NEAR SURFACE DETECTION OF DEPTH-SOURCED SALINE WATER, DUNA-TISZA INTERFLUVE

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Abstarct

In the Duna-Tisza Interfluve in Hungary, and mostly in the Duna-valley, the salinization is a great problem for the agriculture. The amelioration of sodic soils, and the protection of saline wetland areas require the knowledge of the source of salt, and the controls and mechanisms of salt distribution. According to hydrogeological research on the area, two principal forces drive subsurface waters (Tóth and Almási, 2001). Deep overpressures due to tectonic compression and gravity at shallow depths. In the Duna-valley – according to our hydraulic studies – both systems discharge in areas of saline lakes and salt effected soils. According to our hypothesis, the high salinity of the lakes and soils is probably related to the highly saline deep flow system. We have tried to prove this hypothesis with the help of chemical and geophysical measurements in the area of Kelemen-szék lake. The chemical results indicate the presence of saline waters below the lake (~3-5000 mg/l) and fresh groundwater to the east (~2-400 mg/l). Resistivity measurements show similar distribution of the systems to 100-120 m depth. These results suggest the presence of deep saline water near the surface and support the deep origin of high salinity.

Keywords: salinization, geophysical survey, wetland

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Összefoglalás

A Duna-Tisza köze területe, és elsősorban a Duna-völgy a szikesedés által erősen érintett terület, ami nagy problémát jelent a mezőgazdaság számára. A szikes talajok javítása elengedhetetlen, valamint a Duna-völgy sós vizes élőhelyeinek védelme is elsődleges feladat. Ez azonban megköveteli a szikesedés eredetének és a sószállítási mechanizmusoknak ismeretét. A területen végzett hidraulikai feldolgozás kimutatta, hogy a felszín alatti vizeket két hajtóerő tartja mozgásban (Tóth and Almási, 2001). A mély, aljzatból induló túlnyomások és a sekély vizeket hajtó gravitáció. A Duna-völgyben – a hidraulikai feldolgozásunk alapján – a két rendszer egyaránt megcsapolódik a szikes tavak, wetlandek, és szikes talajok zónájában. Feltevésünk szerint a felszíni sós jelenségek a mély eredetű, túlnyomásos rendszer magas oldott anyag tartalmú vizének megcsapolódásához köthetőek. Kémiai és geofizikai vizsgálatokkal próbáltuk alátámasztani hipotézisünket. A kémiai eredmények ”sós”, nagy oldott anyag tartalmú víz jelenlétét mutatták ki a tó alatt, tőle K-re pedig ”édesvíz” válik uralkodóvá. A geofizikai ellenállásmérések alátámasztották ezt a térbeli eloszlást 100-120 m-es mélységig. Az eredmények együttesen igazolták a mély, sós víz felszín közeli megjelenését és a szikesedés mély, felszín alatti víz eredetét.

Kulcsszavak: szikesedés, geofizikai felmérés, vizes élőhely

Introduction

The Duna-Tisza Interfluve (DTI) area of the Hungarian Great Plain is one of the most densely populated regions of Hungary (Fig. 1.). The area between the two rivers is rich in groundwater resources. The main activity of the population is agriculture. Unfortunately, the area is not just plagued by droughts but in the last decades by the effect of overpumping as well. The other main problem is salinization. Large parts of the interfluve are covered by salt affected soils, and salinized wetland areas, principally in the valley of the Duna (Duna-valley). Amelioration of the sodic soils and protection of wetland areas are thus essential. These areas are also habitats of rare migratory birds requiring the protection too. These tasks have to be based on the knowledge of the origin of salt, and the controls and mechanism of the salt-transport as well.

In order to solve the problems of salinization intensive research started in the last two centuries (Tessedik, 1804, Balogh, 1840, Sigmond, 1923 etc). The opinions regarding the origin of salt were different. First Kovács (1960) mentioned the subsurface dissolution and transport of the salts to the Duna-valley area. Other researchers have had the same result that the salt is originating from the deep basinfill and transported and distributed by groundwater (Várallyay, 1967). Nevertheless, the now accepted hypothesis of salinization is that shallow groundwater flowing from higher elevations towards the Duna-valley, converges in the deeper pans and evaporates (Molnár and Murvai, 1976; Kuti, 1977). In our study we attempt to find the right answer to the question with a hydrogeological approach in the Duna-valley, in the case of the saline Kelemen-szék Lake.

