Central European Geology, Vol. 51/3 pp. 203–217 (2008)
DOI: 10.1556/CEuGeol.51.2008.3.3

Soil and wetland salinization in the framework of the Danube–Tisza Interfluve hydrogeologic type section

Judit Mádl-Szőnyi
Department of General and Applied Geology
Eötvös Loránd University, Budapest

József Tóth
Department of Earth and Atmospheric Sciences
University of Alberta, Edmonton, Canada

György Pogácsás
Department of General and Applied Geology
Eötvös Loránd University, Budapest

The Danube–Tisza Interfluve has an agricultural economy but is plagued by severe problems of soil and wetland salinization. The objective of the study was to determine the source of the salts and the controls and mechanism of their distribution. For the Danube–Tisza Interfluve two different groundwater flow regimes, namely a gravity-driven meteoric fresh water regime and an overpressured saline water one, were identified within the framework of the Danube–Tisza Hydrogeologic Type Section (Mádl-Szőnyi and Tóth 2009). It was also recognized that the salts originate partly from the basin sediments and partly from the basin basement. The latter contains NaCl-type water with 10000–38000 mgL^{-1} total dissolved solid content. The vertical flow through conductive faults and the cross-formational ascent of the deep waters, combined with the gravitational systems' geometry and the flow-channeling effect of the near-surface rocks, explain the pattern of soil salinization and the contrasting chemistry between the wetlands of Danube Valley and the Ridge Region.

Key words: gravity-flow, over-pressure, soil salinization, wetland salinization, hydrogeologic type section

Introduction

The Danube–Tisza Interfluve in Hungary (Fig. 1) is an agricultural area and a large part of it is plagued by severe problems of soil and wetland salinization. The genesis and amelioration of salt-affected soils of the grain-growing farmlands

Addresses: J. Mádl-Szőnyi, Gy. Pogácsás: H-1117 Budapest, Pázmány P. sétány 1/C, Hungary,
e-mail: szjudit@ludens.elte.hu
J. Tóth: 1-26 Earth Sciences Building, Edmonton, AB T6G 2E3, Canada
Received: September 1, 2008; accepted: October 27, 2008

have inspired intensive research for more than two centuries (Tessedik 1804; Balogh 1840; Sigmond 1923; Treitz 1924; Arany 1956; Kovács 1960; Várallyay 1967; Erdélyi 1976; Kuti 1977; Molnár and Kuti 1978; Molnár et al. 1979; Kiss 1979, 1990; Kovács-Láng et al. 1999; Tóth 1999; Biró 2003). This research provided among other things important results in outlining the salt-affected surface regions and in understanding the role of groundwater-level fluctuation in the genesis of saline soils. However, to date the source, the controlling factors, and the mechanism of the distribution pattern of salt-affected soils have remained uncertain. The purpose of this paper is to answer these questions within the framework of the Hydrogeologic Type Section for the Danube–Tisza Interfluve (Mádl-Szőnyi and Tóth 2009).

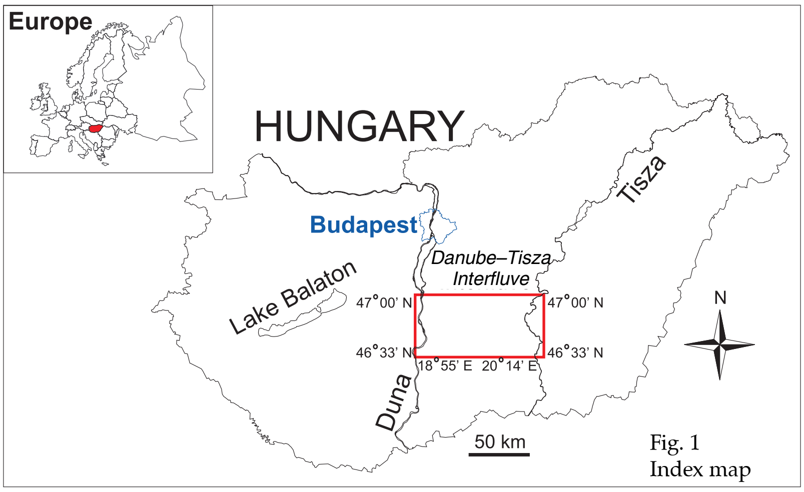


Fig. 1
Index map

The hydrogeologic environment of the study area

The Study Area (SA) is located in the Danube–Tisza Interfluve region of Central Hungary and covers an area of 100 × 65 km (Fig. 2). The surface elevations vary between 80 and 95 m ASL in the valleys, while those of the ridge are about 100 m on the flanks and up to 120–130 m ASL on the divide (Fig. 2).

The Intensive Study Area (ISA) of 39 × 25 km (Fig. 2) is situated in the Danube Valley in the western part of the SA. The wetlands of Lake Kolon and Lake Kelemenszék are as much as 13 km apart. The elevation of the water level of Lake Kolon is 103 m ASL and its surroundings are characterized by freshwater meadows. Lake Kelemenszék, the water level of which is at 92 m ASL, is surrounded by salt-affected soils and halophytic vegetation (Simon 2003).

