Delineating Lake Bottom Structure by Resistivity Image Profiling on Water Surface

Chieh-Hou Yang[1,*], Jiunn-I You[2], and Chiu-Pin Lin[2]

ABSTRACT

Mapping water-bottom features involves in the fields of environmental geophysics and engineering structural studies. Standard direct current (DC) resistivity sounding is widely used to map subsurface structures on land, but it is seldom used to map underwater structures, because the deployment of underwater electrodes along the water-bottom is expensive and cumbersome. Therefore, a cost-effective and non-destructive survey technique is required to map underwater structures.

Recently the development of an automatic multi-electrode system for resistivity image profiling (RIP) has been successful in mapping two-dimensional (2-D) or three-dimensional (3-D) geological structures on land faster than standard DC resistivity soundings. In fact, the RIP method provides higher resolution and greater exploration depth of electrical images. Therefore, it is time to consider whether this advanced RIP technique can be applied to underwater mapping.

The purpose of this paper is to describe the potential of the RIP technique conducted on the water surface to map the sub-water bottom geology. The electrode configuration used in this paper was a pole-pole array. The advantages of this survey technique are its convenience and low expense in operation. In addition, no previous water body and bottom topography corrections are needed for data processing as required for standard DC sounding data collected along the water bottom with underwater electrodes. To seek verification of this new application, a RIP survey was carried out on the water surface of Lake Chung-Dah in northern Taiwan. The shallow stratigraphy underneath the lake was delineated and compared with well data nearby. The RIP results did assist in interpreting the structures underneath the water bottom. The results clearly demonstrate the capability of the RIP technique to resolve an underwater stratigraphy, and the efficiency of the RIP method compared with standard DC resistivity method.

---

[1]Department of Civil Engineering, Ching Yun Institute of Technology, Chungli, ROC
[2]Institute of Geophysics, National Central University, Chungli, ROC
*Corresponding author address: Prof. Chieh-Hou Yang, Office of President, Ching Yun Institute of Technology, Chungli, Taiwan; E-mail: yang@cyit.edu.tw

1. INTRODUCTION

The direct current (DC) resistivity technique can be used in many ways, but is seldom used to map water depth and underwater stratigraphy of lakes or rivers (Daily and Ramirez 1995; Daily et al. 1995; Baumgartner 1996). Typically the geoelectrical resistivity profile obtained on a water surface is affected by the conductivity of a silty / clayey sediment blanket covering on a water bottom; thus both detection and resolution of water bottom stratigraphy decrease with depth. Such applications seem to defy the myth that DC resistivity can work in water. Therefore, an experiment was carried out to test whether DC resistivity sounding can work on a lake environment.

Conventional underwater stratigraphic information can be obtained with underwater DC resistivity sounding (Lagabrielle 1983; Baumagartner 1996). The raw geoelectric data are measured from the underwater electrodes deployed along a water bottom, water body and bottom topographic corrections have to be made on the sounding data before data inversion. Hence it is a laborious task. In addition, a leveling survey for determining the position of electrodes and the topography of the water bottom takes time and money. Recently, the improvement of computer-controlled multi-channel resistivity survey using a multi-electrode array has led to an important development of resistivity imaging for subsurface survey. Resistivity image profiling (RIP), an extension of standard electrical resistivity profiling, has been successful for land surveys. It is particularly suitable for an area where lateral resistivity variation or geological structure renders standard DC inconvenient.

Underwater stratigraphy studies would be more effective, for RIP, if conducted at water surface than at water bottom, because no elevation and water body correction is necessary for sounding data collected at each position. Field experiments were conducted on water surface to evaluate the performance of RIP as a determining underwater stratigraphy method. The Chung-Dah Lake located in the northwestern part of the campus of National Central University (NCU), Chungli, northern Taiwan, was selected. The bottom of the lake was covered by a thin cement layer. The RIP survey results collected on the water surface matched the results of vertical electric sounding (VES) inversion data obtained on land nearby. Therefore, mapping the underwater stratigraphy by using the RIP method on water surface is extremely effective. The strategies of our method associated with this new application are described below.

2. RESISTIVITY IMAGE PROFILING SURVEY

The resistivity image profiling method has been developed recently as an accurate tool for mapping resistivity in a complex subsurface structure, especially at allocation where standard DC resistivity sounding and other techniques are unsuitable (Griffiths and Barker 1993). The principle of this method is to measure the apparent resistivity by sequentially sweeping a quadripole A, B (current electrodes) M, N (potential electrodes) within the multi-electrode

