Journal of Zankoy Sulaimani- Part A (JZS-A), 2013, 15 (1)

گۆڤاری زانكۆی سلیمانی- بەشی A

The 2D resistivity imaging method in mountainous area over different slope

Bakhtiar Qader Aziz

University of Sulaimani, Faculty of Science and Education Science/ Dept. of Geology, bakhtiar_61@yahoo.com.

Abstract:

Assessing the reliability of the 2D electrical resistivity imaging method is investigated in mountainous areas. Several profiles are surveyed on different surface slopes ranging between 17° to 55° degrees. Two types of electrode arrays with different electrode spacing (2.0, 3.0 and 5.0 meters) are used. Repeated measurements are carried out for each profile by using different field parameters such as data density, pulse duration and voltage. The inverse sections are compared with the drilled bore holes in the area. The results show that the 2D resistivity imaging works well in the mountainous area when suitable field parameters are selected. The study has proved that the inverse sections are highly sensitive to the number of data points. The optimal number of data points has direct relation with surface slope, number of electrodes and electrode spread. On the other hand pulse durations and voltages magnitude have no significant effects on the quality of the field data. An empirical equation is suggested for the optimal acceptable number of data points that has a direct relation to the profile length, number of electrodes, electrode spacing and angle of the slope.

I. Introduction

The greatest limitation of 1D resistivity sounding method is that it does not take into account horizontal changes in the subsurface resistivity. A more accurate model of the subsurface is a two-dimensional (2D) model, where the resistivity changes in the vertical direction as well as in the horizontal direction along the survey line.

The 2D electrical resistivity imaging method has now become a wide standard exploration tool in many environmental, groundwater, archaeology and engineering surveys in the world (Dahlin, 1996). Several researches were carried out on a flat area and in different fields, they refer to the applicability of this technique for hydrogeological purposes, borehole setting for groundwater, water quality and aquifer detection in alluvial and carbonate rocks such as Slater et.al. (1997), Mendoza et al. (2000), El-Qady et al. (1999), Williams (2002), Shamsuddin and Sanker (2002), Pham et al. (2002), Slater et al. (2001), Gwaze et al. (2000), Dahlin et al. (1999).

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface soil or rocks can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock.

In a typical survey, most of the fieldwork is in laying out the cable and electrodes. After that, the measurements are taken automatically and stored in the resistivity meter system. Most of the survey time is spent waiting for the resistivity meter to complete the set of measurements. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements (Dahlin and Loke 1998). The number of measurements that can be obtained for electrode spacing, for a given number of electrodes along the survey line, depends on the type of array used. The Wenner array gives the smallest number of possible measurements compared to the other common arrays that are used in 2-D surveys.

The waiting time for the resistivity meter has direct relation to the number of data points and pulse duration. Three different spreads of electrodes were used (2.0, 3.0 and 5.0 meters), so for Wenner array the maximum possible data point number for 72 electrodes is equal to 828 data points while for Wenner-Schlumberger array is a around 1332 data points. This study aims to reduce the waiting time of measurements through minimizing the data points to an optimal number that gives a good 2D resistivity image. In addition, measurements were carried out at the same location by using different pulse duration (250, 500, 1000 and 2000 msec.), for determine their affect on the inverse section. For preserving energy also different voltages were tested (50, 100, 150, 200, 300 and 400 V) and their response on the inverse section were studied.

II. The instrumentation and field procedure

A new modern computerized static type resistivity meter was used called SYSCAL Jr switch-72 (www.iris.com). The complete system consists of the resistivity meter, portable computer, switching unit (link box), six reels of multi-core cables with take-out at electrode points, 72 electrodes and their joining wire, car battery and chargers. The multi-core cables are of reverse type and have take-out string equal to 10.0 meters (a=10.0 m).

SYSCAL Jr switch-72 is a new all-in-one multimode resistivity imaging system; it is designed to perform automatically pre-defined sets of resistivity measurements with roll-along capability. The EI system automatically energizes different electrodes (4-electrode per each reading) to measure apparent resistivities at new horizontal location and depth. A series of 72 stainless steel electrodes are driven 15.0 to 25.0 cm. into the ground at a fixed intervals equal to 2.0, 3.0 and 5.0 meters, accordingly, the total length of the electrodes spread were 142.0, 213.0 and 355.0 meters respectively.

Different surface slopes were selected on Hanjeera and Tasluja mountains which are located 23.0 Kms to the west of Sulaimani City, Kurdistan Region - NE Iraq (Fig. 1). Twenty three profiles were surveyed on different surface slopes ranging from 17° to 55° degrees. Two types of electrode arrays, (Wenner and Wenner-Schlumberger) with different electrodes spacing (2.0, 3.0 and 5.5 meters) were used. Repeated measurements were carried out for each profile by using different field parameters such as data density, pulse duration and voltage. The details of some of the selected profiles were plotted in the Table-1:

Table1: Shows information on some selected profiles.

Profile name	Electrode Spacing (m)	Length (m)	Surface Slope (Degree)	Maximum Investigation Depth (m)	Data Density (Points)	Pulse Duration (Msec.)	Usage Voltage (V)	Type of Array
Pr-1	2	142	22°	20	237-680	500-2000	50-300	Wenner
Pr-2	2	142	25°	20	264-530	250-2000	50-400	Wenner
Pr-3	2	142	30°	20	248-682	250-2000	50-400	Wenner
Pr-4	3	213	55°	35	316-768	250-2000	50-400	Wenner
Pr-5	3	213	50°	35	317-798	500-2000	50-400	Wenner
Pr-6	5	355	17°	60	248-720	250-2000	50-400	Wenner-Schl.
Pr-7	5	355	25°	60	266-760	250-2000	150-400	Wenner-Schl.
Pr-8	5	355	30°	60	339-710	250-2000	50-400	Wenner-Schl.

From geological point of view, the area is covered by limestones rocks of Pilaspi and Sinjar Formations. Gercus Formation also crops out in some parts of the area. It is composed of red clay, marl, sandstone, siltstone and conglomerates (Fig.1).

