A DESIGN OF THREE-DIMENSIONAL SPATIAL DATA MODEL AND ITS DATA STRUCTURE IN GEOLOGICAL EXPLORATION ENGINEERING

Penggen CHENG*, Jianya GONG**, Rong LIU*
* East China Geologic Institute, Linchuan, Jiangxi,344000, P.R.China
Cpg@ecgi.jx.cn or Cpg@rcgis.wtusm.edu.cn
** LIESMRS, Wuhan Technical University of Surveying and Mapping,
129 Luoyu Road, Wuhan, 430079, P.R.China
Jgong@rcgis.wtusm.edu.cn
Working Group IV/2

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ABSTRACT

The key to develop 3-D GISs is the study on 3-D data model and data structure. Scholars have presented some of the data models and data structures. As a matter of fact, because of the complexity of 3-D spatial phenomenon, there are no perfect data structures that can describe all spatial entities. Every data structure has its own advantages and disadvantages. It is difficult to design a single data structure to meet different needs. The important subjects in the 3-D data models are developing a data model that has integrated vector and raster data structures. A special 3-D spatial data model based on distributing features of spatial entities should be designed. We took the geological exploration engineering as the research background and designed a blended data model whose data structures have integrated vector and raster data by adopting object-oriented technique. Research achievements are presented in this paper.

1. INTRODUCTION

The main feature of geological exploration engineering is the three-dimensional object. As the forthcoming of the information age, available tools and methods are being developed to manage all kinds of information in geological exploration engineering. Various types of information management systems, especially Geographical Information Systems (GIS) have been put into practice and provided basic foundation for managing information in geological exploration engineering. However, at present, many GISs mainly processed 2D data. 3D information on the vertical direction is extracted as an attribute value, such as height, air pressure and temperature, on which the spatial operation and processing will be implemented. These operations can't establish a 3-D topological relationship among spatial entities, so that it is difficult to make real 3-D analyses. Obviously, These GISs will be limited in analyzing and visualizing spatial information of geology, mining, urban planning, oceanography, and so on. The only way to solve these problems is to develop 3-D GISs that are based on real 3-D data structure.

Theory study and production development of 3-D GIS are on the stage of researching and exploring. Based on 2D topological data structure, Moloenaar(1993) put forward a 3-D vector data model which was defined by using four elements—node, arc, border and surface. The interior structure of spatial entities was not considered while only spatial entity face was taken into consideration. Thus it was used to describe the regular spatial entities such as buildings and was difficult to give expressions to complex spatial entities in geology and mining. Chen（1995)has made researches on 3-D vector data model based on tetrahedron. There were four basic structure elements--point, segment, triangle, and tetrahedron in this model. The model can represent 3-D spatial entities that can be divided into a series of adjacent tetrahedrons that are not overlapped. Because only the interior partition was considered and the surface forms were not regarded in the model, it is difficult to present line and surface entity in 3-D. Li Deren and Li Qingquan (1997) have presented a hybrid data model based on octree and tetrahedron network. In this model, octree is completely designed and tetrahedron is only partially described. It is efficient in increasing precision and reducing data quantity, and is suitable for describing geological objects with multiple layers. As well Li Qingyuan(1997) has put forward a 3-D vector data model based on point, side, ring, surface and body. In this model, manual building is not regarded so it is only suitable for natural geological entities, which are formed by mutually exclusive and holistic bodies. Gong Jianya (1997) analyzed spatial objects and their relations of 3-D spatial information system in theory, and put forward an object-oriented data model of integrated vector and raster data. In this model, the relations between vector and raster data were based on the identification of an object.

In fact, there are no perfect data structures that can describe all spatial entities. Every data structure has its own characteristics and adaptability. Due to the complexity of 3-D entities and their applications, it is difficult to design a single data structure that is suitable for different cases. A pilot task of 3D data model research is to develop a blended data structure or integrate different data structures. With the differences in different studying fields, the ways to describe spatial entities are of fairly great discrepancies. It is impossible for us to design a data model that is suitable for all kinds of 3-D application areas. We should design a special 3-D spatial data model based on distributing features of spatial entities in the study areas.

