GEOLOGIC MODELING AND VISUALIZATION USING GEOMODEL2003 -VISUALIZATION OF GEOLOGIC BOUNDARIES BASED ON GENERALIZED GEOLOGIC FUNCTION-

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ABSTRACT

The geologic function that assigns a unique geologic unit to every point in the objective 3-D space is a key element of a computer geo-mapping. Algorithms for construction and visualization of 3-D geologic model based on the geologic function have been widely developed. As the concept of geologic boundary is not contained in the geologic function, it was newly defined the generalized geologic function that assigns a pair of directly above and below geologic units to every point in the objective 3-D space.

The generalized geologic function clarifies a boundary of geologic units to be visualized. Visual Basic program Geomodel2003 was developed to visualize geologic boundaries on the objective surface by embedding sub-routines for visualization of geologic boundary which had been developed in the Geomodel2000. We verified the usefulness of the proposed algorithm. Application of Geomodel2003 to a test data in Honjyo area, Akita Prefecture, Japan, proved that the proposed algorithm is valid 3-D geologic modeling.

1. INTRODUCTION

The method of 3-D geologic modeling based on logical model of geologic structure has been developed by Masumoto *et al*. (1997) and Shiono *et al*. (1998). The methods have been proposed to visualize 3-D geologic modeling by Masumoto *et al*. (1999) using GRASS GIS and Sakamoto *et al*. (2000) using Visual Basic program Geomodel2000. It is possible to draw the 2-D geologic map, the vertical geologic section map and the 3-D geologic map. However, there is still unsolved matter concerned about visualization of geologic boundaries, which is one of the most important elements to draw the geologic map.

We propose *the generalized geologic function* which is improved on the geologic function to solve the problem. In our approach, we strictly defined the generalized geologic function. It shows that geologic boundary can be drawing in the geologic map using generalized geologic function. Further, we verified the usefulness of the proposed algorithm. The example of application for the geologic map including the geologic boundaries is shown using a Geomodel2003.

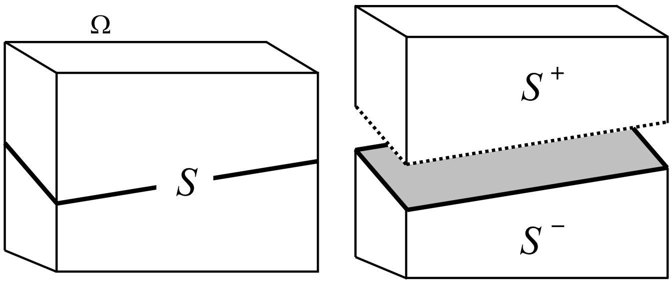

Figure 1. The objective space Ω is divided into two subspaces on surface.

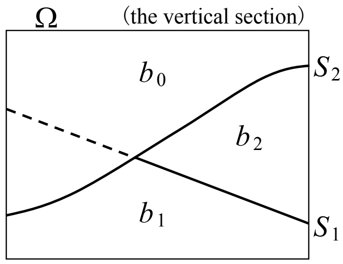

Figure 2. The simple geologic structures.

2. BASIC THEORY

Logical model of geologic structure, *geologic function* and *minset* are explained easily in accordance with Shiono *et al*. (1994, 1998) as a preparation to explain *the generalized geologic function*.

2.1 Logical model of geologic structure

Let an objective 3-D space Ω be a survey area and suppose that the space Ω is divided into two subspaces on surface S. Where S^+ and S^- give subspaces that lie above and below the surface S, respectively (Figure 1). The surface S is contained in subspace S^-, it has the relation of the next way.

$$S^+ \cup S^- = \Omega , \qquad S^+ \cap S^- = \phi . \tag{1}$$

The space Ω is composed of n geologic units (b_1, …, b_n) including open space b_0 (air). Figure 2 shows that the simple geologic structures are expressed as the vertical section. The geologic unit b_1 represent basement rock. When there are sedimentation and erosion, the geologic unit b_2 is formed. Surface S_1 is a geologic boundary surface, and surface S_2 is a topographic surface. The distribution of geologic unit b_1, b_2 and b_0 are expressed as follow;

$$b_1 = S_1^{\,-} \cap S_2^{\,-} , \qquad b_2 = S_1^{\,+} \cap S_2^{\,-} , \qquad b_0 = S_2^{\,+} . \tag{2}$$

The distribution of geologic units b_0, … , b_n are defined by surfaces S_1, … , S_p. The logical relation between the distribution of geologic unit and the surface are termed *logical model of geologic structure*.