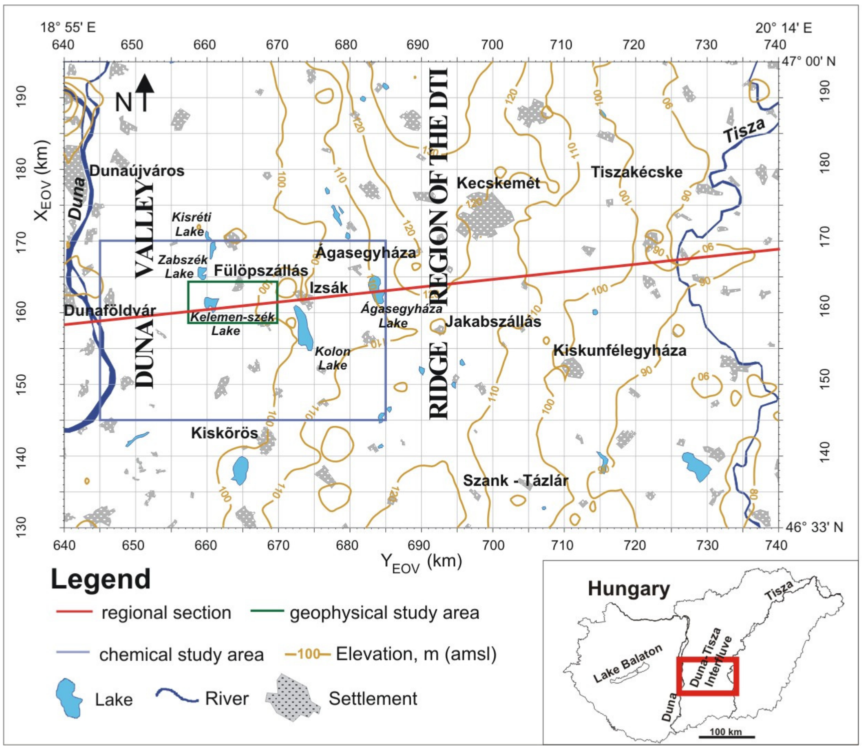

Fig. 1. Research area

Hydrogeological background, results of our former research

In the Duna-Tisza Interfluve, according to a detailed hydraulic study, based on 16000 well-data (Tóth and Almási, 2001) two driving forces are prevalent. Near the surface are situated gravity-driven flow systems, which are perched on deep, over-pressured waters, originating in the Pre-Neogene basinfill. Detailed hydraulic and hydrostratigraphic studies show that the deep-water component approaches the surface in the Duna-valley, where a saline wetland area is found with highly saline lakes (Mádlné Szőnyi et al., 2005, Mádlné Szőnyi and Tóth, 2007) (Fig. 2.). The deep saline water gets close to the surface along tectonic faults and conductive lenses, intercepting the well-conductive aquifer (AF) and the water bearing aquitard layers (AT) (Fig. 3.). According to our hypothesis, the high salt content of the lakes and soils derives from the deep flow system, and thus indicates ascending saline water (TDS (total dissolved solids): 2-40000 mg/l) (Erdélyi, 1989). The more detailed hydraulic results down to 110 m show, that Kelemen-szék lake is situated in the discharge area of the deep system, while the gravity systems are prevalent east of it (Fig.3.) (Mádlné Szőnyi et al., 2005). In the present study we have attempted to verify this hydraulic situation, the connection between the lake and the water of the deep system, and to examine the interrelationship between the two systems close to the surface (100-120 m).

