

# MULTI-SCALE SPATIAL MODELING FOR GEOLOGICAL BODY BASED ON GTP MODEL

CHE De-fu<sup>a,\*</sup>, WU Li-xin<sup>a</sup>, YIN Zuo-ru<sup>b</sup>

<sup>a</sup>School of Resources and Civil Engineering, Northeastern University, Shenyang 110004, China;

<sup>b</sup>Kailuan Mining Group, Tangshan 063000, China;

Commission IV, ICWG II

**KEY WORDS:** Geology, GIS, Application, Modelling, Research, Multi-Scale

## ABSTRACT:

Three-dimensional (3D) modelling of geological body is an important issue of 3D GIS and 3D Geosciences Modelling, and one of the key technologies of digital mine. GTP model and its components are introduced in this paper. According to the relations between chronolith and rock attribute comprehensively, the modelling region, system, series, group and rock characteristics(R- C) are regard as the scale series for geo-spatial data organization and 3D model generation. Meanwhile, the method for 3D multi-scale spatial modelling of geological body is proposed, and its main process includes: 1) to generate Delaunay TIN (D-TIN) of the geological upper surface according to borehole's collar data; 2) to construction geological body model (CGBM) with the scale of "the whole geological body (WGB); 3) to construction model of geological body with the scale of System, Series, Group and R-C; 4) the faults and folds are look as one of scale during multi-scale modelling for geological body. The functions of 3D spatial modelling, visualizing and engineering designing for or on the complex geological body, is developed on GeoMo<sup>3D</sup> and it were verified with an iron mine as an example.

## 1. INTRODUCTION

In recent years, with the urgent requirement for 3D geological information simulation in mining, geological, environmental and rock-engineering domains, the development of 3D geosciences modeling and visualization is very rapid (Breunig et al., 1999; Cambray, D. B., 1993; Wu et al., 2003 ). More than twenty models for 3D geosciences modeling is presented and discussed widely, such as triangular irregular network (TIN), multi-DEM (Zhang and Bai, 2001; Wang and Bai, 2003), TEN (Pilouk et al., 1994; Chen, 1995), 3D Voronoi (Courrioux, et al., 2001) tri-prism (Houlding, 1994; Dai and Zou, 2001; Gong, 2002; Gong and Cheng, 2004; Cheng et al., 2004; Rui et al., 2004), generalized tri-prism (GTP) (Wu., 2004; Qi et al., 2002) and so on ( Bian et al., 2000; Sun and Chen, 2000; Li, 1994). These models can be classified as single models, mixed models and integral models. We can find many deficiencies in some of above these model after comprehensive analysis them: 1) There are so many interactive operations in the modelling process, they are very fussy. 2) The methods of multi-scale modelling for geological body are not studied deeply. 3) The faults and fold' influence aren't considered in these models, it is a limit for these models to be applied widely. In this paper, based on the analysis of previous researches on 3DGM, we propose a new approach for multi-scale modeling and visualization of complex geological body based on generalized tri-prism (GTP) volume.

## 2. CHARACTERISTICS OF GTP MODEL

Data model is the bridge linking real world and computer world; it should reflect the real world naturally and be propitious to the comprehension of real world. Modelling geological entities

according to the original sampling data is the key for data management, data handling and visualization. GTP has six basic geometrical primitives: vertex, edge (TIN-edge, side-edge), triangle, spatial quadrangle and GTP (Che at al, 2006), which is shown in Figure 1. According to the borehole data, GTP model can be degenerated into Pyramid or tetrahedron, which can be used to model the pinch-out, bifurcation, fault and other complex geological structures. Based on previous research achievements on GTP, the components of GTP are modified, as shown in Fig.1, five primary components of GTP, which are respectively Node, Edge (*up-edge*, *down-edge*, *side-edge*, *side-diagonal-edge*), *Up\_Down\_Triangle*(*Up-Triangle*,*Down-Triangle*), *Side\_Triangle* and GTP, are put forward to meet the demands of multi-scale modelling of complex geological body. The concept model, logical model and topology description of the amended model are studied renewably. *Up-Triangle* and *Down-Triangle* is the most important components of GTP volume. If the two elements are confirmed, then the GTP is confirmed.

