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INTEGRATION OF GEOPHYSICAL METHODS FOR GROUNDWATER EXPLORATION IN TURKMENISTAN

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TABLE OF CONTENTS

Page No.

1. EXECUTIVE SUMMARY 2
2. RESEARCH OBJECTIVES 3
3. METHODS AND RESULTS 4
4. IMPACT RELEVANCE AND TECHNOLOGY TRANSFER 13
5. PROJECT ACTIVITIES 14
6. PROJECT PRODUCTIVITY 16
7. FUTURE WORK 17
8. LITERATURE CITED 18

APPENDIX A: FINANCIAL STATUS REPORT

APPENDIX B: PROGRAM OF WORKSHOP

APPENDIX C: LIST OF FIGURES

1. EXECUTIVE SUMMARY

The overall aim of the project was to develop and test a methodology of combined application of several geophysical methods for groundwater exploration and management in Turkmenistan, as well as extensive training of Turkmen geophysicists in using the modern techniques of data acquisition, processing and interpretation.

Based on the analysis of a large amount of geological and hydrogeological data from various areas of Turkmenistan, the Kazganchay area located about 110 km to the southeast of the city of Ashgabad was selected for conducting the geophysical investigations. A relatively large number of water exploration wells located in this region provided a good basis for formulating the hydrogeological problem in the area. A number of geological and hydrogeological cross-sections were built across the wells; along these cross-sections, geophysical surveys were carried out. The surveys included four seismic reflection lines and eight time domain electromagnetic (TDEM) soundings. Processing and interpretation of the seismic and electromagnetic data were performed jointly by the Israeli and Turkmen teams using all the geological, hydrogeological and borehole information available in the study area. Combined application of the seismic and electromagnetic methods resulted in a reliable detection and mapping of water-saturated layers and estimating the groundwater salinity, as well as the amount of relatively fresh water in the detected shallow aquifers of the Kazganchay area. Similar approach can be used in other areas of Turkmenistan and elsewhere.

Training of the Turkmen geophysicists took place both in their offices and during the field works. In addition, a workshop in applying modern geophysical methods for studying the shallow subsurface was organized by Israeli specialists for Turkmen hydrogeologists and geophysicists.

On completion of the project the Turkmen specialists will be able to apply the methodology developed and tested in its framework for solving various groundwater-related problems in different areas of Turkmenistan.

2. RESEARCH OBJECTIVES

Groundwater is of a paramount importance for agricultural development in arid and semi-arid areas of Turkmenistan. The main source of water in these areas is the numerous groundwater lenses of different size and salinity. In order to realize this great water potential, an extensive groundwater exploration is required. Such exploration can be based on a reasonable combination of drilling boreholes and relatively inexpensive surface geophysical methods.

Among various geophysical methods available, geoelectric and seismic techniques seem to be the most suitable for this purpose. Experience shows that although each particular hydrogeological problem can be solved using a specific geophysical technique, the successful solution of the general problem requires a combination of relevant geophysical methods. For example, geoelectric methods are able to accurately detect the depth to a fresh/saline groundwater interface (Fitterman and Stewart, 1986, Goldman et al., 1991,), but they are generally not suited to detect the depth to the water table. At the same time, the combined use of geoelectric and seismic methods may not only facilitate the detection of the groundwater, but also estimate its reserves and salinity (Shtivelman and Goldman, 2000).

The overall aim of the project was to develop and test a methodology of the combined application of several geophysical methods for groundwater exploration and management in Turkmenistan and, in addition, an extensive training of Turkmen geophysicists in using the modern techniques of the data acquisition, processing, and interpretation.

The specific research objectives of the project were defined as follows:

- Studying the shallow subsurface in selected regions using geophysical methods in order to understand the geological structure and hydrogeological situation of the areas;
- Detecting and mapping water-saturated layers in various types of shallow aquifers;
- Subdividing the aquifers into separate sub-aquifers;
- Estimating the groundwater salinity in the detected layers.

3. METHODS AND RESULTS

Within the framework of the project, the following geophysical techniques were applied:

- *High resolution seismic reflection method* for detailed mapping of the subsurface structure and, in particular, detecting and mapping groundwater layers, estimating their lateral extent and identifying tectonic deformations and faults.
- *Seismic refraction method* for detecting and mapping various lithological and hydrological boundaries between shallow subsurface layers and estimating physical parameters (seismic velocities) of the layers.
- *Seismic surface wave method* for estimating shear wave velocities and the Poisson ratio in shallow layers, thus facilitating hydrogeological interpretation of seismic results.
- *Time domain electromagnetic (TDEM) method* for accurate determination of the fresh/saline groundwater interface(s) and estimating water salinity in the subsurface.

Based on the analysis of a large amount of geological and hydrogeological data from various areas of Turkmenistan, the Kazganchay area located to the northeast of the Kopet-Dag ridge and about 110 km to the southeast of the city of Ashgabad (Fig. 1), was selected for conducting the geophysical investigations. A detailed map of the area (Fig. 2) was built on the basis of the geographical, geological, hydrogeological and borehole information provided by the Turkmen partners. The map includes location and basic data (the depth to the water table and water mineralization in mg/l TDS) of all the relevant water wells drilled in the area. It should be noted that the map was built in relative coordinates, since no data in absolute coordinates were available. A number of hydrogeological cross-sections were built for the sites chosen as suitable for geophysical surveys. Figs. 3 and 4 represent two of such cross-sections along lines A-A' and B-B' passing through 14 water wells. The sections show location and lithological characteristics of aquifer and aquiclude units, lateral changes of thickness and lithology of various layers within the

units, and water table and water mineralization in the boreholes. Analysis of the sections shows that they include the following hydrogeological units:

- The upper aquifer unit composed of upper quaternary alluvial deposits (apQ_{3-4}) consisting of sands and clays with rare thin lenses of gravels and pebbles. The total thickness of the unit varies from 2 –3 m to 30 – 40 m.
- The main aquifer unit composed of lower to middle quaternary alluvial deposits (pQ_{1-2}) with the total thickness varying from 70 – 80 m to 160 – 180 m. In the southern part of the section (Kopet-Dag foothills), the unit is represented mainly by gravels and pebbles with inclusions of relatively thin sands and loams, whereas in the central and northern parts of the section, it is dominated by sandy loam with inclusions of gravel and clay layers.
- The aquiclude unit of poorly permeable Neogene sediments (N_2) consisting of compacted sands and clays with the total thickness of up to 280 m.

These and other hydrogeological cross-sections, along with other data, served as a basis for locating seismic lines and electromagnetic measurements.

SEISMIC SURVEYS

Seismic reflection method is a powerful tool for imaging shallow subsurface structure for various purposes and, in particular, for ground-water related problems (Birkelo et al., 1987; Geissler, 1989; Steeples and Miller, 1990; Bruno and Godio, 1997; Shtivelman and Goldman, 2000; Shtivelman, 2003).

The main objective of the seismic surveys carried out in the Kazganchay area was a detailed study of the structure of the shallow aquifers, including the geometry of the main aquifer units, as well as identifying tectonic deformations and faults. For this purpose, four high-resolution reflection lines were shot. The lines were located at two sites to the north of the main road in a general SW – NE direction (Fig. 2). Lines AK-001 through AK-003 were located along profile B-B' (Fig. 3), whereas line AK-004 was located along profile A-A' (Fig. 4). The lines pass in a vicinity of a number of water wells, as shown on the map in Fig. 2.

The survey was performed using the equipment and parameters specified in Table 1. The equipment was provided and operated by the Ahal Geophysical Expedition.

Seismic recorder	Progress-96
Number of channels	48
Energy source	GSK-6 (truck mounted gas system)
Source spacing	5 m
Receivers	Single 10 Hz geophones
Receiver spacing	5 m
Source-receiver geometry	Off-end (source near trace 1)
Time sampling interval	2 ms
Trace length	2 s
Analog filters	Out
Data format	SEGX

Table 1. Equipment and parameters used for seismic surveys.

The overall quality of the acquired seismic data was fair to good. Fig. 5 shows an example of four seismic records from different lines. On the records we can see a number of shallow reflected events at times of 100 – 450 ms.

The acquired data were processed at the GII processing center using the FOCUS processing package by Paradigm Geophysical, and at the processing center of Turkmengeology using the ProMAX package by Landmark. The resulting reflection sections were converted from time do depth using the RMS velocities obtained from the data.

Lines KA-001 – KA-003:

A combined section was constructed along lines KA-001 through KA-003, as represented in Fig. 6. The data from five shallow wells located in a close vicinity of the lines were inserted in the section. In addition, a deeper well (K-12) located about 4 km to the east of the lines, was projected on the section. The well data were used for correlating the seismic events appearing on the section.

Three sequences of reflected events can be identified on the section in Fig. 6. The upper sequence appearing in the depth interval of 40 – 150 m can be correlated to

the shallow Quaternary aquifer. Correlation with the data of wells 459-K and 460-K enables us to identify reflectors related to separate gravel units within the aquifer and thus to subdivide the aquifer into separate subaquifers. The sequence can be traced more or less continuously up to the distance of about 5500 m from the beginning of the section and then from the distance of about 7100 m up to the end of the section. In the interval between 5500 and 7100 m continuity of the sequence is interrupted, apparently by a system of faults, as marked on the section. The second reflection sequence appearing at the depths of 150 – 220 m can be traced as a segment within the distance interval of 5600 – 8000 m. Correlation with the well K-12 shows that this sequence can be related to the upper Neogene aquiclude consisting of an alteration of clays and dense, low porous sandstone layers. The lower reflection sequence appearing in the range of 300 – 500 m may be correlative to the deeper Neogene aquifer presented in well K-12 by carbonate (limestone and dolomite) and sandstone layers. The sequence has a NE inclination and can be traced within the distance range of 1200 – 7500 m. According to the geological data, this aquifer has lenticular shape with bed thinning of carbonate layers and their substitution by terrigene sediments, which can explain the segmented character of the corresponding reflections on the seismic section.

Several fault systems interrupting the continuity of the reflection sequences were identified and marked on the section. The identification of faults is important since they may effect the hydraulic conductivity of various aquifer units. In our opinion, salination (up to 100 g/l) of the main Quaternary aquifer in the northern part of Kazganchay area (wells 317-p and 318-p) may be related to interformational flow of highly mineralized groundwater from lower layers along the fault zones.

Since the reflection section of Fig. 6 does not provide information regarding the uppermost part of the geological section (upper 40 m), we tried to obtain this information using refracted waves. For this purpose we performed interpretation of the first arrivals contained in the common shot records. The resulting refraction depth section is represented in Fig. 7. It should be noted that since the refraction interpretation was made using a simplistic approach (slope-intercept method and a horizontally layered model), the section should be regarded as a schematic representation of the actual depth section. The section in Fig. 7 shows three layers with distinctly different seismic velocities. The thickness of the upper layer appearing with the compressional wave velocity (Vp) of 400 – 800 m/s is about 5 m. The value

of Vp in the second layer is in the range of 1300 – 1700 m/s. The lower layer appearing at the depths of 15 – 20 m, has the Vp value of 1900 – 2400 m/s. Thus, the refraction section complements the reflection section in its upper part. A combined interpretation of both seismic sections allows us to obtain information on the subsurface layers from the surface down to the depth of about 500 m.

In order to facilitate hydrogeological interpretation of the refraction section, an attempt was made to obtain information on shear wave velocities (Vs) within the layers. The values of Vs, together with the corresponding values of Vp, can serve as the basis for evaluating the Poisson ratio (σ) and for estimating the properties of the layer material. For this purpose, we performed dispersion analysis of surface waves on the common shot records (Abraham et al., 1998; Al-Eqabi and Herrmann, 1993; Barrows et al., 1988; Bitri et al., 1998; Chávez-García et al., 1995; Shtivelman, 1999, 2003a). The results of the analysis are represented in Fig. 7 as the average values of Vs and σ within the corresponding layers. According to these results, the upper layer, with Vs = 170 – 260 m/s and σ = 0.4, corresponds to the unsaturated, or partly saturated, uppermost part of the geological section. The second layer, with Vs = 250 – 350 m/s and σ = 0.48, corresponds to water saturated part of the section. Thus, the interface between the two upper layers may be related to the water table. Correlation with the well data shows that the interface is actually close to the water table. The third layer appearing on the section with Vs = 400 – 600 m/s and σ = 0.47, can be apparently identified with the upper gravel aquifer.

Line KA-004:

Reflection depth section along the line is represented in Fig. 8. Since no wells deeper than 40 m can be found in the vicinity of this line, and since the general character of the section is similar to that of the lines KA-001 – KA-003 (Fig. 6), the interpretation of the section can be made by analogy with the section of Fig. 6.