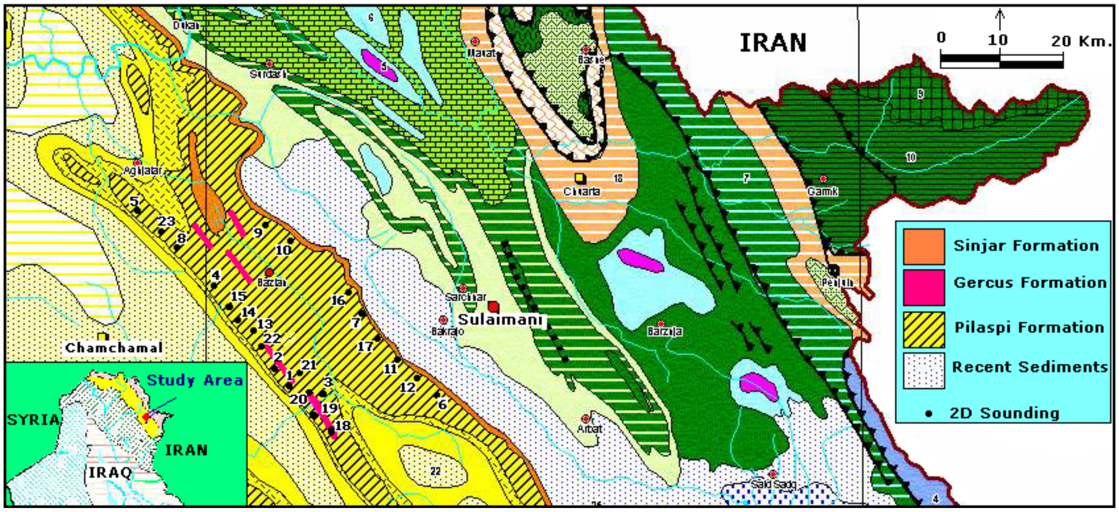

Fig.1: Location and Geological map of the study area (Jassim and Goff, 2006).

III. Interpretation and Discussion

Two dimensional (2D) model interpretation was performed using the last new version of software package "RES2DINV" version 3.54.53, (www.iris.com). It performs smoothness-constrained inversion using finite difference forward modeling and Quasi-Newton techniques (Loke and Dahlin, 2002). An important factor in the inversion process of 2D imaging data is the quality of the field data. Good quality data usually show a smooth variation of apparent resistivity values in the pseudosection. Most of the soundings display good quality, except in some limited locations due to the bedrock on the surface; the quality is changed to poor.

The bad data points were removed from the data set to avoid their effect in the inversion process. These data are exterminated by the aid of plotting the data in profile which helps to highlight the bad data points and remove them from the data set.

The effect of the topography must be taken into account when carrying out an inversion of the data set. For this purpose during the survey for each sounding the elevations of all the electrodes were measured with the aid of GPS and topography map of the area.

The topography correction uses a distorted finite-element mesh (Loke, 2004) was done. The surface nodes of the mesh are shifted up or down so that they match the actual topography. In this case, the topography becomes part of the mesh and it is automatically incorporated into the inversion model.

Profile-1

The measurements on this profile were taken several times using different data densities, pulse durations and voltage (Fig. 2). When the data density ranges from 237 to 310 data points, the subsurface situation is changed continuously (as shown in Figs. 2A, 2B, and 2C). Most reasonable data density is around 363 data points (Fig. 2D). The geological column of the well BH-12 coincides with this inverse section. Further increase in the data density is only waste of fieldwork time and loss of energy source (Figs (2E, 2F, 2G and 2H).

The quality of field data in such complex area is controlled by using maximum pulse durations and voltages. Several spots of high and low resistivities were appeared on the pseudosections when low magnitudes of these parameters were used.

The top soil cover has small thickness ranging between 1.0 to 3.0 meters with a wide range of resistivity values. It is composed of clay, rock fragments and weathered product of the Gercus Formation. Three distinct resistivity zones were identified on the inverse section. The first zone of high range of resistivity values between 400.0 to 1100.0 Ohm.m. It represents the limestone rocks of the Pilaspi Formation. The second zone of intermediate resistivityvalues between 40.0 to 100.0 Ohm.m, which could refer to the sandstone unit of the Gercus Formation (as illustrated in the Fig. 2). The third zone is of low resistivity values (blue color). It represents the weathered product of the Gercus Formation which is composed of clay, sandstone and siltstone.

Profile-2

It extends NE-SW and running through a surface with slope equal to 25° degrees. Few bad data points were recorded, they exterminated manually to remove their effect on the inversion process. The inverse sections calculated and plotted as shown in figure 3.

The most suitable data density is around 361 data points (Fig. 3c). The geological column of the well, BH-13 coincides with the inverse section. No significant variation has been noted as the data density exceeds 361 data points. The same profile with 479 and 530 data points were surveyed several times by using different pulse durations and voltage magnitudes (Figs. 3G and 3H). These parameters have no significant effect on the inverse sections despite the occurrence of some spots of high and low resistivity on the pseudo-sections.

The upper part of the section represents a thin layer of 0.5-3.0 meters thick of clay and limestone rock debris as well as weathered product of the Gercus Formation. Gercus Formation appears at shallow depths and extends to the lower part of the inverse section. Two zones were identified within this formation; zone of low resistivity 7.0-30.0 Ohm.m represents clay and marl layers, while the higher resistivity values 30.0-120.0 Ohm.m represents sandstone layer.

Profile-3

The most realistic models of the subsurface is obtained when the data density approaches 385 data points (Fig. 4D). The geological column of the well BH-14, at the location of electrode 34, coincides with the inverse resistivity section. Also in this location for the profile of the data density 385 different pulse durations and voltages were tested and they haven't show significant effect on the inverse section.

The soil cover thickness ranges between 0.5 to 4.0 meters. It is composed of rock fragments and clay. Beneath the soil cover is the Gercus Formation which shows moderate resistivity values ranges from 10.0 to 70.0 Ohm.m. The high resistivity values within the Gercus Formation may represent sandstone layers that extend from the top to the bottom of the section. There are also some locations show low resistivities 15.0 – 30.0 Ohm.m. That could correspond to fine grain sediments of the Gercus Formation (clay, marl, and siltstones)

Profile-4

The profile length here is 213.0 meters (table-1). More accurate model was obtained when the data density equal to 542 data points as illustrated in the figure5E. However, the variations in the pulse durations and voltages parameters only have their effects on the data quality. A good quality data was obtained at this location though the surface while the surface is rough and several blocks of limestone rocks are scattered on the surface, This is could due to the good contacts of the electrodes to the soil. Aabout 40.0 to 50.0 cms of the electrodes were inserted to the ground, as well as saline water was added to the location of each electrode.

The inverse section of this profile shows the existence of high resistive soil cover 75.0 -1100.0 Ohm.m. Its thickness ranges between 0.5 – 12.0 m and it is mainly composed of clay and limestone rock debris. Gercus Formation comes directly beneath the soil cover. It has moderate resistivity values from 20.0 to 70.0 Ohm.m. The Gercus Formation extends down to the lower part of the inverse section to is about 34.0 m depth.