The objective of this paper was to design an object-oriented three-dimensional spatial data model by using the integration of vector and raster data and its spatial entity data structure. The model was developed based on the features of the entities in geological exploration engineering. Firstly, 3-D spatial data models were discussed. Secondly, all kinds of 3-D phenomena and their description methods in geological exploration engineering were analyzed. Thirdly, based on analyzing several 3-D spatial data models, an object-oriented 3-D data model that has integrated vector and raster data and its data structure were designed. Lastly, with the help of an example of a volcano type iron field, the data model and its structure were shown.

2. ANALYSIS OF 3-D PHENOMENA IN GEOLOGICAL EXPLORATION ENGINEERING

The 3-D phenomena in geological exploration engineering are very complex. According to the formative conditions, the 3-D phenomena can be divided into the natural geological phenomenon and the exploration-engineering phenomenon. The former is the natural geological entities such as ore body, rock, stratum and its break line, gas gather point, and so on. The later are the manpower constructions such as silo, inclined well, drilling, exploring trough, tunnel, pick cavity, and so forth. The natural geological entities are irregular on the face and are complex to describe. The exploration engineering phenomena have more regular shape and they can be described by using the graphical data structure similar to CADs'.

Because spatial distributing features of 3-D phenomena are different, their description methods are of a great diversity. The shape of an ore body, for example, is an irregular close curved surface and we can describe it by using DEMs of the top and bottom surfaces. The ore body grade spatial distribution can be presented by using 3-D trend surface. Stratum interface can be presented by using Digital Elevation Model (DEM). Tunnel consists of regular columns or consecutive sections. We have to measure the horizontal sections in turn to describe the pick cavity. The drilling can be presented by using spatial coordinates of drilling center curve. See Figure 1. As a result, when designing 3-D data model and its data structures of geological exploration engineering, we should deal with them differently according to their own special features, that is to based on the blended data model.

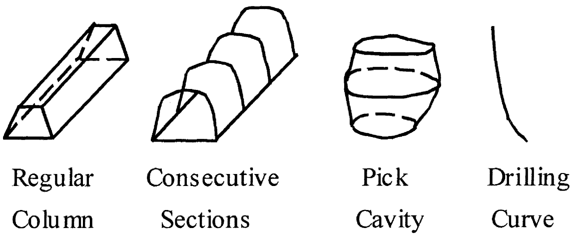

Figure 1. Tunnel, Pick Cavity and Drilling Curve

3. DESIGN OF 3-D SPATIAL DATA MODEL AND DATA STRUCTURE

3.1 Summarization of 3-D Data Model

As the study on 3-D spatial data model has gone deeper and deeper, some data models have come forth, such as data models based on vector, data models based on raster, model based on integrated vector and raster data and object-oriented data models. All kinds of data models have their own characteristic and adaptability. According to the geometric characteristics of data structure, 3-D data structures can be classified into surface-based and volume-based representations. On the format of data description, data structure can be divided into raster-based and vector-based data structure. See Table 1.

Surface based 3-D representation depicts geometric characteristic of objects by micro surface cells or surface elements. Boundary representation is used to describe regular objects mainly in CAD. And other data structures are suitable for describing irregular entities. Volume-based 3-D representation describes the interior of objects by using volume information but not the surface information. In this representation, Constructive Solid Geometry (CSG) is fit for describing regular objects. 3-D raster structure, needle models and octrees are used in denoting irregular bodies. Irregular tetrahedron network is suitable for describing both regular and irregular bodies.

Data Format **Geometrical Characteristics**	**Raster Based**	**Vector Based**
Surface Based Representations	Grids, Facet Model	Shape Model, NURBS, Boundary Representation
Volume Based Representations	3-D Array, Needle Model, Octree	Constructive Solid Geometry(CSG), Irregular Tetrahedron

Table 1. General 3-D Data Structures

Since it is difficult to describe spatial entities efficiently by using only one data structure, the common point of view is to adopt integrated data model. In this way, we can make use of the advantages of different data structures to describe entities with different characteristics and integrate different data structures into one data model, so as to present 3-D geography phenomena efficiently and completely. As we have discussed in section 1, hybrid data model based on octree and tetrahedron network (Li and Li, 1997), and object-oriented data model of integrated vector and raster data (Gong, 1997) are typical examples.

