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Locating Groundwater at Ta-Kang-Shan and Ping-Ting Sites by Geoelectric Methods

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ABSTRACT

A great population growth and rapid industrial development in Taiwan have placed ever increasing demands on the water supply. In fact, since the yield of known aquifers can no longer meet the current needs, new reservoirs must be found for emergency use, especially in those areas with a short of water . Traditionally, the selection of well sites in Taiwan was based on lineaments shown in aerial photographs and on the topographic conditions of a site. As much as this was successful in the past, the number of potential aquifers today continues to decrease rapidly. Conventional groundwater exploration methods do not give satisfactory results; and locating an aquifer by geoelectric represents a significant challenge. However, the combined geoelectric method and conventional methods provides a better approach for site evaluation, especially in those areas of water shortage.

In this paper, it will be shown the way by which geoelectric methods are applied to locate aquifers in poor water storage areas and highlight the propriety of such methods used during this survey. In so doing, useful information as to the aquifer characterization will be acquired. Two selected sites in this study have different geologic settings; one in a volcanic area, the other in a hilly area. All the geoelectric features obtained in these areas not only delineate the water bearing zones clearly but also indicate the depth extent accurately.

(Key words: DC Resistivity, Terrain Conductivity Method, Groundwater)

1. INTRODUCTION

Although geoelectric techniques are popular and successful in locating aquifers around the world (Kelly, 1977; Mazac *et al.*, 1990; Yang, 1992), the chances of their success depend on the features of the aquifer. Various factors affecting the recognition of aquifers with

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geoelectric methods include the size of the reservoir, its physical parameters and the contrast in the conductivity between the aquifer and the bedrock.

This research deals with the detection of aquifers located in a volcanic and a hilly area. The inherent difficulties in site evaluation in those water shortage areas are overcome by combined use of different geoelectric techniques, namely, the direct current (DC) resistivity method and/or the terrain conductivity method (TCM). A good geophysical interpretation is achieved prior to the drilling of the wells. The results provide us with a profound understanding of the structure of the aquifer zones.

2. CASE STUDIES

DC resistivity surveys were carried out at the two selected sites of Ta-Kang-Shan, and Ping-Ting in Taiwan. In order to get a better interpretaton of the field data, TCM measurements were also made during DC soundings at Ta-Kang-Shan for comparsion. The field work and final results at each site are described in the following.

2.1 Ta-Kang-Shan Site

Location and geologic setting: Located in the east of Ta-Kang-Shan in southern Taiwan, the Niu-Chou-Pu Chi River to the west and Road 10 to the north (Figure 1) serve as boundaries. The survey area is about 250,000 square meters. With the whole area covered by the alluvium of Niu-Chou-Pu Chi with a grey mudstone of poor pemeability, intercalated with yellow brown siltstones. Although the topography of the study area is mostly of low relief of an average altitude of 43 m, the difference in the altitude between the ground surface and the valley of Niu-Chou-Pu Chi ranges from 15 to 20 m. According to past records, the study area belongs to a water shortage area. The purpose of field and geophysical surveys is to map the aquifers for future drilling.

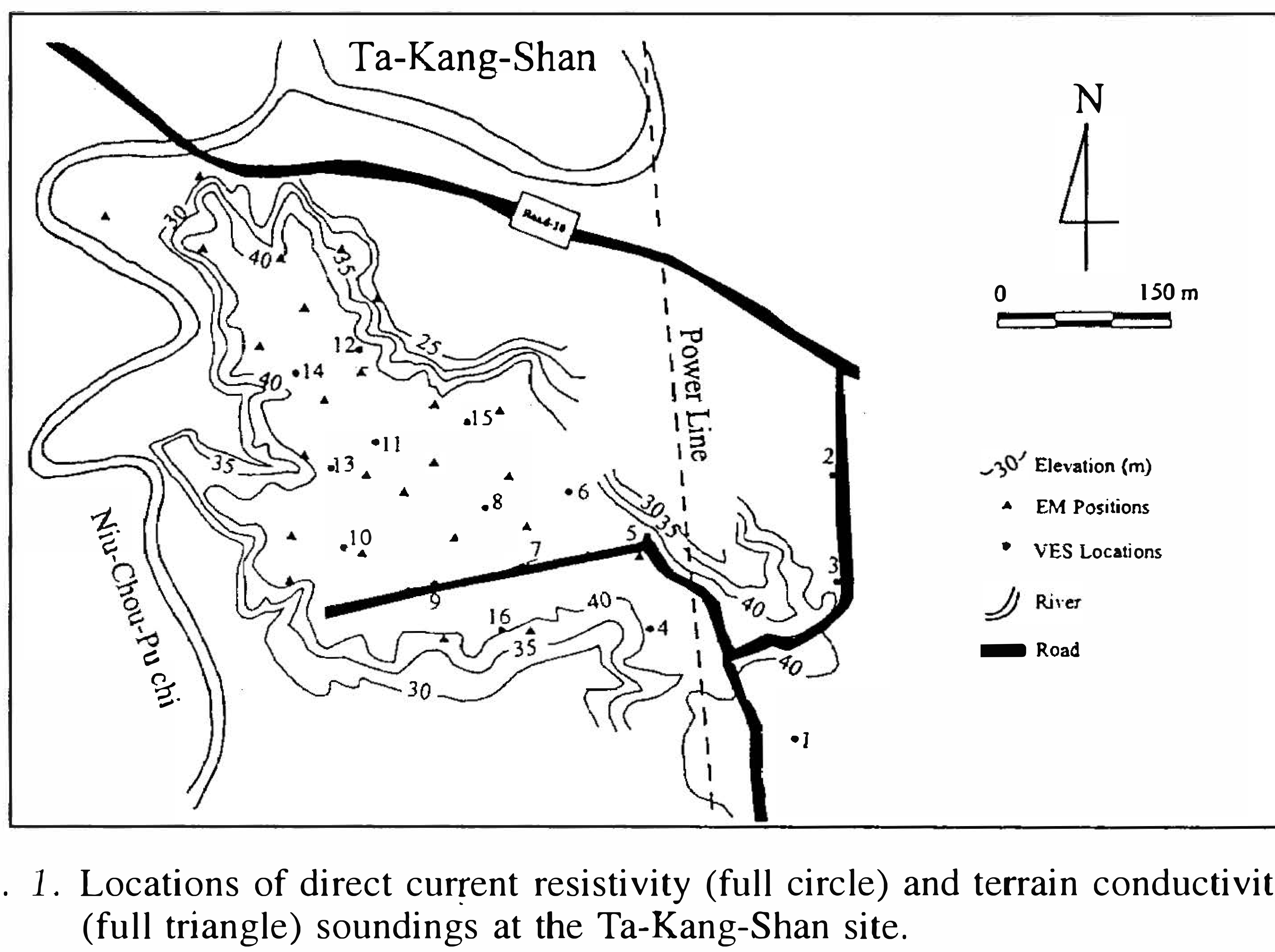


Fig. 1. Locations of direct current resistivity (full circle) and terrain conductivity (full triangle) soundings at the Ta-Kang-Shan site.