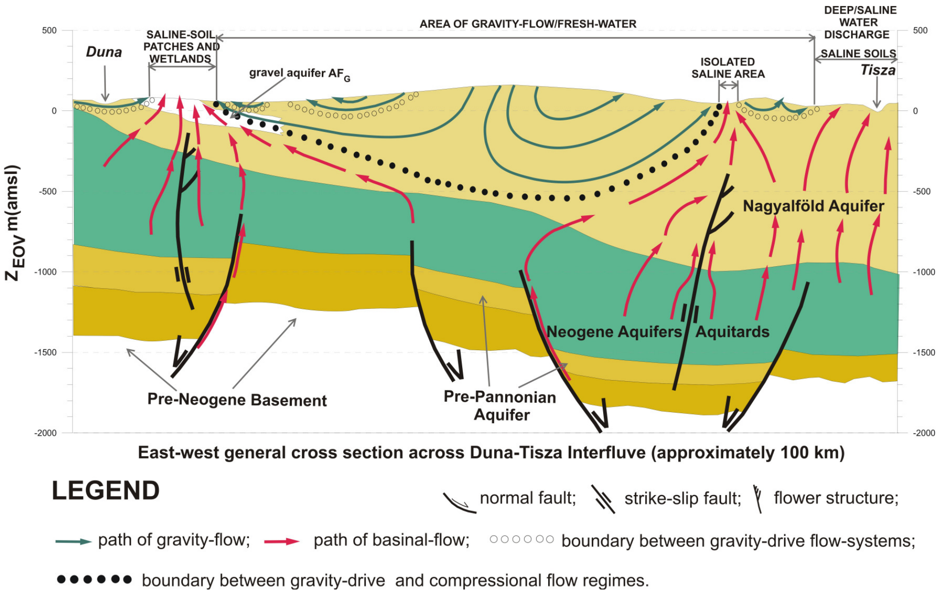

Fig. 2. Schematic hydraulic and hydrostratigraphic cross section of the Duna-Tisza Interfluve (along the regional cross section line shown in figure 1.)

(Mádlné Szőnyi and Tóth, 2007)

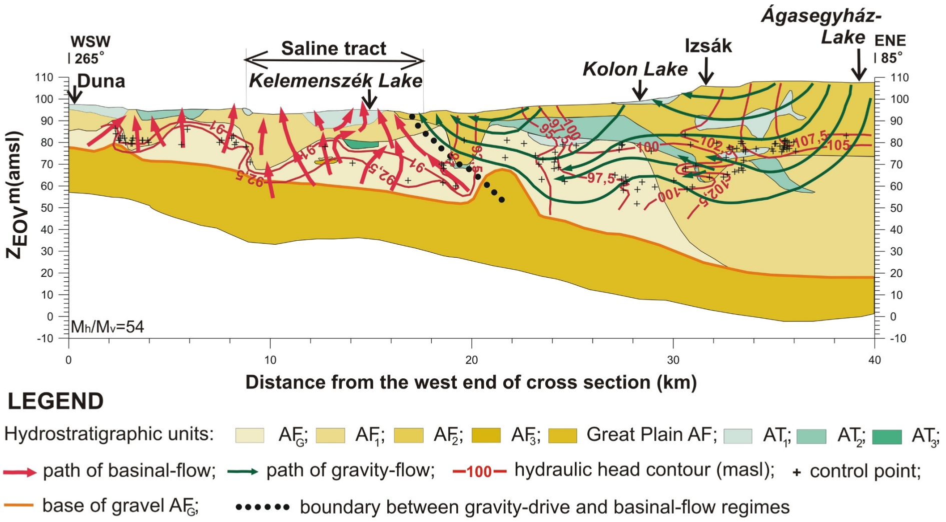

Fig.3. Shallow hydraulic and hydrostratigraphic section (along the regional cross section line, within the chemical study area shown in figure 1.), (Mádlné Szőnyi et al., 2005)

AT:aquitards, AF:aquifers

Applied methods

Identification of waters of the two systems is based on their different chemical composition. The TDS content of the over-pressured system could reach 40000 mg/l, and it has high Cl^- (21000 mg/l) and Na (12000 mg/l) contents as well (Erdélyi, 1989). Although it reaches the surface presumably diluted by shallow groundwater, it can still have higher TDS content than the "fresh" water of the gravity-driven systems. Based on this idea, higher values below the lake, and continuously decreasing TDS values towards east are expected in the groundwater. This distribution could be checked in specific points with examination of the chemical compositions of well waters and spatially by geophysical measurements.

