Research on 3D Geological Modeling Based on ArcGIS and Borehole Data

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Abstract. 3D geological modeling is an important means to visualize and express geological information, analyze and study geological distribution intuitively. Borehole data is the main data carrier in geological research. This paper presents a method to create 3D geological model with the help of ArcGIS software. The method performs modeling preprocessing on the Borehole data and used to build the 3D geological model of rock and surface on the basis of the method of spatial geography data processing, based on the method of Delaunay TIN and Voronoi Diagram-Thiessen Polygon. The results of modeling were visualized by ArcScene software.

Introduction

3D geological model (3DGM) is a technology that is supported by three-dimensional (3D) computer technology, combines the functions of spatial information management, geological interpretation, spatial analysis and prediction, geostatistical statistics, physical content analysis and 3D graphic visualization used to analyze geological information [1].

Modeling is the creating of a 3D geological model. Through computer processing of a series of geological data such as geological borehole and geological section, 3D expression of geological body, geological phenomenon and geological process can be realized by means of data management and 3D visualization technology, Personnel for visual analysis and decision making.

GIS is short for Geographic Information System technology and an important method to store, analyze and express geospatial information by means of computer technology. Among them, the ArcGIS software developed by ESRI company has a strong 3D spatial data processing and presentation capabilities.

There are three commonly used methods of 3D geologic modeling based on section data, borehole data and multivariate data. In the three methods, the first two are more commonly used. The model based on 3D geological modeling of section data has high precision, but the location of rock in the section data is not clear, and the modeling process is less automated which requires professional expertise to interpret section data by the professionals. In this modeling method, a large number of data processing needs human-computer interaction, and the speed of modeling is slow.

The pattern and stratification of the underground rock in the borehole data are relatively clear, and the borehole data has a clear spatial location. So after a simple data processing, through the drilling data it would get the distribution of underground rock information. This is useful for creating 3D geological models with ArcGIS software.

The basic process of 3D geological modeling

The main process of 3D geological modeling based on borehole data includes four stages:

(1) Editing the information of location and elevation in the borehole data table, analyzing the distribution of the underground rock, stratifying the rock reasonably according to the original data;

(2) In ArcGIS software， using the location and elevation of borehole and rock to build model of the upper and lower surface of rock with the Delaunay TIN method, then using the borehole location to determine the range of rock with the Voronoi Diagram-Thiessen Polygon method;

(3) Using the function of extruding between two TINs in the 3D Analyst tool of the ArcGIS software to create the 3D geological model of rock.

(4) Achieving the same lithology rock formation of the merger by the function of spatial data query and spatial data editing in ArcGIS software.

The detailed process is shown in Fig.1.

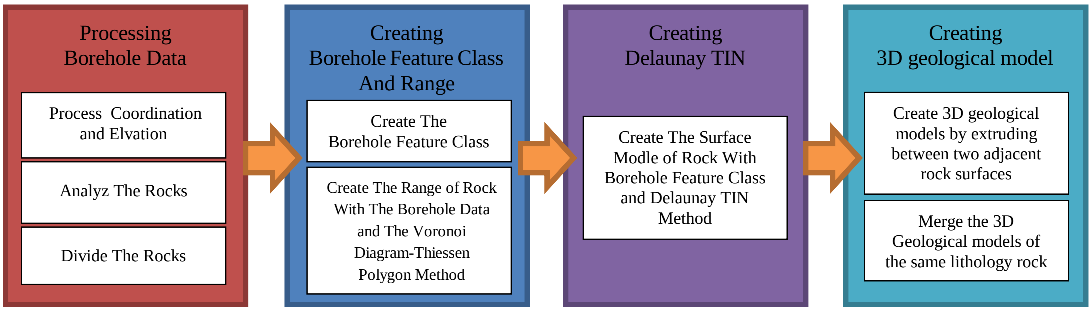


Figure 1. The process of 3D geological modeling based on borehole data

Process Borehole data

The original borehole data is shown in Tab. 1. The data include:

(1) The information of the borehole's plane: location and elevation;

(2) The information of the rock: depth, thickness and subsurface elevation of all rocks.

From the data analysis in Table 1, it can be seen that the maximum number of rock in the test area is four levels, which are the soil layer, the silty clay layer, the mudstone layer and the sandstone layer. Because of the changing role of geological environment in the development stage, it can be seen from the borehole data that the rock in some areas are absent. The structures of rock include: the single sandstone structure, the mudstone and sandstone structure, the soil and sandstone structure, the soil, silty clay and sandstone structure, the soil, mudstone and sandstone structure and the soil, silty clay, mudstone and sandstone structure. The lack of rock and the uncertainty of rock fracture location pose problems to the modeling of the upper and lower rock's surface. In this paper, the data of borehole lacking formation are adjusted by dividing the rock, so that the borehole data can meet the conditions of rock's surface model.