array. As shown in Fig. 1, the configuration of the electrode array in this paper is a two-dimensional (2-D) pole-pole type. In practice, we deployed multi-electrodes at constant separation. The stationary remote current electrode (A current electrode) and potential electrode (N potential electrode) were placed at infinity (usually more than ten times the depth of the survey target) on the opposite sides of the moving array of electrodes along a survey line.
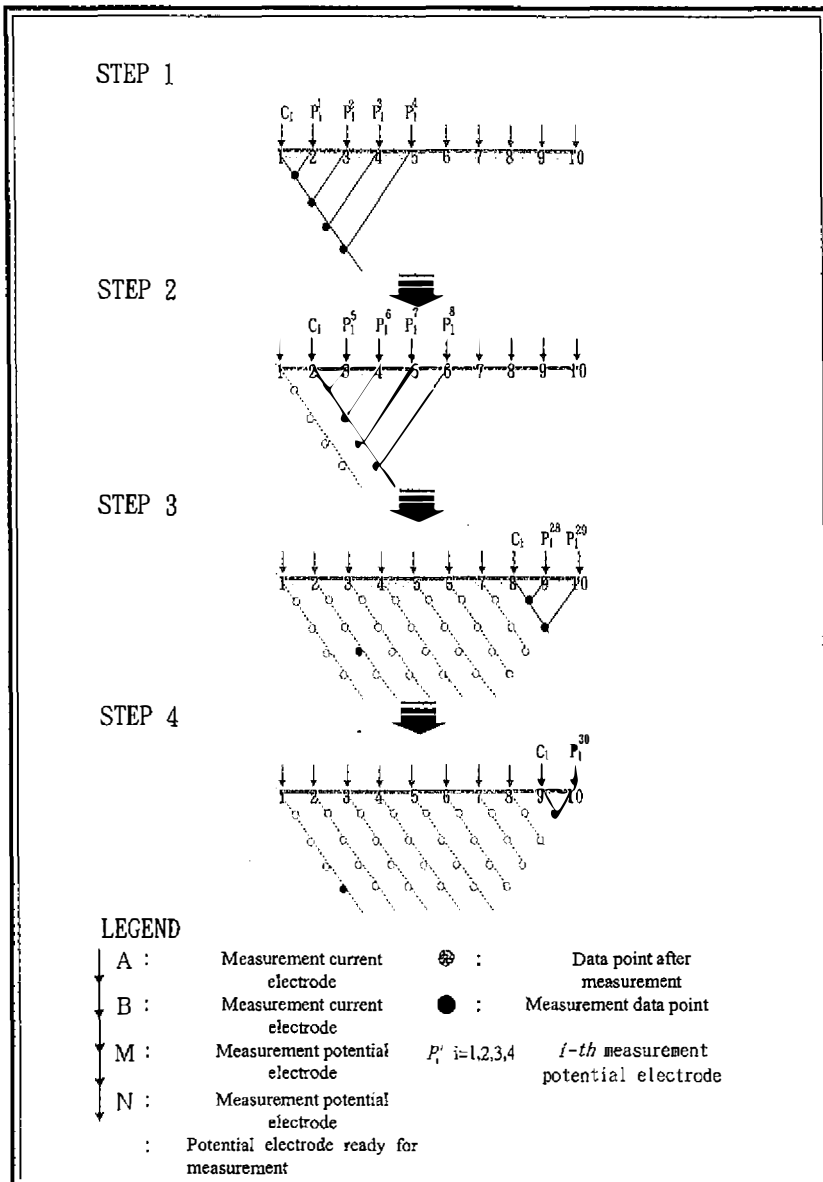

Fig. 1. Steps of resistivity image profiling using a pole-pole array.

Measurements are performed in three steps. The first step is started at either ends of a survey line by setting the end electrode as a temporal fixed current electrode and treating the rest of electrodes as "roll along" potential electrodes. Making a collinear pole-pole resistivity (PPR) measurement of potential between the fixed current electrode and a removable potential electrode in an increasing electrode separation one unit (spacing between electrodes) per measurement. These measurements are continuous until a maximum separation is reached. Second, the fixed current electrode is shifted forward one unit to the next potential electrode position of step one. The same measurements as those of step one are repeated. Finally, the measuring procedure is repeated at each successive new current electrode until the current electrode is shifted to the next location of the farthest potential electrode. During pole-pole RIP traverse measurements, increasing the distance between a fixed position of current electrode and a varied position of the potential electrode will obtain the resistivity information of greater depth. Thus the underwater structures are scanned and imaged by gathering all the successive RIP traverse measurements together; i.e., the measured apparent resistivities are plotted or contoured as functions of electrode spacing on the vertical axis and distance along the profile on the horizontal axis. This reflects qualitatively the spatial variation in resistivity in a vertical cross-section. The apparent resistivity data shown in the cross-section is inverted using a finite element inversion algorithm [RES2DINV (1998)], so that a 2-D image of true resistivity is generated. The method provides a relatively fast acquisition system for locating the lateral resistivity inhomogeneities.

RIP data were acquired using the McOHM 21 resistivity system manufactured by OYO, Japan. During the measurement, two distant electrodes were positioned at a distance of 140 m from the target area. One electrode served as a remote stationary current electrode and the other was a remote stationary potential electrode. A set of point electrodes attached to a bunch of copper wire floated on the water surface. Each point electrode was actually a section of naked copper from a wire whose insulation had been peeled off at a constant separation (1 m interval in this study). In order to make a good contact between the point electrode and the water surface, and also to keep a proper separation between each point electrode, the wires were attached to light polystyrene hosts to keep the electrodes floating on the water surface.

3. SITE INVESTIGATION

To seek verification of the method, a trial test survey was conducted on the lake water surface located on campus of National Central University (NCU). The results illustrate that an underwater profile can be obtained from a lake surface by this new technique. The geological setting, field works and data interpretation at the site are described below.

3.1 Geological Setting

Based on the surface geology and the water well information nearby, the whole area is covered by Quaternary lateritic deposit with a thickness ranging from 3 to 4 m. Underlying the laterite is a gravel bed with high resistivity and a thickness ranging from 9 to 10 m. The gravel bed is underlain by alternate of sandy and clayey layers. The water level is 13 m below

the ground surface.