With the help of geophysical resistivity measurements the different salt contents of pore water can be detected, because the measured resistivity includes the characteristic of the rock and the pore water as well. In the study area the geological strata are subhorizontally bedded, so in a given layer local differences of resistivity originate from the chemical difference in groundwater (smaller resistivity values signify higher TDS content). This way we can examine the spatial distribution of the different water types and the presence of a boundary between the two systems. In the course of the investigation electric (VES (Vertical Electric Sounding) measurements, penetration: 100-120 m) and electromagnetic (RMT) (Turberg et al., 1994; Stiefelhageln, 1998), penetration: 18-25 m) methods were also used.

To realize VES measurements, direct current or alternating current of very low frequency is introduced into the ground via two electrodes (A and B). The potential diffence is measured between the other two electrodes (M and N). The geometrical arrangement of the electrodes could be different, but we applied the Schlumberger array, where the distance between MN is less than fifth of the AB distance. The larger the distance between A and B, from the deeper we get information. Knowing the current intensity (I) and the measured potential difference (ΔV) the apparent resistivity (ρ_a) can be calculated by Ohm's law (1). The K factor in Eq. 2. depends on the electrode arrangement, and is called the geometric factor.

$$\rho_a = K \frac{\Delta V}{I} \tag{1}$$

$$K = \pi \frac{(AB/2)^2 - (MN/2)^2}{MN} \tag{2}$$

From the apparent resisitivity values (ρ_a) the subsurface specific resisitivity distribution is calculated by two computer programs: the PISE (from the Geophysical Department of the VI. University of Paris) and the Schlumberger (improved at CHYN). In this way we get the layer thicknesses and resistivity values as functions of the pore water electrolyte conductivity (Erdélyi and Gálfi, 1988).

The other method applied was the electromagnetic measurements with RMT (Radio MagnetoTellurics 12-240 kHz) instrument. This is a further developed version of the very low frequency electromagnetic instrument VLF-R (Müller, 1982). This method works with low frequency transmitter radiowaves and detects the induced electric and magnetic field in the rock media. The VLF-Resistivity (VLF-R) method measures the relation between the horizontal magnetic field with an induction coil and the electric field using two electrodes placed in the ground. This method determines apparent resistivities at the penetration depth of the used transmitter-frequency (Bosch and Müller, 2005). The RMT method is a further developed variant of the VLF-R that works in a lower, 12 – 240 kHz frequency-range. In the course of the investigation three different frequencies are used, which result in different penetrations. At the detection this equipment provides an apparent resisitivity value (in Ωm) and the phase-shift (in degree) between the horizontal, magnetic and the vertical electric field component. These two parameters allowed data interpretation based on magnetotellurics (MT) to calculate specific resistivity-depth-distribution (Fischer et al., 1981). These specific resistivity values allow us to compile cross sections or distinguish between the effects of the rock and the pore water.

Results of the chemical investigation

In the former, detailed investigations (Mádlné Szőnyi and Tóth, 2007) it was shown, that the saline water of the deep system rises close to the surface along faults and highly conductive lenses, where it is diluted by "fresh" water of the gravity driven system. In the course of the chemical study we looked for the presence of this saline water in the shallow groundwater (down to 60-70 m), to indicate connection between the deeper saline waters and the surface salinization. The chemical study was carried out along a cross section of the hydraulic investigations, for the chemical study area shown in figure 1, down to depths of 60-70 m. The TDS and Cl^- contents were used, because they are the most reliable components, and are indicative of the deep system. Within a distance of 2 km on both sides of the cross section all available chemical data from wells were collected, and complemented with our measured field data. The general distribution of the chemistry of groundwater is delineated along the cross section. The values show the presence of two different hydraulic systems with different chemical compositions to a depth of 60-70 m (Fig 4.). The highest values are observed below the lake (TDS: 2540-5750 mg/l, Cl^-:579-1016 mg/l). The concentrations decrease abruptly to the east (TDS: 246-446 mg/l, Cl^-:6-31 mg/l), supporting the hydraulically based hypothesis. This difference can be detected in the different layers, which shows that the change in chemical composition is independent from the lithology. This also proves the effect of the two systems. Below the lake the values are increasing toward the surface, which indicates the increasing effect of evaporation near the surface. The chemical data prove also the presence of an interface between the two systems, in the same place where the hydraulically indicated boundary was drawn.

