STUDY ON STRATIGRAPHIC CORRELATION SUPPORT SYSTEM FOR 3-D SUBSURFACE GEOLOGICAL MODELING USING BOREHOLE DATA BASED ON LOGICAL MODEL OF GEOLOGIC STRUCTURE

Shinji Masumoto[1], Tatsuya Nemoto[1], Kenichi Sakurai[2]
Susumu Nonogaki[3] and Venkatesh Raghavan[4]

[1]Department of Geosciences, Graduate School of Science, Osaka City University,
3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan
Email: masumoto@sci.osaka-cu.ac.jp Email: tnemoto@sci.osaka-cu.ac.jp
[2]Osaka Information and Computer Science College
6-8-4 Uehonmachi, Tennouji-ku, Osaka 543-0001, Japan Email: sakurai@oic.ac.jp
[3]National Institute of Advanced Industrial Science and Technology, Japan,
Central 7, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan Email: s-nonogaki@aist.go.jp
[4]Urban Information, Graduate School for Creative Cities, Osaka City University,
3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan
Email: raghavan@media.osaka-cu.ac.jp

ABSTRACT

When constructing three dimensional geological model of urban subsurface using borehole data, it takes a long time to perform stratigraphic correlation. The purpose of this study is to develop a high efficiency system for supporting stratigraphic correlation. This system is a part of the 3-D geological modeling system based on the logical model of geologic structure. For development of this system, the following four tasks are now being studied: (1) Display method of borehole data including N-value, (2) Display method of auxiliary image for background, (3) Verification method for logical correctness of each correlation result and (4) High speed estimation method for geological boundary surface.

1. INTRODUCTION

Recently, three dimensional geological models have been utilized in various situations such as planning for natural disaster mitigation and urban development. In urban area, three dimensional subsurface geological models are constructed by using borehole data. The stratigraphic correlation based on borehole information is the most significant and laborious process in geological modelling. Various reports (*e.g.* Matuszak, 1972; Nakagawa, 1984) have been given on the automation of this process over a long time. However, practically these reports are incomplete, then stratigraphic correlations are still made manually by experts of geology. The final purpose of this study is to develop a high efficiency system for supporting stratigraphic correlation. For development of this system, four tasks are now being studied. In this paper, the present situation of this system have been described.

2. BASE SYSTEM

There are various types of software for stratigraphic correlation using borehole data. AIST-Borehole Log Analysis (Kimura, 2011) and GEO-CRE (Nishiyama, 2015) are examples of this software, in Japan. These are standalone packages used for stratigraphic correlation or one of the functions of three dimensional geological modellers.

We have been developing the Web-GIS based three dimensional geological modelling system (Masumoto *et al*., 2004, 2008; OCU GeoModeller (Nonogaki, 2011)). The main system of this modeller is composed of seven function modules ranging from the acquisition of field survey data to the construction of three dimensional models. Figure 1 shows the relationship of the seven modules and the data flow of the system. This system is based on the logical model of geologic structure showing the hierarchical relationship between boundary surfaces and geologic units (Sakamoto *et al*., 1993). It is necessary to prepare the logical model of geologic structure converted from the stratigraphy and structure of the survey area as a basic data. This logical model can be automatically generated based on the stratigraphic sequence and knowledge of geologic structures (Figure 2). Stratigraphic correlation module (Sakurai *et al*., 2008) of this system has been used for the base system of stratigraphic correlation support system. Figure 3 shows example images of the stratigraphic correlation module and 3-D geological models.

3. STRATIGRAPHIC CORRELATION SUPPORT SYSTEM

3.1 Display method of borehole data

The display method of borehole data including N-value was investigated for stratigraphic correlation. In Japan, the format of the Japan Construction Information Center Foundation (JACIC, 1999) is commonly used for displaying of borehole Logs. A lot of information are described in this format. However, it is favorable that the stratigraphic correlation processes are performed with a small information amount to the utmost. From the examination results, the following information were chosen as the display elements for the stratigraphic correlation.

Soil and rock classification (lithofacies, grain size)
Key-bed (*e.g*. fossil, humus and tuff)
N value (Standard Penetration Test: indication of the relative density of the soil)

These are general information of borehole logs. Figure 4 shows the examples of display method. The expression method of the soil and rock classification are used color and width of column displayed on the screen. The width of column is corresponding to the grain size, and narrow column showed small grain size. The three types of expanding direction (right-side, left-side and both-side) are shown in Figure 4. Key-beds are represented with color in the small column beside of main column. N-values are separately represented by line, point, bar graph, or size of circle. By using these displayed images, borehole data can be correlated intuitively.