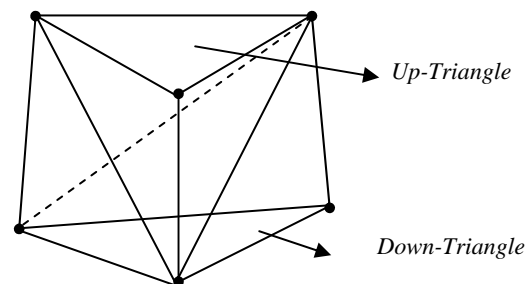


Figure 1 Primitives of GTP component

\* Corresponding author. CHE De-fu, E-mail: chedefu@mail.neu.edu.cn.

### 3. TWO CONCEPTS AND 3D MODELING LOGIC SCALE

According to the need of creating the complex geological body mode, two important concepts such as rock pole body (RPB) and limiting triangle are defined:

**Definition 1:** Take a triangle (named as *btriangle*) from terrain surface TIN, the three vertices of *btriangle* are corresponded to three boreholes' collars, a spatial dimension is created along the three boreholes to the bottoms of *btriangle*, the spatial dimension is defined as rock pillar body (RPB)

**Definition 2:** A RPB is divided into several close parts by some triangles, which are limits for creating faults and strata and are defined as limiting triangles (L-Triangles).

The stratum is the layered rock which forms in certain geological period. The chronostratigraphic unit is refers to the time limit which forms by the stratum. According to analyzing the relation between chronolith and rock attribute comprehensively, the concepts of 3D modeling logic scale, which is "the whole geological body (WGB), system, series, group and rock characteristics(R- C)", is put forward, and shown in Figure 2. The modeling logic scale is the concrete expression of Data organization according to chronostratigraphic unit; it is also the modeling and LOD displaying result. Regarding the continual rock sequence, is opposite in the stratum description from thick to thin, modeling logic criterion from large to small. The logical scale has reflected three dimensional geological modeling logical processes;

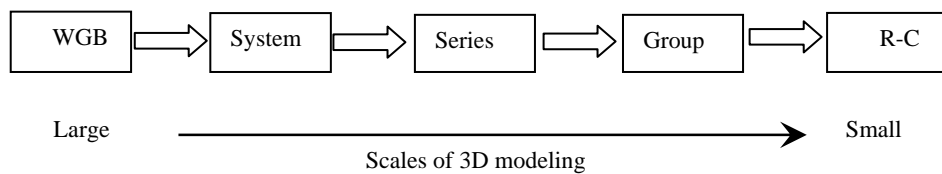


Figure 2 Scales of 3D modeling for geological body

### 4. THE PROCESS OF MULTI-SCALE MODELING FOR GEOLOGICAL BODY THE MAIN FLOW CHART

The main flow chart of multi-scale modeling of geological body is shown in Figure 3, which mainly includes: 1) according to the drill hole constructs ground CD-TIN; 2) take "WGB" as scale construction geological body model (CGBM); 3) take "system, series, group and rock characteristics" as scale CGBM. It is the key of 3D modeling of geological body to creating the limiting triangles of the RPB. The limiting triangles act the part of "limiting" during multi-scale 3D modeling of geological body. For example, the GTP models, creating them based on the scale of series, cannot exceed the limiting of the previous scale of system. In order to add the knowledge of geologist and experts to the result of 3DGM, 3D spatial interactive technology (3DSIT) developed in this paper can be made full use of during the process of 3DGM.

#### 4.1 Generation of terrain surface CD-TIN

In order to establish the topological relationship of boreholes, the borehole collar data should be taken as sample point to generate the Delaunay TIN of terrain surface, which be the base of GTP modeling. There are many algorithms on Delaunay TIN generation, among them the incremental algorithm is simple and easy to extend, so it is appropriate for borehole data. The main points of this algorithm include:

**Step 1:** To define an initial polygon including all borehole collar data;

**Step 2:** To establish initial TIN in the polygon, then repeat the following work to deal with all the borehole collar data: insert a data point *P*, search for the triangle *T* including *P* in the TIN, connect *P* to the vertex of *T* to generate three new triangle;

**Step 3:** To optimize the TIN by LOP.

If the borehole collar data has fault points, constraint D-TIN (CD-TIN) must be constructed. Sequential algorithms for constructing The algorithms for CD-TIN include: divide-and-conquer, incremental, asymptotically optimal algorithm, etc. For all of these algorithms, multiple diagonal exchanging algorithm for inserting constrained boundary in constrained D-TIN is practicable (Li, 1999). This algorithm is applied to solve the insertion and deletion of constraint line in D-TIN.