The Danube–Tisza Interfluve is in the central part of the Pannonian Basin and is underlain by a large orogenic collage which is built up by several tectonostratigraphic terranes (Brezsnyánszky et al. 2000; Hámor et al. 2001). These crustal

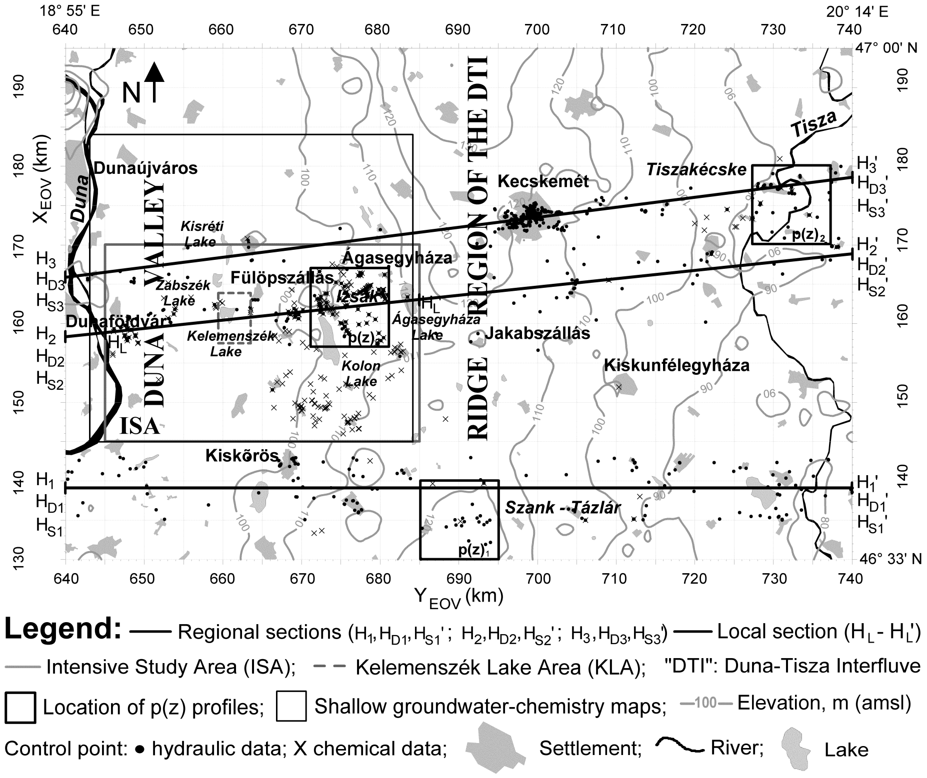


Fig. 2
Location map of the Study Area (SA)

terranes of varying origin reached their present positions through strike-slip movements and/or rotation during the step-by-step closure of the Tethys Ocean. Remnant basins of the former Tethys from the Eocene/Oligocene boundary form a series of basins belonging to the Paratethys (Nagymarosy 1990). The tectogenesis of the sub-basins of the Pannonian Basin system was controlled by the collision effects of the African (Adriatic) and European Plates. The Danube–Tisza Interfluve basins developed approximately above the collision sutures (Royden and Horváth 1988; Rumpler and Horváth 1988; Haas et al. 1999; Hámor et al. 2001; Nemcok et al. 2006).

The Pre-Neogene basement of the SA is made up of "flysch" sediments, carbonates and metamorphics. The multiphase Neogene-Quaternary subsidence was interrupted by inversions generated by deep depocenters, which were filled by detritus eroded from the orogenic belts of the Eastern Alps and Carpathians.

The phases of the Neogene tectonic evolution of the SA are

i) Early Miocene, right lateral wrench-type rejuvenation of the earlier "sutures";

ii) Middle Miocene formation of a network of synrift transtensional troughs;

iii) Late Miocene–Pliocene postrift (thermal) subsidence of the broader interior sag basin of the Great Hungarian Plain;

iv) latest plate convergence generated by late structural inversion and Pliocene–Quaternary left-lateral strike-slip movements (Pogácsás et al. 1989). The Neogene basin fill of semi-consolidated to nonconsolidated marine, lacustrine-deltaic, lacustrine and fluviatile clastics thickens from ~600 m at the Danube Valley in the west to over 4000 m at the Tisza Valley in the east (Juhász 1991).

Hydrostratigraphically (Fig. 3) the Pre-Neogene basement can be characterized by a 10^{-8} ms^{-1} magnitude of hydraulic conductivity (Bérczi and Kókai 1976), while it is 10^{-6} ms^{-1} in the Pre-Pannonian Aquifer. The Late Miocene–Pliocene basin fill is divided into an upper and a lower series of hydrostratigraphic units by the regionally extensive Algyő Aquitard, characterized by an average hydraulic conductivity of $K \sim 10^{-8} - 10^{-7}$ ms^{-1}. Below the Algyő Aquitard, the turbiditic siltstone, sandstone and clay series of the Szolnok Aquifer and the shaly series of the Endrőd Aquitard are characterized by hydraulic conductivities varying between 10^{-9} and 10^{-6} ms^{-1}. The Algyő Aquitard is overlain by the Great Plain Aquifer with an assigned average K of $\sim 10^{-5}$ ms^{-1} (Tóth and Almási 2001).