Profile-5

The inverse section with topography correction is displayed in figure 6. It becomes more stable when the data density is increased gradually to 538 data points (Fig 6E). Higher than this number no distinguish variations have been observed with the increasing of the data points.

The surface is covered by a thin layer (0.5 m) of soil below electrode 64. The thickness of this layer is increasing to 12.0 meters near the location of electrode 13. This layer also shows a wide range of resistivity values especially in some locations where rock debris are abundant on the surface such as at a location below electrodes 48 to 64. Gercus Formation underlain the top soil cover it shows resistivities values between 25.0 – 90.0 Ohm.m and extends down to a depth of 35.0 m. While beneath the electrodes 23 to 39 and at a depth of 17.0 m a part of Gercus Formation shows higher resistivity values from 80.0 to 250.0 Ohm.m. This is could be due to the existence of dense dry sandstone.

Profile-6

Actual inverse section for this profile (335.0 meters length, table-1) was obtained when a data density approaches 554 data points (Fig.7D). Further increase in the data density is wasting of time and has no significant effect, as shown in figure 7E & 7F. The profile of a data density 650 was tested by using different magnitudes of pulse durations 1000 and 2000 msec. and voltages 50.0 and, 400.0 V: Fig. 7G and 7H.

Two significant features have been observed on the inverse section. The first is a zone of low resistivity value. It is represented by blue color, and it has resistivities values range from 9.0 to 27.0 Ohm.m.a resistivity ranges from 9 to 27 Ohm.m. It is related to a loose material such as sand, silt and clay. The second feature is a zone of high resistivities values (30.0 to 117.0 ohm.m). It represents clay and limestone rock debris. The low range of resistivities values through the whole section is due to a dominant of clay over other materials. While a higher magnitude of resistivity value obtained at the NE part of the section due to the existence of more sand and boulders.

Profile-7

The most suitable data density for this profile (surface slope equal to 25°, table-1) is around 620 datum points (Fig. 8D). The geological column of the well BH-17 exactly coincides with the resistivity inverse section. The profile with the same data density 620 datum point was also tested by different pulse durations (250 and 2000 msec.) and voltages (150.0 and 300.0 V) as shown in figures 8G and 8H respectively.

The profile result can easily divided into two different lithological units according to the resistivities values. The low range of resistivities values (10.0 – 30.0 Ohm.m) occurs at electrodes 18 to 38 and down to a depth of 28.0 m., ; below electrodes 39 to 47 and to a depth of 9.0 m.; at electrodes 55 to 63 to a depth of 18.0 m. They represent the loose sand, silt and clay. The upper part of the section shows high resistivities values (35.0 to 200.0 ohm.m). They could be correspond to the rocks debris of limestone rocks and clay materials.

Profile-8

The inverse resistivity section becomes stable when the data density approaches 650 data points, (Fig 9E). For the lower numbers of the datum points the resulted inverse resistivity sections show significantly different models (Figs.9A, 9B, 9C and 9D).

The different resistivities zones can be easily identified. There are low resistivity zones that occur at the location of; the electrodes 12 to 16 and down to a depth of 9.0 m; the electrodes 16 to 48 to depths ranging between 20.0 to 35.0 m, as well as in some other locations. These resistivities zones (9.0 - 30.0 ohm.m) probably represent the loose weathered products of Gercus Formation (mainly sands, silt, and clay). The inverse resistivity section also shows the existence of the upper high resistive zone (30.0 – 400.0 ohm.m) which is composed of limestone rock debris and clay materials. The approximate thickness of this zone is ranges from 10.0 to 35.0 m.

CONCLUSION:

The 2D resistivity imaging method could works very well in complex subsurface geological condition as well as in mountainous areas over slopes ranging from 20° to 55° degrees.

Data density has great effect on the inversion process for obtaining a reliable resistivity image of the subsurface. A more accurate subsurface model is obtained when an optimal data density is selected. According to the current study it has been concluded that the optimum data density for any location mainly depends on the slope of the surface, the electrode spacing and number of electrodes. These parameters are combined together according to the following suggested formula:

Datum Point = 3/√ a * {(No. of Electrode) * a} + (Maximum Spread * Sin Ө)

So according to the above formula the optimum data density for different surface slopes are plotted in the Table-2:

Table 2: Shows different datum density for different surface slope.

Electrode Spacing a (m)	Datum Density (Ө) = 0°	Datum Density (Ө) = 20°	Datum Density (Ө) = 40°	Datum Density (Ө) = 60°
1	213	285	350	398
2	301	349	392	424
3	369	441	506	554
5	476	597	704	783
10	673	916	1129	1288

Ө : is slope angle of the surface

The pulse durations and usage voltages show slight affect on the quality of the field data. It can minimize this affect by inserting the electrodes into the ground as deeper as possible and making good galvanic contact between the electrodes and the surrounding soil.

Wenner and Wenner-Schlumberger arrays gave the same response in such complex area, while the author prefers the later due to larger subsurface coverage

References

Dahlin, T., 1996**:** 2D resistivity surveying for environmental and engineering applications. First Break, **14**, PP 275-284.

Dahlin, T., and Owen, R., 1998**:** Geophysical investigation of alluvial aquifer in Zimbabwe, Procs. 4th Meeting Environmental and Engineering Geophysics, Barcelona, Spain, 14-17 Sept, Pp 69-72.

Dahlin, T., Glatz, D., and Persson, N., 1999**:** Electrical and magnetic investigations of deep aquifers in north Matabeleland, Zimbabwe, Procs., EEGS99, Budapest, Hungary.

El-Qady, G., Sakamato, C., and Ushijima, K, 1999**:** 2-D inversion of VES data in Saqqara archaeological area, Egypt, *Earth Planet Space Journal*, **51**, PP 1091-1098.

Gwaze, P., Dahlin, T., Owen,.R., Gwavava, O., and Danielsen, J., 2000**:** Geophysical investigation of the Karoo aquifer at Nyamandhlovu, Zimbabwe, Procs. EEGS00, Bochum, Germany.

Jassim, S.Z. and Goff, J.C., 2006: Geology of Iraq, publication of Dolin, Prague and Moravian Museum, Brno, 341p.

Loke, M.H., and Dahlin T.2002: A combine Gauss-Newton and Quasi-Newton inversion methods for interpretation of apparent resistivity pseudosections, Paper presented at the 3rd Meeting of the Environmental and Engineering geophysics Society-European Section, Sept. 1997, Aarhus, Denmark.