2.2 Geologic function

As the geologic units b_0, b_1, … , b_n are defined by surfaces, they can be expressed in *minset* (Gill, 1976). The *minset* is a minimum subspace that is divided by the surfaces S_1, … , S_p in the space Ω. Each minset defined by;

$$m_{d1d2\cdots dp} = X_1 \cap X_2 \cap \ldots \cap X_p , \tag{3}$$

$$X_k = \begin{cases} S_k^{\,-} \ ; \ d_k = 0 \\ S_k^{\,+} \ ; \ d_k = 1 \end{cases} \qquad (k = 1, 2, \ldots , p) .$$

Four *minsets* can be defined by two surfaces S_1 and S_2 as follows;

Table 1. The value of function g_1.

M	$g_1(m)$
m_{00}	b_1
m_{01}	b_0
m_{10}	b_2
m_{11}	b_0

$$m_{00} = S_1^- \cap S_2^-, \quad m_{01} = S_1^- \cap S_2^+, \quad m_{10} = S_1^+ \cap S_2^-, \quad m_{11} = S_1^+ \cap S_2^+. \tag{4}$$

When it was provided the logical model of geologic structure, the distribution of geologic units $b_0, \ldots, b_n$ can be expressed the union of minset is generated by the surfaces $S_1, \ldots, S_p$. In the case of Figure 2, *minset* can be derived for the geologic units as follows;

$$\begin{cases} b_0 = (S_1^+ \cup S_1^-) \cap S_2^+ = m_{01} \cup m_{11}, \\ b_1 = m_{00}, \\ b_2 = m_{10}. \end{cases} \tag{5}$$

There is the relation between the set of minset $M = \{m_{00}, m_{01}, m_{10}, m_{11}\}$ and the set of geologic unit $B = \{b_0, b_1, b_2\}$ as shown below;

$$m_{00} \subset b_1, \quad m_{01} = b_0, \quad m_{10} = b_2, \quad m_{11} = b_0. \tag{6}$$

When let a function g_1: $M \to B$ corresponds to the geologic units including their *minset*, a value of geologic function g_1 in Figure 1 is expressed in Table 1.

Further, for a point P (x, y, z) in a space Ω, a *minset* $m_{d1d2\ldots dp}$ can be assigned a value of $d_k = 0$ or $d_k = 1$ depending on whether P (x, y, z) lies S_k^+ or S_k^-, respectively. This correspondence between every point in the space Ω and *minset* is expressed by a function g_2: $\Omega \to M$.

Therefore, the function g: $\Omega \to B$ is expressed to compound the function g_1 and function g_2 as follows;

$$g(x, y, z) = g_1(g_2(x, y, z)). \tag{7}$$

The function g is termed *the geologic function* (Masumoto *et al.*, 1997), assigns a unique geologic unit to every point in the space Ω.

3. GENERALIZED GEOLOGIC FUNCTION

V_ε is a sphere which radius is ε and it's a center point P exists inside of the space Ω. When a point P exists in geologic unit b, sphere V_ε is also included in geologic unit b if it is possible to make radius ε short reasonably. All the value led geologic function g of a point P in V_ε can be geologic unit b. However, when a point P exists on boundary surface between below the geologic unit b and above the geologic unit b', two kinds of geologic units b and b' exist in V_ε that means the value led geologic function g can not be invariable even though how short the radius ε is. Using this property, we propose the method to distinguish whether the position of a point P is in the geologic unit or on the boundary surface.

3.1 Directly above and below minset

When *minset* m_0 and m_1 are generated by the surface S which divided the space Ω into two subspaces, a point P (x, y, z) exists on surface S is included m_0 (Figure 3). A point P' $(x, y, z-\varepsilon)$ lies lower than a point P (x, y, z) by infinitesimal distance ε (>0) is included m_0, as well. *Minset* include a point that lie lower than a point P (x, y, z) by infinitesimal distance is called the directly below *minset* of a point P. And, a point P'' $(x, y, z+\varepsilon)$ lies upper than a point P (x, y, z) by infinitesimal distance ε is included m_1. *Minset* include a point that lie upper than a point P (x, y, z) by infinitesimal distance is called the directly above *minset* of a point P. It can be generally explained by *minset* that are generated by the surfaces $S_1, \dots, S_p$ divides the space Ω into two subspaces. When the concretely properties of surfaces are shown, character code $c_1, \dots, c_p$ is defined by;

$$c_k = \begin{cases} 0 \text{ ; A point } P \text{ lies lower than } S_k \\ * \text{ ; A point } P \text{ lies on } S_k \\ 1 \text{ ; A point } P \text{ lies upper than } S_k \end{cases} \qquad (k = 1, \dots, p) . \quad (8)$$

