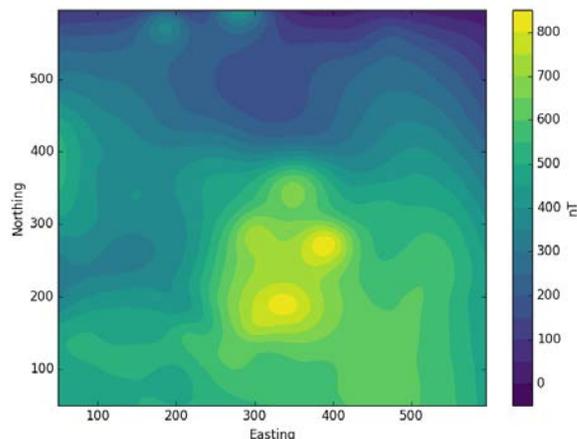
The magnetic data (Figure 4) have the same inducing field strength and direction as that in Denver, Colorado. The most notable anomalies are from an iron-rich deposit that is close to

the surface. However, the data also has a wide frequency range of anomalies, similar to the gravity survey.

We calculated resistivity data (Figure 5) in a middle-gradient survey array. Because of the high conductivity of the shale layers in the model, there are not many influences from deep structure in the apparent resistivity; however, the shape of the anomalies corresponds to the shape of the shallow geology.

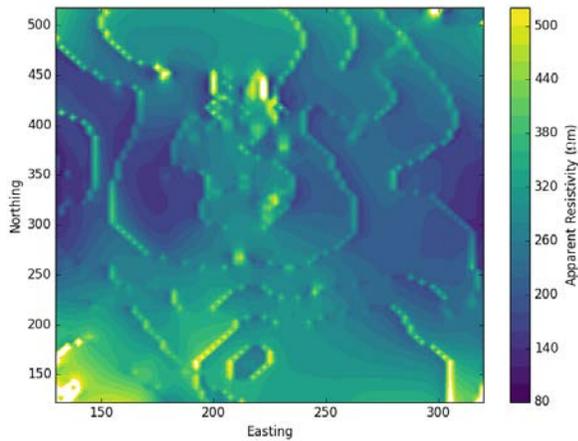


**Figure 3:** Gravity data forward modelled from the geologic model in Figure 1. The largest anomaly is from an intrusion of gabbro at depth, which contributes to its broader anomaly.



**Figure 4:** Magnetic data forward modelled from the geologic model in Figure 1. Most notable are the multiple short wavelength anomalies from a cluster of high-grade iron formations.

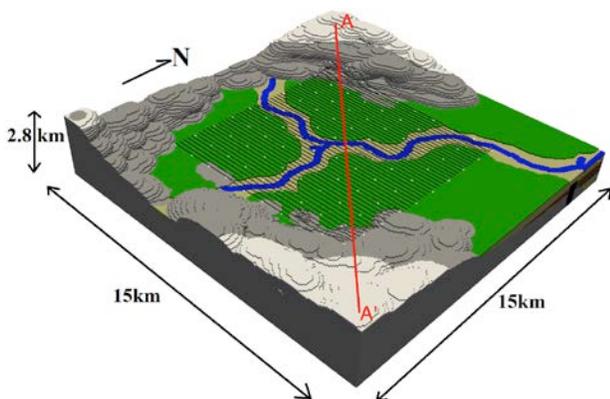
Now we have multiple datasets all over the same region that are suitable for testing geophysical algorithms. These are especially useful for generating test models for joint inversion techniques. Instead of spending hours building our own three-dimensional test model, we can now create a relatively complex test model instantly.



**Figure 5:** Middle gradient apparent resistivity data from the geologic model in Figure 1. The apparent resistivity corresponds to the geology below the surface. Topographic effects due to the discretization of the terrain are easily identifiable.

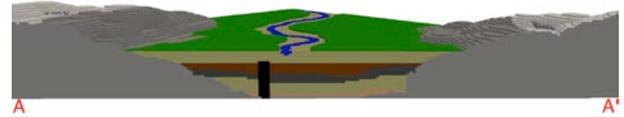
### Basin Model

The basin model in Figure 8 was created using a Minecraft world editor. The process consisted of generating a completely flat Minecraft world. To build the area, we first defined the basement and mountain structure by applying a 3D brush to the area, and then applying a short wavelength smoothing filter. After that, we used a tool to fill the basin in layers to create the sedimentary fill. Finally we added an intrusive dike that cuts through the middle of the model.