Loke, M.H., 2004**:**Tutorial: 2-D and 3-D electrical imaging surveys, mhloke@pc.jaring.my, 127P.

Mendoza, A., Bjelm, L. and Dahlin, T., 2000**:** Resistivity imaging as a tool for groundwater studies at Santo Domingo, central Nicaragua, Procs. EEGS 00 Bochum, Germany, 3-7 September 2000, EL 15.

Pham, V.N., Boyer, D., Mouel, L.J. and Nguyen, T.K., 2002**:** Hydro geological investigation in the Mekong Delta around Ho-Chi-Minh City (south Vietnam) by electric tomography, C.R Geosciences, **334**, PP 733-740.

Shamsuddin, S. and Sanker, K.N., 2002**:** GIS Integration of remote sensing and electrical sounding data for hydrogeological exploration, *Journal of Spatial Hydrolog*y, **2**, No.1, PP 1-12.

Slater, L., Binley, A.M., Zaidman, M.D., and, West, L.J., 1997**:** Investigation of vadose zone flow mechanisms in unsaturated chalk using cross-borehole ERT. Proceedings of the EEGS European Section 3rd Meeting, Aarhus, Denmark, PP 17-20.

Slater, L., Reeve, A. and Glaser, D., 2001**:** Improving understanding of peat land hydrogeology using electrical geophysics, Faculty research, University of Missouril.

Williams, L.J., 2002**:** The role of two-dimensional direct-current resistivity profiling in a water-resource investigation: Application to groundwater exploration and development in igneous and metamorphic rocks of the Georgia Piedmont/ Blue Ridge. Unpublished PhD thesis, Lund University, 187 P.

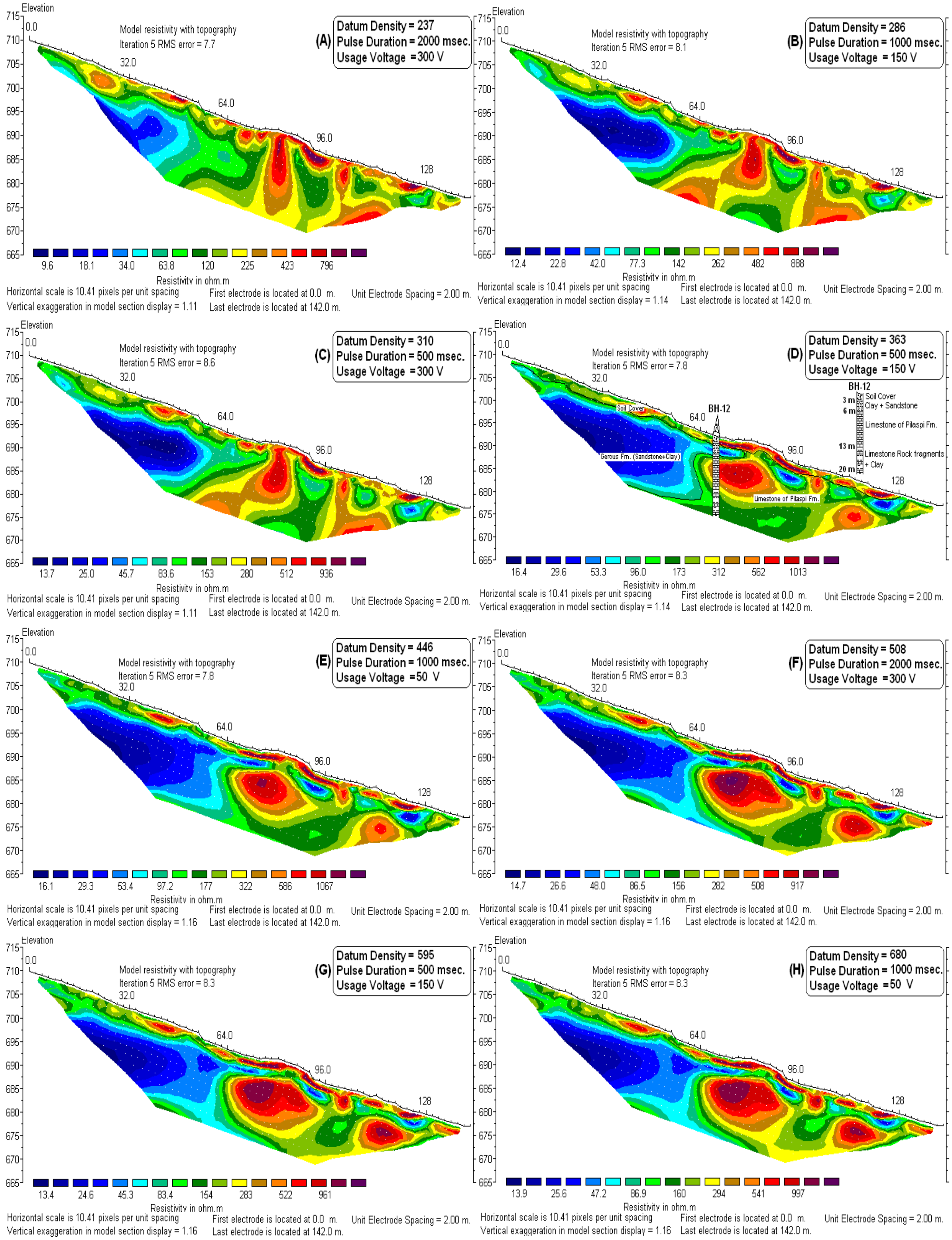

Fig.2 : Inverse sections of the profile-1.

