Available online at www.humg.edu.vn

ESASGD 2016

GIS-IDEAS (2016)

Conference Title: International Conference on GeoInformatics for Spatial-Infrastructure Development in Earth & Allied Sciences (GIS-IDEAS)

Reliability Evaluation of Three Dimensional Geological Model using Borehole Data

Shinji Masumoto[a,*], Tatsuya Nemoto[a]

Venkatesh Raghavan[b], Susumu Nonogaki[c]

[a]*Department of Geosciences, Graduate School of Science, Osaka City University, 3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan*
[b]*Urban Information, Graduate School for Creative Cities, Osaka City University, 3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan*
[c]*National Institute of Advanced Industrial Science and Technology, Japan, Central 7, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan*

Abstract

For providing accurate geological information, it is important to construct the three dimensional geological model including the reliability. In urban area, many three dimensional geological models are constructed from the borehole data. The reliabilities of these geological models are different in area, because the borehole data distributions are not uniform. In this study, the basic theory and methods for evaluating the reliability of three dimensional geological model constructed by the borehole data have been established by using the data density and the geological structure.

Keywords: Reliability; Three Dimensioal Geological Model; Borehole Data; Kernel Density Estimation

1. Introduction

Recently, three dimensional geological models have become increasingly important as social infrastructure information. For solving many problems such as mitigation of natural disaster and environmental pollution in urban area, it is necessary to provide the three dimensional geological model including the reliability. Many of these three dimensional geological models are constructed by the surface modelling using borehole data. In the surface modelling, optimized spline interpolation method has come to be used frequently for the estimation of the geologic boundary surface (e.g. Kimura *et al.*, 2013). Since the reliability of the geologic boundary surfaces using spline estimation method cannot be directly calculated, the reliabilities of these three dimensional geological models are not able to be easily evaluated. Because, the surface to approximately satisfy all of the data can be created by the spline estimation method (e.g. Shiono *et al.*, 2001; Nonogaki *et al.*, 2008). As a countermeasure for this problem, two types of evaluation methods for the reliability of three dimensional geological model had been discussed (e.g. Masumoto *et al.*, 2012). One was the method for geologic boundary surface and the other was the method for three dimensional model space. However, these were simple methods using only data density.

The improved evaluation method for the reliability of boundary surface based on the kernel density estimation using variation of surface shape in addition to data density had been developed (Masumoto *et al.*,

* Corresponding author. *E-mail address:* masumoto@sci.osaka-cu.ac.jp.

2014). In this study, the improved evaluation method for the reliability of three dimensional model space has been developed using complexity of model in addition to the data density.

2. Basic Theory for Reliability Evaluation

In generally, a higher density of data for three dimensional geological modeling provides a higher reproducibility. And, high data density is required for a complex part of geological structure (Fig. 1). According these basics, the evaluation method for reliability of the model space is examined based on the data density corrected by the complexity of geological model. In this method, the data density and the reliability are expressed by the value of voxel model. This voxel model is defined by the set of small rectangular dividing the three dimensional model space in horizontally and vertically.

2.1. Data Density Estimation

A borehole data is not a point but a line segment. Therefore, for the data density estimation, a distance between center of voxel and line segment of borehole is calculated as shown in Fig. 2. To obtain data density for the model space, the kernel density estimation method has been extended to three dimension. Kernel density estimation is a non-parametric method, defined by the following equation *(1)* in one dimension.

$$\hat{f}_h(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \qquad (1)$$

where, $K(u)$ is the kernel function, n is a number of data points, h is a band width and $x - x_i$ is distance between data point x_i and calculation point x.

There are various expressions for the kernel function, such as Triangular, Gaussian and Epanechnikov (Fig. 3). In this case, multivariate kernel density estimation and Gaussian kernel function (equation *(2)*) has been used in accordance with the density estimation for geologic boundary surface (Masumoto *et al*., 2014).

$$K(u) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}u^2} \qquad (2)$$

2.2. Complexity of Geological Model

Homogeneity is used to express the complexity of geological model. The homogeneity $v_{x,y,z}$ is defined by the matching degree of geologic unit between target voxel $g_{x,y,z}$ and around voxel $g_{x+i,y+j,z+k}$ with in a limited space ($\pm l$, $\pm m$, $\pm n$)(Fig. 4). According to this logic, the homogeneity can be calculated by the following equation.

$$v_{x,y,z} = \frac{1}{(2l+1)\times(2m+1)\times(2n+1)} \sum_{i=-l}^{l} \sum_{j=-m}^{m} \sum_{k=-n}^{n} \frac{1}{1 + |g_{x,y,z} - g_{x+i,y+j,z+k}|^a / d^b} \qquad (3)$$

where a is weight for difference of geologic unit, b is weight for distance.