#### 4.2 CGBM with the scale of WGB

The "WGB" scale is the largest scale in the construction three dimensional geological models, it is fit for the three dimensional description and the analysis to the geological body. The main steps of this algorithm as follow:

**Step1:** Take a triangle (assumed as *up-triangle*) from terrain surface CD-TIN, whose three vertices (assumed as  $n_0, n_1, n_2$ ) of this triangle is corresponded to three boreholes collars;

**Step2:** Alone the three corresponding boreholes search to the bottoms points (assumed as  $n_3, n_4, n_5$ ) of each borehole respectively.

**Step3:** The three bottoms points make a limiting triangle (assumed as *down-triangle*);

**Step4:** One GTP is created by regarding as *up-triangle* and *down-triangle* as the GTP' components *Up-Triangle* and *Down-Triangle*;

**Step5:** Repeat step 1 to step 4, until all limit triangles of terrain surface CD-TIN are disposed.

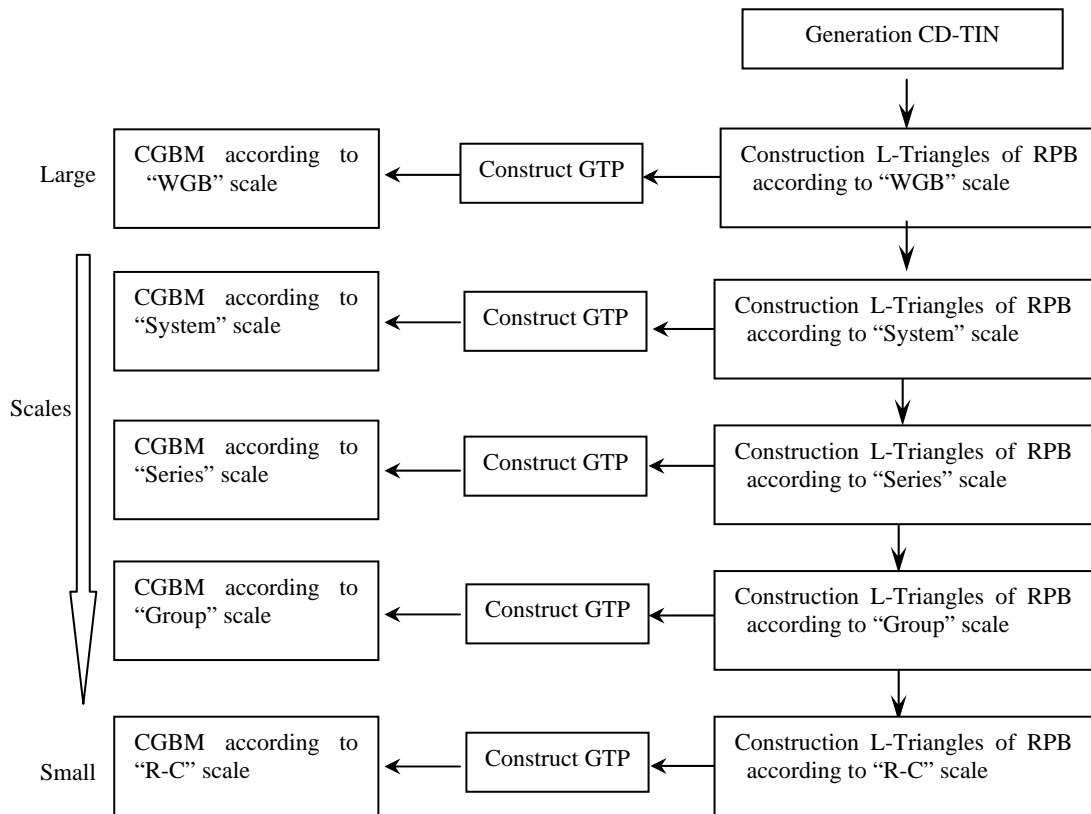


Figure 3. The main flow chart of multi-scale modeling of geological body

#### 4.3 CGBM with the scale of System, Series and Group

The algorithm and process for construction model of geological body with the scale of System, Series and Group are same on the whole, According to the scale from large to small order, the L-T is constructed based on the larger scale. Then, the GTP volumes are created, and all the model of the geological body with this scale is constructed succeed. For example, The main steps of this algorithm for CGBM with the scale of Series as follow:

**Step1:** Take a triangle (assumed as bTriangle) from terrain surface TIN, whose three vertices of this triangle is corresponded to three boreholes collars;

**Step2:** Take two limit triangles (assumed as  $T1$ ,  $T2$ ) from the dynamic array of bTriangle orderly.

**Step3:** From  $T1$  to  $T2$  along the three corresponding boreholes to search the mark for the scale of Series. If all three points that make a limit triangle are searched, the limit triangle is inserted into the limit triangle dynamic array of bTriangle between  $T1$  and  $T2$ .

**Step4:** Repeat steps 2) and 3), until all limit triangles of bTriangle are disposed.

**Step5:** Repeat steps 1) to 4), until all the triangle of terrain surface TIN have been treated.

#### 4.4 Construct the complex geological body with the scale of R-C

The faults and folds are look as one of scale during multi-scale modelling for geological body. In view of the amount, type and correlativity of the faults, the faults are classified to simple faults and complex faults. The faults, which are formed during one geological structure movement, are simple faults (Che at al,2006). There exists no complex relation such as cutting and bad breaking each other among these faults. The faults, which are formed during many times of geological structure movements are complex faults. There are complex relations among these faults. The faults types inside the geological body are judged according to their relations and integrity. If the faults are simple faults, their types are numbered 1, and if the faults are complex faults, their types are numbered by their cutting rations and their integrities. The main points of this algorithm include: .

**Step1:** Take a triangle (assumed as bTriangle) from terrain surface TIN, whose three vertices of this triangle is corresponded to three boreholes collars. A positive integer variable type is defined, type=1;

**Step2:** Take two limit triangles (assumed as  $T1$ ,  $T2$ ) from the dynamic array of bTriangle orderly.

**Step3:** From  $T1$  to  $T2$  along the three corresponding boreholes to search the fault\_down\_point (whose fault type is equal to the variable type). If all three points that make a limit triangle are searched, the limit triangle is inserted into the limit triangle dynamic array of bTriangle between  $T1$  and  $T2$ .

**Step4:** Repeat steps 2) and 3), until all limit triangles of bTriangle are disposed.

5) type= type +1, until all the faults are disposed.

**Step5:** Repeat steps 1) to 4), until all the triangle of terrain surface TIN have been treated.

The fold has complex structures, diverse types and many kinds of combination patterns. So, it is one of the hot and difficult issues in the domain of 3DGM. The key of the modelling of geological body with fold is the construction of the limiting-

triangle, which includes automatic and interactive construction of limiting-triangle. This method puts the detection of fold through the entire process of creating multi-scale geological modelling of geological body. Meanwhile, with the flexible 3D interactive technology developed in this paper, it is easy to construct and to edit GTP model interactively. Hence, the geological body with complicated fold can be accurately generated.

## 5. EXPERIMENTS

Based on the GTP volume, a real-3D GMS (geosciences modeling system) software platform, GeoMo3D, is developed with Visual C++ 6.0, OpenGL and SQL server. A series of borehole including five strata, one fault and fold, obtained from an iron mine, are tested. CGBM with the scale of WGB is

shown in 4(a); Fig. 4(b) shows the constructed 3D faults models and original boreholes together. The geological body models (CGBM with the scale of WGB, System, Group and R-C) are shown in Fig.4 (c), Fig.4 (d) and Fig.4 (e). The complex correlativity between complex fault and fold can be seen clearly in Fig.4 (f).