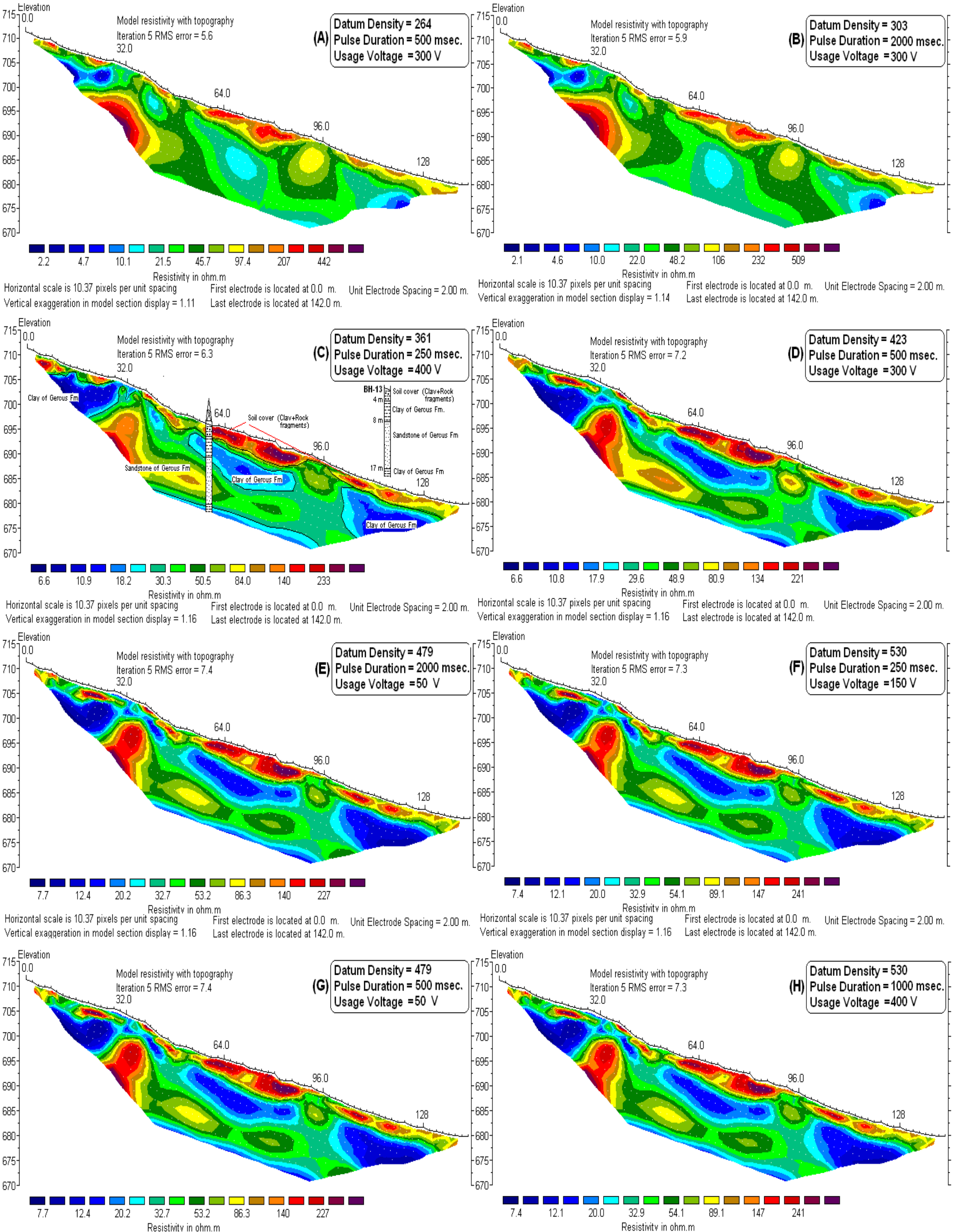

Fig.3 : Inverse sections of the profile-2

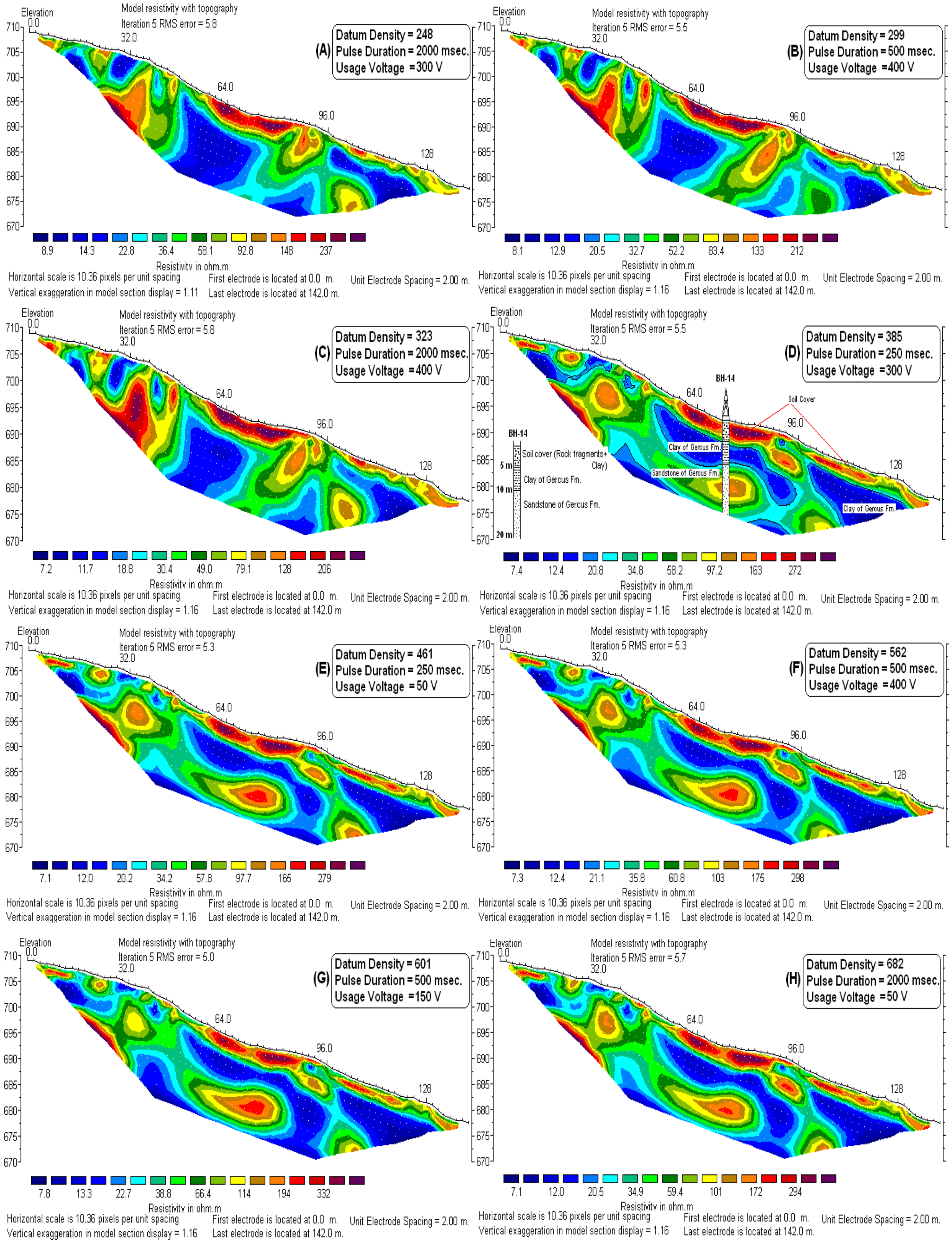

Fig.4 : Inverse sections of the profile-3.