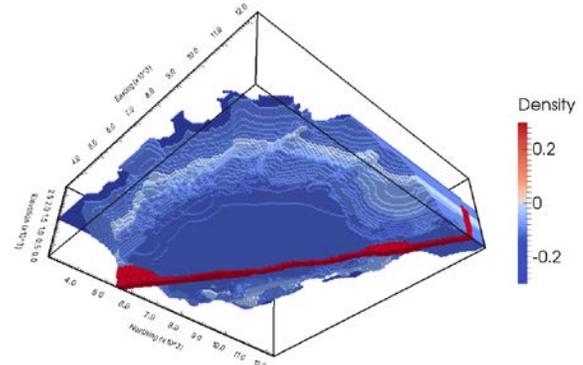


**Figure 6:** Synthetic geological model, mimicking a basin and range with an intrusive dike. The model is complete with layering, near surface inhomogeneities, and long wavelength basement structure. Flight lines for gravity gradient are in black and run east-west, and surface gravity stations are in white.

We used this model to show a test case for the joint inversion of gravity and gravity gradient data. This model was originally used in Capriotti and Li (2014). We converted the model to a density contrast model (Figure 8), and generated terrain corrected gravity and 6-component gravity gradient data with Gaussian noise added.



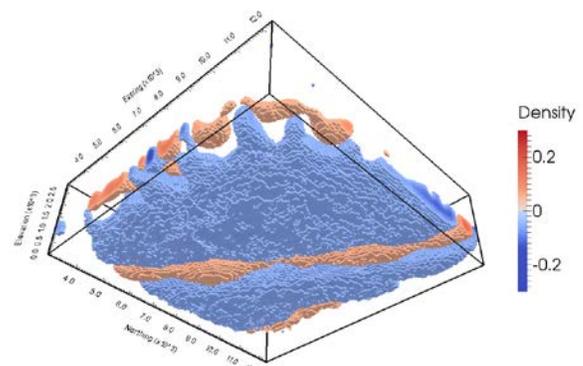
**Figure 7:** Northwest-southeast slice through the synthetic model. Note the layering of sediment and the intrusive dike.



**Figure 8:** The true basin density model. The basement density has been set to the background density, and the density contrasts are shown relative to that. Note the short wavelength, high amplitude density anomaly from the vertical dike, compared to the generally long wavelength densities of the sediment fill.

Gravity and gravity gradient data tend to have differing frequency contents and noise levels. Gravity data is relatively more sensitive to the longer wavelength anomalies in the data, however this data set aliases the short wavelength dike anomaly. Gravity gradient data can be collected faster at a higher accuracy, but is relatively more sensitive to the short wavelength signals.

When we can combine the two data sets, we take advantage of the differing sensitivities. This is demonstrated by the improvements in the recovered density contrast model for the joint inversion of the two data sets (Figure 9).



**Figure 9:** Recovered model from the generalized joint inversion of gravity and gravity gradient data. The inversion was able to take advantage of the differing frequency contents in the multiple datasets.

Now we could have simply tested our algorithm with a block model, but any information we would have taken from this

model would still be questionable when applied to real large-scale data sets. Using the Minecraft world editor allowed us to efficiently build a 3D test model, much closer to real-world conditions.

## CONCLUSIONS

We have used the video game Minecraft and software developed for it to generate large, complex, 3D geologic models. The procedurally generated models using the game along with the modifications RTG and BetterGeo can be used to create practically endless geology from a single random seed. The Minecraft world editors are also powerful tools for designing our own geologic models and allow for export of the geologic data in a simple form.

These models are suitable as a more realistic test of processing and inversion algorithms than the traditional block model. This also leads to the area of using Minecraft for outreach of geophysics in addition to geology. It can also be used as a powerful classroom tool, because it could essentially be used as a synthetic geophysical field laboratory for mineral exploration.

## ACKNOWLEDGEMENTS

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