The upper reflection sequence (apparently related to the Quaternary aquifer) appearing in Fig. 8 at the depths of 50 – 120 m can be traced from the beginning of the line up to the distance of 3500 m. Beyond this interval its tracing is problematic, possibly due to lateral facial changes within the corresponding geological units. The second reflection sequence (apparently related to the upper Neogene aquiclude) appears at the depths of 100 – 300 m and can be traced more or less continuously

along the entire section, except the interval of 1500 – 200 m where it seems to be disturbed by a fault zone. The lower reflection sequence has a NE inclination, similar to the section of Fig. 6; however, here the sequence appears at larger depths (400 – 600 m) than on the section of Fig. 6 (300 – 500 m) suggesting that the corresponding carbonate / sandstone aquifer has a general inclination to the north.

The refraction depth section obtained using the same procedure as described above is represented in Fig. 9 The section shows three layers with the Vp values quite close to those of Fig. 7 The dispersion analysis of surface waves did not produce reliable results on this line; therefore, the values of Vs appearing on the section were taken from the section of Fig. 7 and together with the Vp values were used for computing the values of σ. We can see that the interface between the two upper layers is quite close to the water table, whereas the second interface may be correlated to the upper gravel / sandy gravel aquifer.

TDEM SURVEYS

The time domain electromagnetic (TDEM) method is a leading geoelectric and, moreover, geophysical technique for characterization of groundwater salinity, as well as for delineating and monitoring saline groundwaters (Fitterman and Stewart, 1986; Goldman et al., 1991). Therefore the main objective of the TDEM surveys in Turkmenistan was to test the ability of the method to characterize groundwater salinity under specific hydrogeological conditions of the area.

The TDEM measurements included 8 soundings located along the seismic lines (soundings K1 through K8, Fig. 2). The NW TDEM profile including points K1, K2, K7 and K3 was located in the vicinity of water wells 461-K, 316-P, 21 and 317-P. The SE TDEM profile including points K8, K4, T5 and K6 was located in the vicinity of water wells 437-K, 460-K, 22 and 318-P.

All TDEM measurements were carried out using the so-called central loop array, by means of the Geonics EM-67 TDEM system. The system was brought in Turkmenistan from Israel and it included high power TEM67 transmitter, PROTEM digital receiver and 100m^2 multi-turn receiver coil.

The transmitter loop size in all eight soundings was 100 by 100 m providing the required exploration depth between 150 to 200 m.

All the necessary logistical support, including surveyors, field workers, cars, car batteries, cables, etc., was provided by the Ahal Geophysical Expedition.

The processing and the geophysical interpretation of the TDEM data were carried out using the TEMIX-XL processing and interpretation package by Interpex Ltd., Golden Co, USA (1996). The results of the geophysical interpretation are shown below in the form of 1-D resistivity vs. depth sections, as well as in the form of quasi-2D resistivity cross-sections along approximately the same traverses (only somewhat shorter ones) as the seismic lines (Fig.2).

Station K1 (Fig. 10)

The interpreted TDEM model consists of four layers. The intermediate layer exhibits relatively high resistivity within the depth range between approximately 25 and 54 meters. According to the nearby well 461-K, no significant lithological contrasts are expected in this depth range. The relatively thin gravel horizons encountered within the specified depth range can not explain alone the appearance of such a thick and relatively highly resistive layer. The increased resistivity could therefore be explained by somewhat decreasing salinity compared to shallower sequence (hydrological inversion). The borehole water salinity measurements show slightly brackish water (2720 mg/l TDS) within approximately the same depth range and, thus, testify to the same conclusion. Indeed, most of the shallow salinity measurements in the area exhibit much higher salinities.

The resistivity drop at a depth of approximately 50 m is most likely explained by hydrological (salinity) rather then lithological considerations.

Station K2 (Fig. 11)

The resistivity model obtained at this site is very similar to the above considered one. Although the nearby well, 316-P, is too shallow to provide information on the required depth range, it is reasonable to assume that the hydrogeological interpretation of the previous TDEM point is applicable to this measurement as well.

Station K7 (Fig. 12)

The interpreted resistivity model is similar to those considered above, besides rather significant thickening of the high resistivity layer from about 25 meter at stations K1 and K2 to approximately 65 m at the considered station.

Station K3 (Fig. 13)

This station is characterized by much lower resistivities both at very shallow depths and below the intermediate high resistivity layer. Comparison with the adjacent well 317-P shows excellent correlation between the TDEM resistivity and groundwater salinity measured in the well at shallow depths (approximately 1.6 ohm-m and 90,000 mg/l, respectively). Even more important is the correlation between TDEM and borehole salinity measurements at greater depths. The borehole measurements show a significant drop in the groundwater salinity (approximately by order of magnitude) in the range of depths where the TDEM exhibits higher resistivities. Thus, at this point, the hydrological inversion, which was detected at other points by TDEM alone, has been confirmed by the independent borehole information.

It should be noted, however, that the absolute resistivity values measured at this and all other stations are significantly higher than those measured in Israel and some other countries for the same groundwater salinities (Goldman et al., 1991). According to the Archie's low (Archie, 1942), this phenomenon could be explained by significantly lower porosities in the Kazganchay area than those typical for coastal aquifers of Israel. A quantitative proof of this assumption necessitates special investigations including pumping tests, sample measurements, etc., which are far beyond the scope of the present research. Nevertheless, the consistency of the above mentioned observation, which was exhibited in **all** geoelectrical and borehole measurements used for the correlation, allows us to use the TDEM measurements to characterize groundwater salinity in the area whatever is the origin of the above mentioned phenomenon.

Figure 14 shows the quasi-2D resistivity cross-section, which was compiled by the interpolation of the 1-D resistivity models considered above. The most remarkable feature of the cross-section is the existence of a relatively high resistivity layer in the intermediate depth range, which is characterized by very consistent

resistivity values. This resistivity layer assumingly represents lower groundwater salinities at the depths below 20 m compared to those at shallower depths along the whole TDEM traverse. The layer is thickening towards the NE part of the profile.

Figures 15 through 18 show 1-D resistivity models obtained at stations K8, K4, K5 and K6, which are located along the SE TDEM traverse (Fig. 2). The distribution of resistivities in all four models is very similar to that considered above in greater details for the measurements along the northern profile.

The resulting quasi-2D resistivity cross-section is shown in Fig. 19. Comparison of the northern and southern resistivity cross-sections demonstrates an essential similarity between them, as far as the resistivity values are concerned. The geometry of the interface(s) in both cross-sections is somewhat different, however. The top of the intermediate high resistivity layer is almost horizontal in the northern cross-section, whereas in the southern cross-section it is dipping in the SW direction from about 20 m to almost 40 m. The bottom of this layer also shows different behavior in the both cross-sections, namely it exhibits a structural low within the NW part of the northern cross-section while showing a structural high in approximately the same part of the traverse in the southern cross-section.

COMBINED SEISMIC – GEOELECTRIC INTERPRETATION

As shown above, the results of the seismic interpretation allows us to define the structure of the subsurface, or, more specifically, to detect the water table, to identify various aquifer units and to subdivide them into separate subaquifers. On the other hand, the TDEM results allow us to determine spatial distribution of the subsurface electrical resistivity that can be related either to water salinity or to lithological composition, such as clay content. The combined seismic – TDEM interpretation facilitates characterization of the groundwater salinity within various subaquifers and thus estimation of the amount of fresh water in the aquifer. This can be demonstrated by the results of the geophysical measurements along profile B – B' (Fig. 2). According to the refraction section (Fig. 7), the depth to the top of the upper Quaternary aquifer varies between 15 – 20 m. The corresponding TDEM cross-section (Fig. 19) shows a high resistivity layer dipping in the SW direction from 20 m to about 40 m below a relatively low resistivity layer. The combined analysis of both

sections leads us to the conclusion that the aquifer is generally saturated with relatively fresh groundwater, although in the SW part of the line the uppermost part of the aquifer may contain saline water. At larger depths (up to approximately 150 m), the subaquifers identified on the reflection section (Fig. 6) are characterized by different salinities, namely, the upper subaquifer(s) (up to the depth of about 100 m) are saturated with relatively fresh water corresponding to high resistivity layer in Fig. 19, whereas the lower subaquifer can be saturated by brackish water corresponding to the moderately resistive lower layer in Fig. 19. Similar conclusions can be drawn from the corresponding cross-sections (Figs. 8, 9 and 14) along profile A – A' (Fig. 2).

4. IMPACT RELEVANCE AND TECHNOLOGY TRANSFER

Until now, groundwater exploration in Turkmenistan was conducted mainly by drilling a large number of expensive wells, whereas geophysical investigations were limited solely to the use of electric resistivity method. As a result, many of production water wells were drilled at improper sites. For example, several wells drilled in the northern part of the Kazganchay area fell into a zone of highly mineralized groundwater and proofed unsuitable for drinking and agricultural water supply. Applying the methodology of joint geophysical (seismic and geoelectric) investigations developed in the framework of the project can provide information necessary for estimating the structure and hydrogeological characteristic of the groundwater deposits and water salinity within aquifer layers. The joint geophysical investigations carried out prior to drilling can considerably reduce the number of failed wells. It should be noted that it is the first time that such joint geophysical investigations aimed at delineating groundwater units and characterizing the water salinity within them, were conducted in Turkmenistan.

The project was carried out in a close collaboration between Israeli and Turkmen specialists. Turkmen geophysicists and hydrogeologists from State Corporation "Turkmengeology", Ahal Geophysical expedition and Kopet-Dag Hydrogeological expedition took part in the development and testing of the innovative approach based on a combination of the geophysical methods and were actively involved in all stages of the project, including:

- Analysis of the available information and selection of the study area
- Formulation of the hydrogeological problem in the selected area
- Selection of the appropriate methods for solving the problem
- Designing the geophysical surveys and choosing optimal parameters for data acquisition
- Operating the corresponding field equipment and performing data control in the field
- Using complicated software packages for processing and interpretation of the geophysical data
- Analysis and evaluation of the geophysical results
- Joint geophysical – hydrogeological interpretation of the results

The Turkmen specialists were trained in applying modern geophysical techniques, including data acquisition, processing and interpretation. The training was held in the offices and in the field during the geophysical surveys. They also participated in a workshop on using geophysical methods for studying the shallow subsurface, organized by Israeli specialists.

The knowledge and experience acquired in the framework of the project by the Turkmen specialists from various geophysical and hydrogeological organizations will be applied in future surveys for groundwater exploration.

Five personal computers and a peripheral equipment were purchased and transferred to Turkmen specialists.

5. PROJECT ACTIVITIES

During the period covered by the report, the Israeli and Turkmen partners were involved in the following activities:

- A joint Israeli – Turkmen team (Dr. Shtivelman Dr. Avanesov, Dr. Kuliev and Mr. Gendler) made a number of reconnaissance field trips to the Kazganchay area with the aim of studying the local surface conditions and locating the geophysical surveys. Several alternative sites were examined, taking into consideration specific limitations of the area (settlements, roads, railways, sowing areas, salt marshes, etc.). As the result, a site to the north of the main

road was chosen and a number of seismic lines were located at the site and marked on the map of the area.

- M. Bereza and I. Bayramova prepared all the available geological and hydrogeological information from the boreholes drilled within the Kazganchay area.
- M. Gendler performed processing and interpretation of the geological and hydrogeological data, including preparation of geological cross-sections, schemes of litho-stratigraphical correlation and well location maps.
- Based on the geological and hydrogeological data, Dr. Shtivelman and Dr. Goldman, together with M. Gendler, established location of seismic lines and geoelectric measurements.
- In November 2002, the Israeli team, including Dr. V. Shtivelman and M. Gendler, visited Turkmenistan in order to transfer the technology of performing high resolution reflection seismic surveys, to provide training of the Turkmen partners and to plan and carry out the first phase of seismic data acquisition. In particular, the Israeli team held a series of meetings with local specialists regarding cooperation in groundwater exploration in Turkmenistan. The participants from the Turkmenian side included Dr. O. Atageldyev (State Minister, Chairman of the State Corporation "Turkmengeology"), Prof. K. Kuliev (Vice-Chairman of the S.C. "Turkmengeology") V. Fedin (Chief Geophysicist of the S.C. "Turkmengeology"), Prof. A. Avanesov (Chief Hydrogeologist of the Water Corporation "Senagat-Suv"), I. Bairamova (Head of the Ahal Hydrogeological Expedition) and Ch. Annageldyev (Head of the Ahal Geophysical Expedition).
- Training of the Turkmen geophysicists took place both in the offices of the Ahal Geophysical Expedition of the S.C. "Turkmengeology" and during the field works in the Kazganchay area of the central Kopet-Dag region.
- The seismic field works were conducted by the Ahal Geophysical Expedition under the supervision of Dr. Shtivelman.
- In November 2003, Dr. M. Goldman, M. Gendler and G. Shklyar visited Turkmenistan to perform the second stage of field geophysical works (TDEM survey) and to train Turkmen specialists in using TDEM.