Geoelectric surveys: TCM measurements were made using a Geonics EM-34 at 30 locations (Figure 1). This loop-loop EM system was operated at intercoil seperations of 10, 20 and 30 m for both vertical and horizontal parallel dipole geometries. The maximum depth of penetration for each intercoil separation is shown in Table 1.

Table 1. Maximum Depth of Penetration for EM-34 Measurements with Different Intercoil Separations.

Intercoil Seperation (m)	EM Wave Frequency (Hz)	Depth of Penetration	
		Vertical Parallel dipole	Horizontal Parallel dipole
10	6400	15	7.5
20	1600	30	15
40	400	60	30

The DC resistivity Schlumberger vertical electric sounding (VES) with a maximum half-spacing of 200 m was carried out at 16 positions (Figure 1). An OYO ES-G2 was used in this survey. In order to get better interpretation of the lithology of the surface from DC data, the resistivity measurements were made at known outcrops, The final resistivity spectrum is shown in Table 2.

Table 2. Resistivity Spectrum in Survey Aarea.

Lithology	Dry or Wet	Number of Samples	Resistivity (ohm-m)
mudstone	dry	6	5.6 ~ 16.3
clay	dry	2	13.7~14.4
sandstone	dry	2	36.4~42.0
gravel	dry	2	195~196

Qualitative data interpretation: Apparent resistivity data for both the TCM and the DC were depicted and contoured as pseudoresistivity maps. Those points used to describe the apparent resistivity values were plotted at each station at a pseudodepth equal to array spacing (the loop distance in the TCM surveys or the half electrode spacing (AB/2) in the DC surveys). The apparent resistivity maps for both the TCM data (Figure 2) and the DC data (Figure 3) indicate spatial variation (both horizontal and vertical directions) of the overburden resistivities. An increasing coil spacing in the TCM data and/or larger value of AB/2 in the DC data will reflect deep resistivity features. These figures show that :

(1) The apparent resistivity of deeper layers have less lateral variation at each depth range. However, the values corresponding to each depth tend to decrease with an increase in depth (see Figures 2(b),(c) and 3(b),(c)) except to the shallow depth (Figures 2(a) and 3(a)). Such high and varied apparent resistivity values shown in Figures 2(a) (30 to 40 ohm-m) and 3(a) (10 to 16 ohm-m) indicate the presence of an uneven distribution of muddy sandstone near the surface.

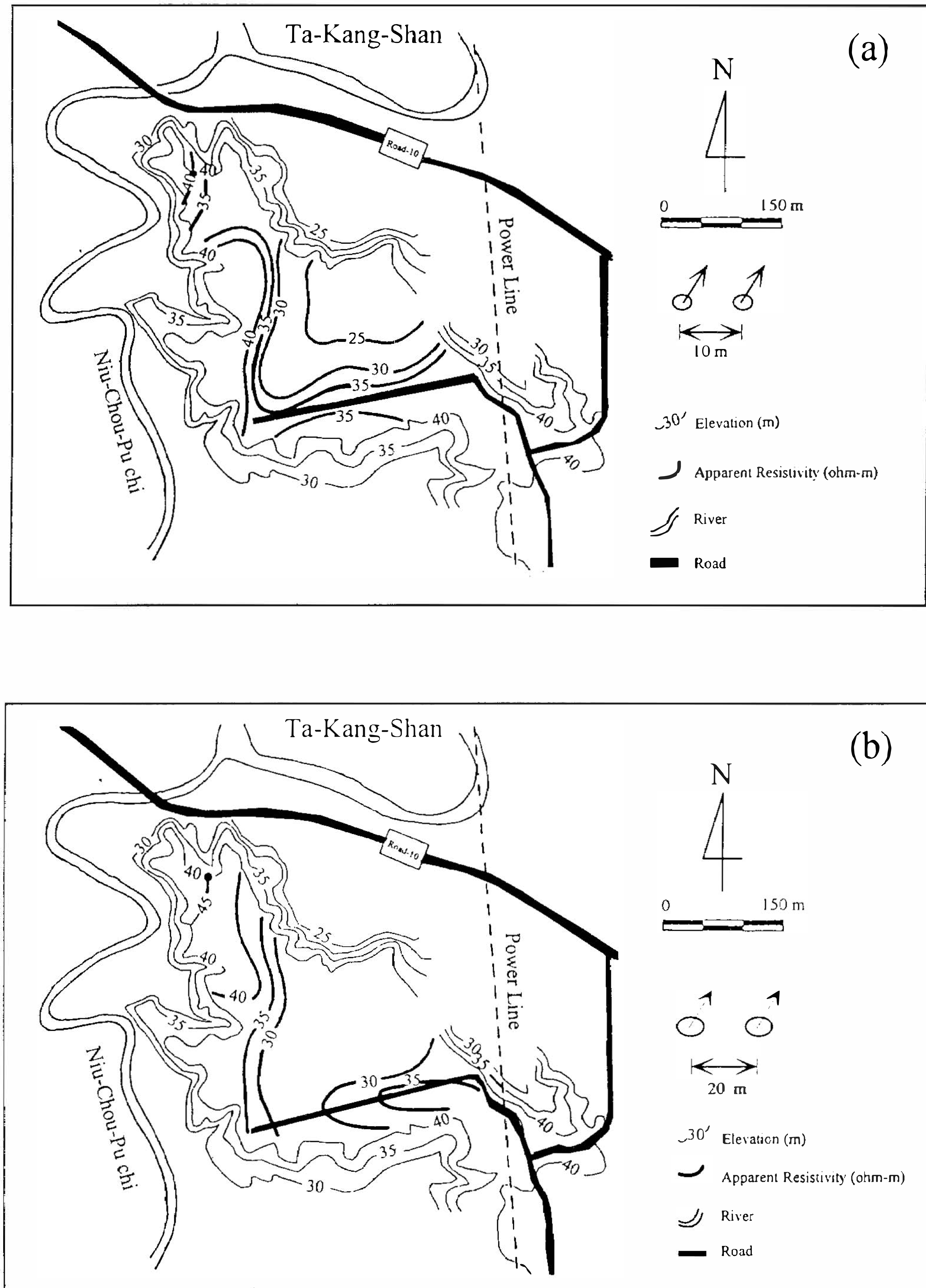


Fig. 2. Apparent resistivity map for terrain conductivity data with different loop distances : (a) 10 m, (b) 20 m, and (c) 40m.