3.2 Design of 3-D Spatial Model

The advantage of raster data structure is the convenience for Boolean operation and high efficiency in spatial analysis, while the disadvantage is low efficient graphical output. Vector data structure is convenient for geometrical transformation and graphical output of high efficiency, but inconvenient for spatial analysis. The integration of vector and raster data redounds to bring into play the advantages of both and learn from each other. Object-oriented technology has come into fashion in computer science and technology. The object-oriented approach has been used to design and implement systems, and design data models in GIS. In the object-oriented data models, an entity, no matter how complex it is, can be described by using an object. The relationship among objects can be established by object identify. Object-oriented data model is able to represent the one-to-many relationship. It supports not only changing record in size but also aggregation objects. It is the ideal model to describe 3-D spatial objects Therefore, when designing 3-D spatial data model, object-oriented data model integrated vector and raster data can be adopted.

3-D spatial objects in geological exploration engineering can be divided into point, line, surface and body in geometry. They can be classified as 0-D (gas gather point, hot well), 1-D (stratum break line, drilling curve), 2-D (surface of ore body, transect of tunnel) and 3-D (ore body and tunnel body). But according to management they can be divided into different management units, for instance, mine, mine lot, mineral deposit and ore body. A management unit can be regarded as a complex space that consists of various of entities, such as regular body, column, irregular body, surface entities, line entities, arc, point entities and so on. Regular body can be presented by CSG, Column by continue sections, Irregular body by DEM, Vaxtixel and irregular tetrahedron network. Surface entities consist of boundary arcs enclosing curve surface, DEMs constructing curve surface and sections. Arcs constitute line entities. Arc entities are described by node points and interior points, and point entities by coordinates (x, y, z).

In a certain spatial extension, an ore deposit, for example, can be assembled a complex object, i.e. a complex object is aggregated of point entities, line entities, surface entities and body entities. In the viewpoint of object-oriented technology, the entities mentioned above could be classified into different object classes based on which we can generalize a superclass named spatial feature class. With regard to the above thinking, we have designed an object-oriented blended data model that integrates vector and raster data structures and is suitable for Geological Exploration Engineering. See Figure 2.

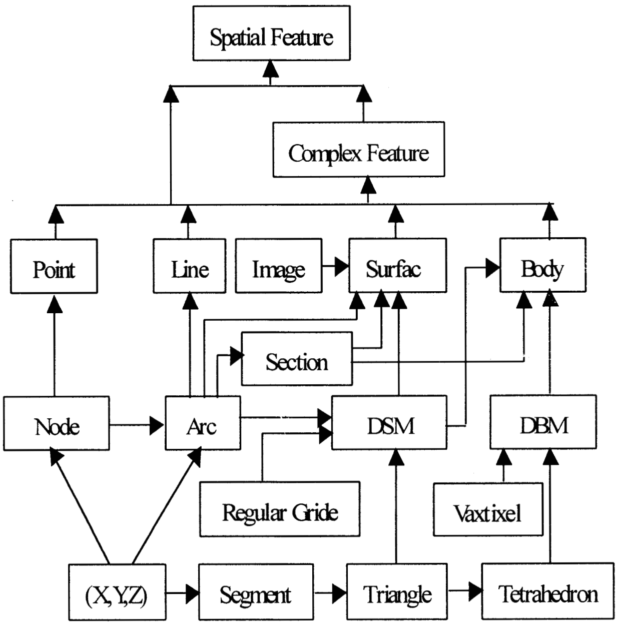

Figure 2. Object-Oriented Blended Data Model Integrated Vector and Raster

Field Name	Identification Symbol	Type	Feature
Surface Identification	SurfaceID	Long	
User Identification	UserID	CString	
Complex Object Identification what is affiliated with	ComplexID	Long	
Boundary Arc Number	ArcNum	Int	
Boundary Arc Identification	ArcID	Long	Length Change
Positive Surface Adjacent Solid Identification	PoSolidID	Long	
Negative Surface Adjacent Solid Identification	NeSolidID	Long	
Pointer Pointing DSM	DSMPointer	Long	
Pointer Pointing Surface Image	IMAGPointer	Long	
Minimal Envelop Body	Envelop	ENV	