- Processing and interpretation of the acquired seismic and electromagnetic data were performed jointly by the Israeli and Turkmen specialists in the offices of GII, S.C. "Turkmengeology" Ahal Geophysical Expedition and Kopet-Dag Hydrogeological Expedition, using all the geological, hydrogeological and borehole information available in the study area.
- In November 2004, a team of Israeli specialists (Dr. V. Shtivelman, Dr. M. Goldman and M. Gendler) visited Turkmenistan in order to carry out a workshop and to perform a joint analysis and interpretation of all the geological, geophysical and hydrogeological data for mapping the aquifer in the Kazganchay area and estimating its properties. The main objective of the workshop was to make the Turkmen specialists acquainted with application of various seismic and geoelectric methods to the problems related to investigation of the shallow subsurface, such as groundwater exploration, civil engineering, environmental studies, archeology and others. The workshop took place in the offices of the State Corporation "Turkmengeology". The participants were geologists, hydrogeologists and geophysicists from the State Corporation "Turkmengeology", Geological Institute, Ahal Geophysical Expedition, Kopet-Dag Hydrogeological Expedition and Ashgabad Methodical Expedition. The program of the workshop is represented in Appendix B.

6. PROJECT PRODUCTIVITY

The project has accomplished all of the proposed goals. The methodology of the combined application of several geophysical methods for groundwater exploration and management in Turkmenistan has been developed and tested jointly by the Israeli and Turkmen specialists in the Kazganchay area of Turkmenistan. The results of its application provided a better understanding of the structure and properties of the aquifers in the area. The Turkmen specialists underwent an extensive training and acquired the knowledge and experience required for future water exploration surveys in Turkmenistan.

7. FUTURE WORK

During the meetings and discussions between the Israeli and Turkmen specialists and especially during the workshop organized by Israeli specialists, the Turkmen geophysicists, geologists and hydrogeologists expressed a great interest in applying various geophysical techniques for studying the shallow subsurface for different purposes, such as groundwater exploration, civil engineering, environmental studies, archeology and others. As a result, it was suggested to set up an experimental - methodical group that might be a basis for developing the near-surface geophysical techniques in Turkmenistan. Such a group might be organized in the framework of the Ahal Geophysical Expedition of the S.C. "Turkmengeology". More specifically, the following complex of geophysical methods was suggested:

- Seismic methods
- Geoelectric and electromagnetic methods
- Proton-magnetic resonance (PMR)
- Geophysical logging

The near-surface geophysical investigations using the above methods could be applied in Turkmenistan in the following fields:

- Engineering geology (construction of bridges, tunnels, power stations, oil and gas pipes, detecting karstic caves and cavities, etc.) and archeology;
- Geological mapping for exploration of various mineral deposits;
- Environmental problems (waste sites, leakage from oil pipes, etc.);
- Hydrogeological investigations of various aquifers down to the depths of 500 – 600 m (identifying the groundwater level, delineating the fresh / saline water interface, subdividing aquifers according to the salinity levels, estimating petrophysical parameters of layers, evaluating the groundwater deposits, etc.).

Establishment of such a group can be a subject of future negotiations between the S.C. "Turkmengeology" and the Geophysical Institute of Israel.

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APPENDIX B

Program of the workshop carried out in the offices of "Turkmengeology" in Ashgabad in November 2004

1. SEISMIC METHODS

1.1 Introduction

1.1.1 Main applications

1.1.2 Equipment and parameters used for shallow seismic surveys

1.1.3 Types of waves and methods

1.2 Shallow reflection surveys

1.2.1 Basic theory

1.2.2 Water-related problems:

- mapping shallow aquifers: examples from different regions

1.2.3 Engineering problems:

- detecting shallow faults - examples

1.2.4 Environmental problems: examples.

1.3 Refraction surveys

1.3.1 Basic theory

1.3.2 Water-related problems:

- mapping water table and/or the top of aquifer - examples

1.3.3 Engineering and geotechnical problems - examples

1.3.4 Environmental problems - examples

1.3.5 Archeological problems - examples

1.4 Shear waves surveys

1.4.1 Basic theory

1.4.2 Water-related problems:

- distinguishing between lithological and hydrological boundaries - examples

1.4.3 Engineering and geotechnical problems - examples

1.4.4 Seismic risk assessment – examples

1.5 Using surface waves for studying the shallow subsurface

1.5.1 Basic theory

1.5.2 Estimating shear wave velocity - examples from land and marine surveys

1.5.3 Imaging subsurface inhomogeneities - examples

1.6 Using diffracted waves for detecting subsurface inhomogeneities

1.6.1 Basic theory

1.6.2 Detecting shallow karstic cavities – examples

1.6.3 Detecting tunnels – examples

2. GEOELECTRIC METHODS

2.1 Introduction

2.1.1 Classification of geoelectric and electromagnetic methods

2.1.2 Non-uniqueness of geophysical and geological interpretations

2.1.3 Principles of integrated geophysical interpretation

2.2 Direct Current (DC) resistivity methods

2.2.1 Principles of 1-D vertical electrical soundings (VES)

2.2.2 2-D/3D resistivity imaging

2.2.3 Case studies: detection of caves, archaeological applications, waste sites exploration (integration with seismics).

2.3 Time domain electromagnetic (TDEM) method

2.3.1 Principles of electromagnetic soundings

2.3.2 Comparison of the TDEM and DC resistivity methods

2.3.3 Case studies: mapping sea water intrusion in different coastal aquifers, characterization of groundwater salinity in different sub-aquifers, preliminary results of the TDEM survey in the Kazganchai groundwater field.

2.4 Nuclear Magnetic Resonance (NMR) method

2.3.4 Principles of the NMR geophysical technology

2.3.5 Comparison with conventional geophysical methods

2.3.6 Case studies: combined application of NMR and TDEM in coastal aquifers of Israel to evaluate amount of fresh groundwater

APPENDIX C

LIST OF FIGURES

Fig. 1 General map of the area

Fig. 2 Location map of the geophysical surveys in Kazganchay area

Fig. 3 Geological cross-section A – A'

Fig. 4 Geological cross-section B – B'

Fig. 5 Examples of seismic records from different lines

Fig. 6 Combined reflection depth section along lines KA-001 – KA-003

Fig. 7 Combined refraction depth section along lines KA-001 – KA-003

Fig. 8 Reflection depth section along line KA-004

Fig. 9 Refraction depth section along line KA-004

Fig. 10 Correlation of the TDEM (station K1) and borehole (461-K) results.

Fig. 11 Correlation of the TDEM (station K2) and borehole (316-P) results.

Fig. 12 Correlation of the TDEM (station K7) and borehole (Kazganchay-21) results.

Fig. 13 Correlation of the TDEM (station K3) and borehole (317-P) results.

Fig. 14 Quasi 2-D resistivity cross-section based on the TDEM soundings along the northern part of the traverse A-A'.

Fig. 15 Correlation of the TDEM (station K8) and borehole (437-K) results.

Fig. 16 Correlation of the TDEM (station K4) and borehole (460-K) results.

Fig. 17 Correlation of the TDEM (station K5) and borehole (Kazganchay-22) results.

Fig. 18 Correlation of the TDEM (station K6) and borehole (318-P) results.

Fig. 19 Quasi 2-D resistivity cross-section based on the TDEM soundings along the northern part of the traverse B-B'.