3.2 Display method of auxiliary image for background

Two types of background images were prepared for the correlation support system. One was profile image of N-Value, and the other was geological profile. The profile image of N-value is created by slicing of 3-D spatial distribution of N-value in voxel format. This 3-D distribution is obtained through interpolation of all borehole data.

The geological profile is created by slicing of 3-D geological model constructed from outlined and correlated borehole data. Figure 5 shows the example images of these background images with borehole data.

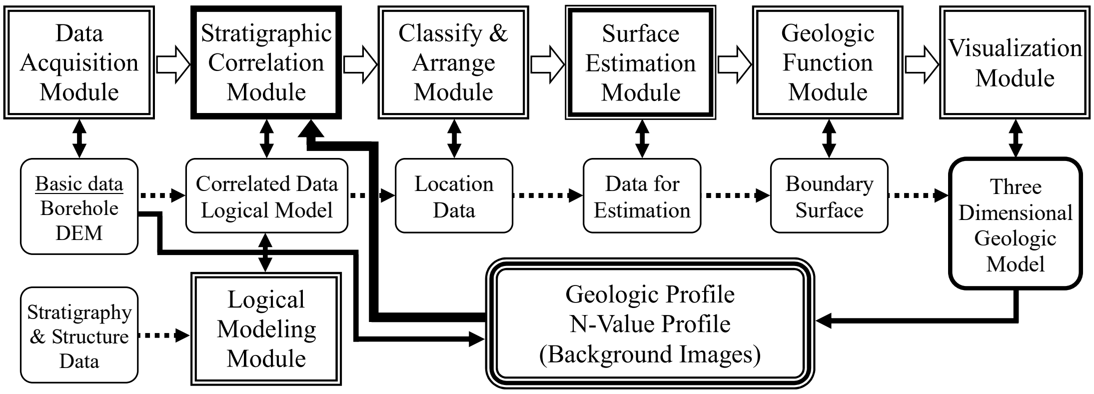

Figure 1. Relationships of the modules and the data flow of the three dimensional geological modeling system.

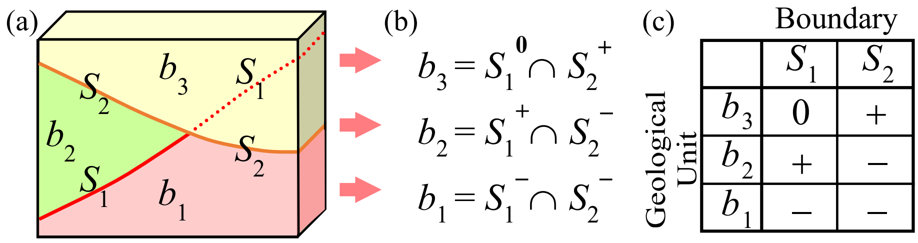

Figure 2. Logical model of geologic structure. (a) Relation between geological units and boundary surfaces, (b) logical model (+; the geologic unit lies above the corresponding boundary, –; the geologic unit lies below the corresponding boundary and 0; no specific relation with the surface) and (c) relational table.