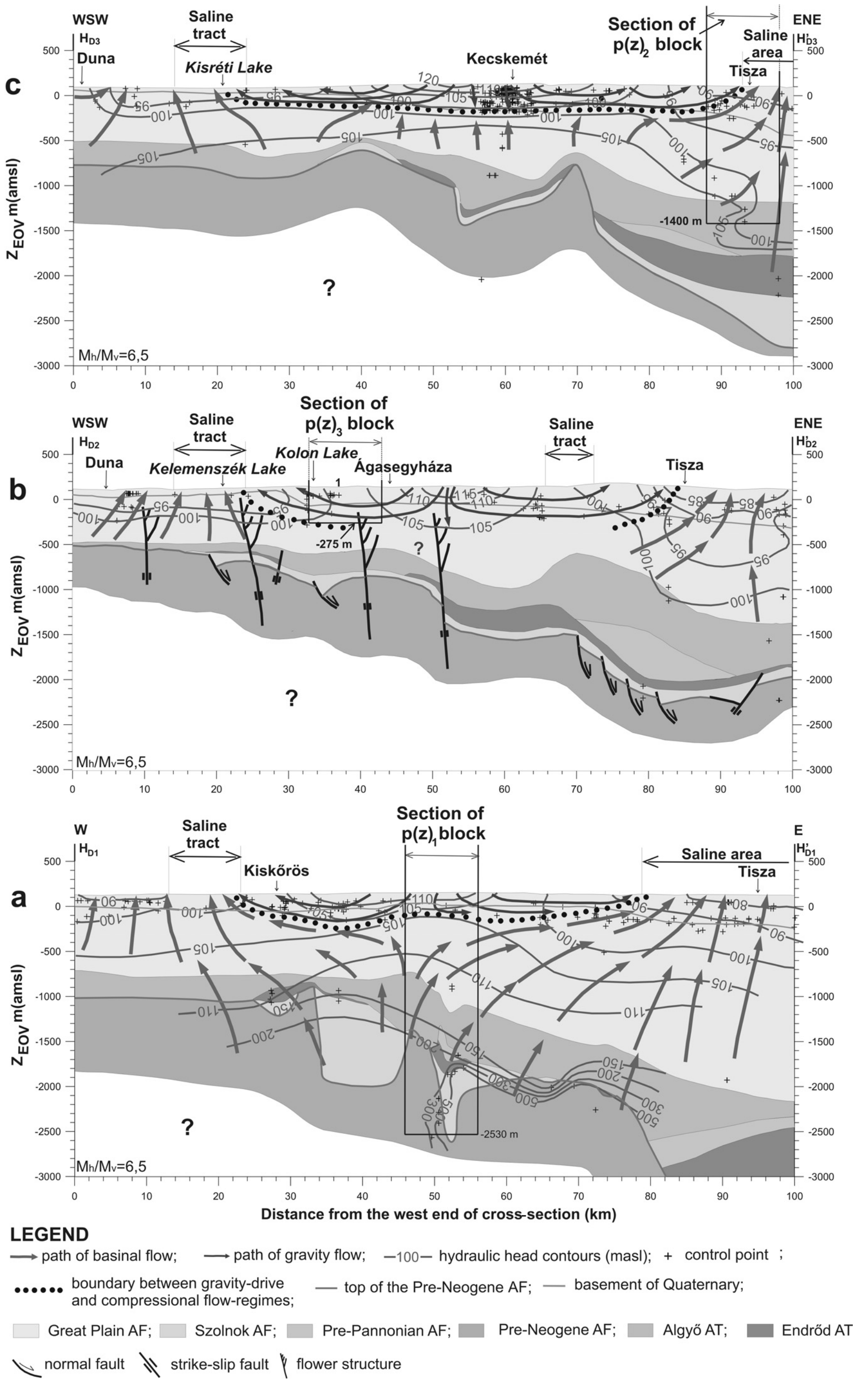
The climate of the Danube–Tisza Interfluve is moderately continental; the average annual temperature is 10–11 °C and the yearly precipitation is roughly 550–600 mm. The annual precipitation is sufficient to maintain the water table within 6 to 8 m below the surface of the ridge region, and within 0 to 1 m in the valleys of the Danube and Tisza rivers (Kuti and Kőrössy 1989).

Database and Applied Methods

To derive coherent maps and cross-sections, previously compiled data sets were used. These include water level, pore pressure and chemical analytical data from water wells and hydrocarbon exploration wells, water samples from water wells and lakes, core samples and petrophysical data, well logs, seismic sections, and an ecologic landscape map. Altogether 179 wells, 56 seismic sections and 1379 hydraulic-head data were interpreted. Based on the revision and updating of these data sets groundwater flow-distribution maps were compiled at the following scales: 1:250 000 for the Study Area (SA); 1:50 000 for the Intensive Study Area (ISA) and 1:50 000 for the Lake Kelemenszék Area (KLA, Fig. 2). Vertical scales of the compiled cross-sections varied from 1:20 000 through 1:2 500 to 1:500.

Available information on the groundwater chemistry is unevenly distributed both laterally and with depth. The water-chemistry database comprised approximately 300 analyses from water- and hydrocarbon wells and 19 analyses

Fig. 3 ⟶
Regional Deep Hydrostratigraphic and Hydraulic Sections (from Mádl-Szőnyi and Tóth 2009)


c
WSW
H_{D3}
Duna
Saline tract
Kisréti Lake
Kecskemét
Section of p(z)$_2$ block
Saline area
Tisza
ENE
H'_{D3}
-1400 m
?
Mh/Mv=6,5
b
WSW
H_{D2}
Duna
Saline tract
Kelemenszék Lake
Section of p(z)$_3$ block
Kolon Lake
Ágasegyháza
-275 m
Saline tract
Tisza
ENE
H'_{D2}
?
Mh/Mv=6,5
a
W
H_{D1}
Saline tract
Kiskőrös
Section of p(z)$_1$ block
Saline area
Tisza
E
H'_{D1}
-2530 m
?
Mh/Mv=6,5
Z_{EOV} m(amsl)
Distance from the west end of cross-section (km)
LEGEND
path of basinal flow; path of gravity flow; —100— hydraulic head contours (masl); + control point ;
boundary between gravity-drive and compressional flow-regimes; top of the Pre-Neogene AF; basement of Quaternary;
Great Plain AF; Szolnok AF; Pre-Pannonian AF; Pre-Neogene AF; Algyő AT; Endrőd AT
normal fault; strike-slip fault; flower structure

from dug wells (Simon 2003) for the KLA (Fig. 2). Owing to the diversity of the sources and analyses, only the Na^+, Cl^-, and Total Dissolved Solids (TDS) content were considered. For the characterization of the ecological landscape of the SA, "The Map of the Present Bio-Habitat of the Danube–Tisza Interfluve" (Biró 2003) and an unpublished soil data set were used for the SA.