Table 6. Surface Entity Structure

Field Name	Identification Symbol	Type	Feature
Section Identification	SectionID	Long	
Column Object Identification what is affiliated with	ColumnID	Long	
Boundary Arc Number	ArcNum	Int	
Boundary Arc Identification	ArcID	Long	Length Change
Minimal Envelop Body	Envelop	ENV	

Table 7. Section Structure

Field Name	Identification Symbol	Type	Feature
Solid Identification	SolidID	Long	
User Identification	UserID	CString	
Complex Object Identification what is affiliated with	ComplexID	Long	
Surface Number Constituted Solid	ArcNun	Int	
Surface Identification Constituted Solid	ArcID	Long	Length Change
Adjacent Solid Number	AjacSolidNum	Int	
Adjacent Solid Identification	AjacSolidID	Long	Length Change
3-D Trend Curve Surface Parameter Inner Body	3-DTCSP	TDTSP	
Attribute Description	AttrDes	CString	
Minimal Envelop Body	Envelop	ENV	

Table 8. Solid Entity Structure

Field Name	Identification Symbol	Type	Feature
Sidetrack Information Block Identification	STInfoBID	Long	
Start Traverse Point Identification	StartTravPID	Long	
End Traverse Point Identification	EndTravPID	Long	
Sidetrack Point Number	STPNum	Int	
Sidetrack Point Information	STPInfo	STPINFO	Length Change

Table 9. Sidetrack Information Block Structure

Field Name	Identification Symbol	Type	Feature
Column Identification	ColumnID	Long	
User Identification	UserID	CString	
Complex Object Identification what is affiliated with	ComplexID	Long	
Section Number	SectionNum	Int	
Section Identification	SectionID	Long	Length Change
Adjacent Solid Number	AjacSolidNum	Int	
Adjacent Solid Identification	AjacSolidID	Long	Length Change
Attribute Description	AttrDes	CString	
Minimal Envelop Body	Envelop	ENV	

Table 10. Column Entity Structure

Field Name	Identification Symbol	Type	Feature
Traverse Point Identification	TravID	Long	
Traverse Point Name	TravPName	Cstring	
User Identification	UserID	Cstring	
Backsight Traverse Point Identification	BackTravPID	Long	
Aheadsight Traverse Point Identification	AheadTravPID	Long	
Tunnel Identification what is affiliated with	TunnelID	Long	
Coordinates	Location	LOC	
Sidetrack Information Block Identification	SidetrackInfoID	Long	
Minimal Envelop Body	Envelop	ENV	