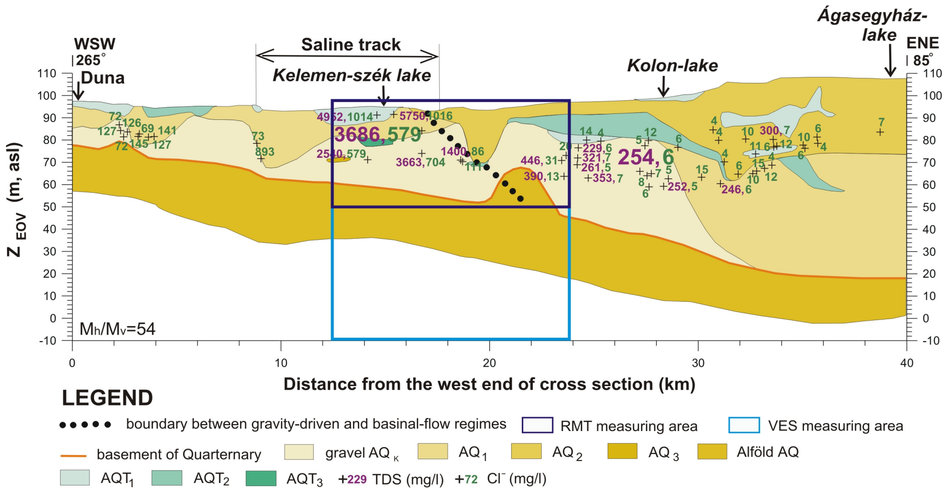

Fig. 4. TDS and Cl^- content of the groundwater

Geophysical results

The geophysical measurements were carried out in the close vicinity of the hydraulic cross section. On figure 4 the bigger quadrangle shows the area and the penetration of the VES, and the smaller area of the RMT measurements. The locations of the measurements are shown in figure 5. The RMT measurements were carried out along a section, while the VES measurements in close vicinity of existing boreholes and wells, where the lithology is known in detail. This way in the course of interpretation it was possible to separate the effect of the lithology and the effect of the pore water more reliably.

