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Research Article

Automatic Drawing of the Complicated Geological Faults

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Abstract: In order to solve the problems about automatic drawing of complicated geological faults, a series of approaches are proposed. Based on the practical geological exploration, original data are collected, analyzed, standardized and stored in computer. The modeling methods of single fault are discussed, including linear fault and irregular fault. Based on topological relations between faults and the degree of their importance, the faults are divided into several levels. According to the levels, the cutting relationships of strata and faults, faults and faults are determined. Then the shapes of multi-faults and strata can be drawn automatically. We have used measured data to verify these methods. The results show that they are effective and feasible. And they can provide sufficient raw data for three-dimensional modeling based on sections.

Keywords: Automatic drawing of faults, complicated faults, geological faults, levels of faults, three-modeling geological modeling

INTRODUCTION

Modeling method based on sections (Wu and Xuhua, 2004; Zhong *et al*., 2006; Zhong *et al*., 2005) is one of the common methods in many three-dimensional geological modeling technologies (Zhang-lin *et al*., 2011; Qu, 2006; Che *et al*., 2008; Xiang *et al*., 2009). This method requires a lot of section data. Unfortunately the section data is often insufficient. In order to complete the modeling, a lot of interactive operations have to be used, which greatly reduces the efficiency of the modeling. Sections generated automatically can solve the problem of the lack of section data. But one of the difficulties is how to generate faults especially complicated faults automatically.

In this study, we discuss a series of approaches. Firstly the original data are processed, which are collected, analyzed, standardized and then stored with different forms in the computer. Then the Strata Recovered Technique (SRT) to be used to simulate strata cut by single fault. According to topological relations between faults and the degree of their importance, complicated faults are divided into several levels. Combined with fault scale, the relationships of strata and faults, faults and faults are determined. The shapes of multi-faults and strata can be drawn automatically. So the geological sections can be generated automatically.

These methods have been verified effective through measured data provided by KaiLuan Coal Mine.

DATA PROCESSING

In order to facilitate the computer read and processed, the original data need to be standardized, including collection, classification, analysis and generalization. The different type of data should be stored in different ways. After standardization the data types can be divided into three categories: character data, numeric data and graphics data.

Character data: Character data is the main form of Chinese characters, alphabetic characters and numeric characters. This kind of data is stored in the data table. The fault attribute data are stored with this data type. The following are three fault tables which should be used later:

- **The fault elements table:** The main fields include fault name, fault index, fault properties, fault level, fault strike, fault dip, fault dip angle and fault throw etc.
- **The irregular fault table:** The main fields include fault index, inflection point coordinates(x, y, z), fault strike, fault dip, fault dip angle and fault throw etc.
- **The fault vector graphic table:** The main fields include vector graphic name, strata order, the name of fault index field, the name of fault throw field etc.

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Numeric data: Numeric data are also stored in the data table. The drilling sample data are this kind of data type. The following are two drilling data tables:

- **The inclined drilling sample data table:** The main fields include core number, core length, deviation angle, Azimuth, strata order etc.
- **The vertical drilling sample data table:** The main fields include core number, core roof coordinates (x, y, z), core length, strata order etc.

Graphics data: There are many kinds of graphics data, which can be recorded in graphical form. For example, some geological sections generated with digital logging data or digital earthquake data. These data can be used directly. In addition, there are many paper maps, such as geological maps, topographic maps, geological sections and contour maps etc. These study maps should be converted into document form by some hardware device (such as laser scanner) and then be converted into vector graphics by using software, such as CAD, GIS or other software.

SINGLE FAULT MODELING

Linear fault modeling: The shape of linear fault is simple and regular. It has fixed dip, dip angle and fault throw. We can deduce the shape of fault according to its properties and some control points. Wuqiang etc., provided an effective method (Wu and Xu, 2003). As shown in Fig. 1, P_1 (x_1, y_1, z_1) P_2 (x_2, y_2, z_2) are control points, $\overline{p_1 p_2}$ is fault strike, θ is fault dip angle, we can get two symmetrical fault plane. According to the fault dip, the fault plane equation can be determined. United the equation and section plane equation, the fault line equation can be got.