3.2 Vertical Electric Soundings

In order to know the geoelectric layer in the study site, two Schlumberger vertical electric soundings, VES 1 and VES 2, were carried out near the lake. The location of VES 2 is closer to the lake than that of VES 1. As shown in Fig. 2, both VES sounding results indicate that the
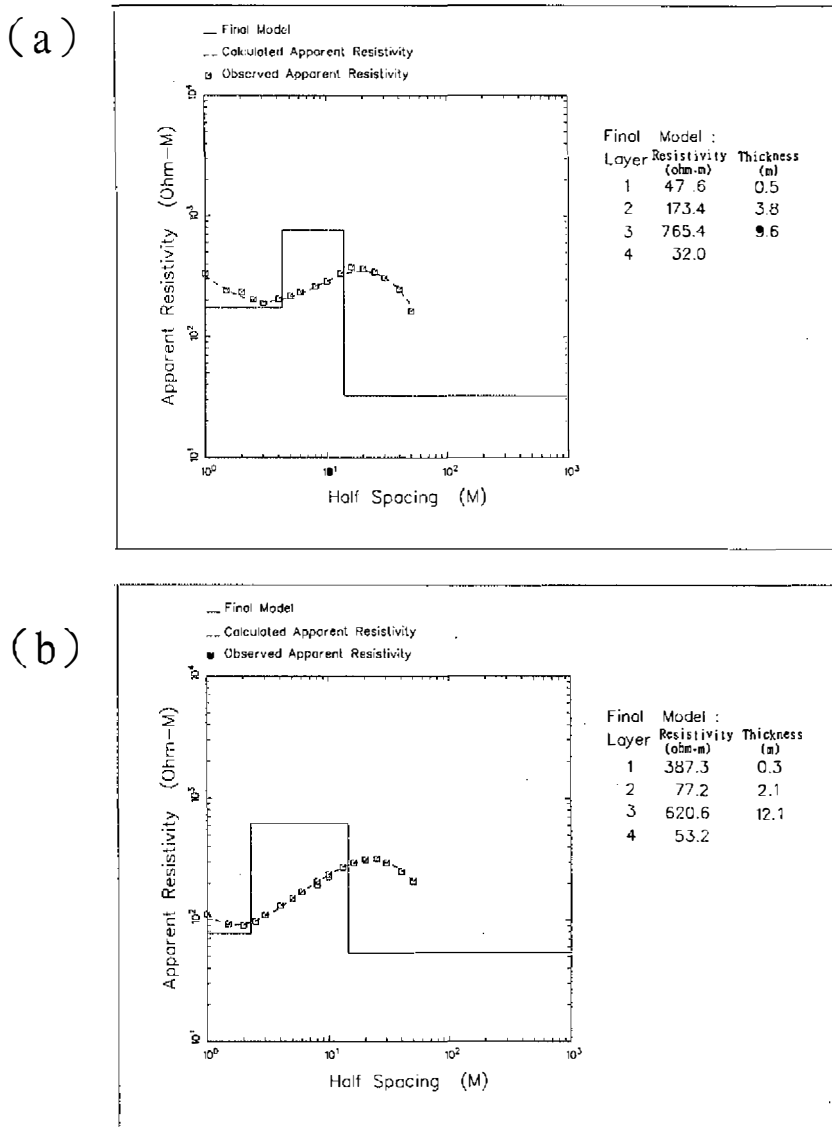
(a)

Final Model :

Layer	Resistivity (ohm·m)	Thickness (m)
1	47.6	0.5
2	173.4	3.8
3	765.4	9.6
4	32.0	

(b)

Final Model :

Layer	Resistivity (ohm·m)	Thickness (m)
1	387.3	0.3
2	77.2	2.1
3	620.6	12.1
4	53.2	

Fig. 2. Interpretation of VES curves measured at sounding location (a) VES 1, and (b) VES 2.

main feature of the geoelectric layers in the study area is K-type; a high resistivity layer between two low resistivity layers. An overburden of low resistivity (77-387 ohm-m) layer with a thickness of 2 to 4 m is interpreted as a laterite. The second high resistivity (620-765 ohm-m) layer is interpreted as a gravel bed. The thickness of the gravel bed ranged from 10 to 12 m. The bottom layer is alternate sand and clay layers with lower resistivities (32- 53 ohm-m) associated with aquifers. These can be identified from the logs of a water well nearby.

3.3 Lake Bottom Stratigraphy Mapping

A preliminary test survey was carried out at Lake Chung-Dah with a size of 100 m x 100 m. The depth of water varied from 0.8 to 1 m. A thin cement layer covered the lake bottom to prevent the leakage of water. Line 1 in an SE-NW direction was located in the southwestern corner of the lake. Line 1 had a length of 31 m and an inter-electrode separation of 1 m. In order to distinguish the difference between the sounding results on the land and on the water surface, the first 17 m of the western end of Line 1 was on the water surface and the remaining 14 m was on the land. Pole-pole RIP measurements were carried out from the water surface to the land. The dipole separation factor "n" value varies from 1 to 15. The maximum depth of exploration was about 15 m. The apparent resistivity pseudosection shown in Fig. 3 indicates that the resistivity value increased as the depth increased except that of S75°E side ranging from 18 to 26 m, where a high resistivity zone associated with an aggregation of pebbles is located on the bank. Figure 4 is the RIP inversion data shown in Fig. 3. Referred to the lithological logs of the wells, the lake water resistivity (around 80 ohm-m), and also the
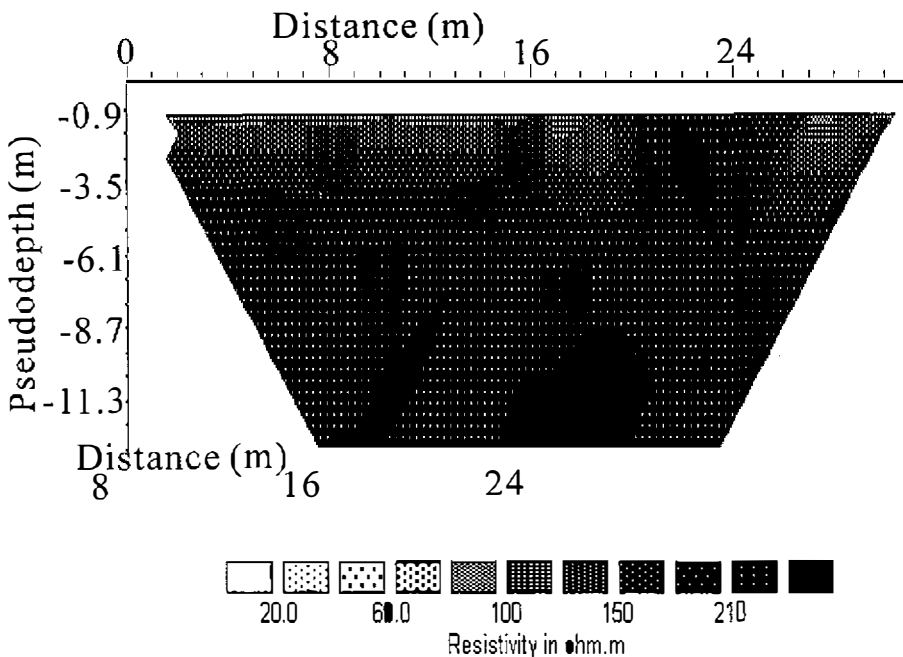