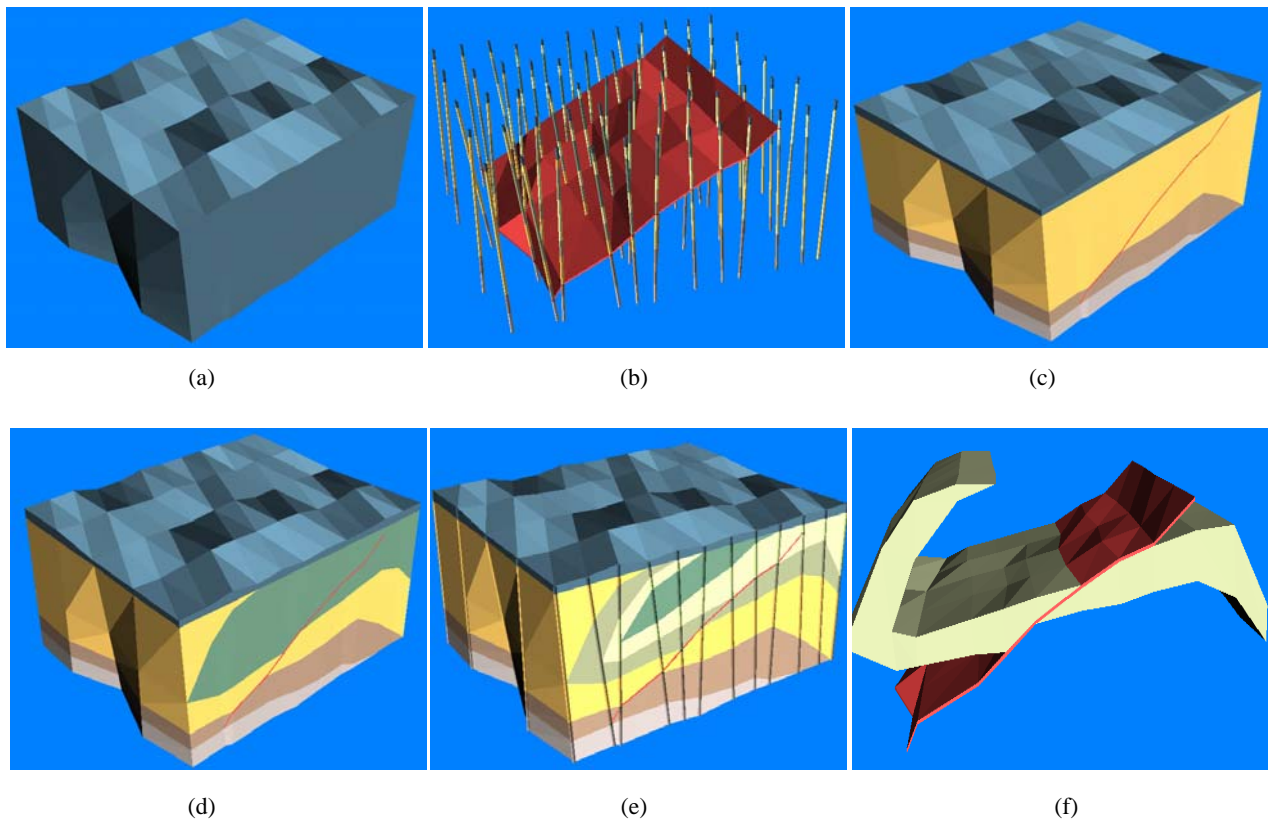


Figure 4. The experimental results of multi-scale modelling of geological body.

## 6. CONCLUSIONS

The GTP model is a powerful spatial data model for real-3D geosciences modelling and visualization. According to the relations between chronolith and rock attribute comprehensively, the modelling region, system, series, group and R-C are taken as the scale series for 3D model generation. Meanwhile, the method for 3D multi-scale spatial modelling of geological body is proposed. The developed GeoMo<sup>3D</sup> software platform and its practical application case in iron mine, show

that the GTP model and the method of multi- modelling and visualizing application are feasible.

## ACKNOWLEDGEMENT

This research is jointly supported by the National 863 High-Tech Program of China (ratified No. 2007AA06Z108, 2006AA12Z216), the Natural Science Fund of China for Distinguished Young Scholars (No. 50525414), the National Natural Science Foundation (No. 40571137).