Table 1. The borehole data (section)

ID	Dpt	Elv	Coord		Silty clay layer			Mudstone layer			Sandstone layer			Soil layer		
			X	Y	Dpt	Th	Elv	Dpt	Th	Elv	Dpt	Th	Elv	Dpt	Th	Elv
ZY01	10.4	887.56	33751.09	80139.50							10.4	10.4	877.16			
ZY02	8.2	891.56	33727.98	80144.34	3.3	1.2	888.26				8.2	4.9	883.36	2.1	2.1	889.46
ZY03	8.2	891.65	33702.31	80149.72	3.8	1.4	887.85				8.2	4.4	883.45	2.4	2.4	889.25
ZY04	10.2	890.21	33679.30	80154.70	3.2	1.5	887.01				10.2	7	880.01	1.7	1.7	888.51
ZY05	8.3	891.12	33757.61	80158.22							8.3	8.3	882.82			
ZY06	10.3	891.69	33731.91	80163.62	3.5	0.9	888.19				10.3	6.8	881.39	2.6	2.6	889.09
ZY07	8.3	891.9	33706.15	80168.85	3.1	0.6	888.8				8.3	5.2	883.6	2.5	2.5	889.4
ZY08	8.4	892	33680.63	80174.60	2.7	1.3	889.3				8.4	5.7	883.6	1.4	1.4	890.6
ZY09	10.1	896.81	33761.91	80178.79	2.4	1.1	894.41	4.4	2	892.41	10.1	5.7	886.71	1.3	1.3	895.51
ZY10	10.2	897.12	33740.00	80183.38				4	1.4	893.12	10.2	6.2	886.92	2.6	2.6	894.52
ZY11	9.8	895.66	33717.80	80188.03	3.2	0.9	892.46				9.8	6.6	885.86	2.3	2.3	893.36
ZY12	10.6	897.32	33695.78	80192.65	2.7	1.2	894.62				10.6	7.9	886.72	1.5	1.5	895.82
ZY13	8.4	897.45	33765.37	80196.66	2.1	1.1	895.35	4	1.9	893.45	8.4	4.4	889.05	1	1	896.45
ZY14	10.3	898.26	33743.68	80200.94				4.6	3.4	893.66	10.3	5.7	887.96	1.2	1.2	897.06
ZY15	8.2	896.53	33721.43	80205.33	3.5	1	893.03				8.2	4.7	888.33	2.5	2.5	894.03

Dpt: Depth (m); Elv: Elevation (m); Coord: Coordinate (m); Th: Thickness (m).

Taking the ZY01 borehole data as an example, as shown in Table 1, the structure of rock under the ZY21 borehole is the soil and sandstone structure. According to analysis the complete rock, two rocks are missing. Here we average the sandstone layer into three layers, where have the same thickness and attribute, as shown in Table 2. And then calculate the upper and lower surface elevation of each rock formation, after finishing the rock surface data as shown in Table 2.

Table 2. The borehole data (After processing, section)

ID	X	Y	S1	1th	S2	2th	S3	3th	S4	4th	S5
ZY01	33751.09	80139.50	887.56	sandstone	884.96	sandstone	882.36	sandstone	879.76	sandstone	877.16
ZY02	33727.98	80144.34	891.56	soil	889.46	clay	888.26	sandstone	885.81	sandstone	883.36
ZY03	33702.31	80149.72	891.65	soil	889.25	clay	887.85	sandstone	885.65	sandstone	883.45
ZY04	33679.30	80154.70	890.21	soil	888.51	clay	887.01	sandstone	883.51	sandstone	880.01
ZY05	33757.61	80158.22	891.12	sandstone	889.04	sandstone	886.97	sandstone	884.89	sandstone	882.82
ZY06	33731.91	80163.62	891.69	soil	889.09	clay	888.19	sandstone	884.79	sandstone	881.39
ZY07	33706.15	80168.85	891.90	soil	889.40	clay	888.80	sandstone	886.20	sandstone	883.60
ZY08	33680.63	80174.60	892.00	soil	890.60	clay	889.30	sandstone	886.45	sandstone	883.60
ZY09	33761.91	80178.79	896.81	soil	895.51	clay	894.41	mudstone	892.41	sandstone	886.71
ZY10	33740.00	80183.38	897.12	soil	894.52	mudstone	893.82	mudstone	893.12	sandstone	886.92
ZY11	33717.80	80188.03	895.66	soil	893.36	clay	892.46	sandstone	889.16	sandstone	885.86
ZY12	33695.78	80192.65	897.32	soil	895.82	clay	894.62	sandstone	890.67	sandstone	886.72
ZY13	33765.37	80196.66	897.45	soil	896.45	clay	895.35	mudstone	893.45	sandstone	889.05
ZY14	33743.68	80200.94	898.26	soil	897.06	mudstone	895.36	mudstone	893.66	sandstone	887.96
ZY15	33721.43	80205.33	896.53	soil	894.03	clay	893.03	sandstone	890.68	sandstone	888.33