Irregular fault modeling: Irregular fault refers to the fault which has irregular shapes, variable dip, dip angle and fault throw. The Strata Recovered Technique (SRT) can be used in irregular fault modeling. The SRT is the inversion of the strata developmental history. It can restore the original state of the strata plane before cut by fault. Then calculate the intersection line equation of strata plane and fault plane. So the fault line equation is got. Along the fault line, one part of strata should be moved up; the other moved down certain distance which should be determined by the fault throw. Finally the strata and the fault are adjusted to the most appropriate state.
The rule of the SRT:

- Base on the basic geological law and the fault development law
- Take full account of the relationship between the fault and strata that cut by the fault
- The reasoning should use the measured data firstly and then combined with other speculated data or interpretation data

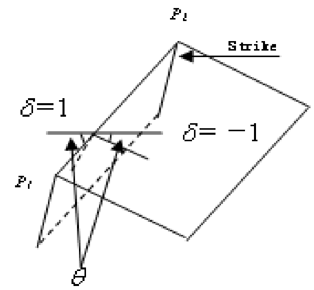

Fig. 1: Method of solving the fault line equation

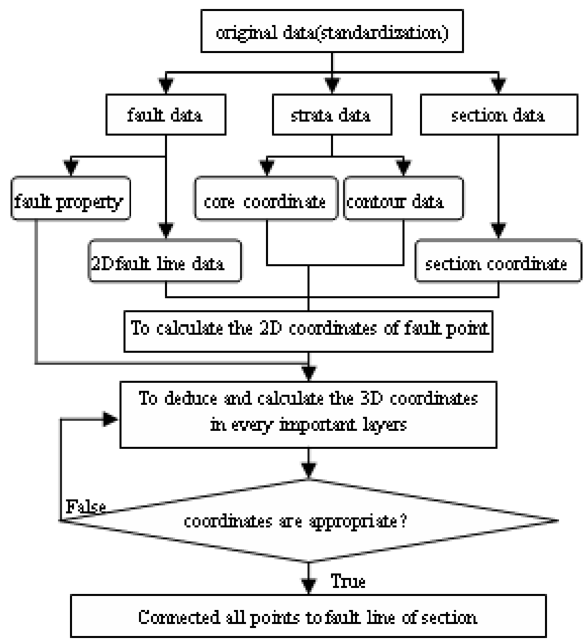

Fig. 2: Flow chart of generating irregular fault lines

- If there are contradictions or conflicts in raw data, the high reliability data would be selected
- If there are different precision data, for example 2D data and 3D data, they should be unified into the same precision firstly (Qu, 2006)

The algorithm of drawing fault line: The irregular fault which has complicate shape should be separated several parts. Each part should has same properties. Shown as in Fig. 2, the process are:

- **Standardize original geological data:** The original data which have different data type and accuracy should be converted into standard format and be stored in corresponding data table or .shp file.
- **Calculate the 2D coordinates of fault points:** The fault lines which get from different important layers(mine layer) intersec with section plane. We can get several intersection(fault points) from different layers. Shown as Fig. 3, the α_1, α_2 and α_3

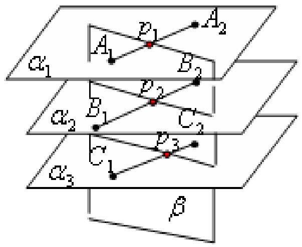

Fig. 3: The algorithm of generating fault line

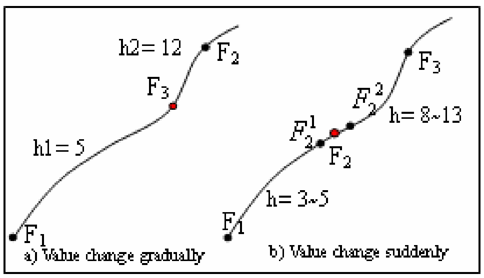

Fig. 4: The processing of variable fault throw

are three layers, the β is section plane, A_1A_2, B_1B_2 and C_1C_2 are fault F_1 which appears in the different layers, the point p_1, p_2 and p_3 are intersection (fault points). we can calculate the 2D coordinate of all fault points.

- **Deduce 3D coordinates of the fault:** Based on the core 3D coordinates and contour data on the every layers, the 3D coordinates of the fault can be deduced.d) Connect to form the fault line. We connect p_1, p_2 and p_3 to form the fault F_1 appeaed in the section β.

The processing of variable fault throw: There are two kinds of fault throw. The one is fixed throw whose vaule is fixed. The other is variable throw whose value is changed. There are two types of variable throw:

- The vaule of throw changes incremented or decremented gradually. we can calculate the fault throw vaule of any point in fault line using cubic spline interpolation method. Shown as Fig. 4a, the fault throw of F_1 is 5 and F_2 is 12. We can calculate the vaule of F_3 using above method.
- The vaule of throw changes suddenly. This kind of fault should be divided into several parts in the inflection point, in which the fault throw value changes suddenly. Shown as Fig. 4b, from F_1 to F_2 the fault throw is 3~5. From F_2 to F_3 the fault throw is 8~13. The value changes suddenly in the F_2 point. We get the two points F_2^1, F_2^2 close to F_2 point, suppose the value is 5 in F_2^1 point, the value is 8 in F_2^2 point. So the fault is divided into three parts. The fault throw should be calculated using the above method.