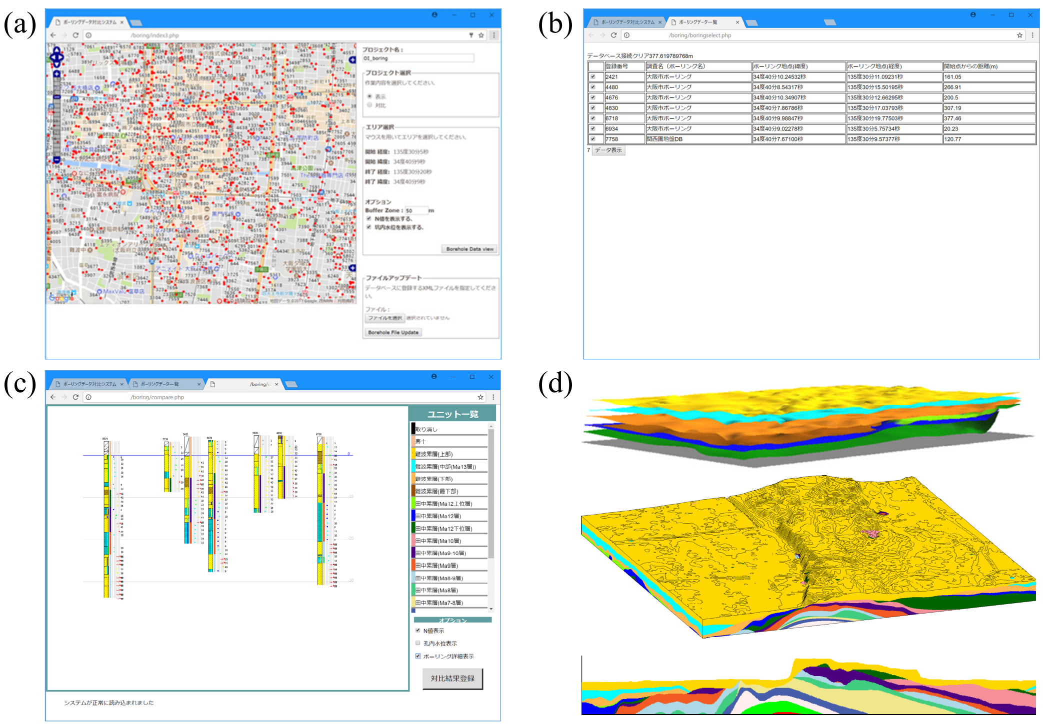

Figure 3. Example images of the stratigraphic correlation module and 3-D geological models. (a)-(c) Stratigraphic correlation module, (d) 3-D geological models.

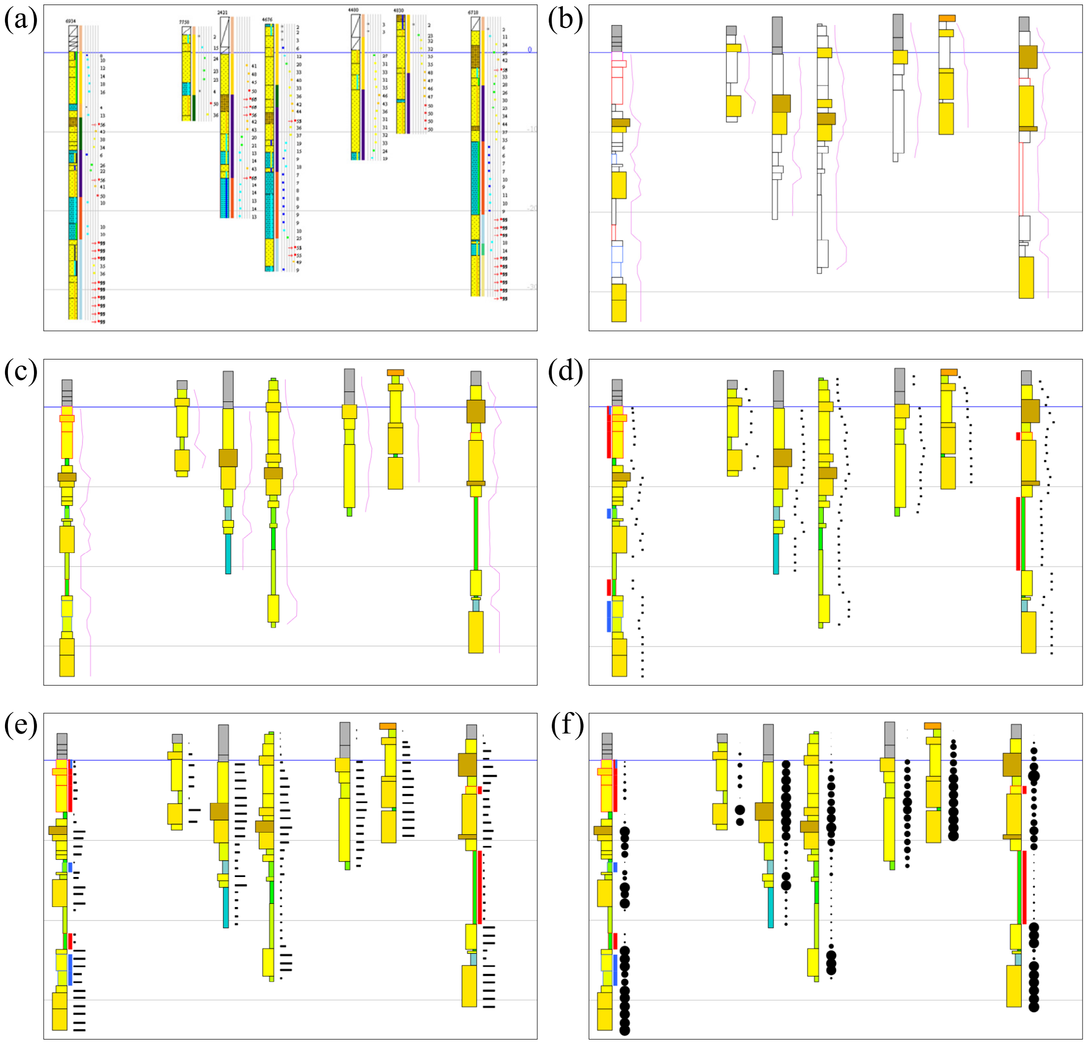

Figure 4. Examples of borehole description. (a) Original image of Web-GIS 3-D modeling system. (b)-(f) improved images of this support system.