The surfaces and Rock layer modeling

Create the borehole feature class

ArcGIS software cannot directly use the data table to build the 3D model. First, using the method "Create feature classes from an XY table" in ArcGIS to create a borehole features class that is generated from the data table, and the location of borehole feature comes from the corresponding property field in the data table, the result of the created features is shown in Fig. 3.

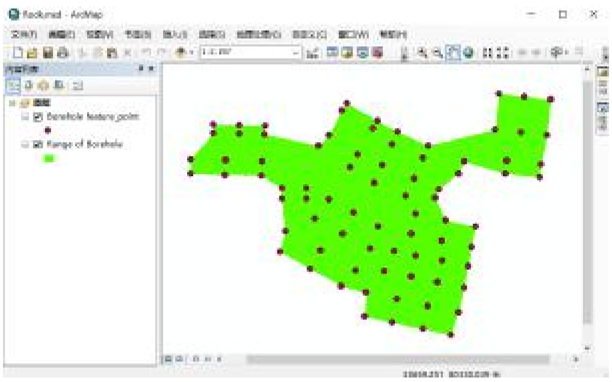


Figure 3. The borehole features

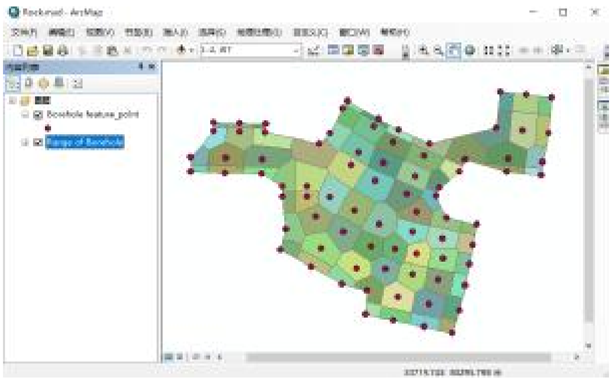


Figure 4. The range of rock distribution with the borehole features

Create the range of rock distribution with the borehole features

Rock distributions with different lithology cannot be obtained directly from the borehole data and need to be determined through calculations. The borehole data are considered as discrete points with interdependence.

The range of rock distribution under each borehole is related to the borehole location, and can be is represented by the Voronoi Diagram-Thiessen Polygon. The Voronoi Diagram-Thiessen Polygon method is used here to study and calculate the rock distribution; it's a common method to determine the continuous distribution of features by the discrete data. The range of the same lithology distribution around each borehole generated by the borehole point features, it can be completed by the function of “Create Thiessen Polygon" in ArcToolBox. The result of range is shown in Fig. 4.

Create the rock surface models by the Delaunay TIN method

The model of rock surface is needed to be created by Delaunay TIN method. It can be created by the "Create TIN" command dialog in ArcToolBox. In the dialog, the input feature class and the elevation property field must be set accurately. It must be noted, that is four rocks have five surfaces. So when creating the surface models by Delaunay TIN method, the input feature is the borehole feature class and the elevation property field is set as the elevation field of the current rock surface. The rock surface modeling results is shown in Fig. 5.