## REFERENCES

- Bian, F. L., Fu, Z. L., Hu, Z. F., An objected-oriented integrative 3D data model. *Journal of Wuhan Technical University of Surveying and Mapping*, 25 (4), pp.294-298.
- Breunig, M., 1999. An approach to the integration of spatial data and systems for a 3D geo-information system. *Computers and Geosciences* 2 (1), pp39-48.
- Cambray, D. B., 1993. Three-dimensional modeling in a geographical database. In: *Proceeding of Auto Carto 11*, Berlin, pp. 338-347
- Che DF, Wu LX. Study on 3D Modeling Method of Faults Based on GTP Volume. In: *Proceeding IGASS 2006*, pp. 336-339.
- Che DF, Wu LX, Chen XX, Xu L. Modeling and visualizing methods for real 3D geosciences model based on amended generalized tri-prism (GTP). *Journal of the China Coal Society*, 2006, 31(5):576-580(in Chinese)
- Chen X Y., 1995. A workstation for three-dimensional spatial data research. In: *The Fourth International Symposium of LIESMARS*, Wuhan, pp.42-51.
- Courrioux, G., Nullans, S., Guillen, A., Boissonnat, J. D., Repousseau, P., Renaud, X., Thibaut, M., 2001. 3D volumetric modeling of Cadomian terrain (Northern Brittany France): an automatic method using Voronoi diagrams. *Tectonophysics*. 33 (1), pp..181-196
- Dai, W. J., Zou, Z. R., 2001. Study of the volume-based 3-dimensional GIS data model. *Mine Surveying*, (1), pp.20-22.
- Gong, J. Y., Cheng, P. G., Liu R., et al., 2002. Study on 3D modeling and visualization in geological exploration engineering. In: *Proceeding ISPRS Commission II Symposium on Integrated Systems for Spatial Data Production*, Custodian and Decision Support, pp. 133-138.
- Gong, J. Y., Cheng, P. G., Wang, Y. D., 2004. Three-dimensional modeling and application in geological exploration engineering. *Computers and Geosciences* 30 (4), pp391-404.
- Houlding, S. M., 1994. 3D geoscience modeling—computer techniques for geological characterization. Springer, New York, 303pp
- Li, L. X., Tan, J. R., 1999. Multiple diagonal exchanging algorithm for inserting constrained boundary in constrained Delaunay triangulation. *Chinese Journal of Computers*, 22 (10), pp.1115-1118.
- Pilouk, M., Tempfli, K., Molenaar, M., 1994. A tetrahedron-based 3D vector data model for geoinformation. In: Molenaar, M. (Ed.), *Advanced Geographic Data Modeling*. Sylvia De Hoop, Geodesy Press, pp. 129-140.
- Qi, A. W., Wu, L. X., Li, B., Li, J. M., Yang, Z. D., 2002. Analogical tri-prism: a new 3D geo-spatial modeling methodology. *Journal of China Coal Society*, 27 (2), pp.158-163.
- Rui, X. P., Yang, Y. G., Xi, Y. T., 2004. Study into visualization of 3D stratum based on triangular prism. *Journal of China University of Mining and Technology*, 33 (5), pp.584-588.
- Shi, W. Z., 1996. A hybrid model for 3D GIS. *Geoinformatics* 1, pp. 400-409.
- Shi, W. Z., 2000. Development of a hybrid model for three-dimensional GIS. *Geo-Spatial Information Science*, 3 (2), pp.6-12.
- Sun, M., Chen, J., Zhang, X. Z., A 3DCM data model based on surface partition. *Acta Geodaetica et Cartographica Sinica*, 29 (3), pp.257-265.
- Wang, C. X., Bai, S. W., He, H. J., 2003. Study on geological modeling in 3D strata visualization. *Chinese Journal of Rock Mechanics and Engineering*, 22 (10), pp. 1722-1726.
- Wu, L. X., Shi, W. Z. and Christopher, G. M., 2003. Spatial modeling technologies for 3D GIS and 3D GMS. *Geography and Geo-Information Science*, 19 (1), pp. 5-11.
- Wu, L. X., 2004. Topological relations embodied in a generalized tri-prism(GTP) model for a 3D geosciences modeling system. *Computers and Geosciences*, 30 (4), pp. 405-418.
- Wu, L. X., Shi, W. Z., 2005. On three-dimensional geosciences spatial modeling. *Geography and Geo-Information Science*, 21 (1), pp. 1-4.
- Zhang, Y., Bai, S. W., 2001. An approach of 3D stratum modeling based on tri-prism volume elements. *Journal of Image and Graphics* 6 (3), pp. 285-290.