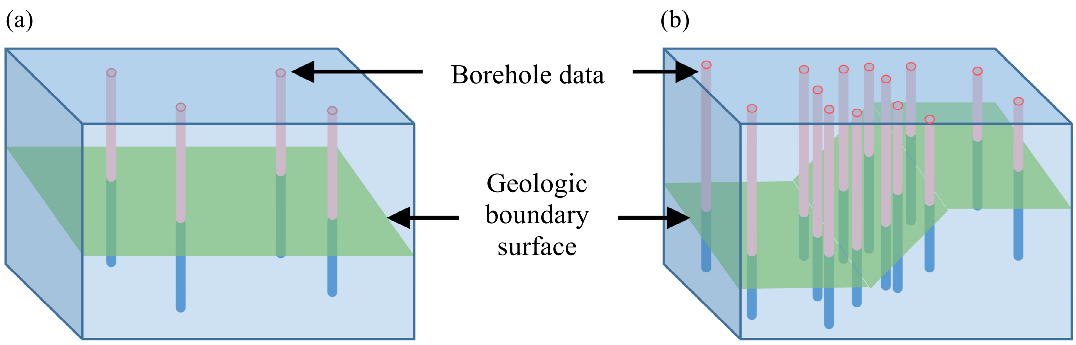

Fig. 1. Borehole data density and complexity of geological structure
(a) Simple case of geological structure and (b) complex case of geological structure.

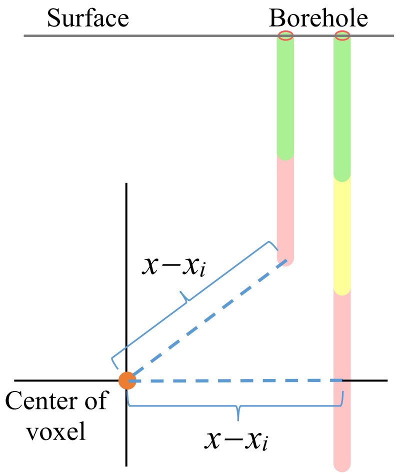

Fig. 2. Distance between center of voxel and line segment of borehole data

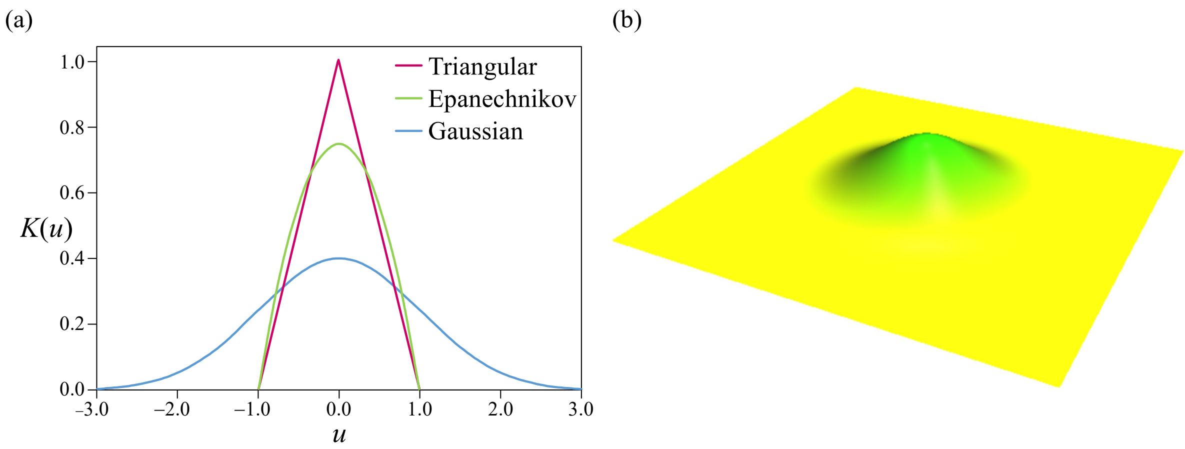

Fig. 3. Examples of kernel function for data density estimation
(a) Examples of kernel function and (b) two dimensional shape of Gaussian function.