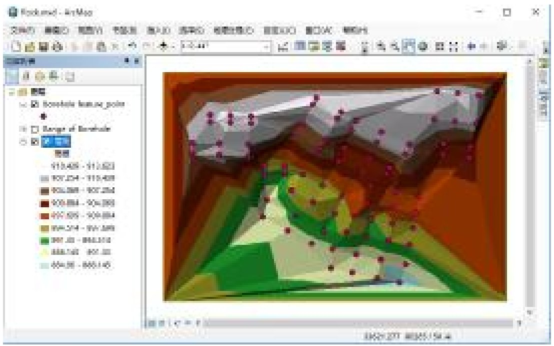


Figure 5. the rock surface models by the Delaunay TIN method

Create 3D geological models by extruding between two adjacent rock surfaces

The creating of the 3D geological models can be saved in four multipatch feature classes that completed by the “Extrude between two TINs” command dialog in the 3DAnalyst toolset of ArcToolBox. The extruded features are two TIN features that need to set for stretching. Note that there must be a range for the constructor features as the bounds, and ArcGIS supports either the polygon or line feature classes as ranges. In this paper, the distribution range of rock created by borehole data is taken as the boundary, and the division of the models is completed while extruding. The result of the 3D geological models is shown in Fig. 6.

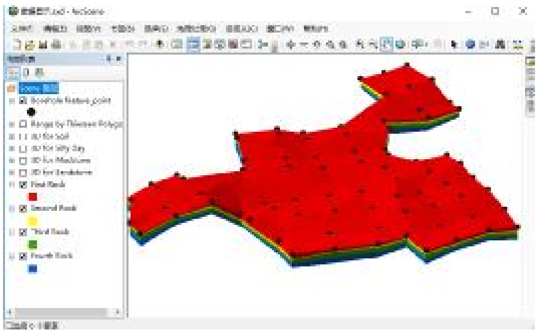
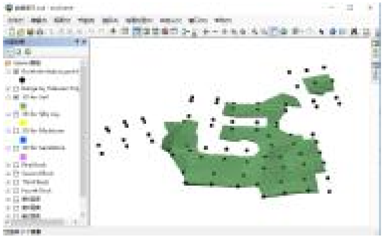


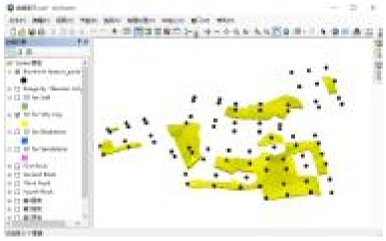
Figure6. The 3D geological models by extruding between two adjacent rock surfaces

Merge the 3D Geological models of the same lithology rock

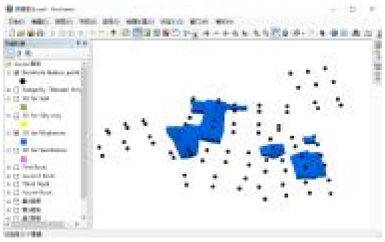
There are different lithology rock models in the same multipatch feature class, and each of which has a range that matches the Voronoi Diagram - Thiessen Polygon that created by borehole. So the 3D Geological models of the same lithology rock need to merge in a multipatch feature classes. With the powerful spatial location querying and analysis capabilities in ArcGIS, the 3D Geological models of the same lithology rock can be extracted from different multipatch feature classes by using "Select by the commands of Attributes" and "Select by Location". The 3D Geological models of the same lithology rock are shown in Fig. 8.



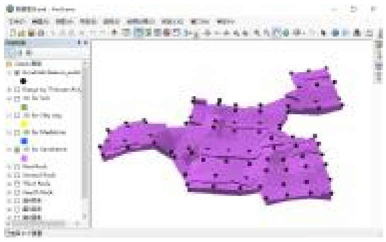
(a) The 3D geological models of the soil layer



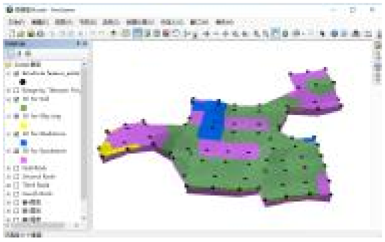
(b) The 3D geological models of the silty clay layer



(c) The 3D geological models of the mudstone layer



(d) The 3D geological models of the sandstone layer



(e) All the 3D geological models

Figure 7. The 3D geological models by extruding between two adjacent rock surfaces

Conclusions

In this paper, borehole data is used as the data source for modeling. By using the function of spatial data processing and analysis in ArcGIS, the 3D Geological models of the rock are created by using the Voronoi Diagram - Thiessen Polygon method and the Delaunay TIN method based on the rock surface model that were created, and the method of attribute selection and location selection is used to merge the 3D Geological models of the same lithology rock. The models can be visualized and analyzed in ArcSence software. The modeling method proposed in this paper is simple and efficient, and has some practical value. It has a certain meaning to study the distribution of rock distribution with different lithology in a large area.

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