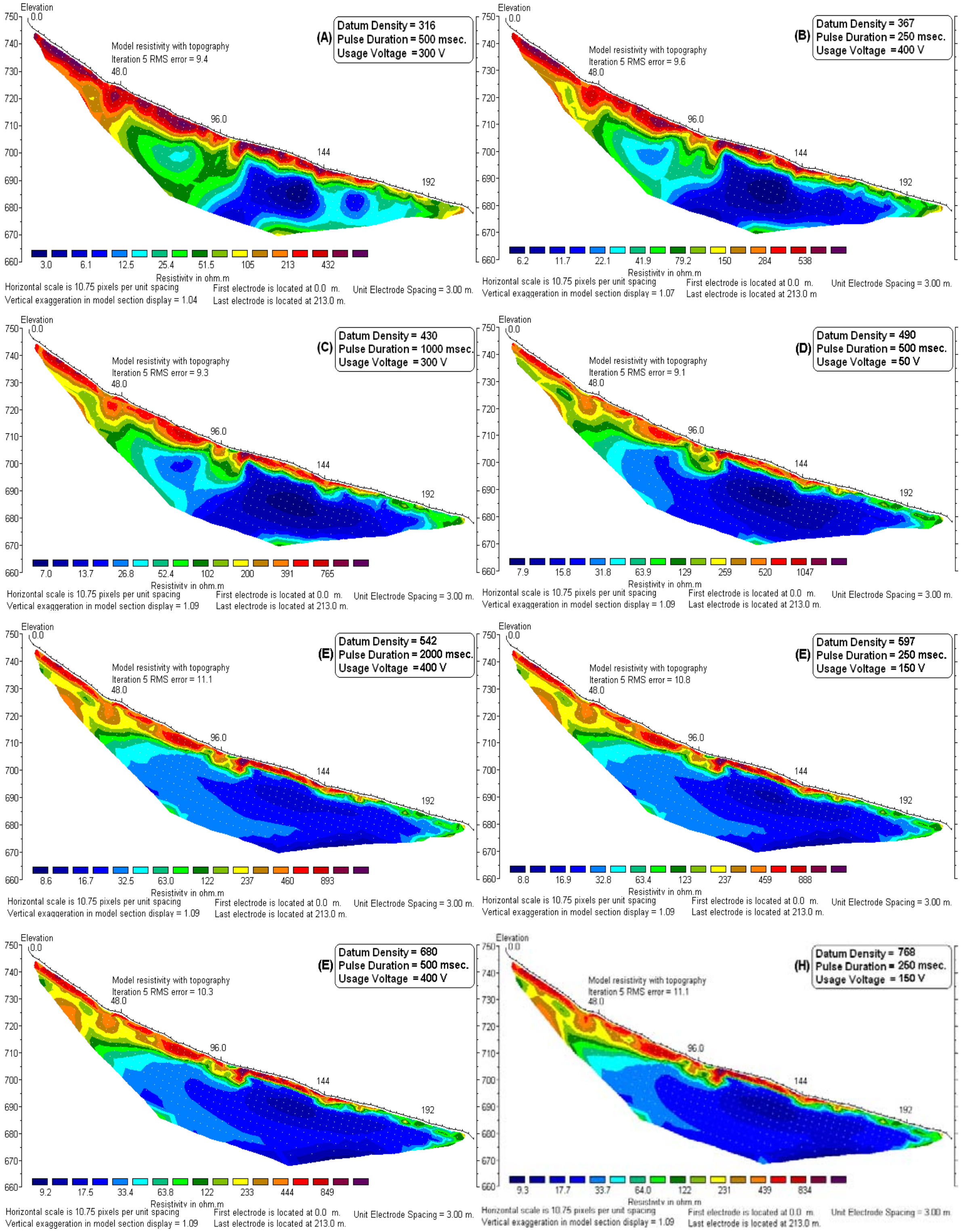

Fig.5 : Inverse sections of the profile-4.