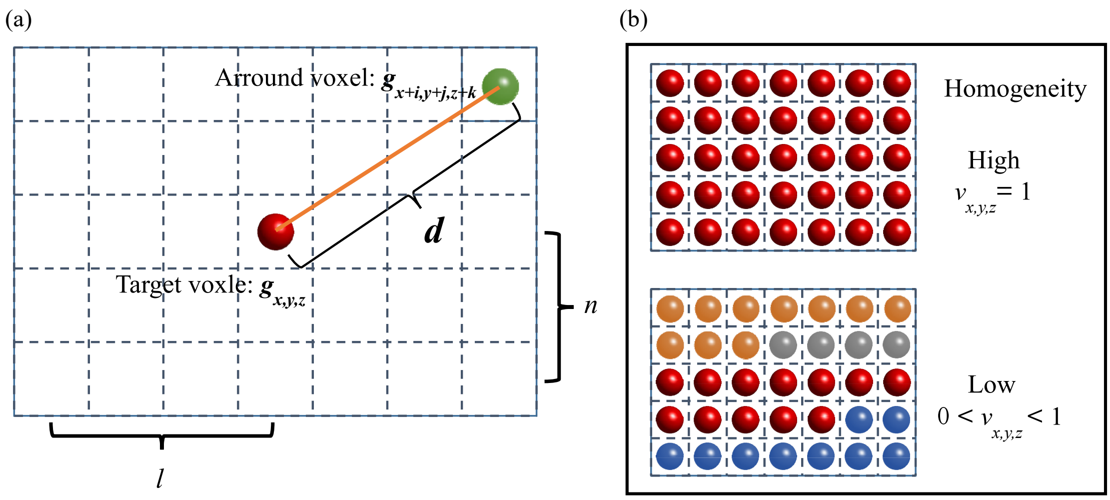

Fig. 4. Homogeneity $v_{x,y,z}$ of geological model in vertical geologic section
(a) Definition of distance *d* and (b) examples of different homogeneity.

3. Example of reliability

As an example, the reliability of model space have been calculated using test data shown in Fig. 5(a) and (b). Three dimensional geological model in surface modelling form constructed by this test data is shown in Fig 5(c). For the homogeneity calculation this geological model is converted to voxel model. The homogeneity of the model space is calculated by equation *(3)* using this voxel geological model.

The results of kernel data density estimation using various h are shown in Figure 6. It can be inferred from these results that if band width h is small then density is high around data point. Thus, the result of $h = 60$ is used as the data density of this model space. The results of the homogeneity, the data density and the reliability calculated by these data are shown in Fig. 7 as in the vertical sections.

As the example of visualization, the vertical geologic sections are shown by changing brightness corresponding to the reliability in Fig. 8. And, the horizontal geologic sections are shown by changing transparency corresponding to the reliability in Fig. 9.