Fig. 1 General map of the area

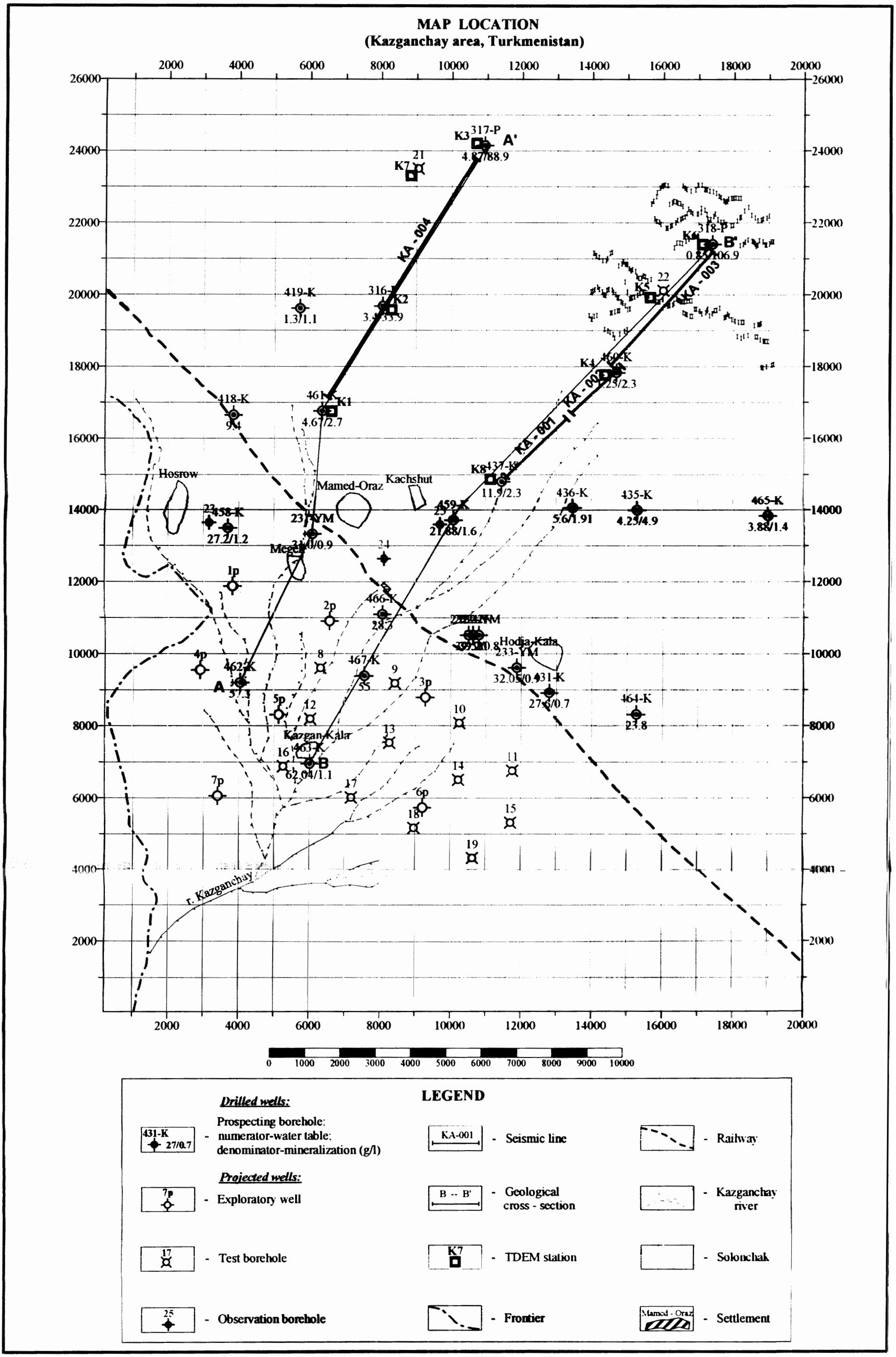

Fig. 2 Location map of the geophysical surveys in Kazganchay area

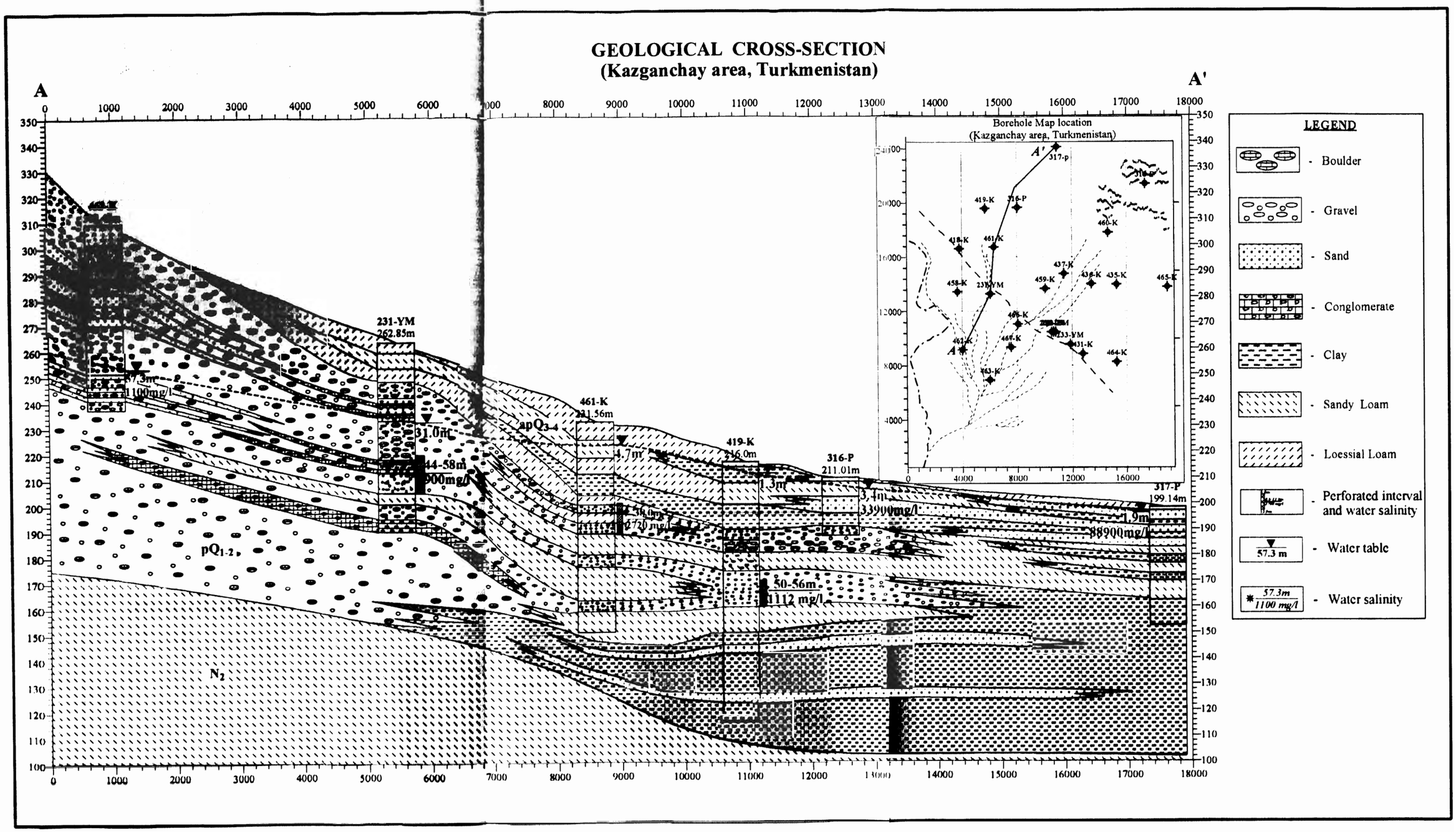

Fig. 3 Geological cross-section A - A'

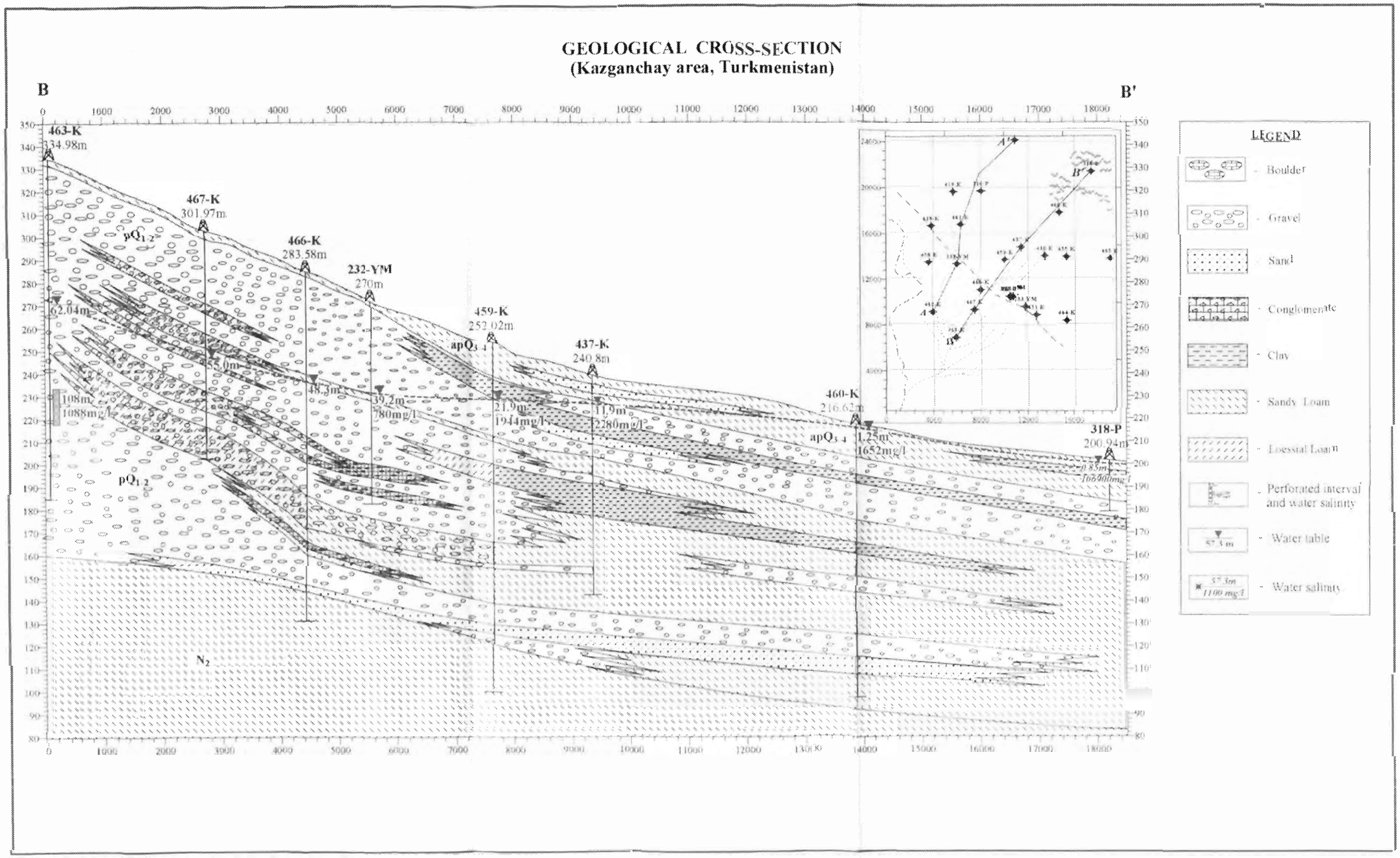

Fig. 4. Geological cross-section B - B'.

