The work compares and evaluates different possibilities of 3D visualization of geological layer in a Geographic Information System (GIS). The investigations are done by using ArcGIS Pro - a software developed by Esri – because it offers strong 3D visualization functionalities. Workflows for creating 3D boreholes, 3D solids and voxel layers are generated. In addition, a toolbox for the visualization is implemented into ArcGIS Pro. The research shows that ArcGIS offers strong possibilities for 3D visualizations of geological layers. Especially 3D boreholes and voxel layer can be created in a few steps. The generation of 3D solids is possible but has some disadvantages. The toolbox gives good results and is particularly suitable for people who are not used to working with a GIS.

*Keywords: 3d model, geological layer, GIS*
Introduction

For a better and sustainable management of our earth’s resources an important element is the realistic representation and visualization of the basic parts of the earth. As many resources are directly or indirectly related to geology, the descriptive visualization of geological layers may help for instance in explorative data analysis. Today, mostly geological maps are still visualized in 2D with a description of the different types of basements and rocks. Intrinsically, geological layers need a three-dimensional representation, thus in order to obtain better and clearer information about geological situations, 3D visualizations are more representational.

Geographic Information Systems (GIS) play an increasingly weighty role in coping with these tasks, because in a modern GIS it is possible to collect, display and analyze geological data not only in 2D. ArcGIS Pro – developed by Esri – is one of the most used Geographic Information Systems. It also has strong 3D spatial data processing and presentation capabilities.

The aim of this study is to create and evaluate workflows for the visualization of 3D geological layers in a GIS. For this purpose, the datasets are displayed with different approaches from ArcGIS Pro and the respective workflows are discussed and compared. Furthermore, a toolbox for an automatic visualization is generated. The created toolbox consists out of different scripts that can be used to visualize geological data in different ArcGIS projects. For using the toolbox, the 3D Analyst and the Spatial Analyst extensions must be available. Potential user of this toolbox are geologists who can use it to prepare and plan their fieldwork as well as to visualize the results. The study includes workflows for the generation of 3D boreholes, 3D solids and voxel layers.

The workflows and the visualization results are compared to one another. Therefore, two different study areas are used. One is the Wadi Feiran Basin in Sinai, Egypt; the second is New South Wales (NSW), Australia. For the Wadi Feiran Basin a Digital Terrain Model (DTM), a geological map as polygon shapefile and a scanned map with the location of wells is given. For New South Wales a geological dataset is used which is provided by the NSW Office of Water – National Groundwater Information System. It is supplied by the Australian Government Bioregional Assessment Program. The dataset contains around 142 000 boreholes all over NSW.

Method and Results

One possibility to visualize geological data is to create 3D point feature classes to make the geological units along boreholes visible. As input data, a Digital Terrain Model and the location of the boreholes are necessary. An appropriate workflow is to use a point feature class containing a feature for each geological unit at each location, extract the raster values from a DTM and calculate the height relative to the sea level from the top and the bottom of a geological layer. Table 1 shows as an example the values of the attribute table for the 3D point feature class of one well in the Wadi Feiran Basin.

<table>
<thead>
<tr>
<th>ID</th>
<th>Raster value (meter above sea level)</th>
<th>From Depth (meter)</th>
<th>To Depth (meter)</th>
<th>Description</th>
<th>Elevation (meter above sea level)</th>
<th>Extrusion (meter above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>1533</td>
<td>0</td>
<td>38</td>
<td>Alluvium Deposit</td>
<td>1533</td>
<td>1495</td>
</tr>
<tr>
<td>16</td>
<td>1533</td>
<td>38</td>
<td>500</td>
<td>Basement Rocks</td>
<td>1495</td>
<td>1033</td>
</tr>
</tbody>
</table>

The raster value is the value, which is extracted from the DTM (i.e. the surface elevation above sea level). From Depth describes the top of the geological layer, 0 means that the unit starts on the surface. To Depth is the value for the thickness of the geological layer. In the Description the geological unit is named. The Elevation and the Extrusion describe the start and the end of the geological layer in meter above the sea level.
The resulting 3D point feature class can be added to a scene in ArcGIS Pro. Within the scene settings for extruding the 3D points by the thickness of the geological unit has to be set. The 3D point feature class can be used for the further process to create more complex 3D models.