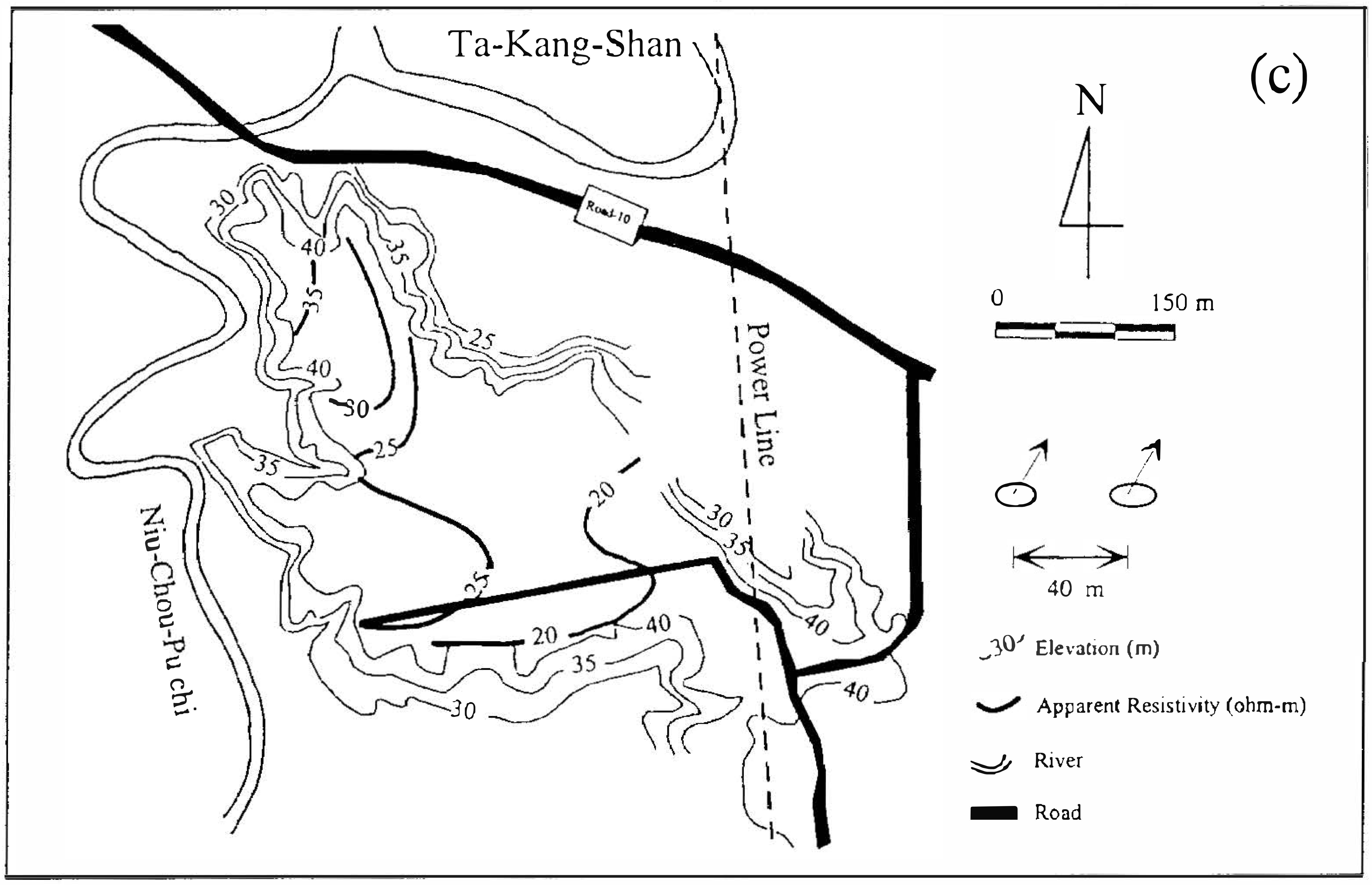


Fig. 2. (Continued)