3.3 Verification method for logical correctness of each correlation result

The logical correctness of each correlation result compared with the logical model of geologic structure can be check by improved version of GeoSEQ (Iwamura *et al*., 2012). GeoSEQ is a program to generate constraints of geological surface from survey data based on logical model.

3.4 High speed estimation method for geological boundary surface

It is desirable that reflection of each correlation result for 3-D model can be checked in real time. The geological boundary surface estimation process for construction of the 3-D geological model takes a time (at least few minutes). The BS-Horizon program (Nonogaki *et al*., 2008, 2017a) are used for this estimation process. Generally, borehole data includes an important inequality elevation data. The height of bottom is an inequality elevation data, because the boundary surface passes under the bottom of borehole. In this case, the estimation method of boundary surface requires iterative calculation for determination of

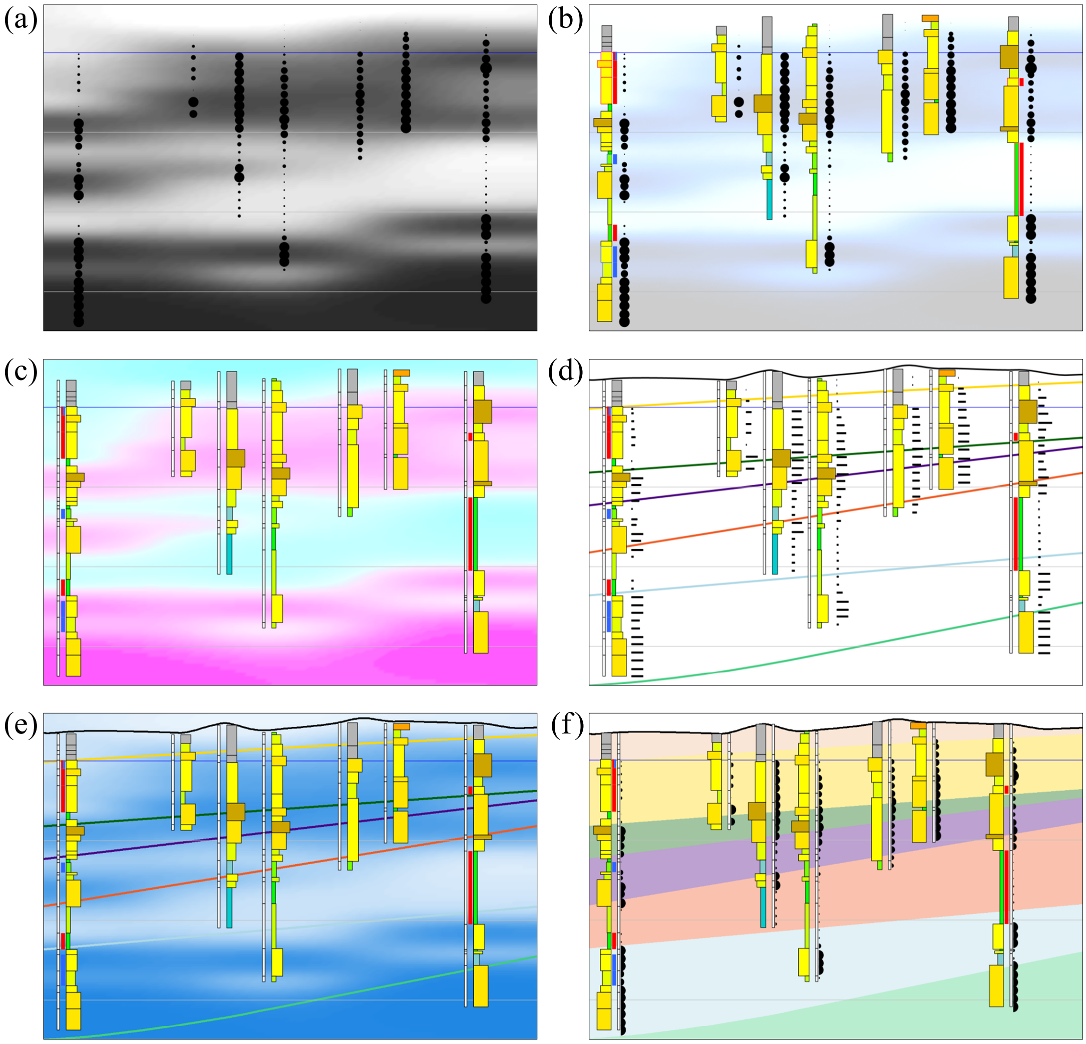

Figure 5. Example images of background with borehole data. (a)-(c) N-vale profile expressed by greyscale, or colors, (d) geological boundary profile, (e) N-Value profile with geological boundary and (f) geological profile.