When a point P does not exist on surface S, character codes are composed of binary number, 0 and 1. It is exhibited that character codes is index as well as function g_2. When a point P exists on surface S, character codes include *. Therefore, it is defined function $g_2' : \Omega \rightarrow M \times M$ that assigns a pair of the directly above and below *minsets* (m, m') to every point P (x, y, z) in the objective 3-D space Ω. Next, we explain an example of execution to go after a pair of the directly above and below *minsets* (m, m'). It show that the five point $P_1, \dots, P_5$ corresponds to value of g_2'. In the case of a point P_1 (x_1, y_1, z_1) lies lower than both surfaces S_1 and S_2, $c_1\, c_2$ is 0 0;

$$g_2'(x_1, y_1, z_1) = (m_{0\,0}, m_{0\,0}) . \quad (9)$$

In the case of a point P_2 (x_2, y_2, z_2) on surface S_1 and lower than surface S_2, $c_1\, c_2$ is * 0. When * interchanges 0 and 1, it gets two character code 0 0 and 1 0;

$$g_2'(x_2, y_2, z_2) = (m_{0\,0}, m_{1\,0}) . \quad (10)$$

In the case of a point P_3 (x_3, y_3, z_3), P_4 (x_4, y_4, z_4) and P_5 (x_5, y_5, z_5);

$$g_2'(x_3, y_3, z_3) = (m_{1\,0}, m_{1\,1}) , g_2'(x_4, y_4, z_4) = (m_{0\,1}, m_{1\,1}) , g_2'(x_5, y_5, z_5) = (m_{0\,0}, m_{1\,1}) . \quad (11)$$

3.2 Generalized geologic function

The every point P in the space Ω is corresponded to a pair of *minset* (m, m') by function g_2. Therefore, *minset* m lies directly lower than a point P is corresponded to geologic unit $g_1(m)$ including the point by function $g_1 : M \rightarrow B$. *Minset* m' lies directly upper than a point P is corresponded to geologic unit $g_1(m')$ including the point by function g_1, as well. Through this method, it is possible to define the function $g' : \Omega \rightarrow B \times B$ that corresponds to a pair of geologic units lie in both directly a above and below the point P. The function g' is termed *the generalized geologic function*. The generalized geologic function g' is possible to define by;

$$g'(x, y, z) = g_1'(g_2'(x, y, z)) . \quad (12)$$

It show that the five point (P_1, … , P_5) of Figure 3 corresponds to value of g' in Figure4. In the case of a point P_1 (x_1, y_1, z_1) lies lower than both surfaces S_1 and S_2;

$$g_2'(x_1, y_1, z_1) = (m_{00}, m_{00}), \qquad g_1(m_{00}) = b_1 . \tag{13}$$

Therefore,

$$g'(x_1, y_1, z_1) = g_1'(g_2'(x, y, z)) = (g_1(m_{00}), g_1(m_{00})) = (b_1, b_1) . \tag{14}$$

In the case of a point P_2 (x_2, y_2, z_2) , P_3 (x_3, y_3, z_3), P_4 (x_4, y_4, z_4) and P_5 (x_5, y_5, z_5);

$$g'(x_2, y_2, z_2) = (b_1, b_2), \qquad g'(x_3, y_3, z_3) = (b_2, b_0),$$
$$g'(x_4, y_4, z_4) = (b_0, b_0), \qquad g'(x_5, y_5, z_5) = (b_1, b_0) . \tag{15}$$

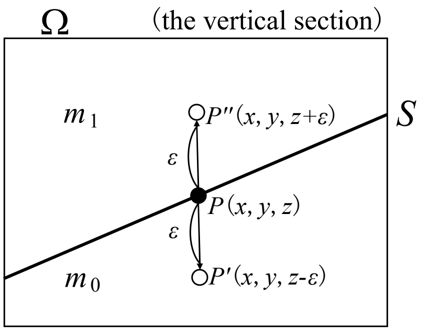

Figure 3. The directly above and below *minset* of a point *P*.