Table 11. Traverse Point Structure

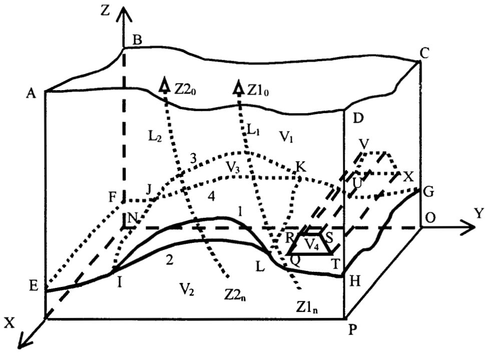

Figure 5. A Volcano Type Iron Field

3.4 Example

As Figure 5 shows, it is a geological exploration-engineering phenomenon of a volcano type iron field. In this geological exploration engineering, the following are the spatial entities included: V_1 is a volcanic rock, V_2 is a magma rock, V_3 is an iron ore deposit, V_4 is a transportation tunnel, L_1 and L_2 are drilling curves. These spatial entities constitute a complex object V. Some of the data structures and topological relationship are shown in Table 15~21. We can pick-up expediently description data of a spatial entity and topological relationship between the spatial entities according to these tables. For example, when we want to get the description information of iron core V_3, firstly, from table 16 we can find the surface identify 30002, In addition, spatial relationship of tunnel is more complex. It is similar to road network in two-dimensional plane. We can present their topological relationship by making use of network model. Tunnel can be described by making use of traverse in tunnel. For example, a tunnel spatial relationship is shown in Figure 3 can be presented by a network model in Figure 4.

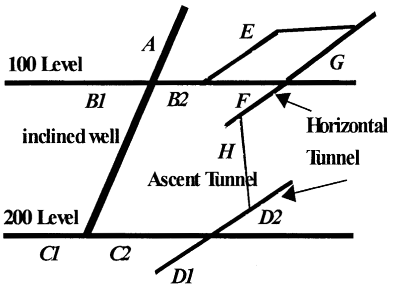

Figure 3. Tunnel Spatial Distributing

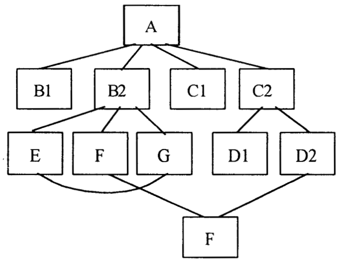

Figure 4. Tunnel Reticulation Model

3.3 Design of 3-D Spatial Entities Data Structure

When design data structure of 3-D spatial entities we should design all kinds of data structures and the topologic relationship between them, which are described in Figure 2. Some objects' description methods of data structures and topologic relationship, such as DEM, vaxtixel, image, irregular tetrahedron network and so on, have been defined and presented in Document [3,12], and we do not discuss here. For the convenient of spatial analyses and visualization of 3-D spatial objects, we should add a minimal volume parameter that envelops spatial objects in various data structures. In this paper we only design the data structures of point, node, arc, line, surface, section, column, body and complex object. Beside, the drilling and tunnel network are especial spatial objects, we should design especial data structures for them, such as drilling structure, traverse point structure, sidetrack information block structure and tunnel line structure. According to the logic relationship of the complex object, bodies, surfaces, line, and point objects, we create the topologic relationship between the objects. The concept of body, surface, lines and point is dynamic. They can exchange in different scale or different study emphasis. In this paper, we give data structure definitions of 13 kinds spatial entities. See the Tables from 2 to 14. We have designed ENV, LOC, TDTSP and STPINFO data structures. LOC is a point location structure, ENV is the minimal volume parameter structure, and TDTSP is the parameters of a 3-D trend surface describing ore body grade. And STPINFO is the side information block of tunnel. Their definitions are as below:

struct LOC{ double X, double Y, double Z};
struct ENV { LOC LOCmin, LOC LOCmax };
struct TDTSP { long P0, ……,long Pn};
struct STPINFO { double StrLen, double LeftWidth, double RightWidth }.

Here, Pi is the factor of parameter i in 3-D trend surface. StrLen is the straight distance, LeftWidth is the left side width and RightWidth is the right side width in the side information block of tunnel.

Field Name	Identification Symbol	Type	Feature
Point Identification	PointID	Long	
User Identification	UserID	CString	
Complex Object Identification what is affiliated with	ComplexID	Long	
Coordinates	Location	LOC	
Minimal Envelop Body	Envelop	ENV	

Table 2. Point Entity Structure

Field Name	Identification Symbol	Type	Feature
Node Point Identification	NodeID	Long	
Coordinates	Location	LOC	
Associate Arc Number	ArcNum	Int	
Associate Arc Identification	ArcID	Long	Length Change
Minimal Envelop Body	Envelop	ENV	