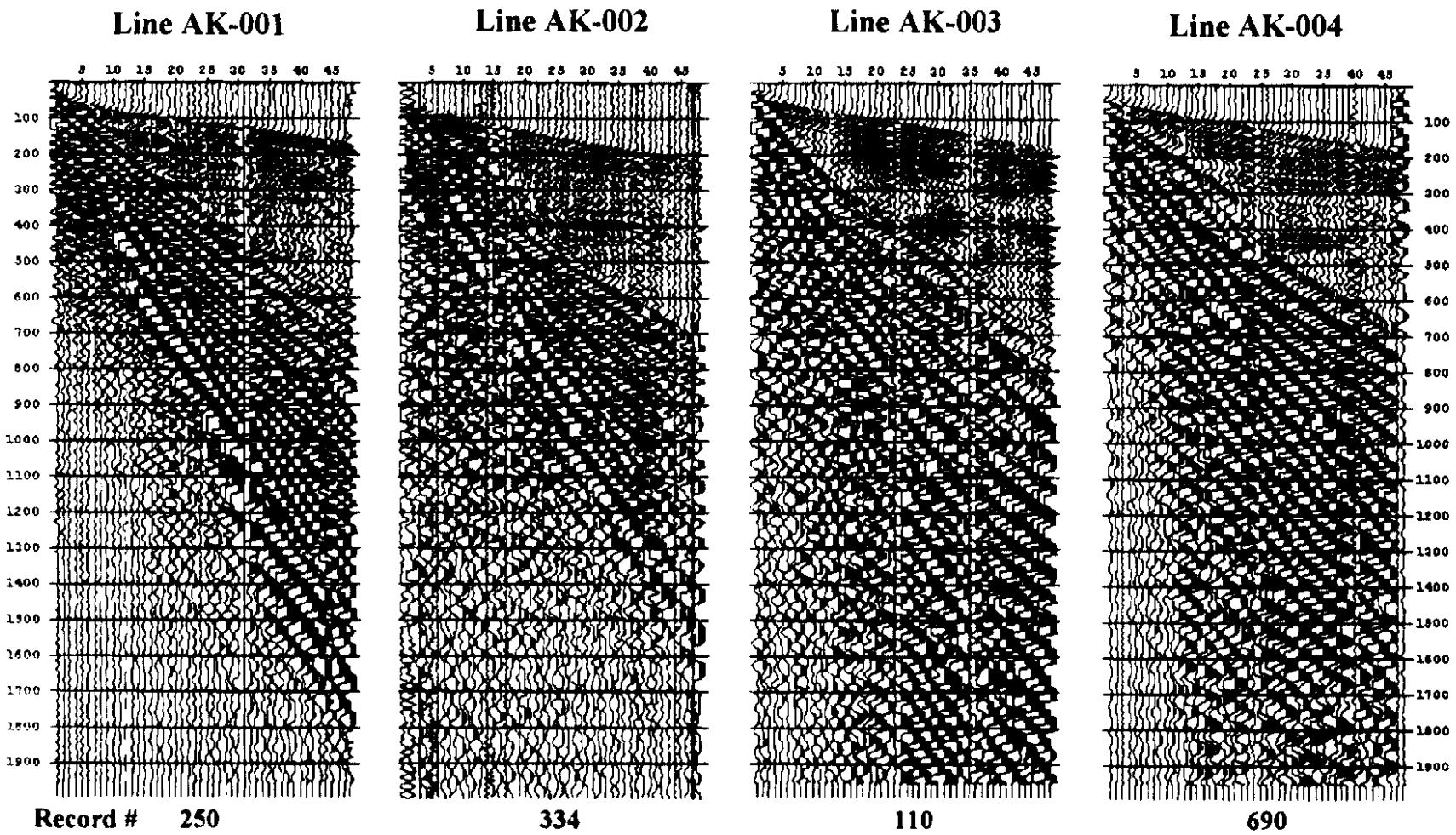

Fig. 5 Examples of seismic records from different lines

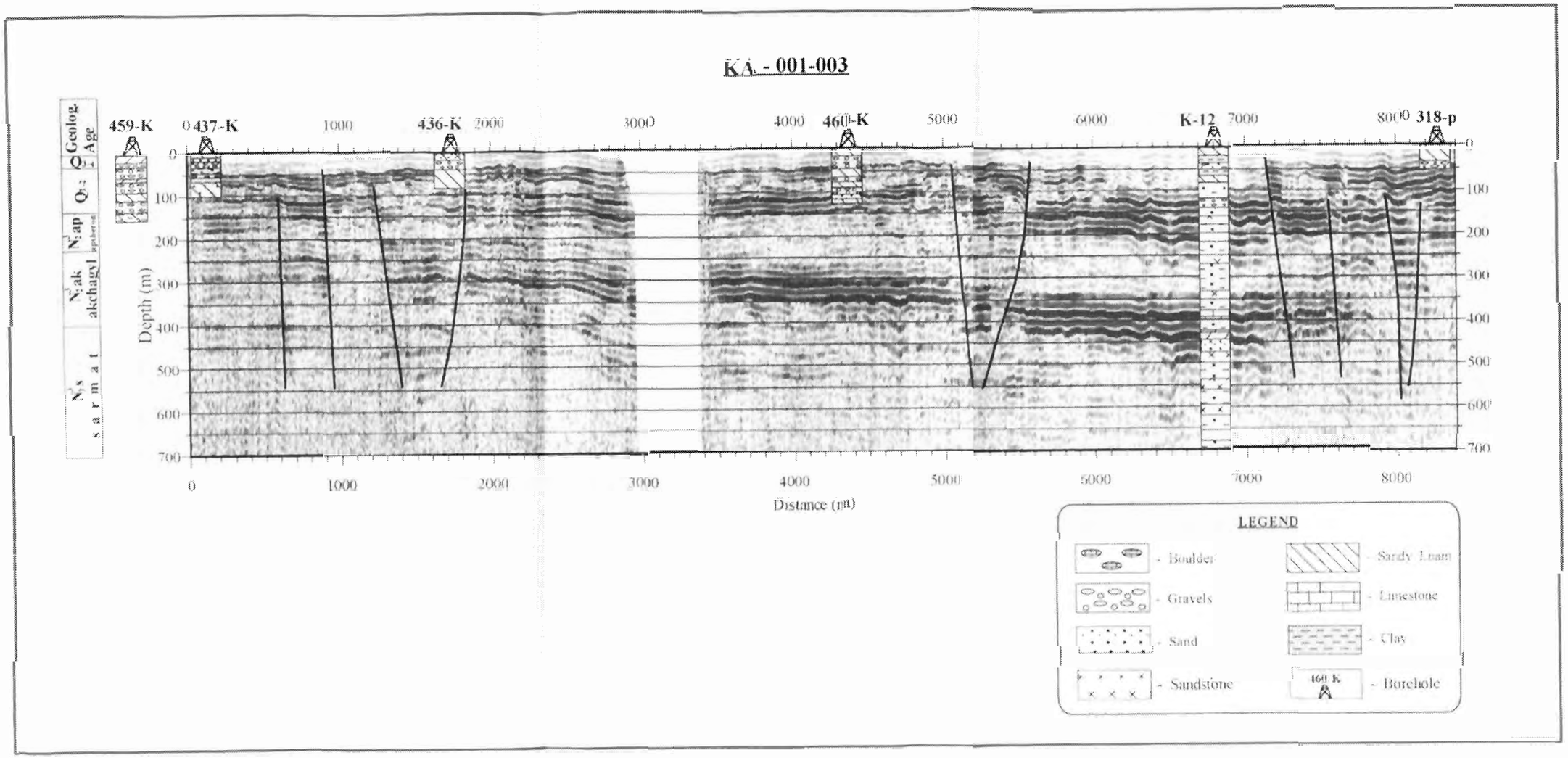

Fig 6 Combined reflection depth section along lines KA-001 - KA-003

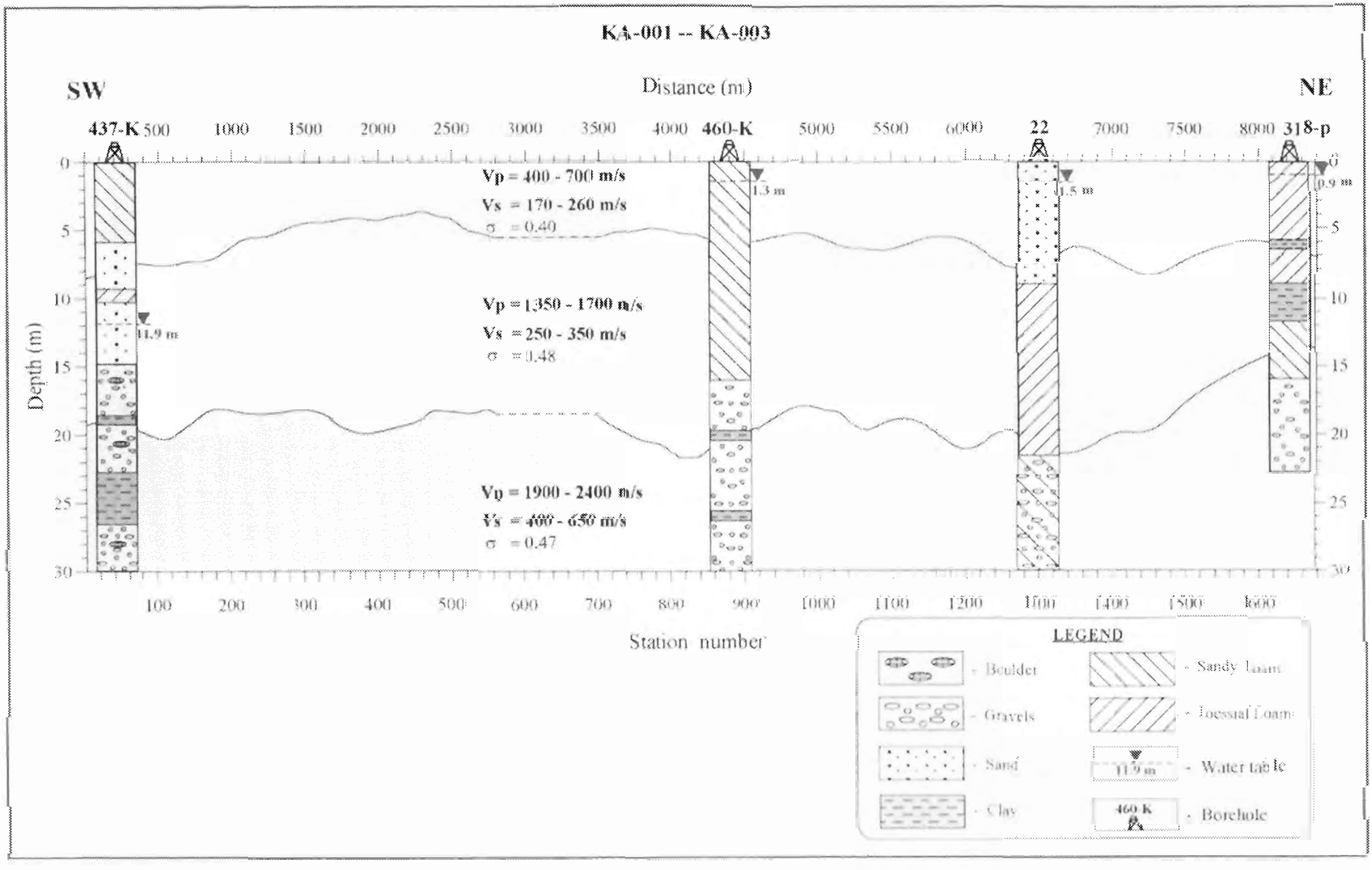

Fig. 7 Combined refraction depth section along lines KA-001 - KA-003

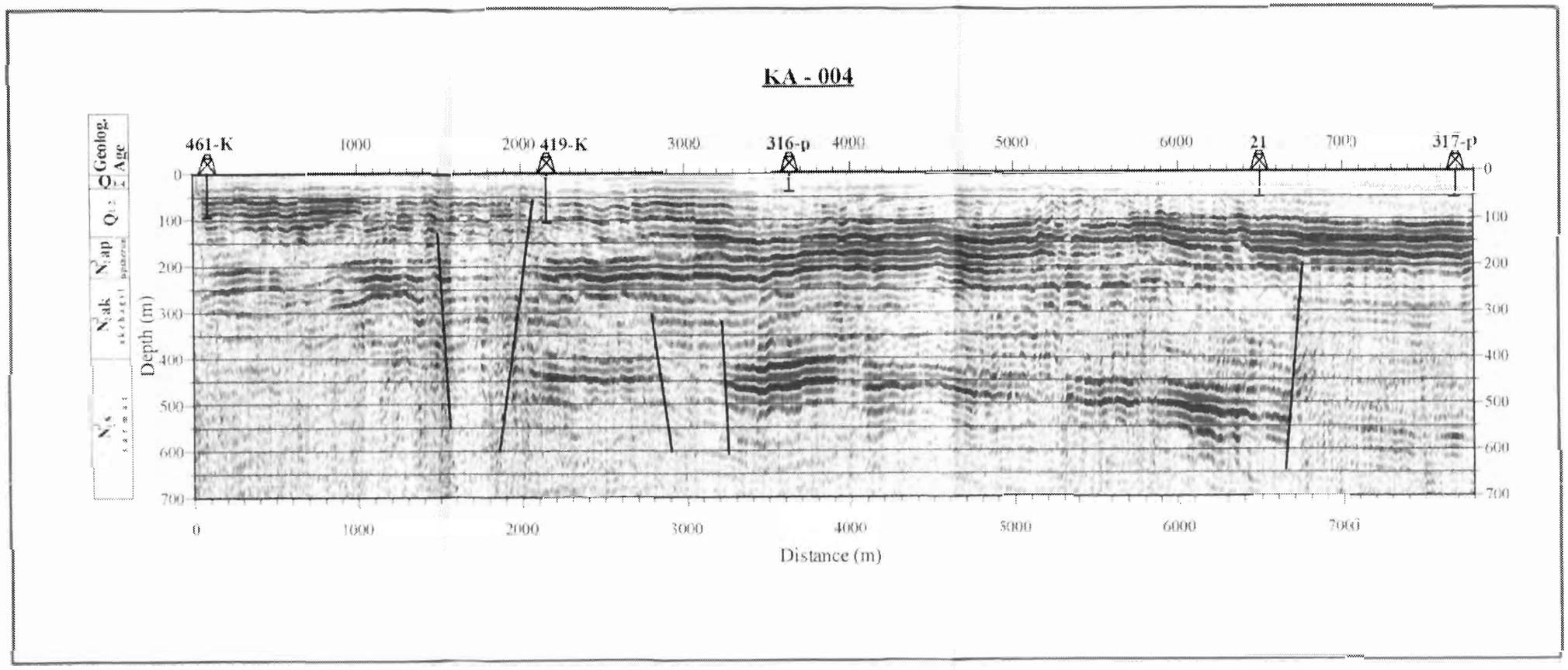

Fig. 8 Reflection depth section along line KA-004.

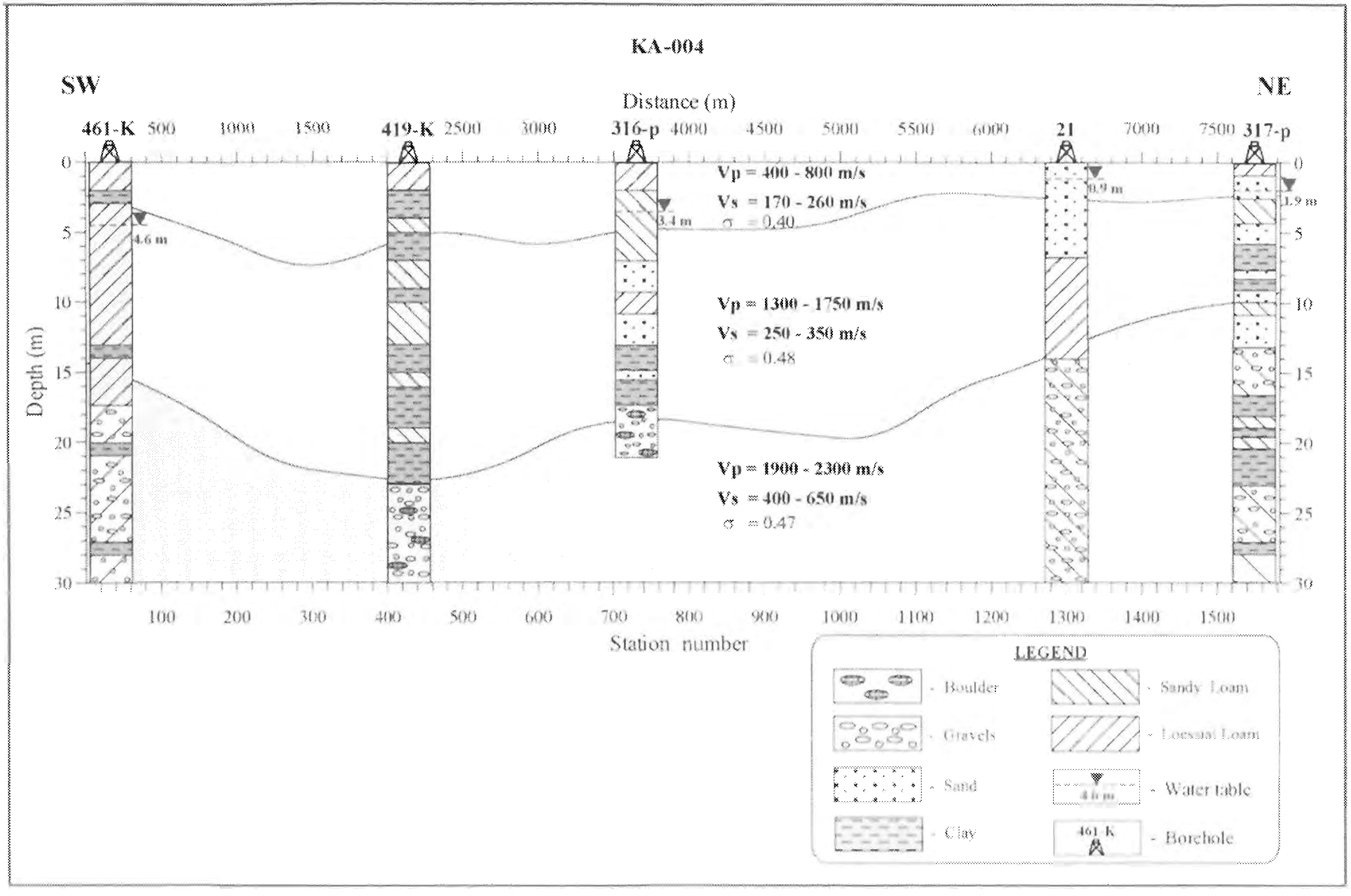

Fig. 9 Refraction depth section along line KA-004.