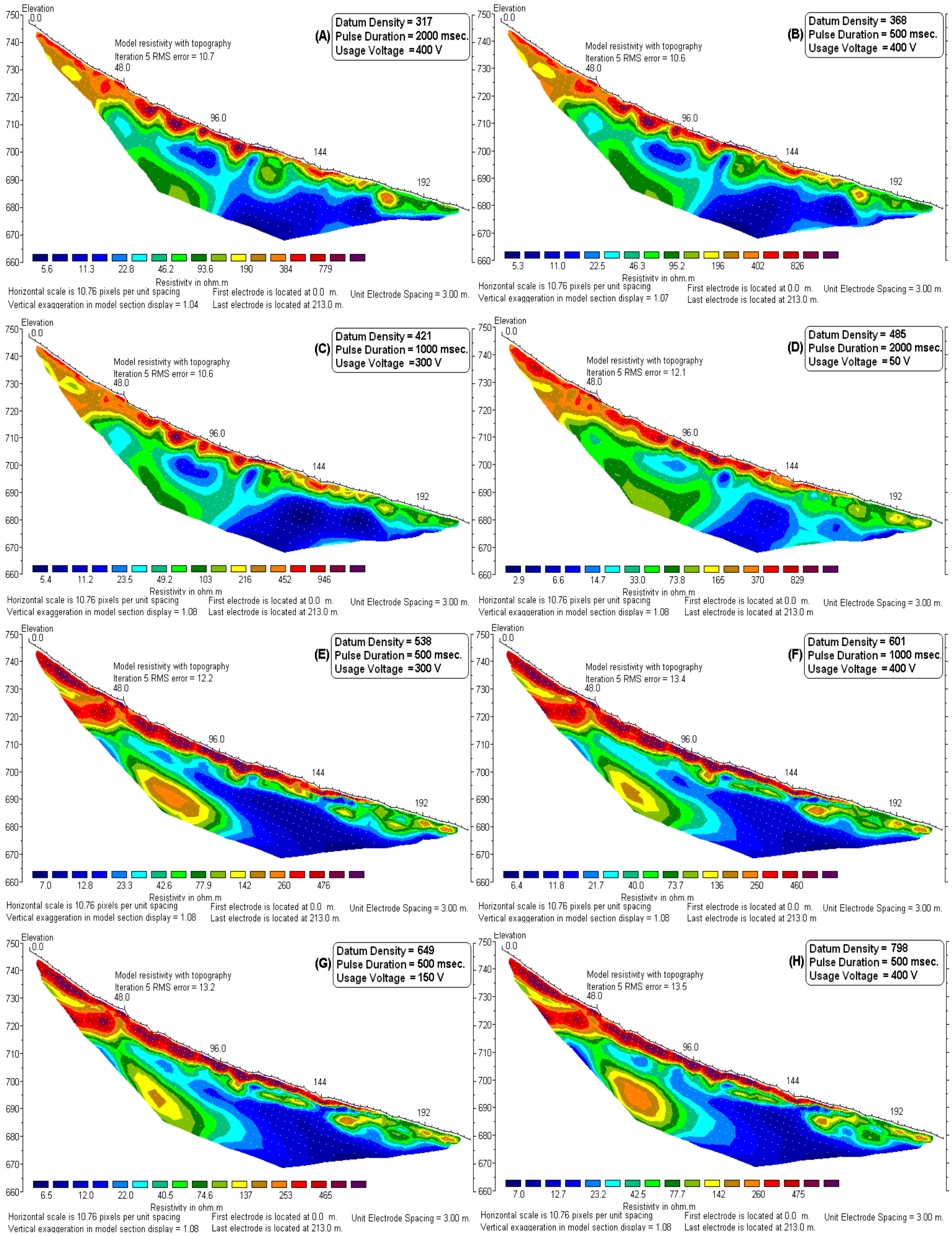

Fig.6 : Inverse sections of the profile-5.

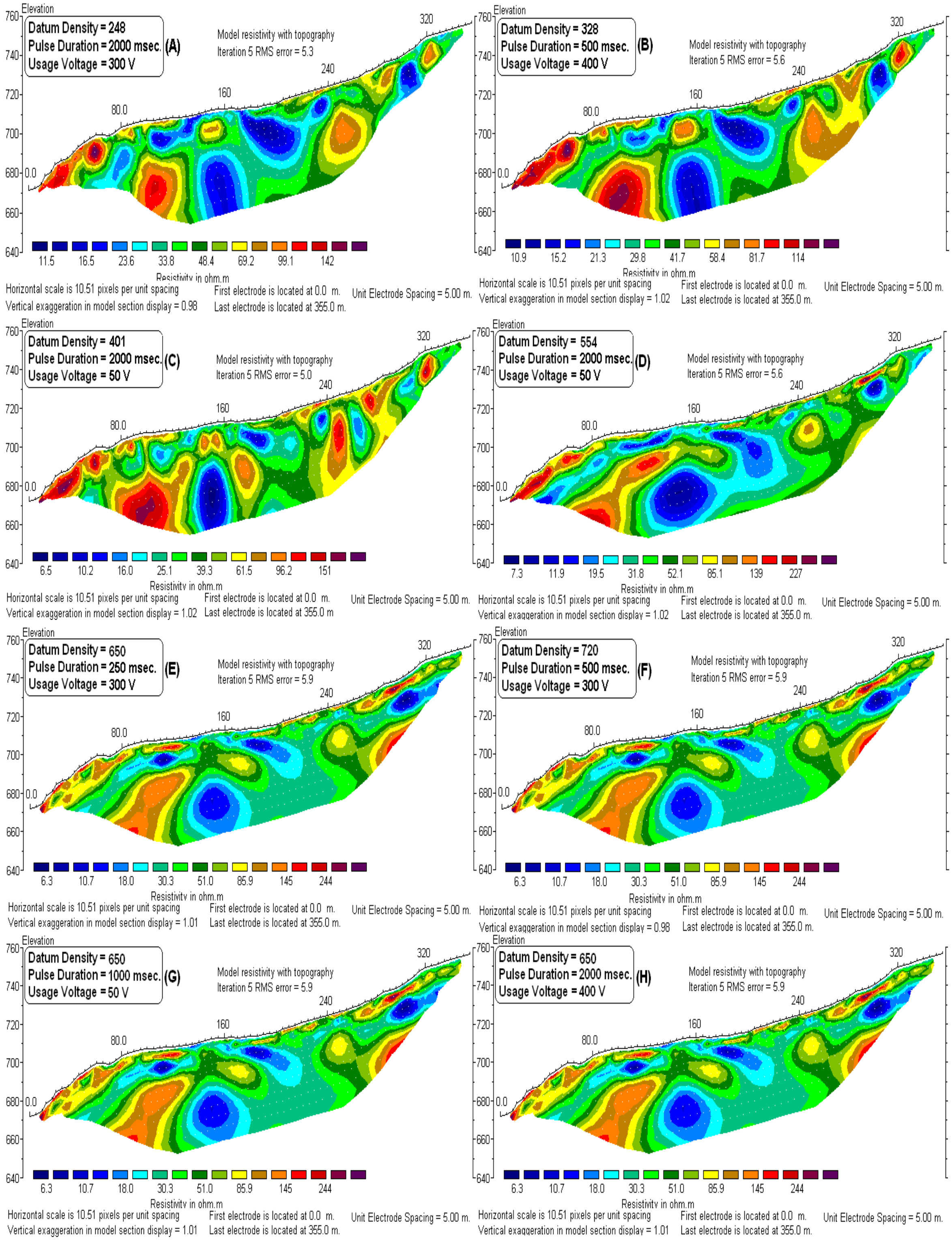

Fig.7 : Inverse sections of the profile-6.