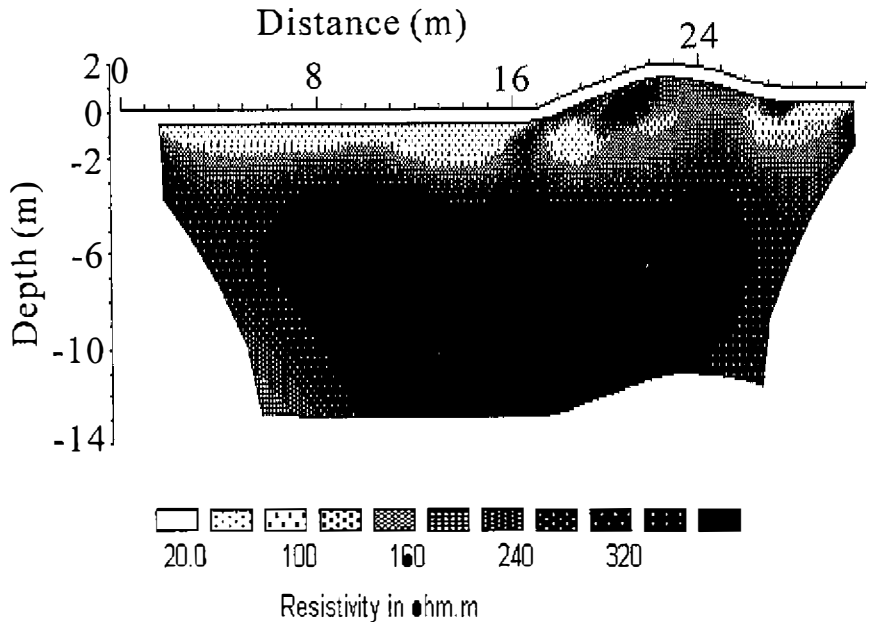*Fig. 3.* Apparent resistivity pseudosection of Line 1

Fig. 4. Inversion results from the data shown in Fig. 3.

Schlumberger VES inversion data, the lower resistivity (≤ 80 ohm-m) zone extending from water surface to a depth of 0.9 to 1 m is interpreted as the water body. Underneath the water bottom is laterite with a thickness less than 3 m and resistivity ranging from 80 to 160 ohm-m. Underlying the laterite is a water saturated high resistivity (≥ 160 ohm-m) gravel bed with a thickness ranging from 9 to 11 m. The presence of uneven distribution of high resistivity anomaly shown in the gravel layer reflected the heterogeneousness of the gravel bed. The lowest layer is alternate of sandy and clayey layers with a resistivity less than 200 ohm-m. The depth of this layer is greater than 14 m and most likely associated with an aquifer. The depth of the aquifer predicted by the VES data is comparable to that of drilled water wells nearby. Thus interpretation of lake-bottom stratigraphy from RIP on water surface is possible.

The high topography of the bank shown in the S75°E side of Line 1 between 18 and 26 m has high resistivity associated with pebbles filling the bank. At the right end of S75°E side of the resistivity profile, the influence of bank (pebble) effect (also the resistivity) decreased as the distance from the bank increased. The K type of resistivity section shown in the S75°E side (right side of Fig. 4) of the resistivity profile is comparable to the lithological logs in the wells. Thus lower resistivity laterite is on the top of the high resistivity gravel bed, and low resistivity alternations of sandy and clayey layers underlie the gravel bed. In addition, the flat lake bottom can be recognized from RIP section.

3.4 Ground Penetrating Radar Survey

Since ground penetrating radar (GPR) sounding is an effective method for imaging near-surface structures (Annan 1996; Delaney 1992), GPR data were collected on the water surface

along Line 1. The radar responses were used to check the accuratcy of the water depth and water bottom structure estimated by pole-pole RIP measurements. Figure 5 shows that the water depth is about 1 m. The water depth decreases towards the western end of the bank. The depth of exploration for the structure under the water bottom is limited by the severe attenuation of the radar response.