Evaluation and Results

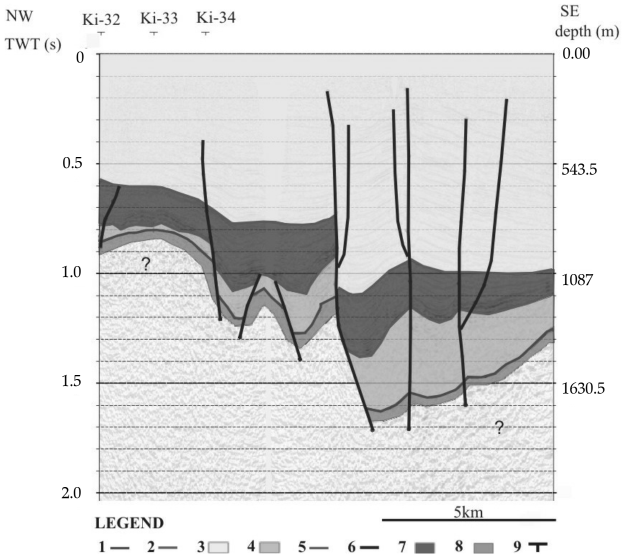
Groundwater flow

Based on the compiled three regional deep hydrostratigraphic and hydraulic sections (H_{D1}–H_{D1}', H_{D2}–$H_{D2,}$' H_{D1}–H_{D3}') (Figs 2, 3a, b, c) two distinct groundwater flow regimes could 3e recognized within the SA: a locally recharged regime of gravity-driven meteoric water with its flow field adjusted to the topography-controlled water table, and a deeper regime of the ubiquitously ascending waters rising from the over-pressured deep zone. The divide between these diverging systems correlates fairly well with the north-south striking topographic crest of the Danube–Tisza Interfluve area, as was displayed on the hydraulic cross-sections (Fig. 3a, b, c). The recharge areas merge on the ridge and form a single north-south running belt of about 25 to 35 km width. As can be seen in the figures beyond the recharge and midline-areas on both sides, the flow paths turn upward and the discharge areas appear. The gravitational discharge area is roughly parallel with the Danube River on the west side of the SA (Fig. 3a, b, c). The discharge zone is some 20 km wide on the eastern side of the Danube. In the other part of the SA, along the Tisza River, the discharge zone becomes progressively narrower from south to north.

The penetration depth of the meteoric regime varies between 250 and 450 m (Fig. 3a, b, c). The gravitational and overpressured flow regimes below the gravitational recharge appear to be sharply separated; their waters can presumably mix across the boundary by water-level fluctuation, dispersion, and diffusion. The flow direction in both regimes is universally upward under the gravitational discharge (Fig. 3a, b, c). Thus the meteoric or deep origin of water in these areas cannot be determined from the hydraulic data alone.

In Fig. 3b the results of the seismic interpretation are also displayed. The seismically identified wrench fault structures can dissect the regional aquitards and influence the Neogene sedimentary sequence. If they behave as conductive faults a short-cut can develop between the Pre-Neogene basement water and that of the near surface sediments. An interpreted seismic section (Ki-3) in Fig. 4 provides a good example of this phenomenon. In the middle of this section, beside the aquifers and aquitards a normal fault can be seen which has a lateral displacement as well. The lateral movement is responsible for the development of positive and negative flower structures. These structures connect the basement and the shallow aquifers (Mészáros 2005).

Fig. 4
Hydrostratigraphically and tectonically interpreted seismic section (Ki-3; Mészáros 2005 Fig. 6.6). 1. base of the Pre-Pannonian; 2. base of the Great Plain Aquifer; 3. Great Plain aquifer; 4. Pre-Pannonian Aquifer; 5. base of Algyő Aquitard; 6. structural element; 7. Algyő Aquitard; 8. Pre-Neogene basement, 9. crossing seismic profiles



The vertical superposition of overpressured and gravitational flow regimes was examined on pressure-elevation profiles. In the sampling square of the Izsák pressure profile, $p(z)_3$ crosses the hydraulic section H_{D2}–H_{D2}' and includes relatively high areas in its NW quadrant, and parts of the low-lying Lake Kolon in the SW (Figs 2, 3b, 5).

The plot shows a subhydrostatic pressure gradient ($\gamma \sim 8.397$ MPakm^{-1}) from the surface to z~50 m ASL (d~48 m), a nearly hydrostatic gradient ($\gamma \sim 9.807$ MPakm^{-1}) between z~50 m ASL and z~–50 m , and a superhydrostatic one from z~–50 m ASL to –260, indicating, respectively, recharge, throughflow, and discharge conditions (Fig. 5).