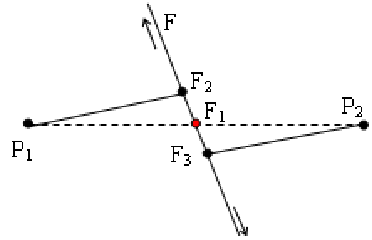

Fig. 5: The processing of strata cut by single fault

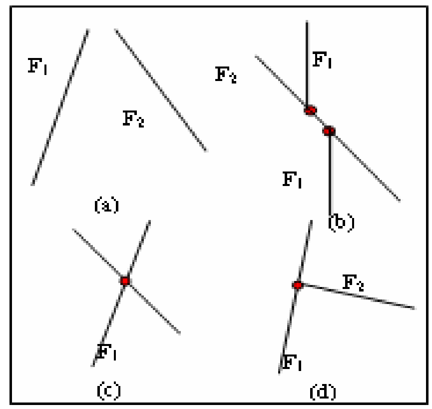

Fig. 6: The spatial relationship between two faults

The processing of strata cut by single fault: The strata are cut into two parts by fault. One part should be moved up; the other one moved down along the fault plane.

Shown as Fig. 5, stratum P_1P_2 is cut by fault F. First we calculate the coordinate of intersection point F_1. Then according to the fault properties (normal fault or reverse fault) and fault throw, we can get the coordinate of F_2 and F_3. The stratum P_1P_2 is cut into P_1F_2 and F_3P_1.

It should be pay attention that the stratum line is irregular curve constituted by a series of discrete points instead of straight constituted by two points. So the each discrete point should be moved different distance. For example, in the Fig. 5, the point F_2 should be moved the distance which equal to the length of the fault throw. The moving distance of other points along from the point F_2 to the point P_1 should be reduced gradually with a certain rule. If the point P_1 is the measurement point, its moving distance is 0.

COMPLICATED FAULT MODELING

Fault level: The faults formed earlier may be cut by the other faults formed later, even be cut into two relatively independent parts. There are three spatial topological relations between two faults. The first is neighbor relation. In Fig. 6a, fault F_1 and F_2 are neighbor without touching. The second relation is intersecting without movement, shown as Fig. 6c and d. In Fig. 6c,

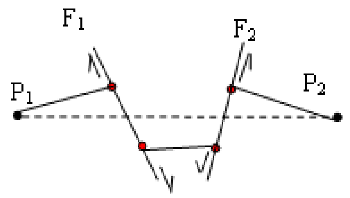

Fig. 7: The processing of same level faults

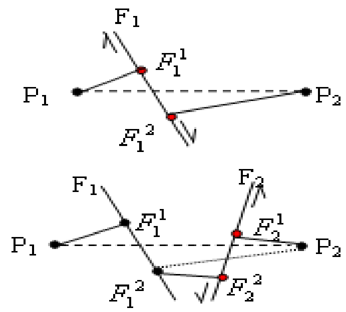

Fig. 8: Fault F_1 level is higher than fault F_2

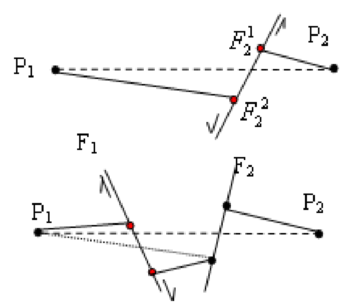

Fig. 9: Fault F_1 level is lower than fault F_2

the two faults intersect without relative movement, looks like X. In Fig. 6d, the two faults intersect at a point which is the endpoint of one fault, looks like T. The third relation is intersecting with movement. In Fig. 6b, fault F_1 is cut into two parts by fault F_2. Each part moves some distances along F_2.

Based on topological relations between faults and the degree of their importance, faults are divided into several levels. The basic principle is: the major fault level is higher than the secondary fault; the early fault level is higher than the later; the level of fault F_1 cut by F_2 is higher than the fault F_2.

The processing of strata cut by multi-level faults: If the stratum is cut by several faults in the section, we adopt the following methods to deal with the faults:

- **The same level:** If the level of faults is same, the faults should be processed following a certain direction one by one, for example following the extending direction of the section. Shown as Fig. 7, the stratum P_1P_2 are cut into three parts by fault F_1 and fault F_2.