4. FURTHER STUDIES

Following the success of the test survey, measurements were carried out on Lines 2, 3, 4 and 5 two months after the measurement on Line 1. Each line was parallel to Line 1 with an inter-line spacing of 5 m for Lines 2 and 3 and for Lines 7m for Lines 4 and 5. Pole-pole RIP measurements were taken on the water surface along each line. Each Pole-pole RIP line had an inter-electrode separation of 1 m, and the dipole separation factor "n" value varied from 1 to 15. The maximum depth of exploration was about 15 m. During the measurements, the water level had lowered to 80 cm, and the resistivity of the water had decreased to 50 ohm-m. The apparent resistivity profiles of Lines 2, 3, 4 and 5 are shown in Fig. 6. For comparison, the apparent resistivity of Line 1 is also shown in Fig. 6. As shown in the figure, the resistivity
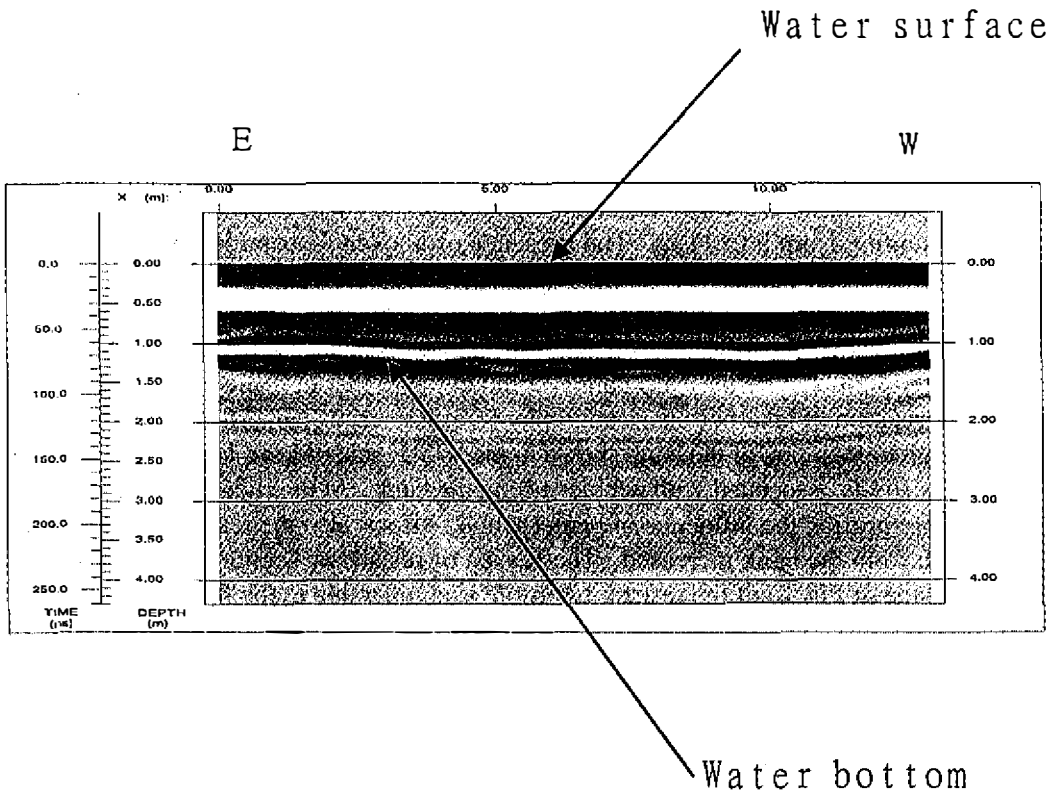

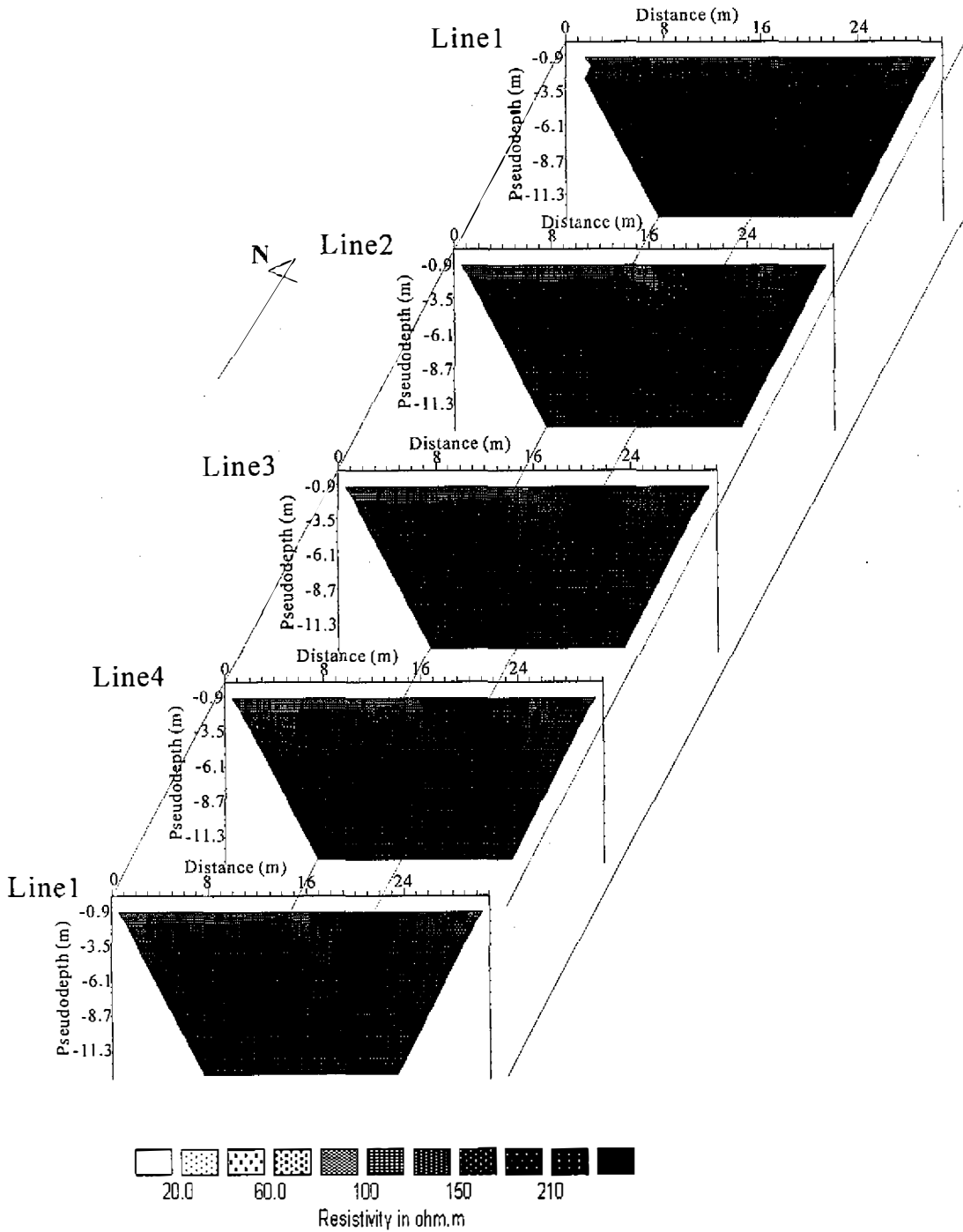*Fig. 5.* Radar section collected on the water surface in the Lake Chung-Dah.