The local hydrostratigraphic and hydraulic section H_L–H_L', along H_2–H_2' (Fig. 2) shows the groundwater flow pattern to the west of Ágasegyháza (Fig. 6). The depth of the section is approximately 60 m and the horizontal and vertical scales are 1:50 000 and 1:500, respectively. The flow distribution and the effect of the high and low-permeability hydrostratigraphic units appear to have a strong influence on the dual hydraulic role of Lake Kolon, namely recharge and discharge. The extended shallow lens of the fluvial aquitard AT_1 at 31–36 km causes the flow paths originating in the recharge area at Lake Ágasegyháza to deflect upward into the wetlands between Izsák and Lake Kolon (Fig. 6). On the other hand, the thick gravel Aquifer (AF_G) attracts recharge water across the overlying clays and silts of fluvial aquitard AT_2 from above, including Lake Kolon. This water then merges with that derived from farther east, closer to the divide and, possibly with some ascending deep water. Part of this mixture ultimately discharges into Lake Kelemenszék.

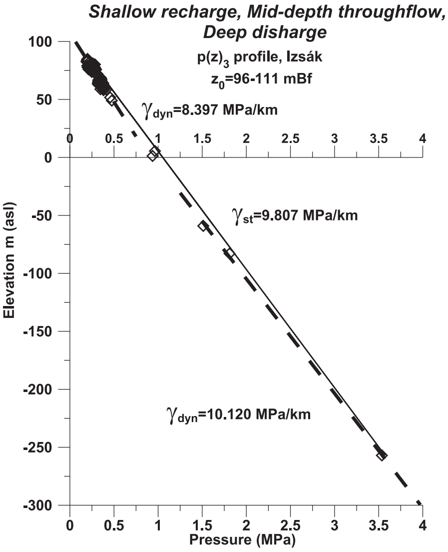


Fig. 5
Pressure-elevation ($p(z)_3$) profile at Izsák

Water salinity

The above-mentioned flow geometry and the role of faults as short-cuts between water of the basin basement and shallow aquifers were analyzed from the point of view of salts which are responsible for surface salinization. The first question was whether the chemical composition of waters in the basement can be the source of surface salinization. For this reason the archive chemical data from the basement's water of the SA were examined (Fig. 7).

The Total Dissolved Solid content of the 13 samples shows broad heterogeneity (38316–9915 mgL^{-1}); nevertheless the hydrogeochemical facies of these waters seems to be homogeneous. All water samples are of

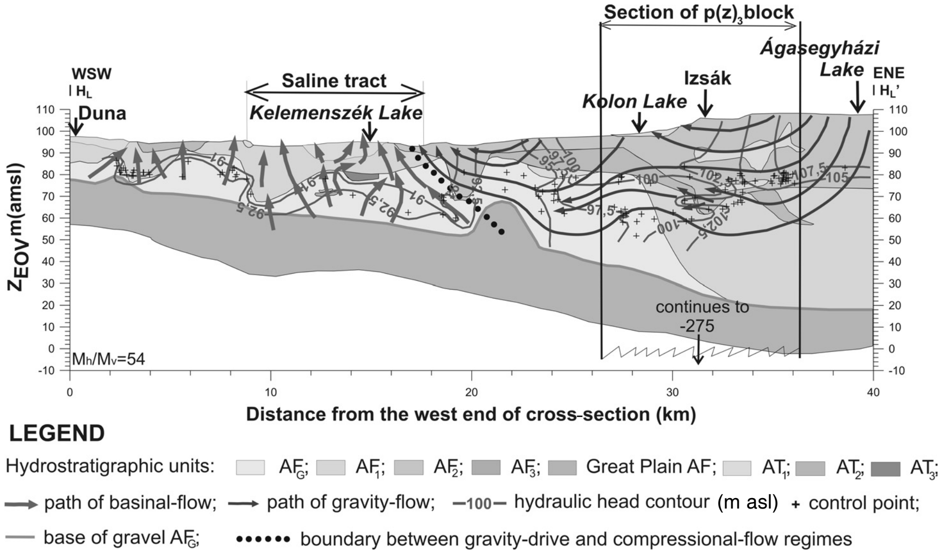


Fig. 6
Local hydrostratigraphic and hydraulic section (from Mádl-Szőnyi and Tóth 2009)

the NaCl-type. This is proved by the Na^+/Cl^- ($mmolL^{-1}$) plot where the average of the molal quotient is 1.0 (standard deviation: 0.1).

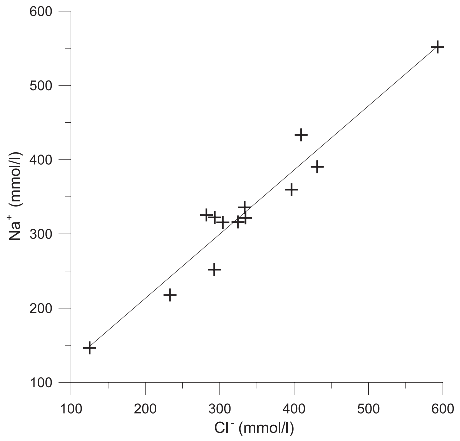


Fig. 7
Na^+/Cl^- ($mmolL^{-1}$) plot of the water chemical data from the Pre-Neogene basement

Archive water samples from the Neogene basin fill are very few compared to Pre-Neogene data. From 35 data the Na^+ and Cl^- analyses were available only for 10 samples simultaneously. The Na /Cl ($mmolL^{-1}$) quotient is 7.33 (standard deviation: 3.88), indicating that this water is surely not of NaCl-type, but belongs to the $NaHCO_3$-type which is characteristic for the Great Hungarian Plain. This group is not homogeneous. The Cl^- concentration for approximately 15% of the samples from the Great Plain Aquifer exceeds 100 mgL^{-1}. It can be interpreted that in the Neogene sedimentary basin fill $NaHCO_3$-type water sporadically has a higher Cl^- content. In all cases, these high Cl^- concentrations are paired with TDS values of at least 2.5 times the group arithmetic mean. Significantly, all sample of this subgroup come from sites in the ISA between meridian Y_{EOV} =664 km and the Danube river. Here, the Pre-Neogene basement rises up to within 800 m below surface (Figs 2, 3).