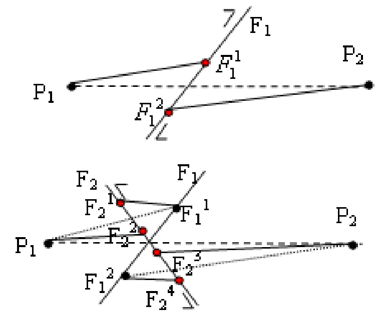

Fig. 10: Faults intersect to form X shape

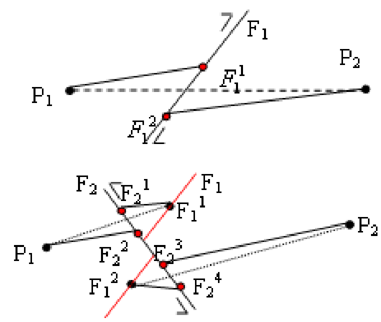

Fig. 11: The fault is cut and moved

- **The different level:** If the level of faults is different, the higher level faults should be processed firstly. Shown as Fig. 8, the level of fault F_1 is higher than F_2. The stratum P_1P_2 is cut into two parts $P_1F_1^1$ and $F_1^2P_2$. Then fault F_2 cut stratum $F_1^2P_2$, which is cut into $F_1^2F_2^2$ and $F_2^1P_2$. The Fig. 9 shows another situation, that the level of fault F_1 is lower than F_2.

If the faults cut each other we should consider the topological relations between faults.

If the relation of faults is intersecting without movement, we process them with the following method. Shown as Fig. 10, Fault F_1 intersects F_2 at a point without movement, looks like X. The level of fault F_1 is higher than F_2. They cut stratum P_1P_2 into four parts.

If the relation of faults is intersecting with movement we deal with them shown as Fig. 11. The fault F_1 cut stratum P_1P_2 firstly. Then it is cut into two parts by fault F_2.

The $F_1^1F_2^2$ is moved up a distance along F_2 and $F_2^3F_1^2$ is moved down a distance along F_2. The stratum is cut into four parts.

APPLICATIONS

The methods have been implemented in computer platform using Visual C++ and OpenGL. Shown as Fig. 12, the sections contained complicated faults are generated automatically using the measured data from KaiLuan Coal Mine.

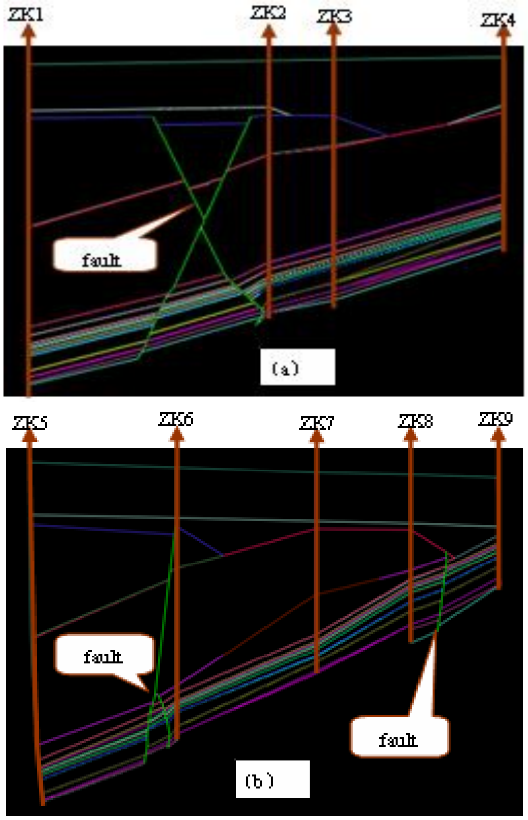

Fig. 12: The sketch section of faults cutting stratum

Figure 12 shows the zk1, zk2….zk9 are drilling numbers. There are two faults in Fig. 12a. The relation of faults is intersecting with movement. In Fig. 12b, there are three faults. Two of them intersect at the point which is endpoint of one fault, looks like T.

Known as the information from sections, the methods are feasible and effective.

CONCLUSION

The automatic drawing of the complicated faults is the key of generating geological sections. This study proposes a series of approaches to solve the problem. Firstly, the original data are collected and processed. After being standardized, they are stored in different forms. Secondly, we discuss the single fault modeling method. Include linear fault and irregular fault. Thirdly according to the spatial topological relations and the degree of their importance, the faults are divided into several levels. Finally, according to the level of fault and other relevant data, we can determine the relationships of fault and fault, fault and strata and the shape of faults and strata. In order to confirm the practical result of the methods, we test them using some measured data. The results show that the method is effective. They can provide sufficient raw data for three-dimensional modeling based on sections.

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