Fig. 6. Collations of apparent resistivity pseudosections of Lines 1, 2, 3, 4 and 5 (depth zero for the water surface).

structures of Lines 2, 3, 4, and 5 are quite similar to that of Line 1. Figure 7 is the RIP inversion data shown in Fig. 6. The geoelectric layers shown in each profile are comparable to the others except for the deepest water depth shown in Line 1. This is due to less precipitation after measurement of Line 1 started. If we neglect the difference of water depth measured at two different times, the structure underlying the lake bottom shown in each section of Fig. 7 is quite simple, i.e., a flat horizontal layer structure. The top layer underneath the water bottom is laterite with a thickness less than 3 m, then a gravel bed with a thickness ranging from 9 to 11 m, and bottom that alternate sandy and clayey layers. A remarkable downward extended low resistivity zone at 16 m in each profile may be associated with water leakage zone.

5. TEMPORAL WATER BOTTOM RESISTIVITY IMAGE PROFILING

Measurements have been taken on the water surface along Lines 2, 3, and 4 five months after the first measurement. The water level had decreased to a depth of 50 cm, and the water resistivity had decreased to 55 ohm-m. The spread length of each sounding was 14 m with an inter-electrode separation of 1 m. The maximum depth of penetration was 14 m. The apparent resistivity profiles of Lines 2, 3 and 4 are shown in Fig. 8. Since the distance between the current electrodes is greater than the water depth, the influence of the water body may be neglected. In addition, there is no topography correction for a flat water-bottom. Therefore, we neglect the topographic and water body correction for the resistivity sounding data collected along the water bottom. The apparent resistivity structures shown in the Figs. 6 and 8 are clearly similar of Lines 2, 3 and 4. Figure 9 is the RIP inversion data shown in Fig. 8. The geoelectric layer structures of all the survey lines shown in Fig. 9 are comparable to one another. The resistivity profiles shown in Fig. 9 and the corresponding profiles shown in Fig. 7 are also a good match, i.e., each resistivity section shown in the figures has similar water-bottom stratigraphy. Less variations of the resistivity images measured at different times indicates that the proposed water bottom resistivity stratigraphy can be mapped by RIP on the water surface. The proposed survey technique suggested by the authors is faster and more economical than that of the standard resistivity sounding measured along the water bottom. However, this survey technique still has room for improvement, both in field technique and data processing.