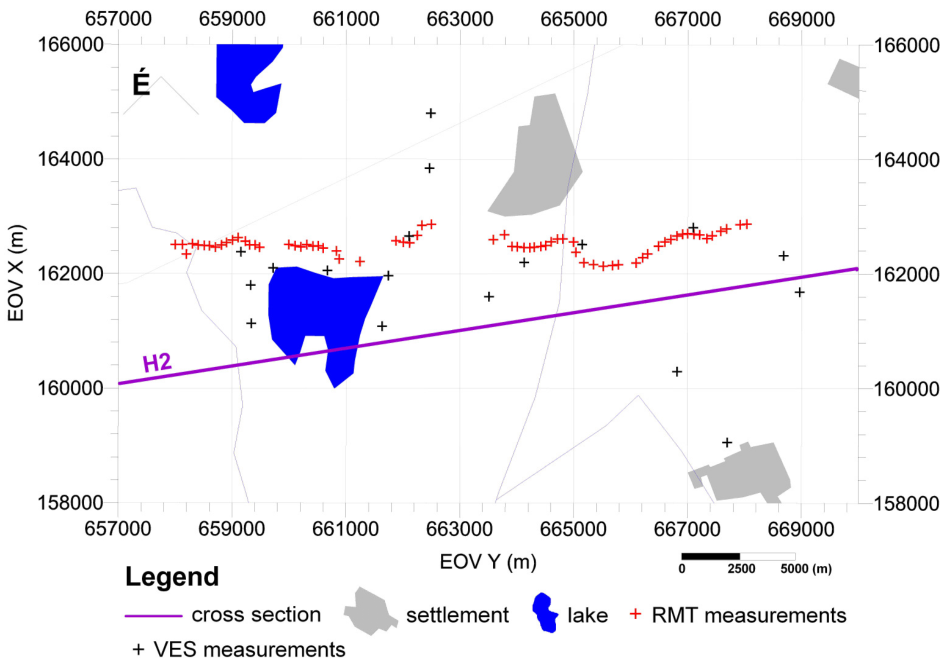

Fig. 5. Area of the geophysical measurements

The measured resisitivity values are represented on the area of the two quadrangles on figure 4 and correlate with the hydrostratigraphy. The hydrostratigraphy was compiled from the boreholes, where the VES measurements where carried out. The different, coloured layers signify different hydrostratigraphic units (Mádlné Szőnyi et al., 2005). The black numbers show the resistivity of the rocks, if these contained with fresh water (2-300 mg/l). These values are known from the literature and are refined with the locally measured K (hydraulic conductivity) values. The distribution of the specific resistivity values are shown by isolines in figure 6, 7, 8. According to the RMT results (red isolines) the measured values are smaller then the fresh water filled values below the lake (20-30 Ωm) (Fig.6.). This distribution is proved till ~ 20 m, in the silt layer above, and in the gravel (the lightest yellow layer) as well. Towards east the measured values increase and reach the black values, thus supporting the hydraulically based hypothesis (Fig.2.). The VES measurements (blue isolines) show the same distribution (Fig.7.). In every layer, west from the supposed boundary of the two systems much smaller resistivity values were measured, than those expected from sediment saturated with fresh water (2-300 mg/l). The biggest differences are in the lightest yellow gravel layer. This deviation can be followed in every layer to a depth of 100 m, which indicates the presence of highly saline groundwater. To the east the resistivity values are continuously increasing and reaching the black values, which means that the salinity of the groundwater is decreasing. Comparing the result of the two different geophysical methods, the distribution of the values agrees well (Fig. 8.). The 30 Ωm transition values shown by both methods could represent the boundary between the “saline” and the “fresh” water. This boundary does not represent a sharp change between the two different water types, rather a gradual transition over a distance of ~2-3 km. This transition was suggested by the chemical and hydraulic results too, and application of the geophysical methods its definition could be improved.