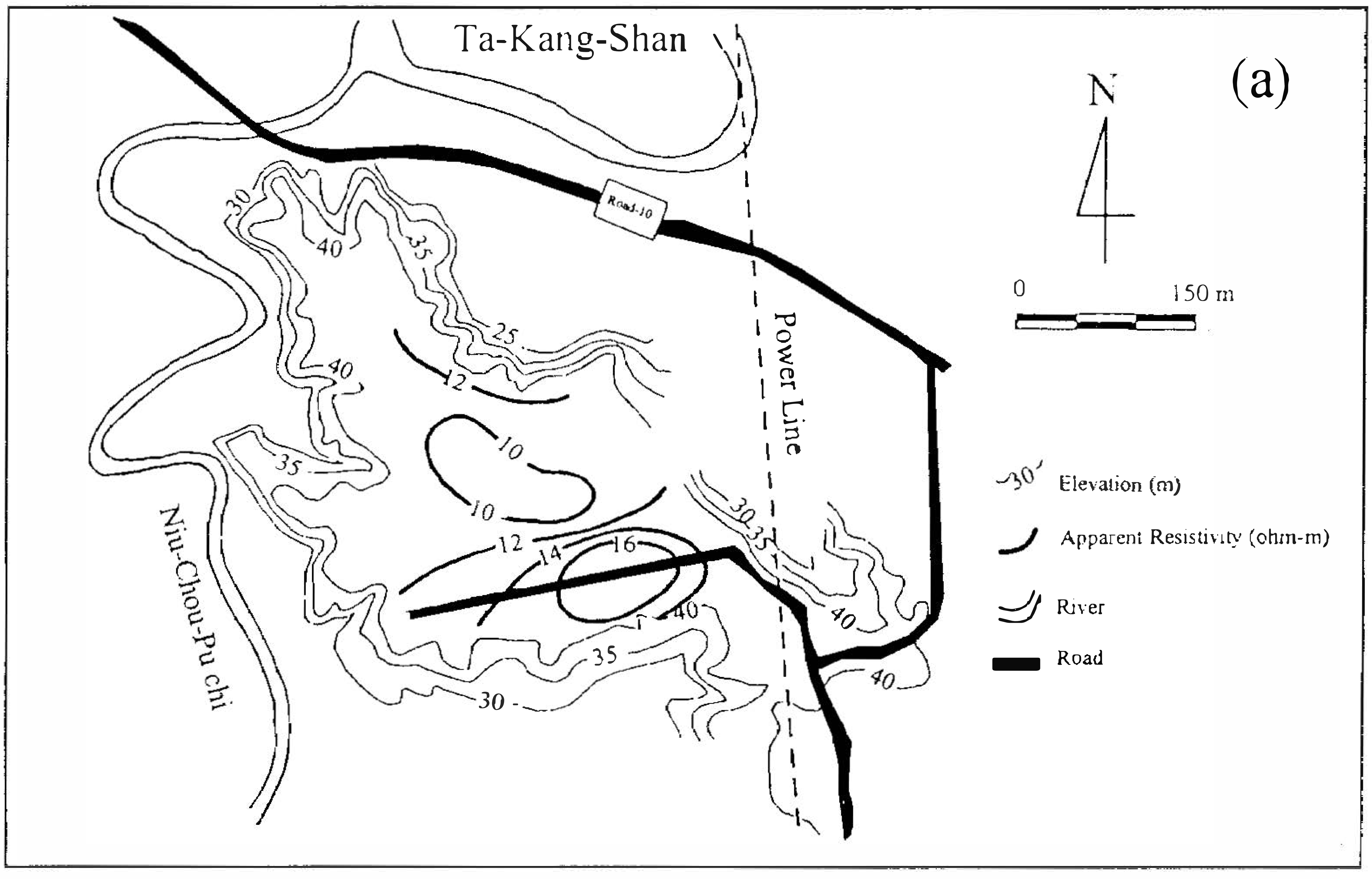
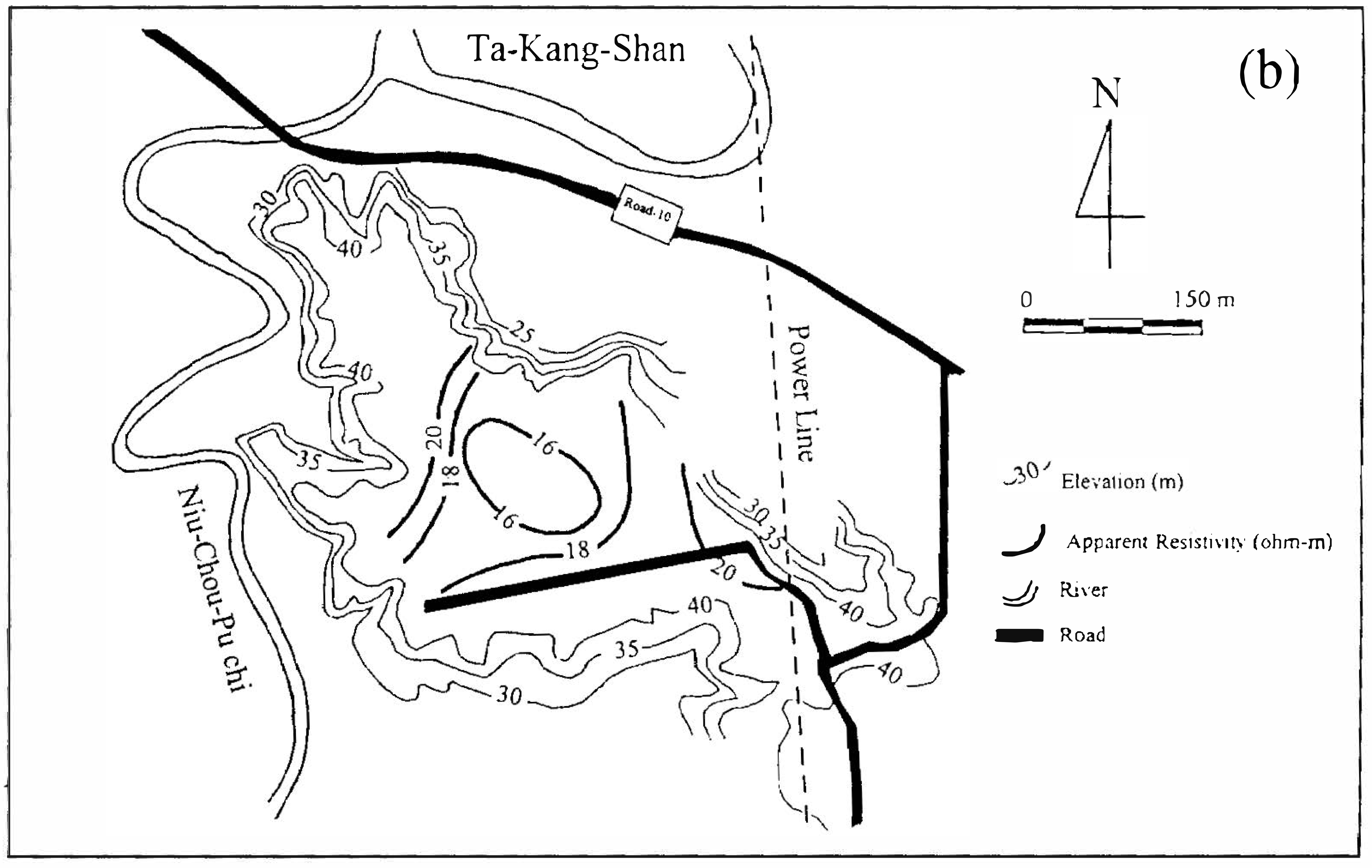


Fig. 3. Apparent resistivity map for direct current resistivity data with different half-distances: (a) 6 m, (b) 60 m, and (c) 200 m.