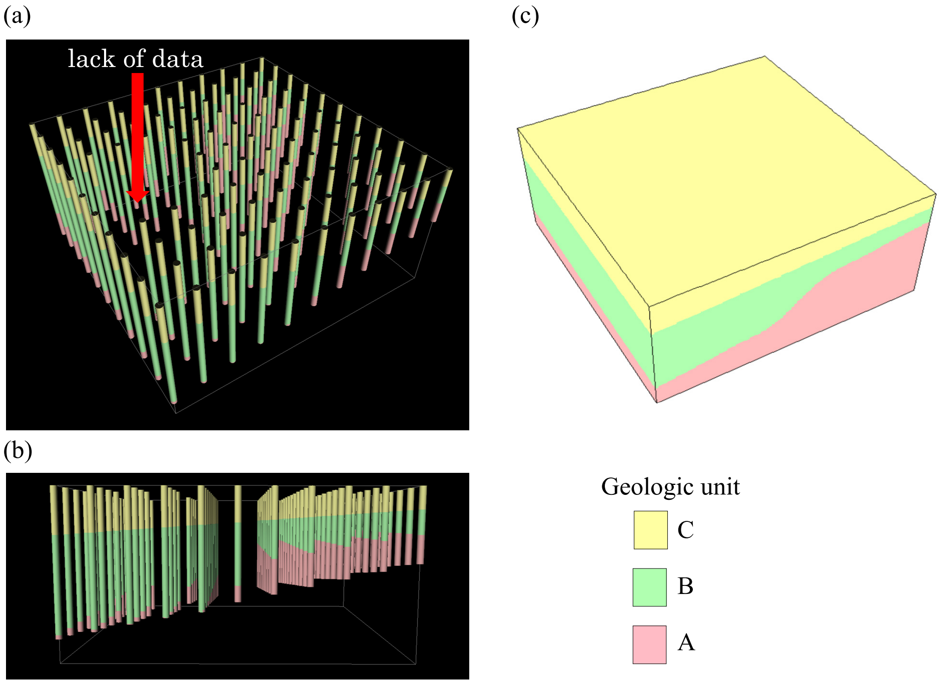

Fig. 5. Test data for reliability calculation
(a) (b) Test borehole data and (c) three dimensional geological model constructed by using test data.

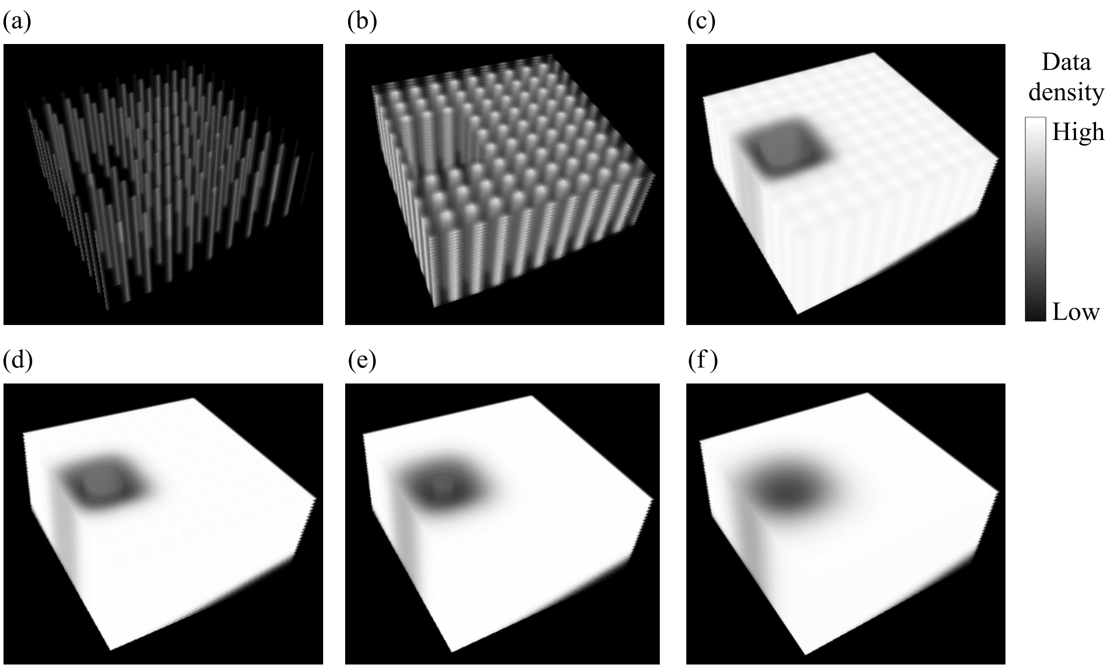

Fig. 6. Results of kernel density estimation
(a) h = 10, (b) h = 25, (c) h = 50, (d) h = 60, (e) h = 75 and (f) h = 100.