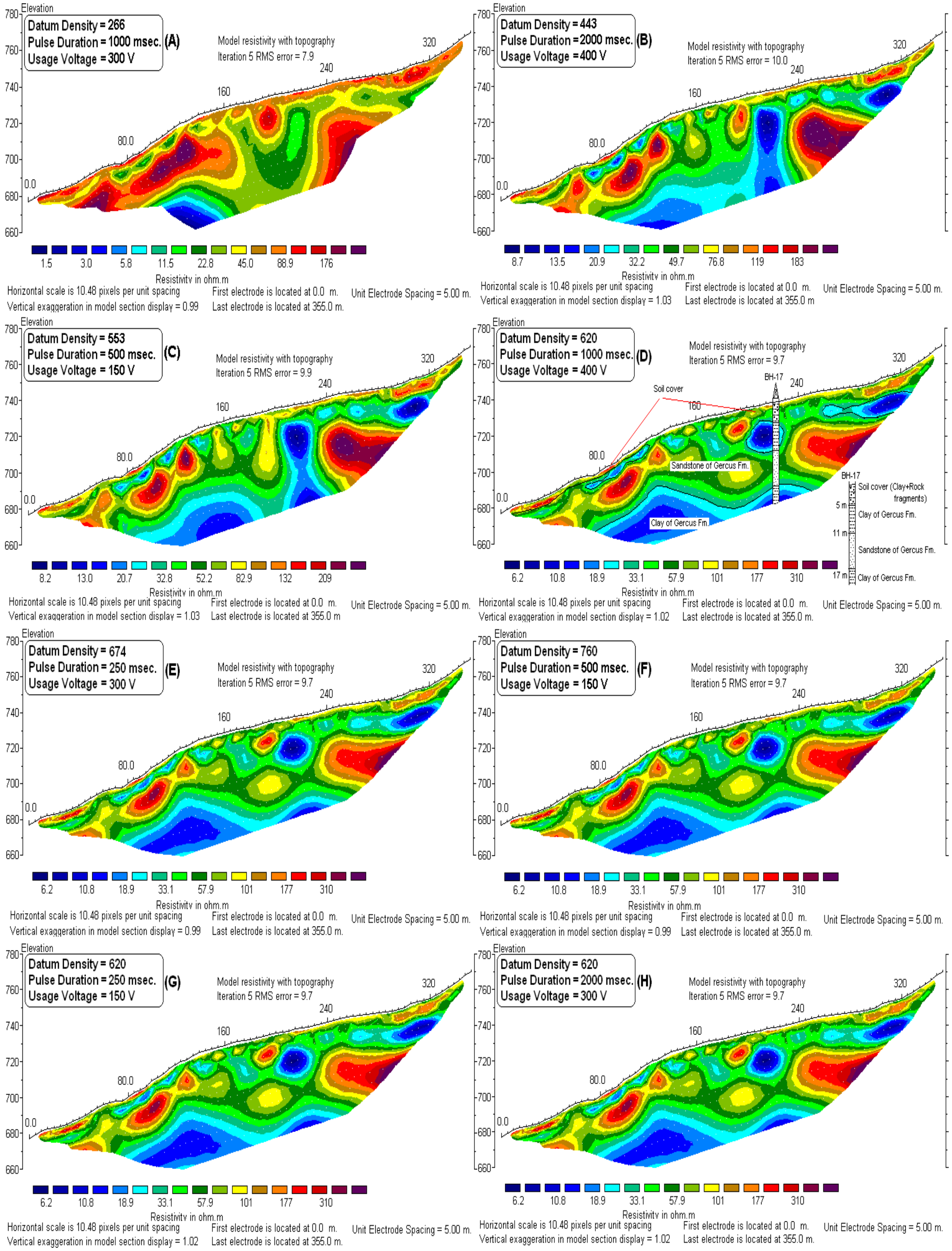

Fig.8 : Inverse sections of the profile-7.

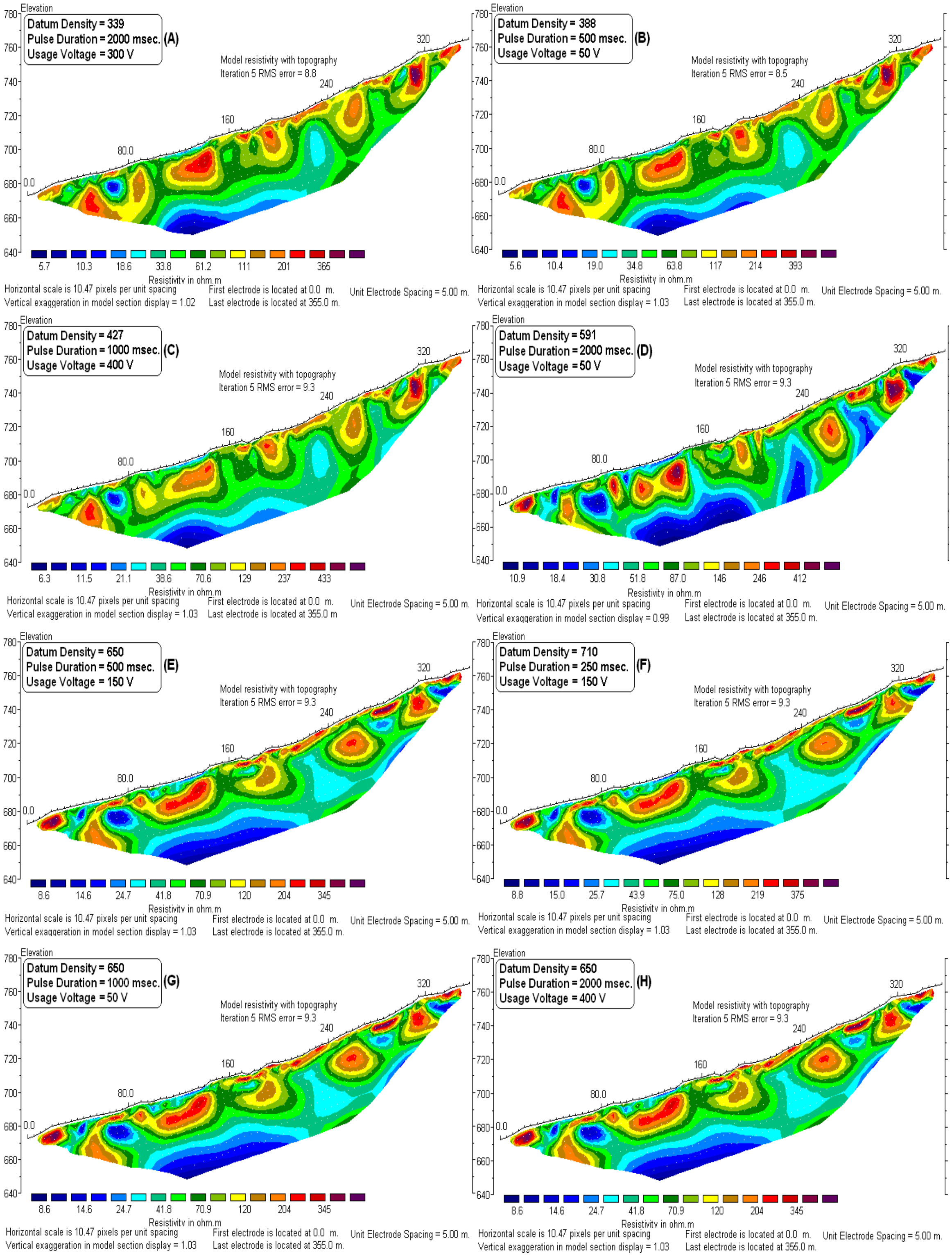

Fig.9 : Inverse sections of the profile-8.