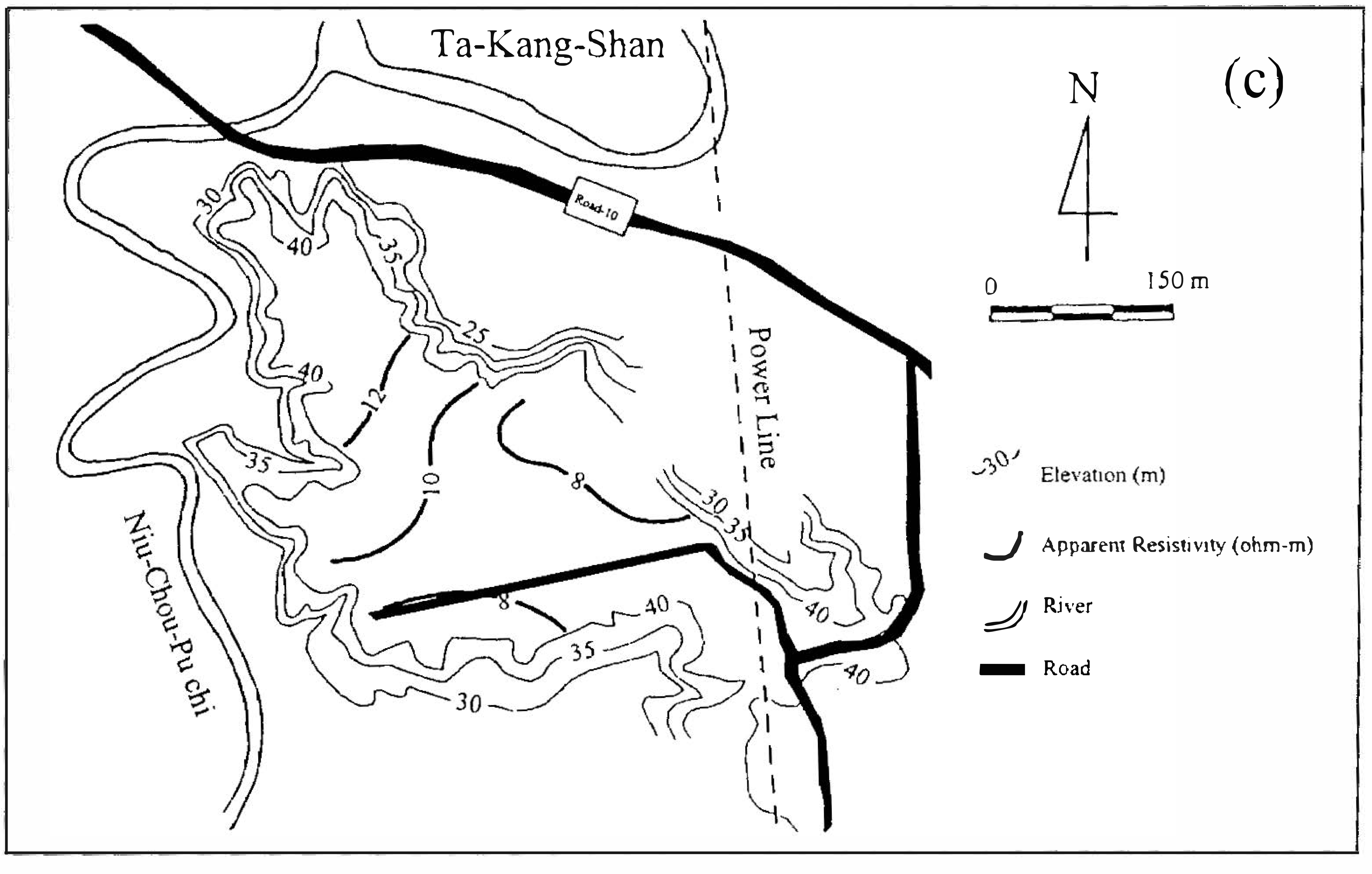


Fig. 3. (Continued)

(2) Figure 3(c) shows no significant variation in apparent resistivity. The average of the apparent resistivity values in this map was 10 ohm-m. The low uniformly distributed resistivity values at this depth imply that the deep layers are composed of uniform mudstone.

Quantitive data interpretation: The one-dimensional inversion scheme developed previous by Zodhy (1989) and Jupp and Vozoff (1975) is used in this study to convert the sounding data to geoelectric structure. The geoelectric layers finally can be grouped into 5 layers, namely A, B, C, D and E respectivity. Layer A has a resistivity ranging from 9 to 25 ohm-m which corresponds to the brown muddy top soil. Layer B has a resistivity varying from 7 to 14 ohm-m which is believed to be mud interlayered by fine sand layers. Layer C is the highest resistivity zone (17 to 31 ohm-m) which corresponds to a mud layer intercalated fine sand and pebble, or alternated of sandy mudstone and sandstone. Layer D corresponds to the mudstone with intercalating sandy mudstone that has a resistivity ranging from 8 to 12 ohm-m. The last E layer is composed of the lowest resistivity (2.5 to 7.1 ohm-m) bedrock consisting of homogeneous mudstone. Based on this resistivity classification, layers A and B can be interpreted as being the alluvial soil of the river with their combined thickness about 2 to 5 m. Local groundwater may be found in this layer. The unconformity between the layers B and C may coincide with the erosion surface of an anicent river.

Figure 4 shows the map of the depth of the top of C layer, a feature which corresponds to the base of a buried channel. The thickness of the overburden of layer C increases in the northern or northwestern direction. This indicates that the flows of the groundwater may be concentrated to the northern part of the survey area.

The high resistivity of layer C is an indication of its being a good reservoir. However, the poor pemeability of this layer deteriorates its potential as a good aquifer, even though its average thickness is 30 m. The characteristics of the DC sounding curves also indicate

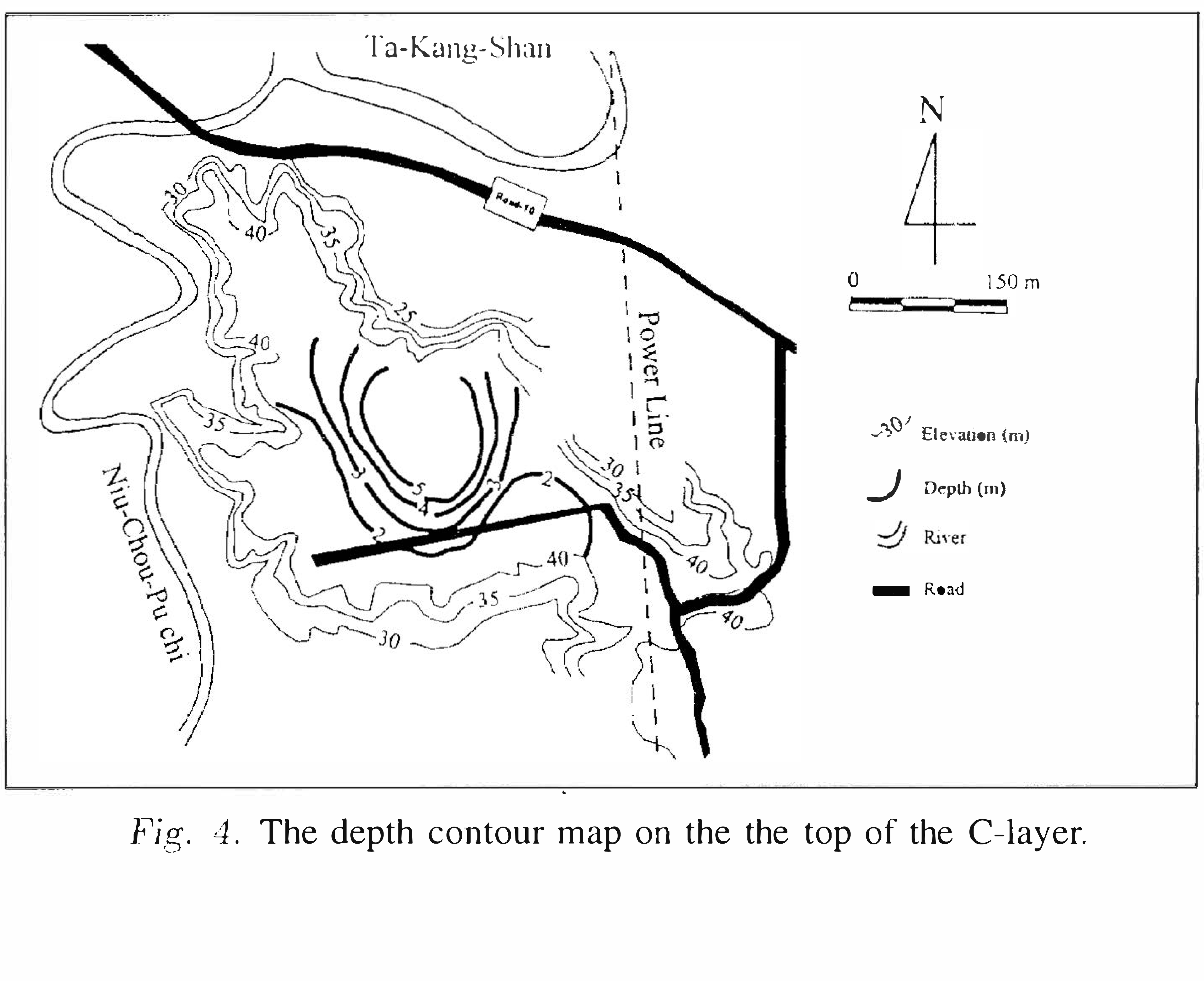


Fig. 4. The depth contour map on the the top of the C-layer.

a minimum depth of 150 m for the deep aquifer, therefore making the possibility of deep aquifers being present still uncertain.