optimal result. It is necessary to improve the surface estimation method to increase speed and efficiency of this process. For the solution to this problem, introductions of multi-core CPU and GPGPU were examined. The OpenMP and OpenACC are used for these parallel programming. As a result, the processing speed is increased threefold, but real-time calculation is yet to be realized. In addition to this, a new surface estimation program is currently being developed using knots arranging method (Nonogaki *et al*., 2017b).

4. CONCLUSION

Four tasks for development of stratigraphic correlation support system have been discussed. These tasks are still in development, except the verification method for logical correctness. In the present state, there is a limit to speed up the surface estimation for geological modeling. In particular, the calculation time of surface estimation is increased due to the increase of the number of data, as the correlation process advances. Consequently, it will become even more difficult to update the geological profile for background image. To solve this problem, we plan to replace the high-spec GPGPU. Furthermore, the considerations on the sequence of selecting the borehole and the update timing of the background image are necessary at the time of correlation process.

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

REFERENCES

Iwamura, S., Masumoto, S. and Shiono, K., 2012. Algorithm to Determine Logical Model of Geologic Structure Based on Field Survey Data - Property of Contact Surface -. *Geoinformatics* 23(1), 3-16. (in Japanese with English abstract)

Japan Construction Information Center Foundation, 1999. *Manual (draft) of Creating the Borehole Logs.* 55p. (in Japanese)

Kimura, K., 2011. Opening of Borehole Data Processing System to the Public. *AIST TODAY* 2011-2, 19.

Nishiyama, S., 2015. Introduction of 3D Geologic Analysis System "GEO-CRE". *Proceedings of 2015 Geoinformatics Symposium, Japan Society of Geoinformatics*, 77-107. (in Japanese)

Nakagawa, T., 1984. Subdivision of So-called Alluvial Deposits by Soil Engineering Properties and Application to Database System of Ground Geology. *Geological data processing* 9, 49-60. (in Japanese with English abstract)

Nonogaki, S., Masumoto, S. and Shiono, K., 2008. Optimal Determination of Geologic Boundary Surface using Cubic B-spline. *Geoinformatics* 19(2), 61-77. (in Japanese with English abstract)

Nonogaki, S., 2011. Current Trends and Issues in Three-Dimensional Geologic Modeling System Based on Geologic Boundary Surface. *Geoinformatics* 22(3), 131-142. (in Japanese with English abstract)

Nonogaki, S., Masumoto S. and Nemoto T., 2017a. High-speed Gridding System for Geological Surfaces using Multi-threading Technology. *International Journal of Geoinformatics* 13(1), 1-10.

Nonogaki, S., Masumoto S. and Nemoto T., 2017b. Knots Arranging Method for Estimation of Geological Boundary Surface using Bi-Cubic B-Spline. *Geoinformatics* 28(2), 70-71. (in Japanese)

Masumoto, S., Raghavan, V., Yonezawa, G., Nemoto, T. and Shiono, S., 2004. Construction and Visualization of Three Dimensional Geologic Model Using GRASS GIS. *Transactions in GIS* 8(2), 211-223.

Masumoto, S., Nonogaki, S., Ninsawat, S., Iwamura, S., Sakurai, K., Nemoto, T., Raghavan, V. and Shiono, K., 2008. Development of Prototype System for Three Dimensional Geologic Modeling based on Web-GIS. *Proceedings of International Symposium on GeoInformatics for Spatial-Infrastructure Development in Earth and Allied Sciences (GIS-IDEAS) 2008*, 83-88.

Matuszak, D. R., 1972. Stratigraphic Correlation of Subsurface Geologic Data by Computer. *Mathematical Geology* 4(4), 331-342.

Sakamoto, M., Shiono, K., Masumoto, S. and Wadatsumi K., 1993. A Computerized Geologic Mapping System Based on Logical Models of Geologic Structures. *Nonrenewable Resources* 2, 140-147.

Sakurai, K., Ninsawat, S. Shiono, K. and Masumoto, S., 2008. Support System for Lithofacies Correlation of Borehole Data as a Basic Tool of Three Dimensional Geologic Modeling. *Geoinformatics* 19(2), 82-83. (in Japanese)