To create 3D solids, the points at the bottom of each geological unit need to be interpolated, to get a planar surface. By evaluating the results of different interpolation methods, the kriging method turned out to be the one with the most appropriate results. The raster layers for the single geological layer can be visualized in an ArcGIS scene to display first results in 3D.

After converting the single raster layers and the DTM to Triangulate Irregular Networks (TINs) a multipatch feature can be extruded between the two TINs. The multipatch feature represents the boundary of a 3D feature, thus the creation of cross-sections of the results is not optimal. Overall, the solids give a good overview of the geological situation of an area.

Voxel layers are available since the update 2.6 of ArcGIS Pro. They are suitable for the visualization of complex data, such as geological layers, in 3D. Voxel layers can represent continuous as well as discontinuous data. Soil types and geological data are discontinuous data because theoretically they have clear boundaries. Butler (2020) published a workflow for creating voxel layers out of discrete data. The first step is to reclassify the describing text field for the geological unit into an integer field; next a 3D Empirical Bayesian Kriging is performed. The result is a 3D geostatistical layer that shows horizontal transect at the assigned elevation. A netCDF-file must be created from the geostatistical layer. In netCDF-files multidimensional scientific data can be stored. The resulting file can directly be added to an ArcGIS scene.

The workflows described had been carried out manually and by using the implemented toolbox. The toolbox consists out of different scripts that are built up on one another. Script number one and script number two are used for creating 3D solids; script number three separates the generated 3D point feature class for the boreholes into each geological unit, carries out the kriging interpolation and converts the calculated raster layers into TINs. Script number four takes the TINs as an input, extrudes between those and saves the multipatch feature class in a geodatabase. The last script creates a voxel layer from a point feature class containing boreholes.

Figure one shows an example of two boreholes in the Wadi Feiran Basin, Sinai. The surface, as well as the 3D boreholes can be seen. The boreholes are starting in alluvium deposit and are running into basement rocks. As basement rocks are the oldest geological unit, no other unit is laying underneath. For this reason, the depth can be extruded to a fixed value. Displaying geological layers through 3D boreholes gives an initial overview of the geological situation of an area. In addition, gaps and potential errors can be detected.

In figure two, a 3D model of the geology of a part from the Wadi Ferian Basin is shown together with a basemap. The solids consist out of two features. One feature for the alluvium deposit and one for the basement rocks. In figure three on the left, the 3D solid can be seen and on the right side, a generated profile view within an ArcGIS scene is presented.
To create a voxel layer a test area in the Great Artesian Basin in NSW is used, because the geology description is more complex in this region. The voxel layer has an extent based on the minimum and maximum x, y and z values of the boreholes. Figure four shows the generated voxel layer. It is possible to create horizontal and vertical slices for the voxel layer, which can be seen in figure five.

**Conclusion**

The results shown in the figures above are all generated by the help of the implemented toolbox. The visualization by using the tool has advantages and disadvantages. One disadvantage is, that for
generating the 3D boreholes the workflow is semiautomatic, because the settings for the extrusion of the boreholes, needs to be done manually within the scene in ArcGIS. However, the automatic calculation of the boreholes makes it easy to interpolate the subsurface and create 3D solids and boreholes. It is important to note that the generated 3D point feature class can be used as an input to create more complex 3D models.

The creation of 3D solids using the toolbox also has positive and negative consequences. A major disadvantage is that the interpolation cannot be adapted much, to different situations. Furthermore, the boundaries of the 3D solids are only set by the extent of the point feature class, whereas with the manual workflow, the geometric situation around the boreholes can be visualized more individually. However, with the toolbox, the user does not need any specific knowledge of the individual functions in ArcGIS Pro, as well as instructions are given and the scripts build up on one another, thus a reasonable outcome is generated.

Another result of the research is that for creating voxel layers the different geological units do not have to lie one below the other, which makes the work with a bigger amount of boreholes easier, especially, when the structure of the geology differs along the boreholes. When creating a 3D solid based on boreholes, it is recommended to use boreholes, that have the same geological structure, otherwise the tool to extrude between the generated TINs will give an error.

As geometry type of the 3D solids is a multipatch feature, the cross-sections only show the boundaries of the solids (figure 3). In contrast voxel layers are filled and can represent cross-sections by creating slices that also can be saved as separate views. A drawback of the voxel layers is that; a cube is created that does not show the structure of the terrain. If the 3D model is created with 3D solids, the shape of the terrain can be recognized because the DTM is also used for the visualization.

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