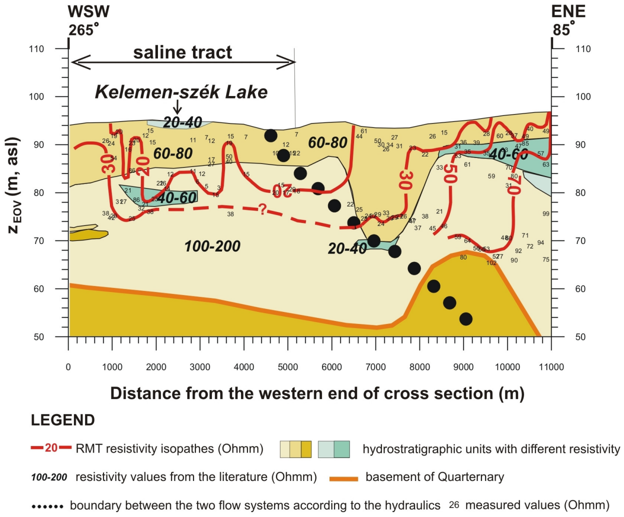

Fig 6. RMT measurements

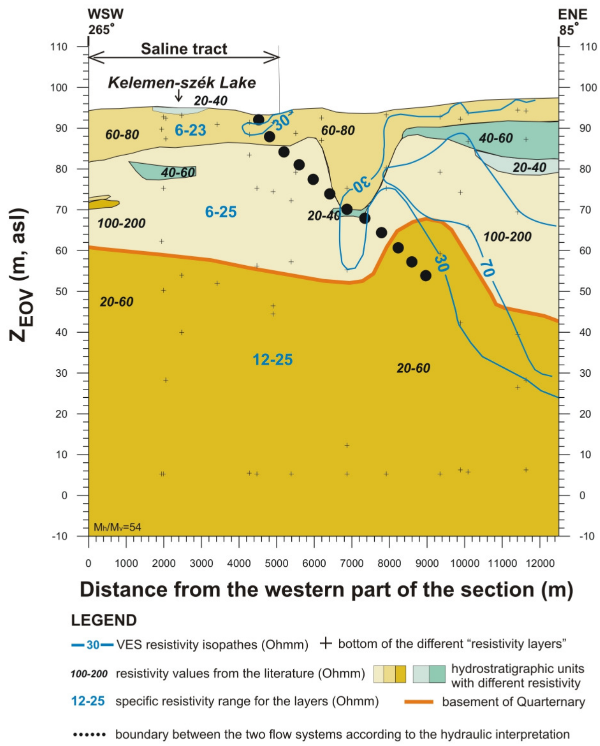

Fig 7. VES interpretation

According to this distribution highly saline water fills the pores in the surroundings of the lake to a depth of 100 m, and “fresh water” of a gravity system dominates the eastern part of the area. In addition, the resistivity measurements support also the presence of an interface between the two water types.

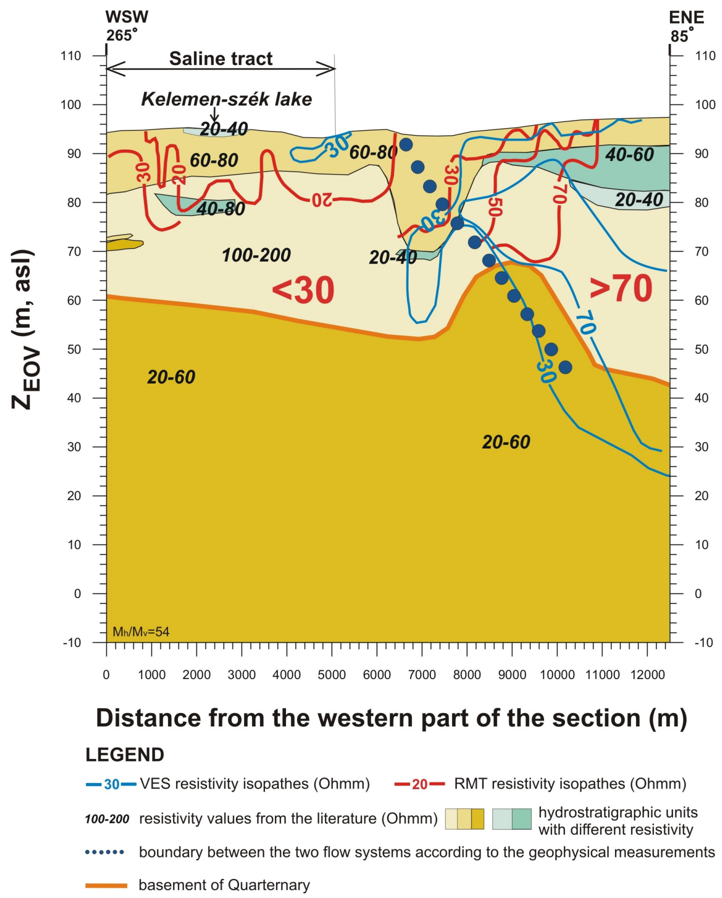

Fig 8. Geophysical results

Conclusion

Knowledge of the origin of salt and salt transport is essential for the amelioration of the sodic soils in salinization plagued areas.

We attempted to find the origin of salt in the Duna-valley, and understand salinization with three different methods. We tried to verify the hydraulic based hypothesis with the help of the interpretation of the chemical data and the geophysical measurements. The three methods provided the same result. The study area is affected by two different groundwater flow system. A deep flow system dominates in the surrounding of the lake, and it rises to the surface. This highly saline water discharges in the lake (presumably diluted by the fresh water), providing the source of salt for the lake and the sodic soils. Towards the east, the "fresh" water of the gravity system is prevalent. The investigations have revealed also the presence of an interface between the two systems.

These results prove the deep origin of the salt and salinization. The study corroborates our former observations concerning the groundwater flow systems of the Duna-Tisza Interfluve. The methods are applicable to and the results useful in further investigations of the area. The results are not only new scientifically, but are relevant also to amelioration of sodic soils, management of thermal water resources of the area, water management and protection of the agricultural environment.

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