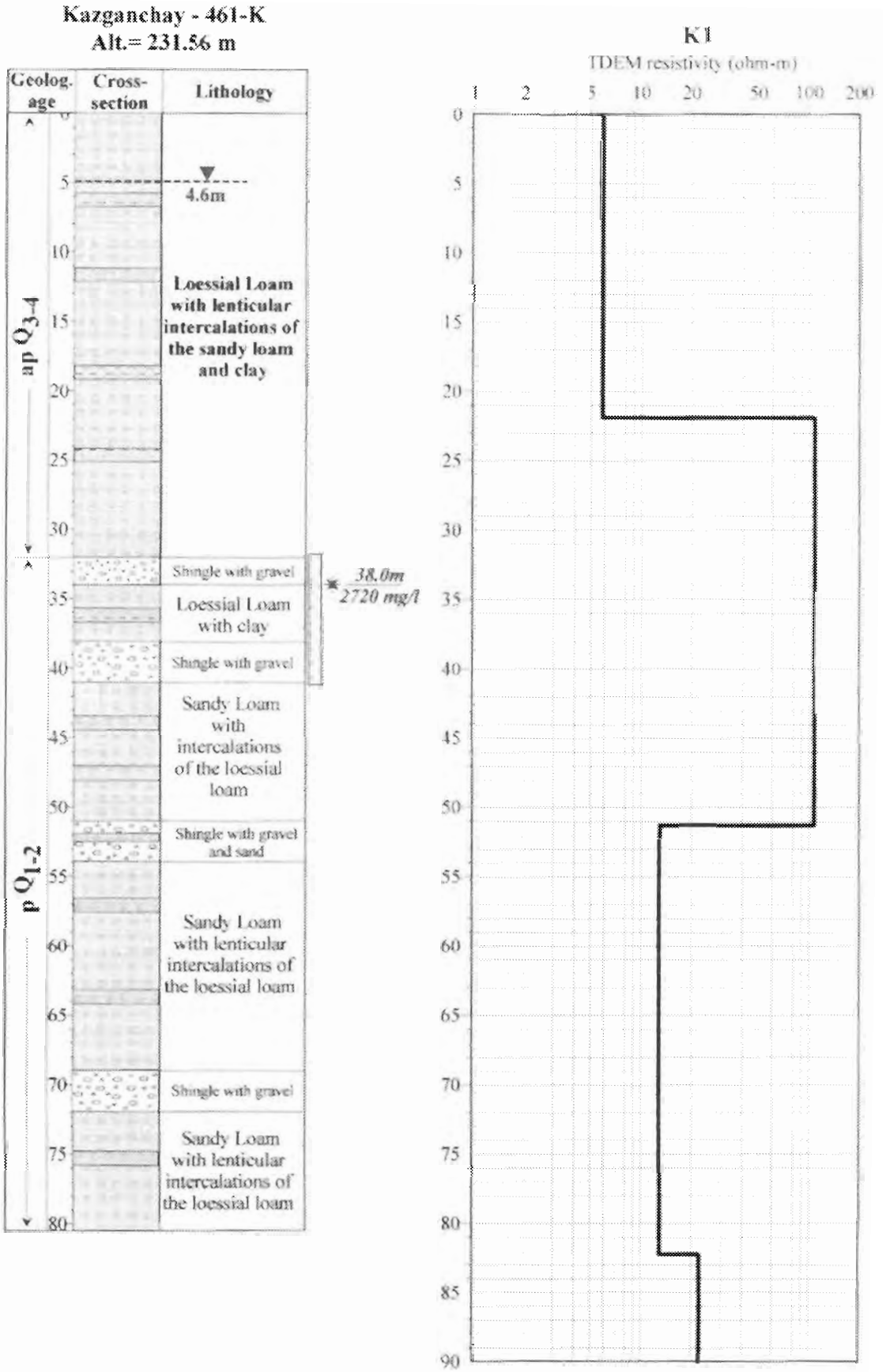

Fig. 10 Correlation of the TDEM (station K1) and borehole (461-K) results

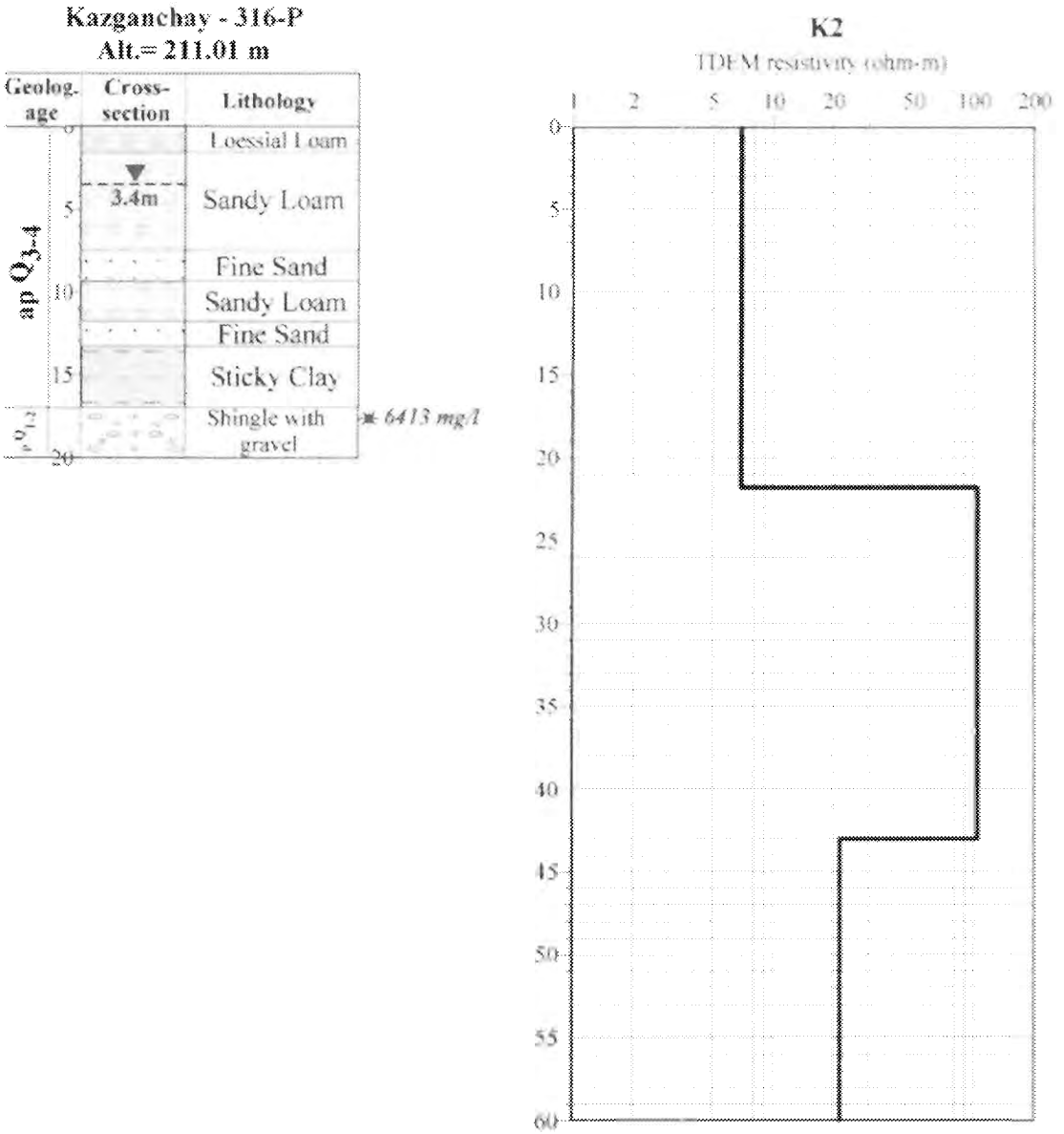

Fig. 11 Correlation of the TDEM (station K2) and borehole (316-P) results.

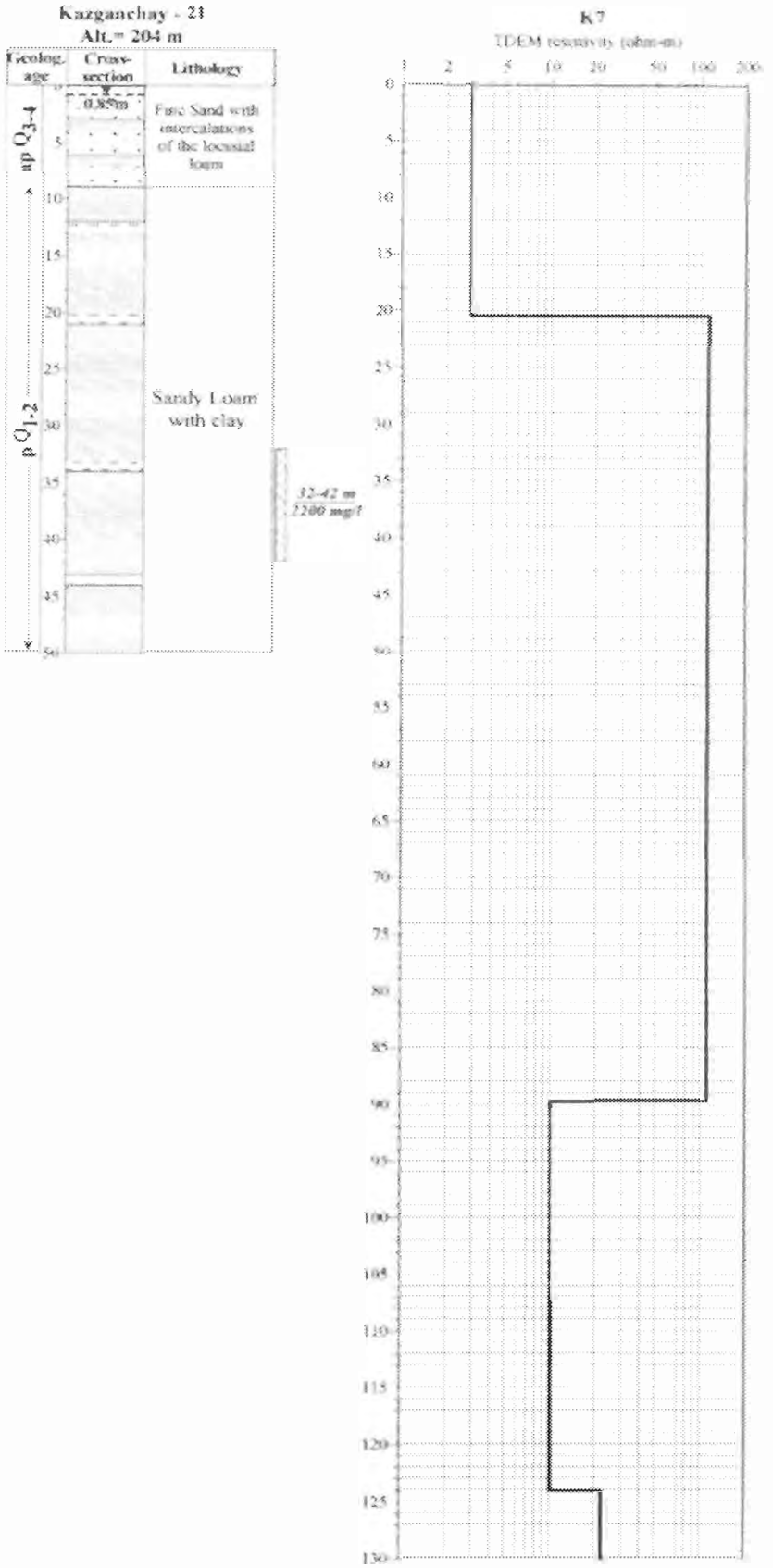

Fig. 12 Correlation of the TDEM (station K7) and borehole (Kazganchay-21) results.