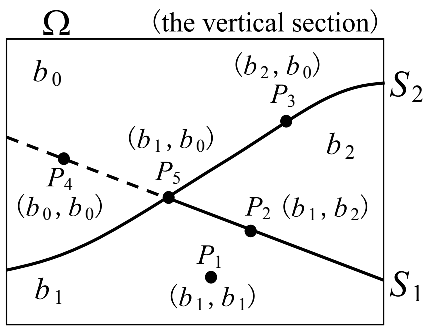

Figure 4. The value of generalized geologic function *g′* on their five points.

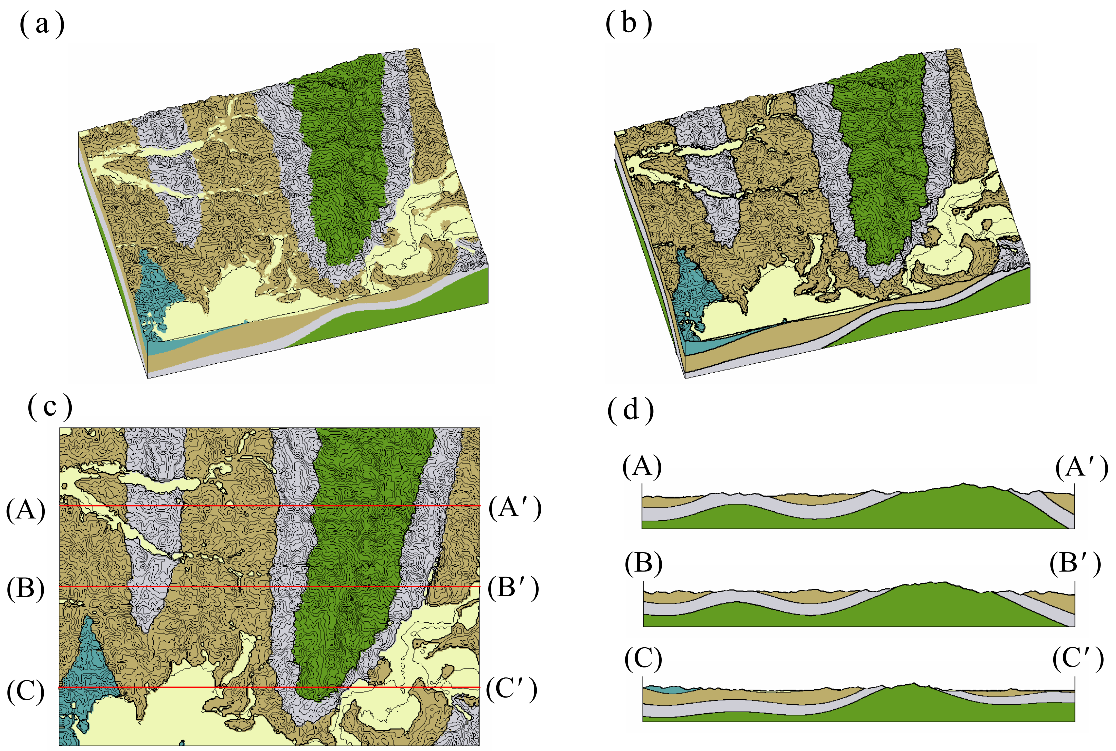

Figure 5. Example of the various geologic map using Geomodel2003.
(a), (b) the 3-D geologic map (in the case of including the geologic boundaries and not.). (c) the 2-D geologic map. (d) the vertical geologic section map on (c).

4. VISUALIZATION OF GEOLOGIC BOUNDARIES ON GEOMODEL2003

We added algorithms to distinguish the geologic boundary using generalized geologic function and produced Visual Basic program Geomodel2003. Example of the 2-D geologic map, the vertical geologic section map and the 3-D geologic map are presented in Figure 5 using Geomodel2003. The study area is located in Honjyo region of Akita Prefecture, Northeast Japan using data extracted from geologic map (Osawa *et al*., 1977).

5. CONCLUSION

We defined the generalized geologic function with corresponds to a pair of geologic units lie both directly a above and below the every point in the objective 3-D space based on geologic function. It is possible to distinguish the geologic boundary with applying generalized geologic function to a point on surfaces. We developed the theory and algorithms to visualize the geologic boundary through this concept, produced Visual Basic program Geomodel2003. As we improved sub-routine which had been developed before, thus the geologic boundaries can be visualized on the various geologic maps. There must be a potential to deal with the geologic boundaries in GRASS GIS, when this method is introduced to GRASS GIS.

6. ACKNOWLEDGMENT

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