2.2 Ping-Ting District

The Ping-Ting District, site located in the Hsiao-Ping-Ting area, Tanshui, in northern Taiwan, covers an area of 33.8 hectares. Because the Nan Kuo corporation was planning to develop a new community in this area, a groundwater survey was carried out to find new aquifers to meet the increasing water demands in the future. The exploration included two steps: a DC survey to determine the locations for test wells and well loggings and pumping tests at each test well.

Geologic setting: Located in an andesitic area, the site has a maximum variation of altitude of about 125 m. The whole area is covered by light yellow to dark grey weathered volcanic detritus with outcrops of andesite either on the site or in the surroundings. In the past, no groundwater was found in 27 boreholes with depths ranging from 10 to 35 m. The lithofacies from the logs show that the overburden consists of weathered red-brown muddy fine sand with detritus, hard red-brown andesite and grey tuff.

DC sounding: 15 vertical electric soundings (VES) with a Schlumberger array were carried out in the site (Figure 5). The maximum half spread spacing was 400 m. Sounding locations numbered 8 to 12 were sequentially distant from the site and became closer to the known spring or wells. The purpose of selecting those locations was to compare the DC results obtained from the site with the known groundwater sources. The OYO ES-G2 was used to collect the sounding data.

Data interpretation: All the VES curves obtained from the sounding locations were K type except those at location number 8. Those curves are interpreted to be three layers. The top layer, (A layer) with a thickness ranging from 7 to 18 m and a resistivity varying from 90

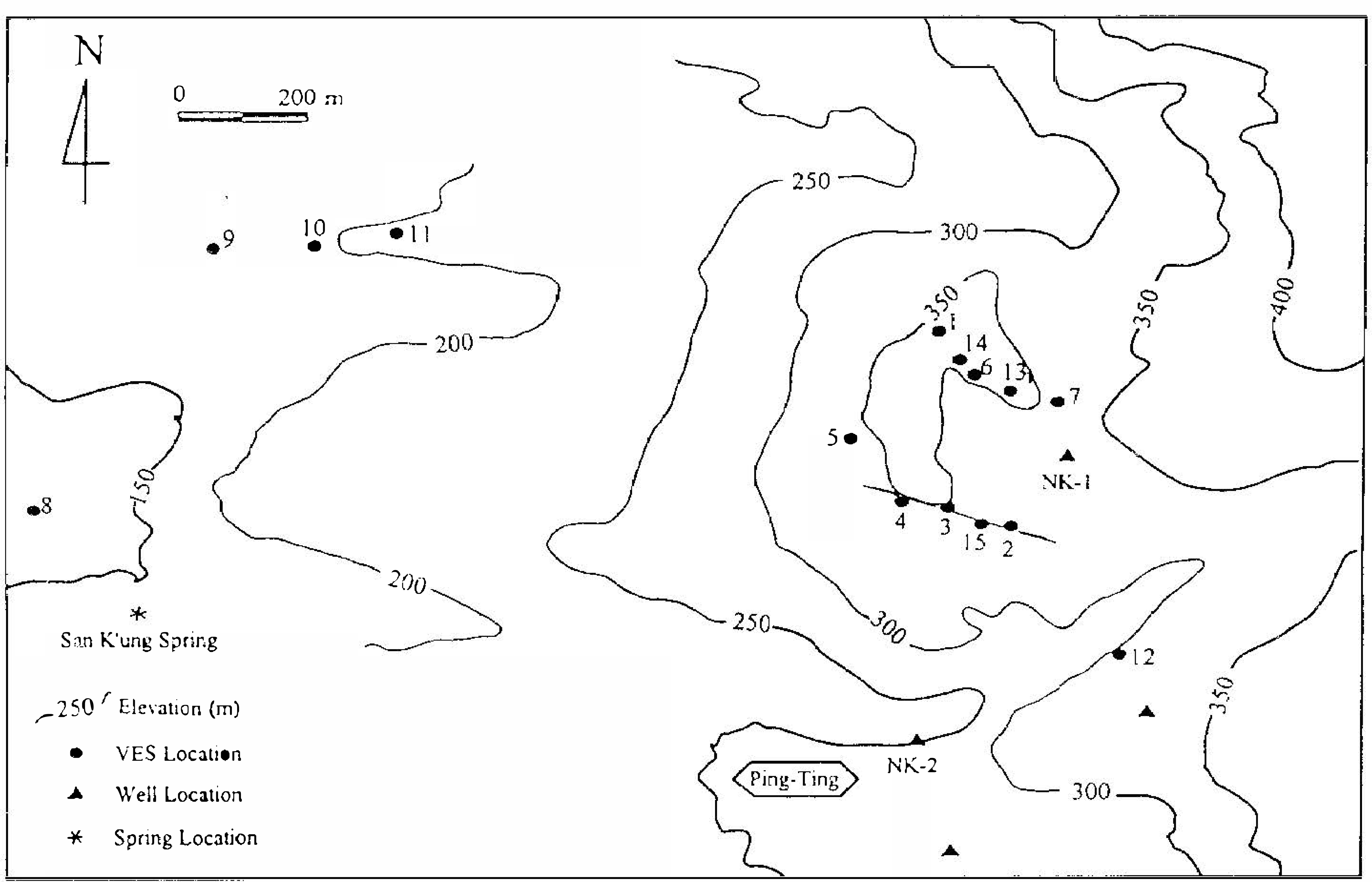


Fig. 5. Locations of Schlumberger vertical electric sounding at the Ping-Ting district.

to 550 ohm-m, consists of muddy sand intercalated with detritus. The second layer (B layer) with high resistivity (1000 to 1900 ohm-m) corresponds to fresh andesities with a thickness varies from 140 to 181 m. The last layer (C layer) has a resistivity varing from 100 to 260 ohm-m at a depth from 170 to 190 m, and it is composed of loose volcanic breccia. This layer may represent the main body of the aquifer. Figure 6 shows the interpreted section along VES locations 4, 3, 15 and 2.