Table 3. Node Point Structure

Field Name	Identification Symbol	Type	Feature
Arc Identification	ArcID	Long	
Start Node	StartNode	Long	
End Node	EndNode	Long	
Adjacent Polygon Number	AdjPolyNum	Int	
Adjacent Polygon Identification	AdjPolyID	Long	Length Change
Line Entity Identification Include This Arc	LineID	Long	
Interior Point Coordinates String	LOCString	LOC	Length Change
Minimal Envelop Body	Envelop	ENV	

Table 4. ARC Structure

Field Name	Identification Symbol	Type	Feature
Line Identification	LineID	Long	
User Identification	UserID	CString	
Complex Object Identification what is affiliated with	ComplexID	Long	
Arc Number Included	ArcNum	Int	
Arc Identification Included	ArcID	Long	Length Change
Body Number Passed	PassSolidNum	Int	
Body Identification Passed	PassSolidID	Long	Length Change
Minimal Envelop Body	Envelop	ENV	

Table 5. Line Entity Structure

-30003, etc, which construct iron core; secondly, we can pick-up the parameters of surfaces and arcs in table 17 and 18. We can also get the relationship between the body entities from table 17.

Field Name	Identification Symbol	Type	Feature
Tunnel Line Identification	TunnelID	Long	
Tunnel Name	TunnelName	Cstring	
User Identification	UserID	Cstring	
Complex Object Identification what is affiliated with	ComplexID	Long	
Start Node	StartTPID	Long	
Tunnel Line Number Link Start Node	SNLinkTNum	Int	
Tunnel Line Identification Link Start Node	SNLinkTID	Long	Length Change
End Node	EndTPID	Long	
Tunnel Line Number Link End Node	ENLinkTNum	Int	
Tunnel Line dentification Link End Node	ENLinkTID	Long	Length Change
Traverse Point Number	TravPNum	Int	
Traverse Point Identification	TravPID	Long	Length Change
Section Number	SectionNum	Int	
Section Identification	SectionID	Long	Length Change
Minimal Envelop Body	Envelop	ENV	

Table 12. Tunnel Line Structure

Field Name	Identification Symbol	Type	Feature
Drilling Identification	DrillD	Long	
Drilling Name	DrillNum	CString	
Prospect Line Name What it Located	ProsLinName	CString	
Drilling Orifice Center Coordinates	CenLoc	LOC	
Drilling Depth	DrillDepth	double	
Surface Number Passed	PassSurNum	Int	
Surface Identification Passed	PassSurID	Long	Length Change
Solid Number Passed	PassSolidNum	Int	
Solid Identification Passed	PassSolidID	Long	Length Change
Drilling Curve Line Location Coordinates	LOCString	LOC	Length Change
Minimal Envelop Body	Envelop	ENV	

Table 13. Drilling Entity Structure

Field Name	Identification Symbol	Type	Feature
Complex Object Identification	ComplexID	Long	
User Identification	UserIDID	Long	
Contain Object Number	ContObjNum	Int	
Contain Object Identification	ContObjID	Long	Length Change
Attribute Description	AttrDescr	CString	
Boundary Surface Number	BsurfNum	Int	
Boundary Surface Identification	BsurfID	Long	Length Change
Minimal Envelop Body	Envelop	ENV	

Table 14. Complex Entity Structure

4. CONCLUSION

In this paper, we take the geological exploration engineering as our research background. Based on analyzing several traditional 3-D spatial data models, we have designed a blended three-dimensional spatial data model, which has integrated vector and raster data structures and been classified into 18 spatial objects. In object-oriented technique, the spatial entity, no matter how complex it is, can be considered as an object and can be described by using a certain structure, as a result that it is easy and natural to understand it. The spatial data structures we designed have taken the relationships among spatial objects into account, so as to handle and visualize spatial objects conveniently.