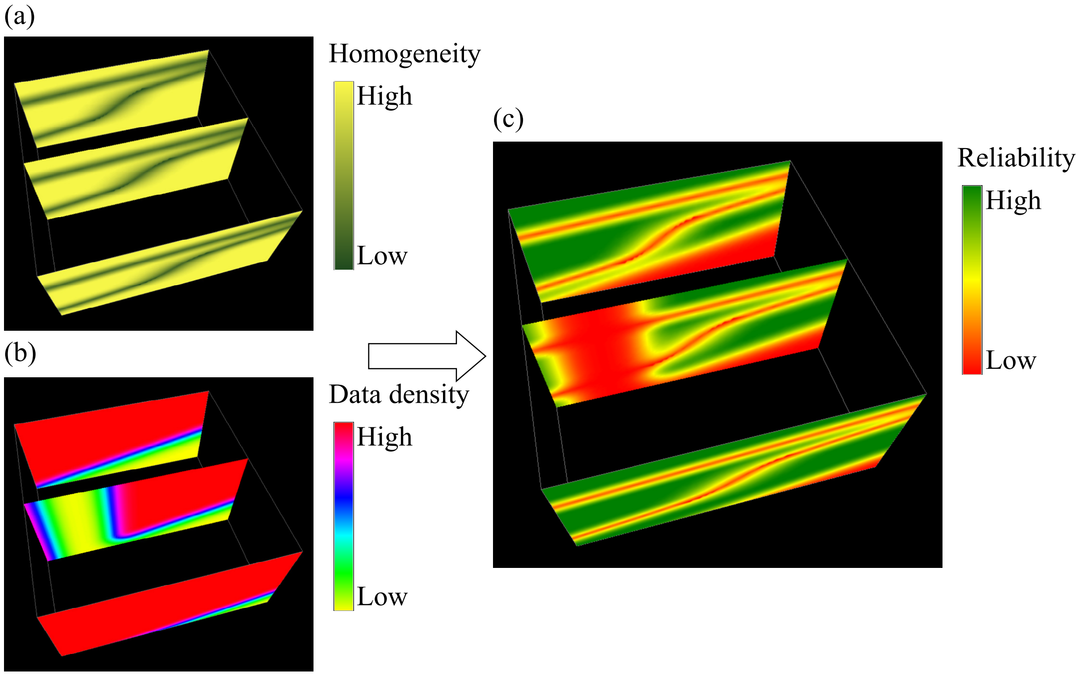

Fig. 7. Results of calculation
(a) Homogeneity, (b) data density and (c) reliability.

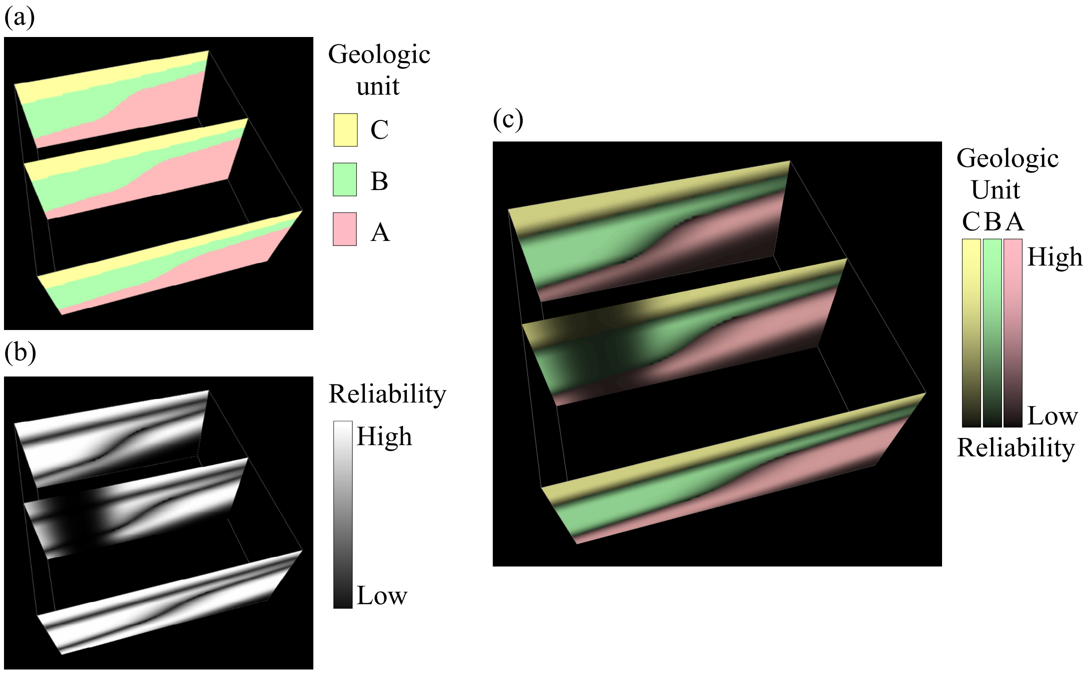

Fig. 8. Examples of visualization for reliability using brightness
(a) Vertical geologic sections, (b) reliability and (c) vertical geologic sections with reliability using brightness.