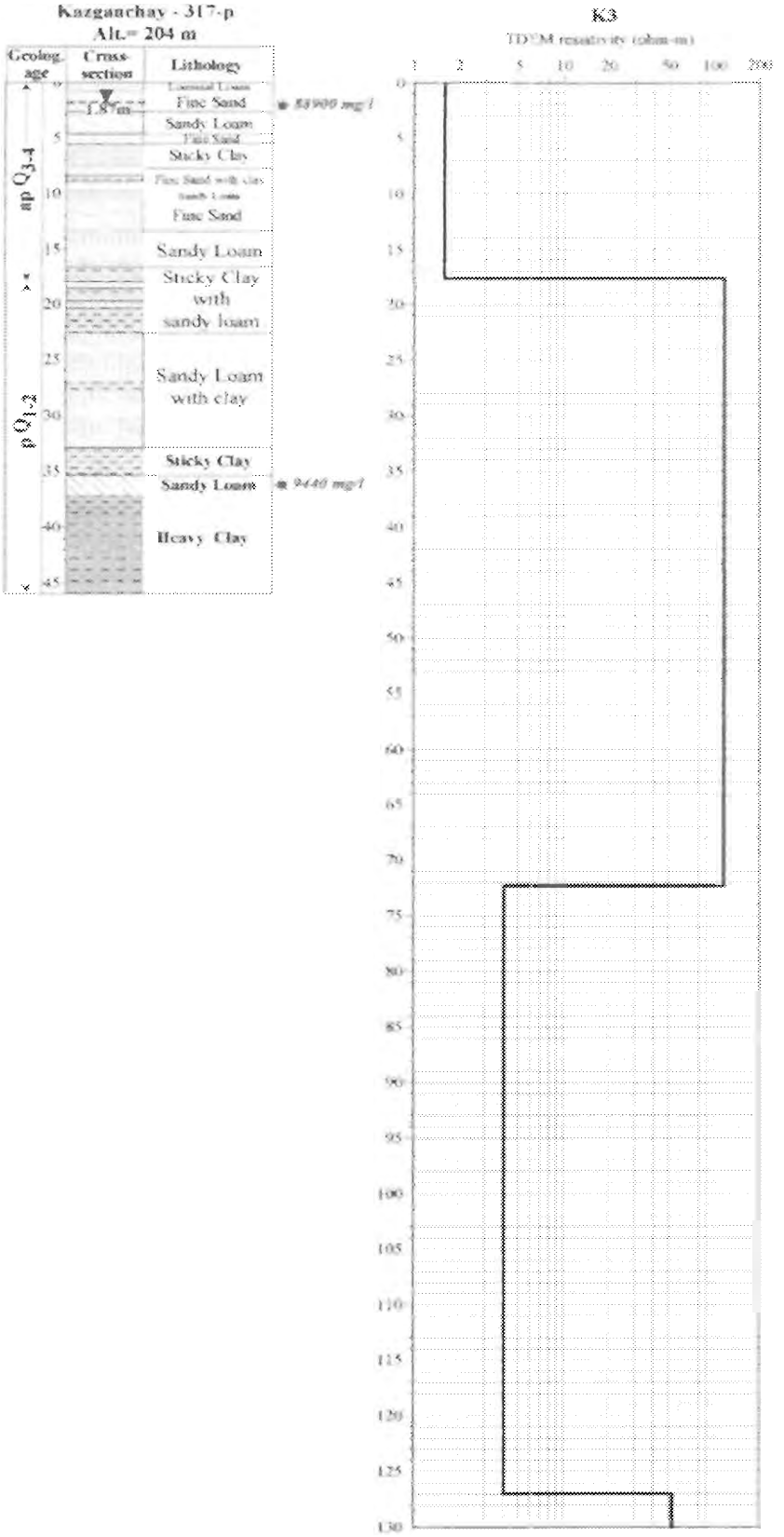

Fig. 13 Correlation of the TDEM (station K3) and borehole (317-P) results.

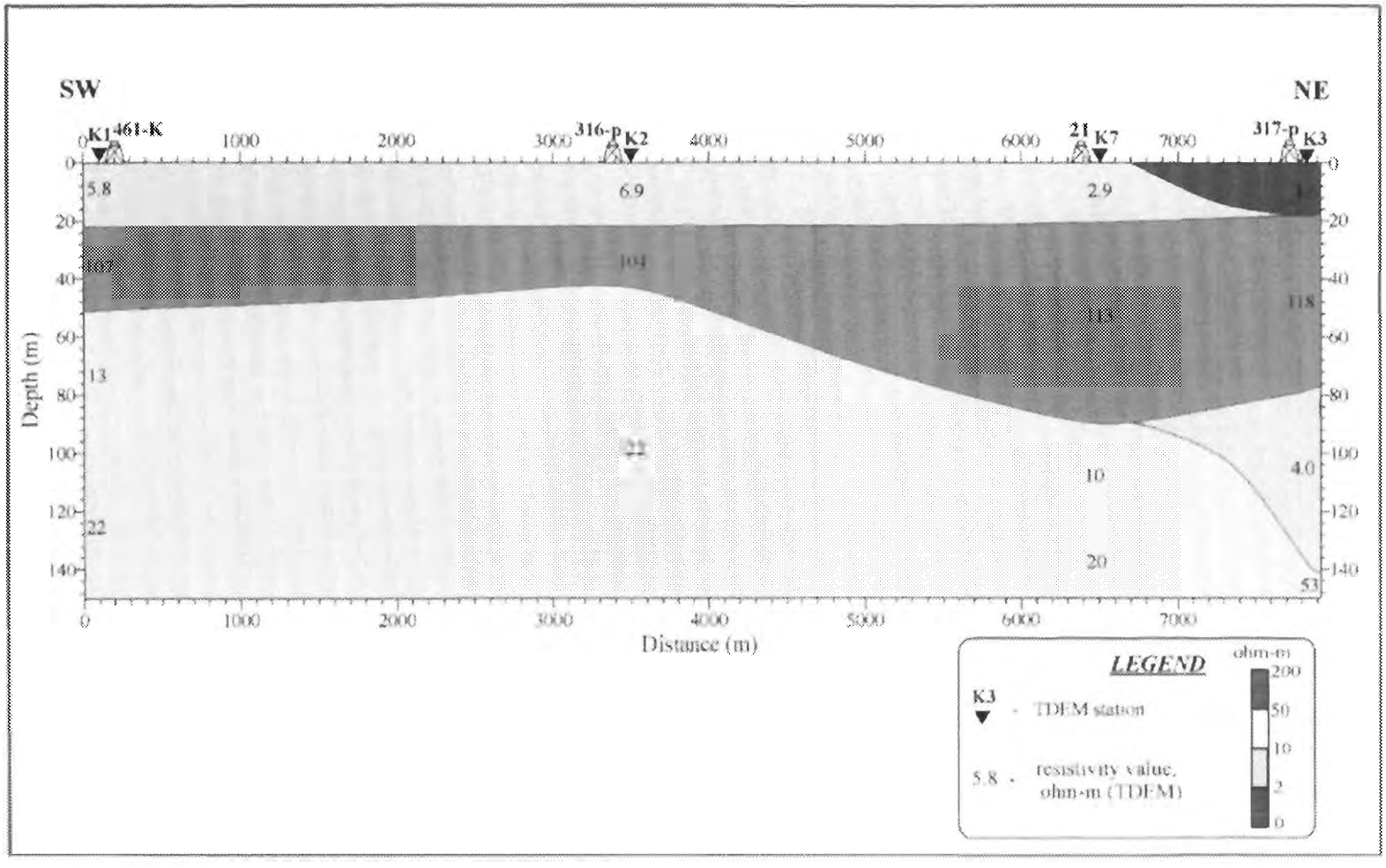

Fig. 14 Quasi 2-D resistivity cross-section based on the TDEM soundings along northern part of the traverse A-A'.

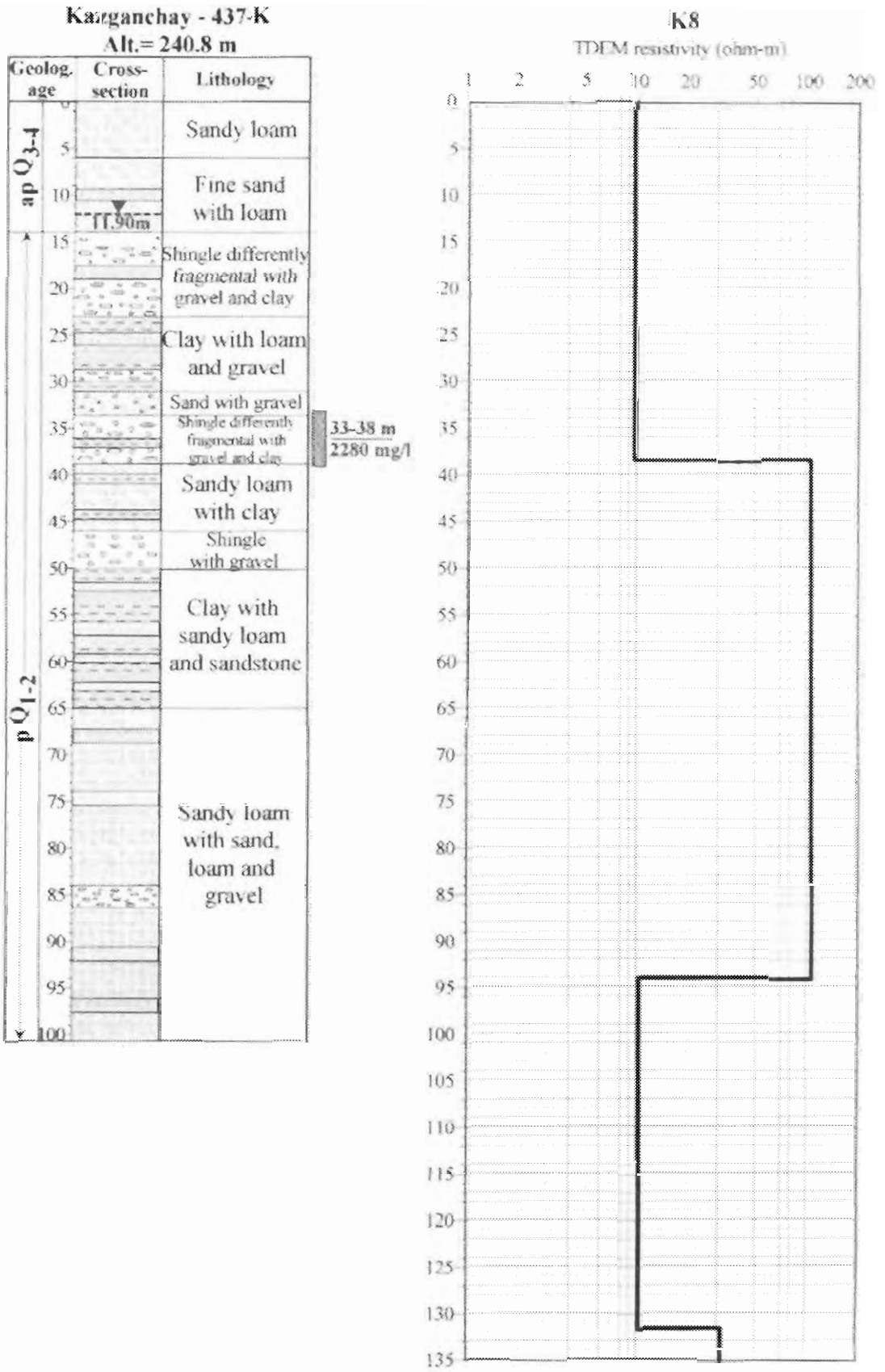

Fig. 15 Correlation of the TDEM (station K8) and borehole (437-K) results.

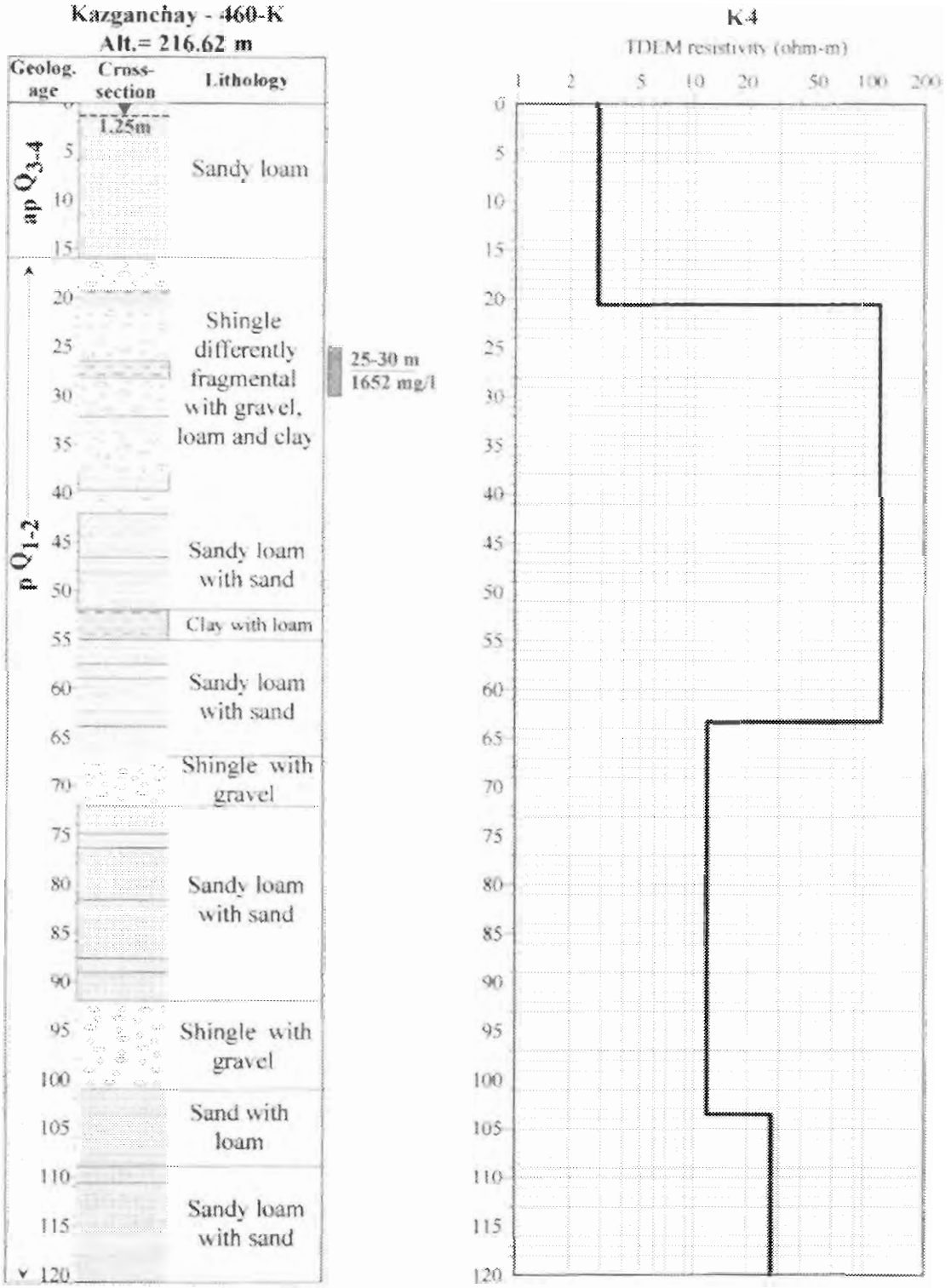

Fig. 16 Correlation of the TDEM (station K4) and borehole (460-K) results.