6. CONCLUSIONS

Although underwater materials surrounding often interferes with the geoelectric signal, and the increase of the conductivity of the water causes difficulty in identifying the subsurface structure. water surface RIP method provides detailed underwater stratigraphy as conveniently and effectively as does on land. The method has the advantage of using the underwater electrode array along the water bottom does not provide. We believe that the experiment introduced here has demonstrates a powerful method that can improve depth investigation underneath a water bottom. In addition, the proposed technique can be extended to a non-destructive underwater mapping stratigraphy in a greater depth of water area (such as a reservoir) where the explosive seismic method is prohibited. Measuring the potentials can be done using
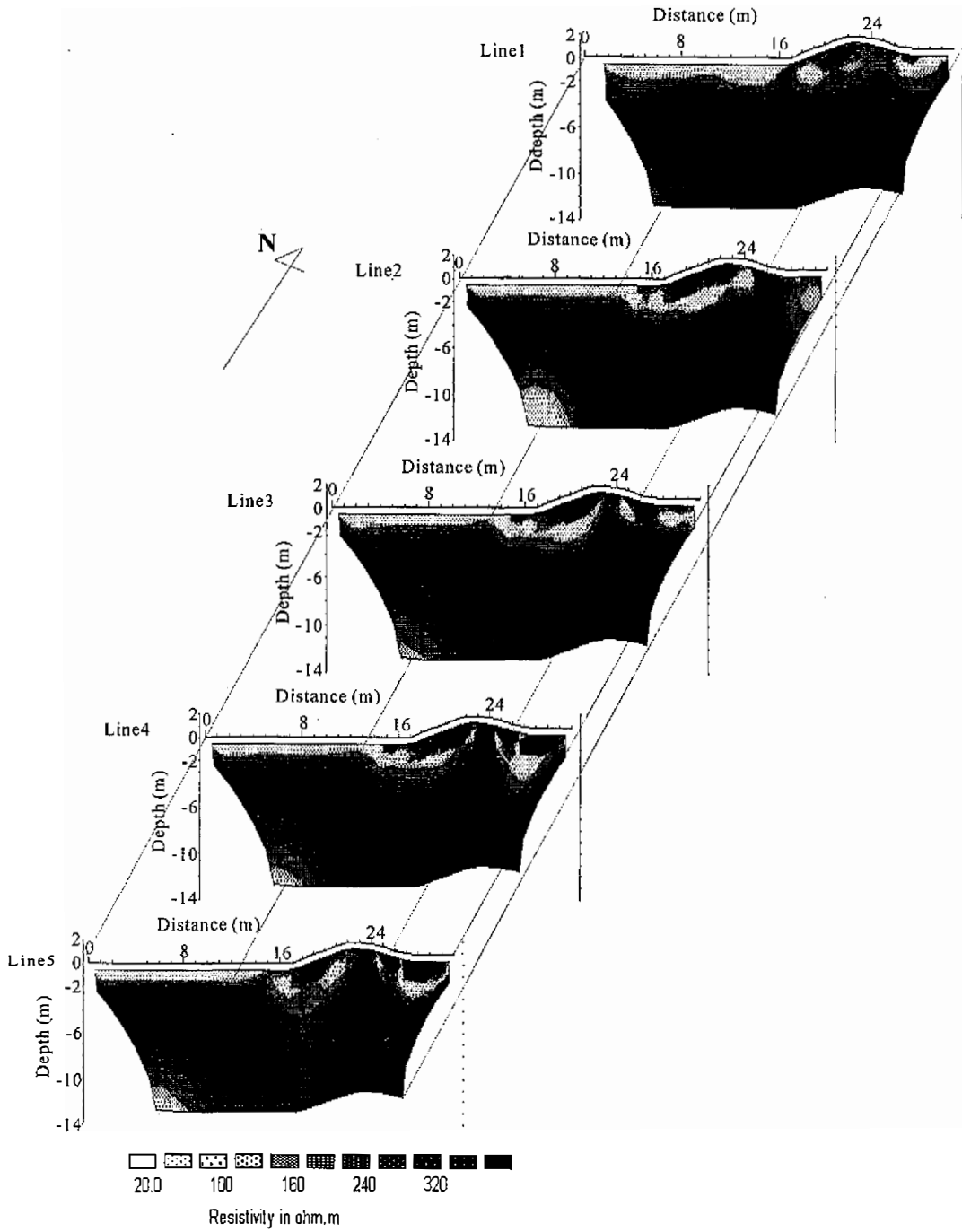
Fig. 7. Inversion results from the data shown in Fig. 6 (depth zero for the water surface).
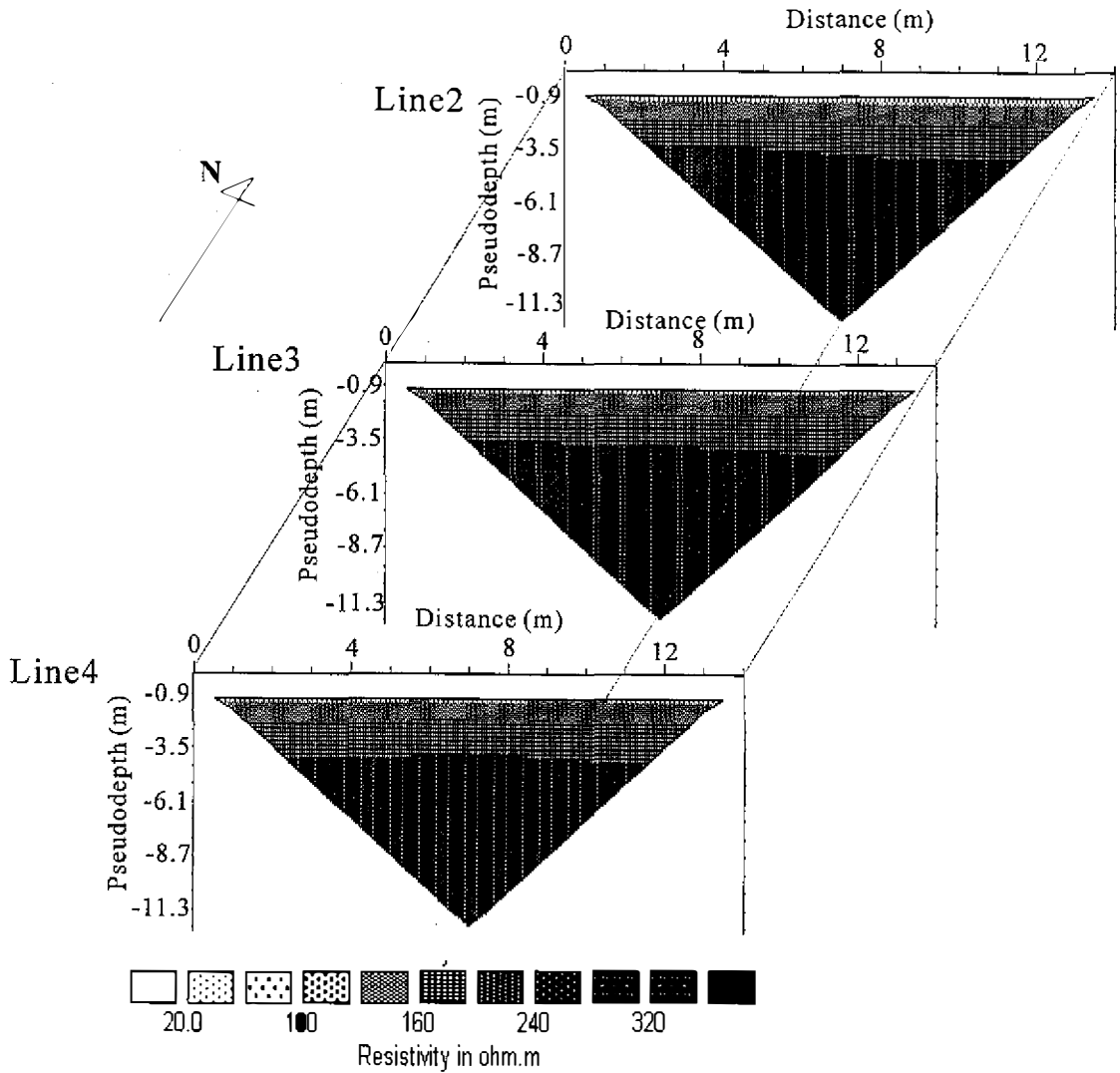
Fig. 8. Collations of apparent resistivity image for profiles, 2, 3 and 4 once after
the first measurements started (depth zero for the water surface).