The distribution of TDS and Cl^- in shallow (<60 m) groundwater is demonstrated along a local section H_L–H_L' (Figs 2, 8) for the ISA. The TDS values range between 230 and 450 mgL^{-1}, and Cl^- between 3 and 30 mgL^{-1} in the eastern part of the section, especially in the Lake Kolon area and uphill from it. In contrast, concentrations for the same constituents are between 1400 and 2540 mgL^{-1}, and 110 to 580 mgL^{-1}, respectively, beneath the KLA (Figs 2, 8). Still farther west, Cl^- ion concentrations range between 70 and 150 mgL^{-1}, and may reach 890 mgL^{-1} locally. The boundary between the areas of TDS>1000 mgL^{-1} and Cl^- >100 mgL^{-1} to the west, and TDS<1000 mgL^{-1} and Cl^- <100 mgL^{-1} to the east, coincides with the boundary between the gravity-driven and ascending basement origin flow regimes (Figs 3b, 6, 8).

Soil Salinization and Vegetation Features

The Ecological Site Map (Fig. 9) shows the soil and wetland salinity for the SA (Fig. 2). It is characterized by regional patterns of contrast in soil types and plant ecology. The ridge region has freshwater meadows on its crest and both flanks, while saline soils, saline lakes and marshes, and phreatophytic and salt-tolerant

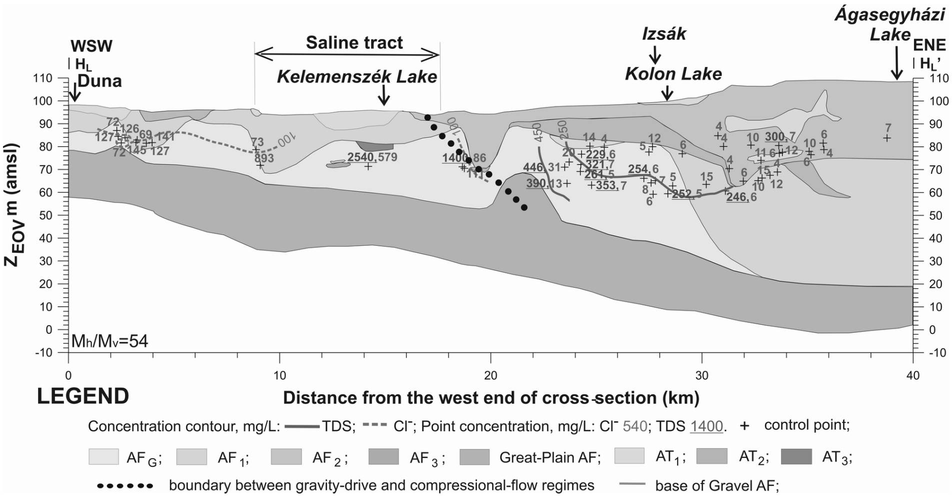


Fig. 8
Local water salinity section (modified from Mádl-Szőnyi and Tóth 2009)

vegetation dominate in the river valleys. South of the city of Kecskemét, saline and freshwater marshes alternate over a tract of land, widening southward, on the lower reaches of the ridge's eastern flank toward the Tisza River. Saline soils occur on both sides of the Interfluve, generally below elevations of approximately 95 to 100 m ASL on the east flank, and 90 to 95 m ASL on the west flank (Figs 2, 9). The upslope boundaries of these areas run roughly parallel to the north-south oriented topographic elevation contours. Areas of salt-affected soils of irregular size and shape give way to patches of non-saline soils without any apparent regularity over the entire 25 to 30 km width of the Danube Valley (Figs 2, 9).

The transition between the saline and non-saline soils is relatively sharp, particularly on the west flank as, for instance, between Lakes Kolon and Kelemenszék. Similarly, saline and fresh-water wetlands are divided by a north-south running boundary on the west flank (Y_{EOV} =664-660) (Fig. 9), with the fresh-water lakes of Kolon and Ágasegyháza on the upslope side, and the north-south strip of the Kisréti, Zabszék, and Kelemenszék saline lakes at lower elevations. Sporadically, and apparently irregularly, small areas of salt-affected soils, meadows, and shallow marshes also occur at higher elevations, closer to the Interfluve's crest.