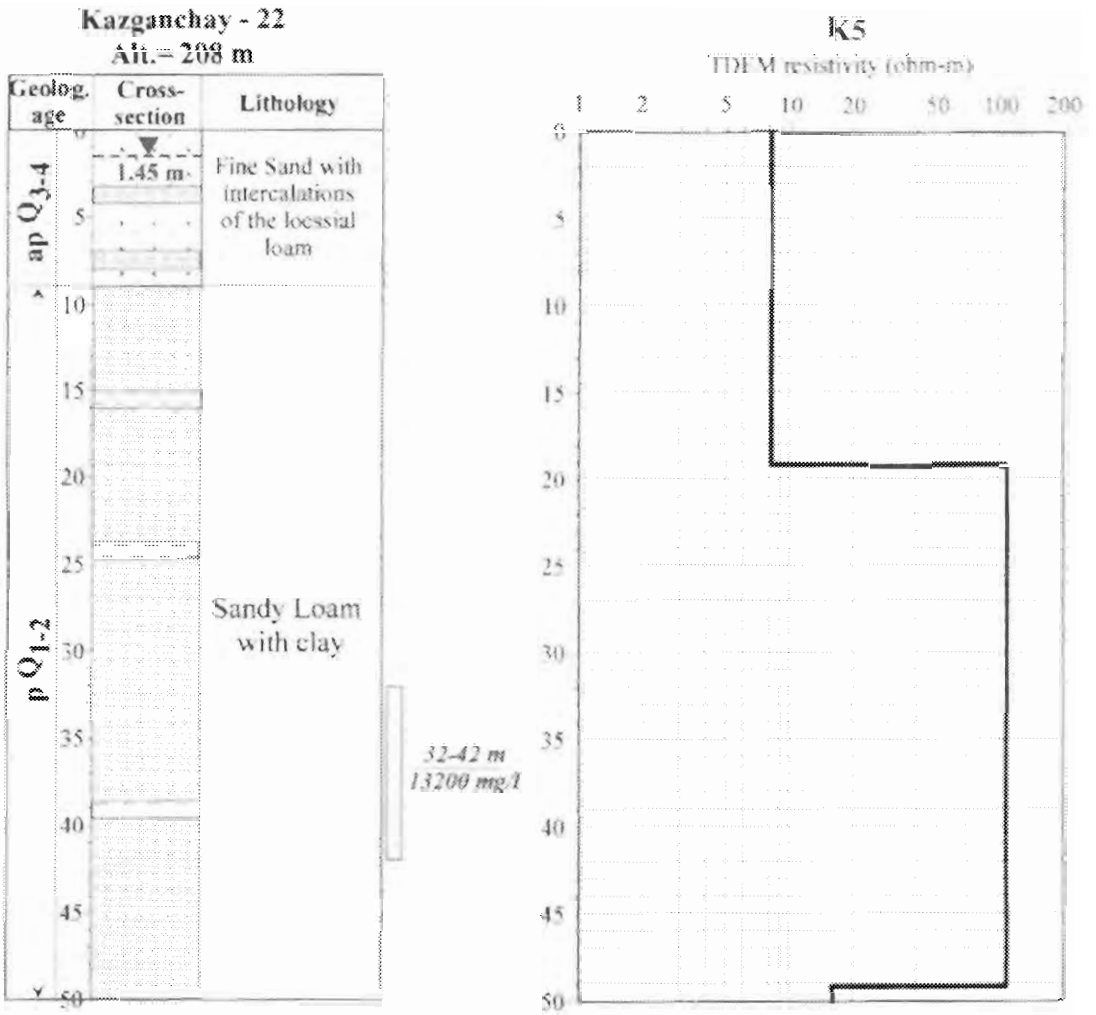

Fig. 17 Correlation of the TDEM (station K5) and borehole (Kazganchay-22) results.

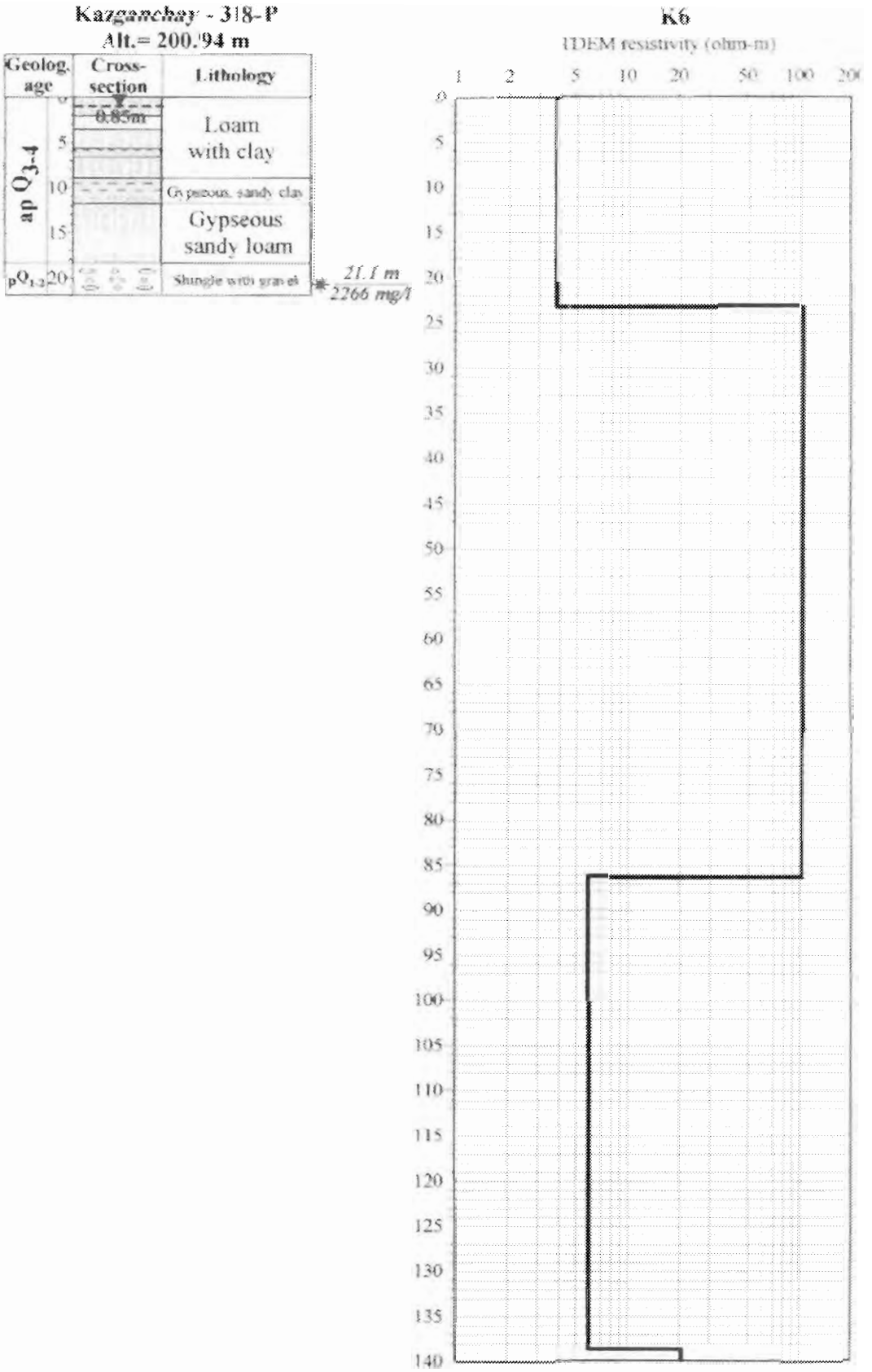

Fig. 18 Correlation of the TDEM (station K6) and borehole (318-P) results

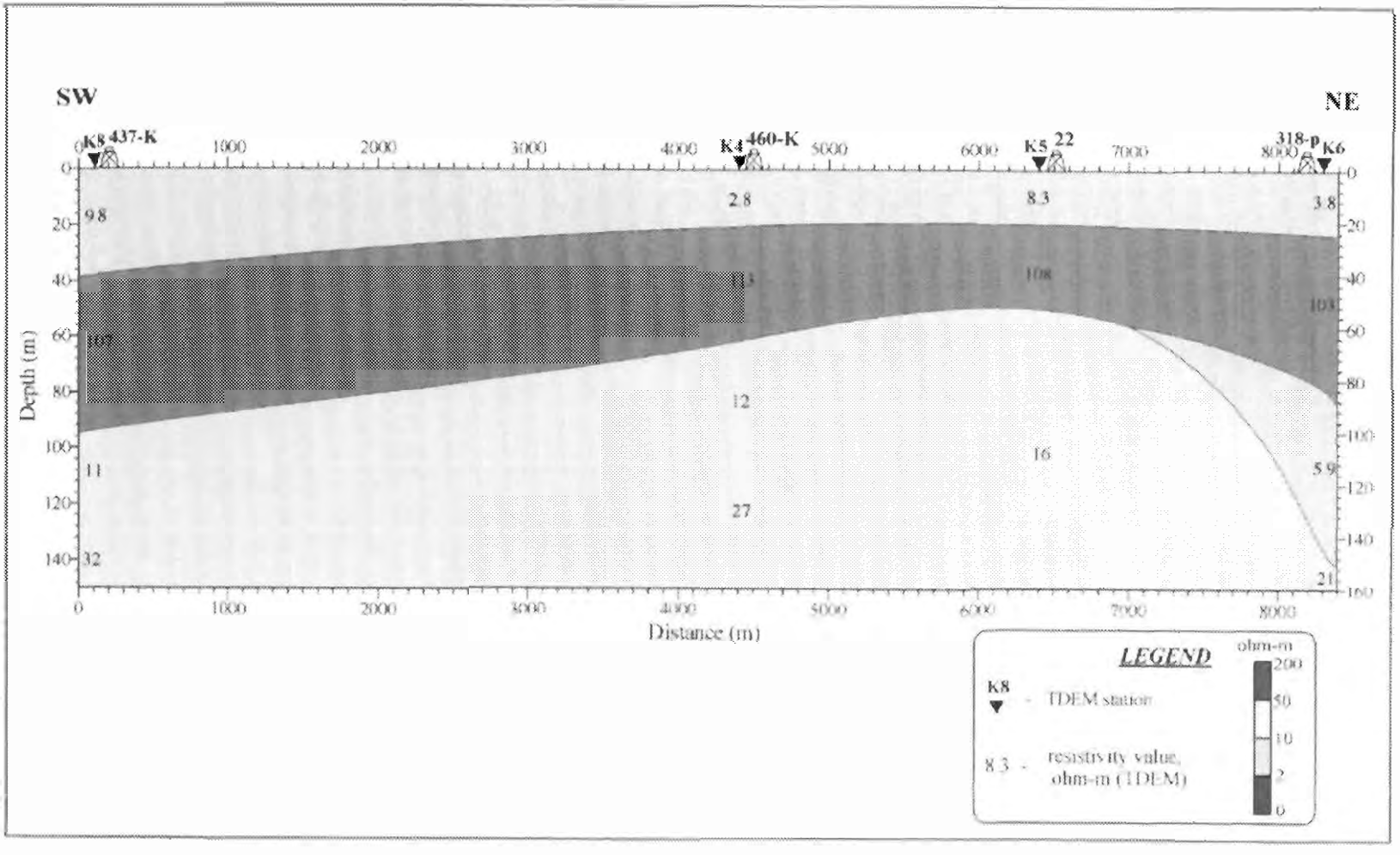

Fig. 19 Quasi 2-D resistivity cross-section based on the TDEM soundings along northern part of the traverse B-B'.