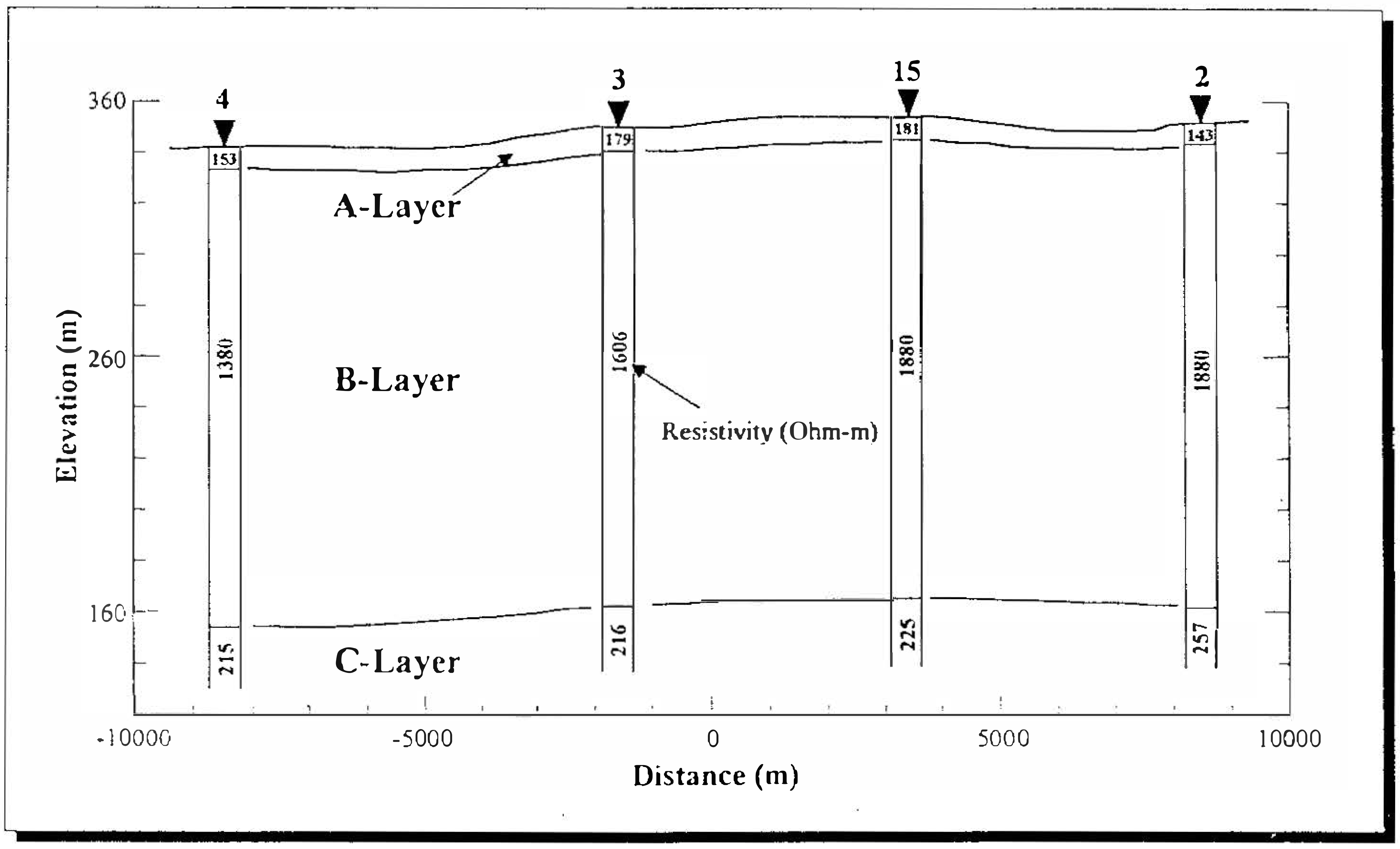


Fig. 6. Interpreted section along the sounding locations numbered 4, 3, 15 and 2.

Comparing the geoelectric sections and the well information shown in Figure 7(a) with Figure 7 (b) and also the geologic features of the springs located outside the site indicate that the whole area has the same aquifer. The springs probably represent the western extension of the aquifer. From this point of view, the estimated depth of the aquifer on the site is about 160 to 180 m, leading to the conclusion that the proper drilling locations are close to the sounding position number 2.

Well logging: Two wells named NK-1 and NK-2 were drilled (Figure 5) to a depth of 250 m and 165 m, respectively. The lithological sequences and logs (Figures 7 (a) and 7 (b)) do match the geoelectric model obtained from the DC data. An obvious drop in temperature is shown in the temperture logs at depth of 92 m for NK-1 well and at 1.62 m for the NK-2 well. The presence of groundwater flow lowers the temperture gradient at these depths. The temperture gradients of both wells show the trend of increasing with depth. Caliper measurements at the NK-1 well indicate that the first 31 m has no obvious variation due to casing. An abrupt change in the logging curve from the depth of 30 to 50 m represents a potential well collapse and may indicate that highly fractured layers are present at this depth range. From the depth of 50 to 146.8 m , local variations shown in the curves are presence of massive andesites. No obvious variation in the caliper curve was observed at a depth greater than 146.8 m meaning that the cementation of the layers in this range is quite different from the overburden.

The gamma logs show that there is a distinct boundary in each well, namely, at 169 m for the NK-1 well and at 105.3 m for the NK-2 well. The intensity of the gamma ray does increase with the depth in both wells.

(a)