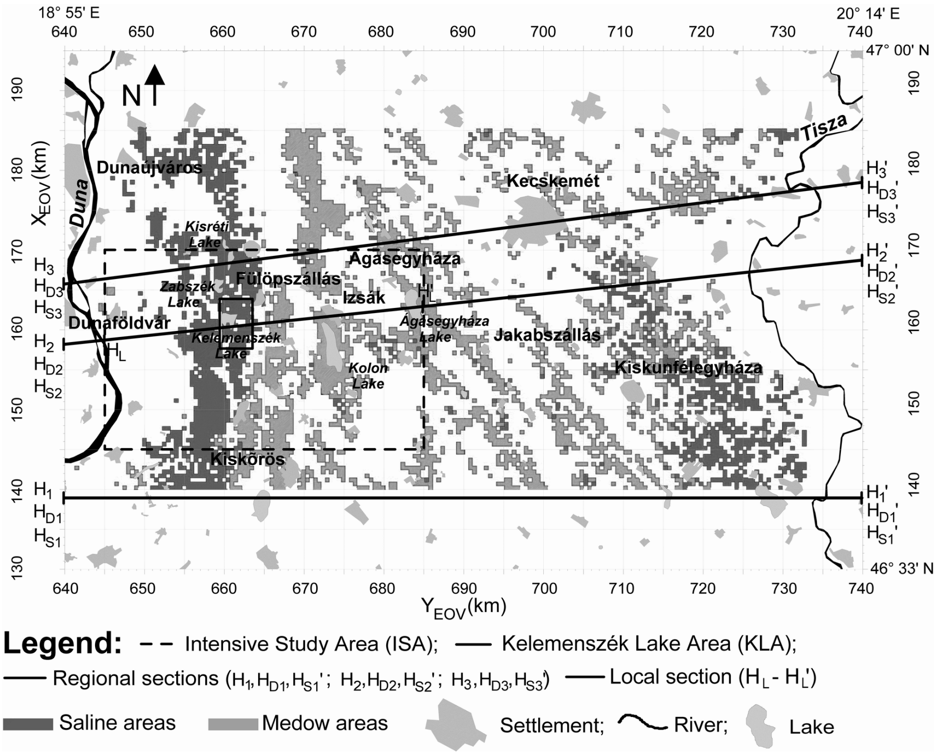


Fig. 9
Ecological site map for the Danube–Tisza Interfluve (from Mádl-Szőnyi and Tóth 2009)

Interpretation

The results of this study can be interpreted within the framework of a coherent schematic hydrogeologic section (Fig. 10) (Mádl-Szőnyi and Tóth 2009). Two groundwater flow-domains were identified in the area: a gravity-driven meteoric fresh water one with a TDS less than 500 mgL^{-1} and an over-pressured deeper domain of saline water (Fig. 3). The total dissolved solid contents of the saline water decreases from 30000 to 10000 mgL^{-1} in the basement to a minimum of 1500–6000 mgL^{-1} in the near-surface zone (Fig. 8). The gravity-flow pattern conforms to the topography, while hydraulic heads are uniformly more than 10 m above surface from depths below 350–400 m (Fig. 3). The gravity systems are hydraulically perched by the ascending over-pressured water. The superjacent fresh-water "lens" forces the ascending deep water toward discharge areas in the valleys of the Danube and the Tisza. The pathways of ascending water are influenced by the eastward-dipping Pre-Neogene basement, and the variable

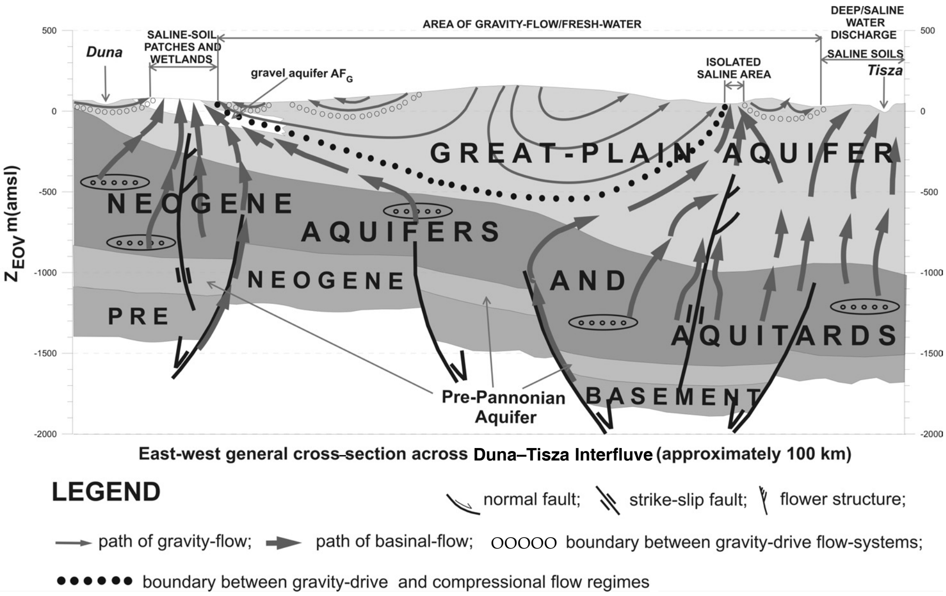


Fig. 10
The Danube–Tisza Interfluve hydrogeologic type section, Hungary (Mádl-Szőnyi and Tóth 2009)

thickness and tectonic structure of the aquitards. Beside the tectonically-controlled ascent of the deep water, cross-formational flow through the matrix of the aquitards cannot be excluded. Flower structures dissect the aquitards in the basin, providing direct hydraulic connections between basement and the upper aquifers. The energy of gravitational systems is not sufficient to push the fresh water as far as the true Danube channel in the western part of the SA; their water is therefore already discharged in the Danube Valley. In this area deep saline water and the meteoric water are conveyed together along a gravel aquifer into the Danube Valley (Figs 2, 3, 6, 8). This highly permeable gravel bed subcrops at the eastern edge of the valley, causing Lake Kelemenszék to be saline. Lake Kolon receives meteoric groundwater in a through-flow position, whence its fresh chemical character (Figs 5, 6, 8). The cross-formational and/or tectonically-controlled ascent of the deep water, combined with the gravitational systems' geometry and the flow channeling effect of the near-surface rocks, explain the contrasting chemistry between Lakes Kelemenszék and Kolon, as well as the origin and pattern of soil salinization (Fig. 9). The energy of the gravitational systems also increases with the increase of the topographical elevation in the eastern part of the Danube–Tisza Interfluve from south to north (Fig. 3a, b, c). Consequently, the discharge of gravity flow is shifted gradually from west to east in a northward direction. Toward the north, ascending salt water is discharged only beyond the Tisza River. However, isolated saline areas can occur in the Interfluve's fresh-water areas as well, possibly owing to some conductive structures reaching within 200 m from the surface.