the underwater electrodes suspended in any depth. The success of the method depends upon
the appropriate design of survey parameters. As demonstrated, this new application is open to
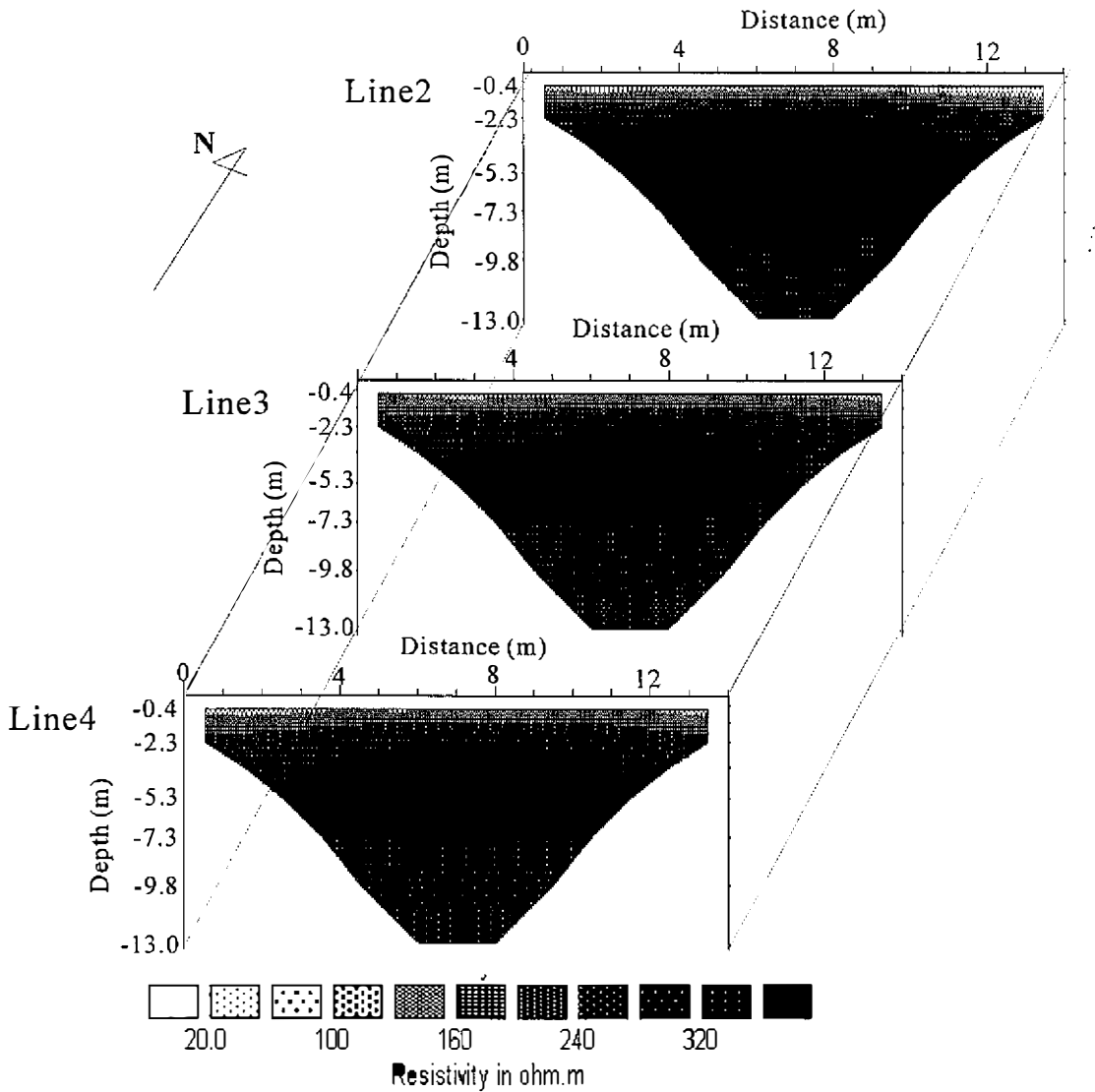further refinement, both in instruments and in survey techniques.

Fig. 9. Inversion results from the data shown in Fig. 8 (depth zero for the water surface).

REFERENCES

Annan, A. P., and J. L. Davis, 1977: Impulse radar applied to ice thickness measurements and freshwater bathymetry. *Geological Survey of Canada*, **77-1B**, 63-65.

Baumgartner, F., 1966: A new method for geoelectrical investigations underwater. *Geophysical Prospecting*, **44**, 71-98.

Daily, W., and A. Ramirez, 1995: Electrical resistance tomography during in situ Trichloroethylene remediation at the Savannah river site. *J. Appl. Geophys.*, **33**, 239-249.

Daily, W., A. Ramirez, D. LaBrecque, and W. Barber, 1995: Electrical resistance tomography experiments at the Oregon Graduate Institute. *J. Applied Geophysics*, **33**, 227-237.

Delaney, A. J., P. V. Sellmann, and S. A. Arcone, 1992: Sub-bottom profiling: a comparison of short-pulse radar and acoustic data. *Special paper of 4th Intern. Conf. on GPR*, 149-157.

Griffiths, D. H., and R. D. Barker, 1993: Two-dimensional resistivity imaging and modelling in areas of complex geology. *J. Appl. Geophys.*, **29**, 211-226.

Lagabrielle, R., 1983: The effect of water on DC resistivity measurements from sea, river or lake floor. *Geoexploration*, **21**, 165-170.

Loke, M. H., 1998: RES2DINV Ver. 3.3 for windows 3.1, 95 and NT, Advanced Geosciences, Inc, 40p.