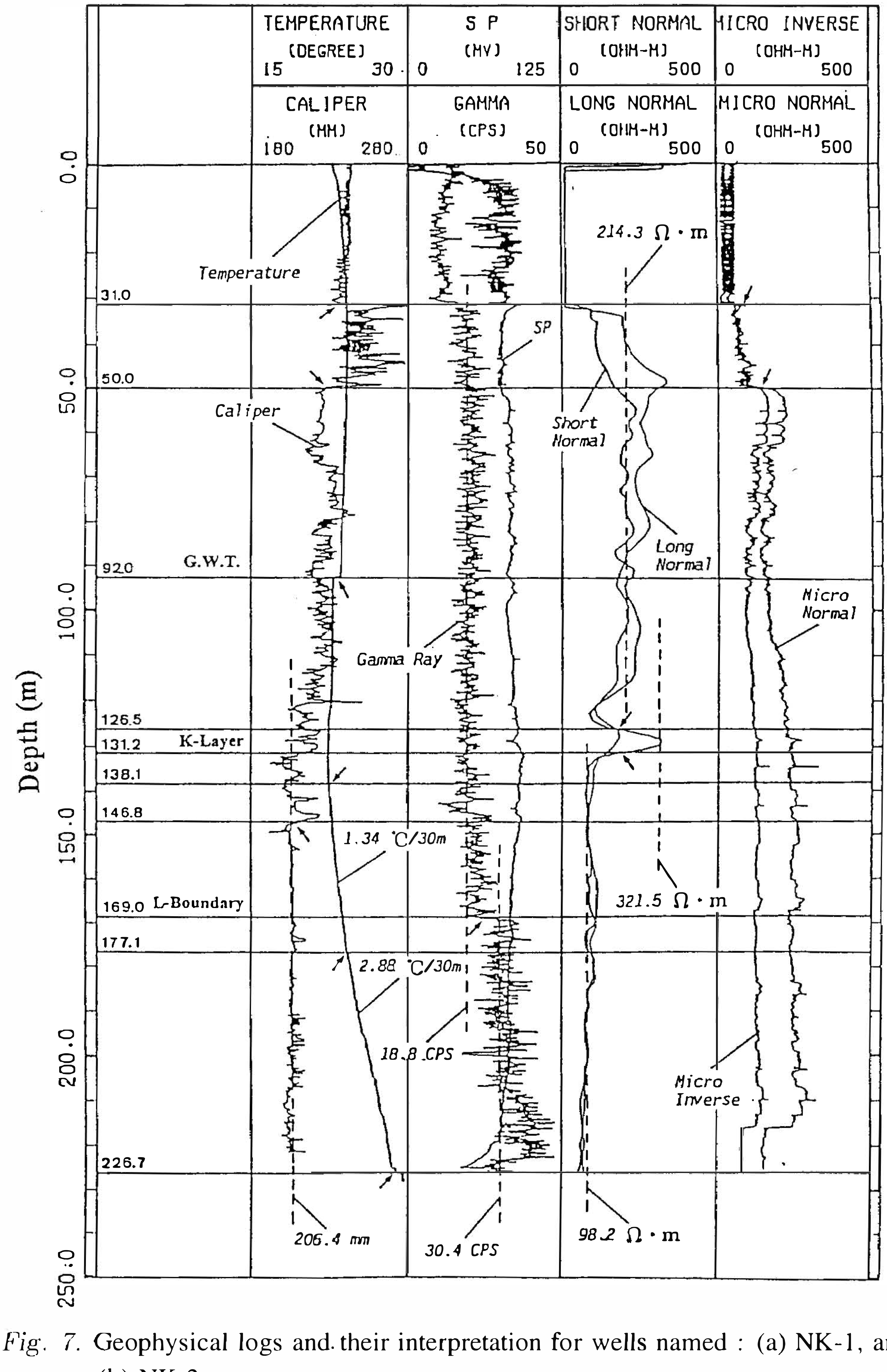


Fig. 7. Geophysical logs and their interpretation for wells named : (a) NK-1, and (b) NK-2.

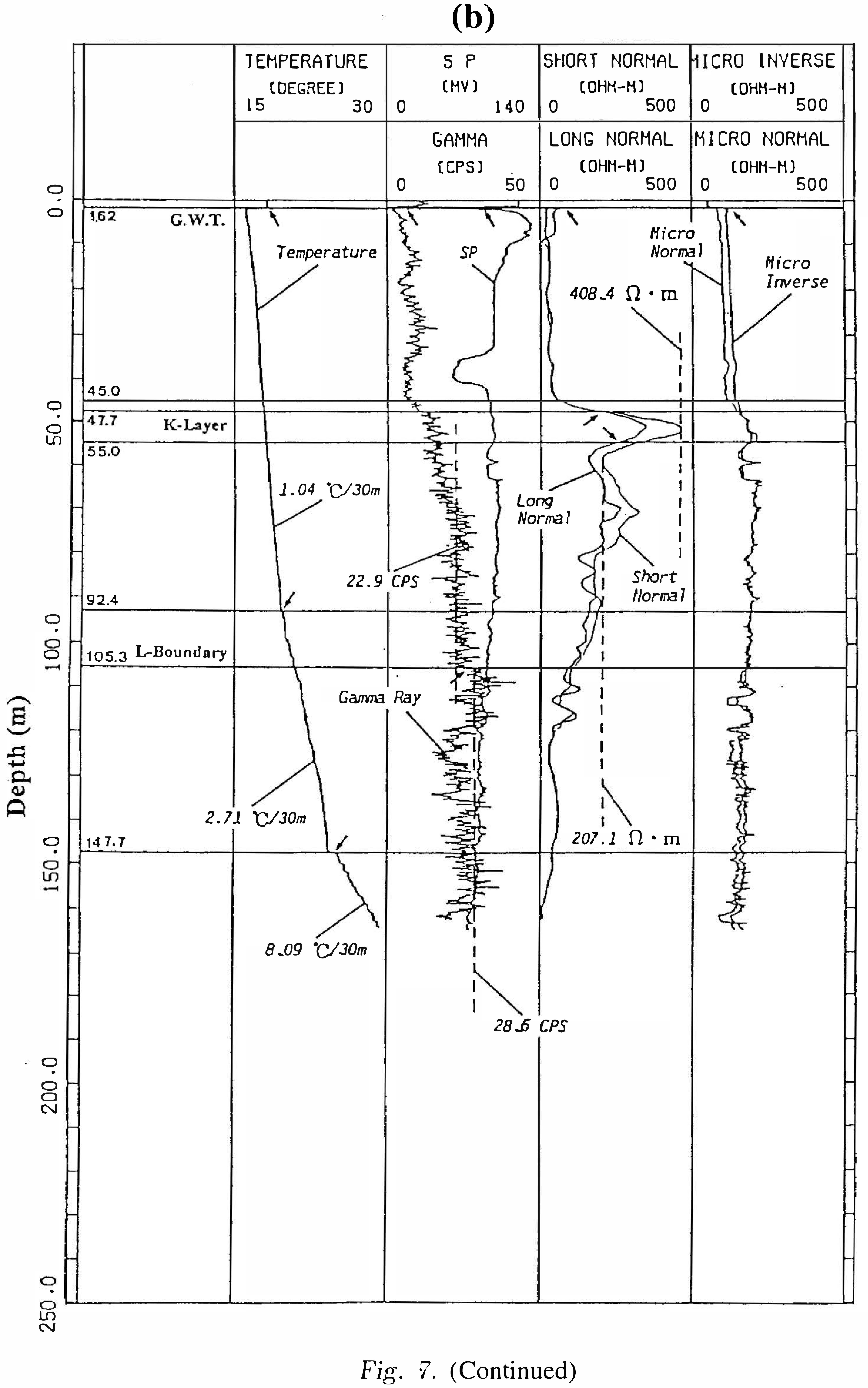


Fig. 7. (Continued)

The E-log shown in the NK-1 well is quite similar to that of the NK-2. However, the depth of the high resistivity zone shown in the NK-1 well is shallow than that in the NK-2 well. The main aquifer in each well is underneath the high resistivity zone. Based on the logs, the estimated depth of the aquifers is 169 m for NK-1 well and 105.3 m for the NK-2 well. The pumping test shows that the yield of NK-1 well is 320 cubic meters per day and for the NK-2 well 350 cubic meters per day.

3. CONCLUSIONS

The two groundwater surveys described in this paper achieved their objectives of determining an effective geoelectric methods for hydrology studies on the sites of special geologic settings. Locating aquifers on both an andesite site and on a hilly site is successful. The sounding results are confirmed by the drilled wells. The optimum performance of the methods is site dependent. A judiciously selected sounding method can be used successfully in those water shortage areas.

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