4. Conclusion

The expression method of the reliability for the model space of three dimensional geological model constructed by the geologic boundary surfaces which are estimated by spline interpolation using borehole data has been developed. It became possible to evaluate the reliability for both geologic boundary surface and model space with these results.

However, the considerations for parameter are not adequate to practical use. For the practical application, further development and improvement of these reliability expression methods and visualization methods are necessary.

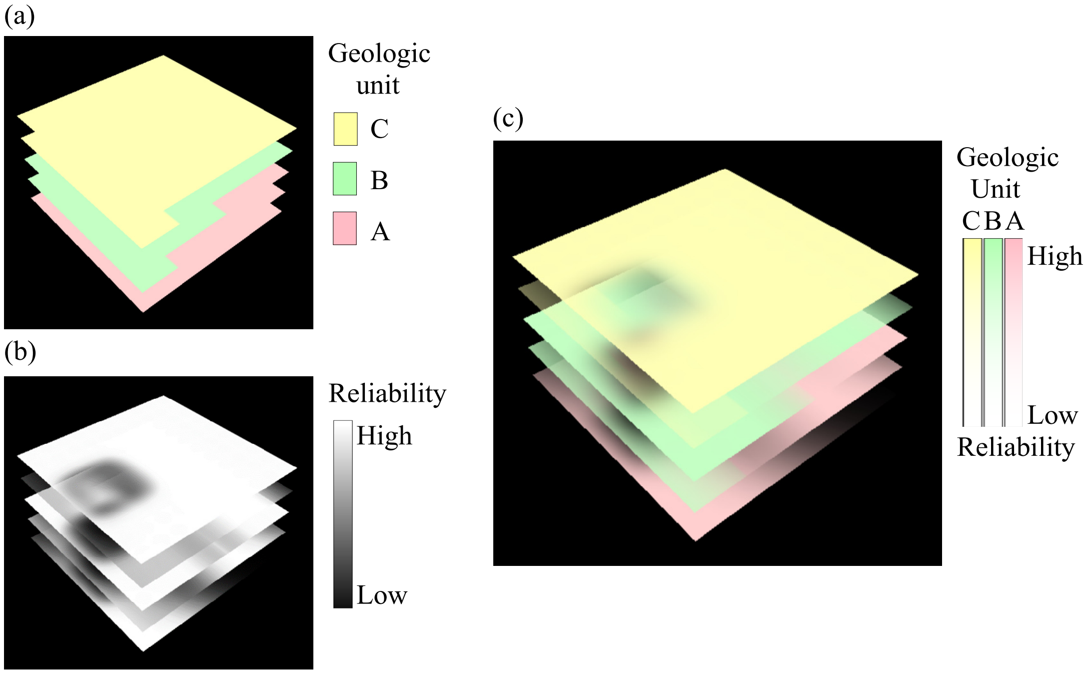

Fig. 9. Examples of visualization for reliability using transparency
(a) Horizontal geologic sections, (b) reliability and (c) horizontal geologic sections with reliability using transparency.

Acknowledgements

This study was supported by KAKENHI (25330134 and 16K00158; Grant-in-Aid for Scientific Research by Japan Society for Promotion of Science).

References

Kimura K., Masumoto S., Takano O. and Nemoto T., 2013. Recent progress in the three-dimensional geological modeling. *Jour. Geol. Soc. Japan*, 119(8), 509-514.

Masumoto S., Nemoto T., Nonogaki S., Tawara H. and Raghavan V., 2012. A study of expression method for reliability of three dimensional geologic model. *Proceedings of International Conference on GeoInformatics for Spatial-Infrastructure Development in Earth and Allied Sciences (GIS-IDEAS) 2012*, 83-88.

Masumoto S., Nemoto T., Raghavan V. and Nonogaki S. 2014. An Investigation on Evaluation Method for Reliability of Three Dimensional Subsurface Geological Model. *Proc. Intern. Symp. GeoInformatics for Spatial-Infrastructure Development in Earth and Allied Sciences (GIS-IDEAS) 2014*

Nonogaki, S., Masumoto S. and Shiono K., 2008. Optimal determination of geologic boundary surface using cubic B-spline. *Geoinformatics,* 19(2), 61-77.

Shiono K., Noumi Y., Masumoto S. and Sakamoto M., 2001. Horizon2000：Revised Fortran program for optimal determination of geologic surfaces based on field observation including equality-inequality constraints and slop information. *Geoinformatics*, 12(4), 229-249.