Field Name	Data
Complex Object Identification	10005(V)
User Identification	4500
Contain Object Number	6
Contain Object Identification	10001,10002,10003 10004,20001,20002
Attribute Description	………
Boundary Surface Number	6
Boundary Surface Identification (Replaced by Boundary Surface name)	-ABCD,CDOP,MNOP,ABMN, BCON,-ADPM
Minimal Envelop Body	……

Table 15. Complex Entity V

Field Name	Data		
Solid Identification	10001(V_1)	10002(V_2)	10003(V_3)
User Identification	3110	3120	4010
Complex Object Identification what is affiliated with	10005	10005	10005
Surface Number Constituted Solid	8	8	4
Surface Identification Constituted Solid	30001,-30002, -30004,30005, 30006,…	30003, 30004, …	30002, -30003, ….
Adjacent Solid Number	3	2	2
Adjacent Solid Identification	10002,10003, -10004	10001, 10003	10001, 10002
3-D Trend Curve Surface Parameter Inner Body	…	…	…
Attribute Description	Volcanic Rock	Magma Rock	Iron Ore
Minimal Envelop Body	…	…	…

Table 16. Solid Entity

Data model designing is only the first steps of our study. The future work is to put the model into practice combining examples in geological exploration engineering and perfect the data structures of spatial entities constantly. According to the current software development environment, what we have selected are as follows: WindowsNT operating system, VC++ programming language, relation database such as Access and SQL Serve, OpenGL graphics library.

Field Name	Data					
Surface Identification	30001 (ABCDA)	30002 (J3KL1IJ)	30003 (J4KL2IJ)	30004 (KGHLK)	30005 (ABEFA)	30006 (ADHL1IEA)
User Identification	1110	1120	1120	1130	1140	1140
Complex Object Identification what is affiliated with	10005	10005	10005	10005	10005	10005
Boundary Arc Number	4	4	4	4	4	6
Boundary Arc Identification (Replace by Arc Name)	AB,BC, CD,DA	J3K,KL, L1I,IJ	J4K,KL,L2I,IJ	KG,GH,HL,LK	AB,BE,EF,FA	AD,DH,HL,L1I,IE ,EA,0,-QRSTQ
Positive Surface Adjacent Solid Identification	10001	10003	10002	10002	Null	10001
Negative Surface Adjacent Solid Identification	Null	10001	10003	10001	10001	Null
Pointer Pointing DSM	…	…	…	…		…
Pointer Pointing Surface Image	…	Null	Null	Null	Null	Null
Minimal Envelop Body	…	…	…	…	…	…

Table 17. Surface Entity Structure

Field Name	**Data**			
Arc Identification	40001 (DA)	40002 (L1I)	40003 (KL)	40010 (QRSTQ)
Start Node	D	L	K	Q
End Node	A	I	L	Q
Adjacent Polygon Number	2	2	3	2
Adjacent Polygon Identification	30001 30006	30006, …	30002, 30003, 30004	30006 30010
Line Entity Identification Include This Arc	Null	Null	Null	NULL
Interior Point Coordinates String	…	…	…	…
Minimal Envelop Body	…	…	…	…

Table 18. ARC

Field Name	**Data**
Column Identification	10004(V_4)
User Identification	5010
Complex Object Identification what is affiliated with	10005
Section Number	2
Section Identification	30010, -30011
Adjacent Solid Number	1
Adjacent Solid Identification	10001
Attribute Description	Tunnel
Minimal Envelop Body	……

Table 19. Column Entity

Field Name	**Data**	
Section Identification	30010	30011
Column Object Identification what is affiliated with	10004	10004
Boundary Arc Number	1	1
Boundary Arc Identification (Replace by Arc Name)	QRSTQ	UVWXU
Minimal Envelop Body	…	…

Table 20. Section

Field Name	**Data**	
Drilling Identification	20001	20002
Drilling Name	L_1	L_2
Prospect Line Name What it Located	KTX-101	KTX-101
Drilling Orifice Center Location	…	…
Drilling Depth	205.6	189.8
Surface Number Passed	1	2
Surface Identification Passed	30002,30003	30004
Solid Number Passed	3	2
Solid Identification Passed	10001,10003,10002	10001,10002
Drilling Curve Line Location Coordinates	…	…
Minimal Envelop Body	…	…

Table 21. Drilling

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