Summary and Conclusion

The Danube–Tisza Interfluve has an agricultural economy but is plagued by severe problems of soil and wetland salinization. Protection of wetlands and saline marshes is a significant task for nature conservation activity. The objective of the study was to determine the source of the salts and the controls and mechanisms of their distribution in the frame of the Danube–Tisza Hydrogeologic Type Section (Mádl-Szőnyi and Tóth 2009).

To this end, flow-patterns and the salinity of groundwater based on archive data were evaluated within a 100 × 65 km area, with emphasis on the wetlands of Lakes Kolon and Kelemenszék at the western flank of the area. In the Danube–Tisza Interfluve a gravity-driven meteoric fresh water regime and an overpressured saline water one were identified (Mádl-Szőnyi and Tóth 2009). In the framework of the type section the sources of the surface salinization were found to be NaCl-type water of the Pre-Neogene basement and $NaHCO_3$-type water of the younger sediments. The NaCl-type water of the Pre-Neogene basement reaches the near-surface sediments mainly through conductive faults due to overpressure. The cross-formational ascent of the deep NaCl- and the Na HCO_3-type water of the basin, combined with the gravitational systems' geometry and the flow-channeling effect of the near-surface rocks, explains the pattern of soil salinization and the contrasting chemistry between the saline-type Lake Kelemenszék and the fresh-water type Lake Kolon.

Acknowledgements

The authors are pleased to acknowledge the assistance and contributions received from the Kiskunság National Park (A. Iványosi-Szabó) and the Institutes for Soil Science (Zs. Bakacsi) and Agricultural Chemistry, and Ecology and Botany (Zs. Molnár) of the Hungarian Academy of Sciences. In the chemical data interpretation, the contribution of I. Varsányi, professor of hydrogeochemistry (University of Szeged, Hungary) is highly acknowledged. Particular thanks are due to Sz. Simon, R. Varga, and F. Zsemle for their technical contribution. The research was supported by the Hungarian Science Foundation (OTKA) grant No. T 047159 for J. Mádl-Szőnyi, No. T-060861 for Gy. Pogácsás and the Canadian Natural Sciences and Engineering Research Council's "Discovery grant" No. A-8504 for J. Tóth.

References

Arany, S. 1956: A szikes talaj és javítása (The Salt-Affected Soil and its Amelioration). – Mezőgazdasági Kiadó, Budapest, 407 p. (In Hungarian.)

Balogh, J. 1840: A magyarországi szikes vidékek (The salt-affected soil regions of Hungary). – Természettudományi Pályamunkák, A Magyar Tudós Társaság, Buda, 123 p. (In Hungarian.)

Bérczi, I., J. Kókai 1976: Hydrogeological features of some deep-basins in SE-Hungary as revealed by hydrocarbon exploration. – In: Rónai, A. (Ed.): Hydrogeology of Great Sedimentary Basins. Hungarian Geological Institute, Mémoires XI. Budapest. pp. 69–93.

Biró, M. 2003: A Duna–Tisza köze aktuális élőhelytérképe (The Map of the Present Biohabitat of the Danube–Tisza Interfluve). – In: Molnár, Zs (Ed): A Kiskunság száraz homoki növényzete (Sand dunes in Hungary, Kiskunság). Természet BÚVÁR Alapítvány Kiadó, Budapest. (In Hungarian.)

Brezsnyánszky, K., J. Haas, S. Kovács, T. Szederkényi 2000: Geology of Hungary 2000-Basement Geology. – Hungarian Geological Institute, Budapest. Special Publication.

Erdélyi, M. 1976: Outlines of the hydrodynamics and hydrochemistry of the Pannonian Basin. – Acta Geologica Academiae Scientiarium Hungarica, 20, pp. 287–309.

Haas, J., G. Hámor, L. Korpás 1999: Geological setting and tectonic evolution of Hungary. – Geologica Hungarica Series Geologica, 24, pp. 179–196.

Hámor, G., Gy. Pogácsás, Á. Jámbor 2001: Paleogeographic/structural evolutionary stages and related volcanism of the Carpathian-Pannonian Region. – Acta Geologica Hungarica, 44/2–3, pp. 193–222.

Juhász, Gy. 1991: Lithostratigraphic and sedimentological framework of the Pannonian (s.l.) sedimentary sequence in the Hungarian Plain (Alföld), Eastern Hungary. – Acta Geologica Hungarica, 34, pp. 53–72.

Kiss, I. 1979: Vízfeltörések szerepe a szikes talajok "tarkasága" kialakításában (The role of groundwater outbreaks in the "variegation" of salt-affected soils). – Botanikai Közlemények, 66/3, pp. 177–184. (In Hungarian.)

Kiss, I. 1990: A vízfeltörések formái és szerepük a szikes területek kialakulásában (The forms and role in the genesis of salt-affected areas). – Hidrológiai Közlöny, 70/5, pp. 281–287. (In Hungarian.)

Kovács, Gy. 1960: A szikesedés és a talajvízháztartás kapcsolata (Relation between soil salinization and the groundwater budget). – Hidrológiai Közlöny, 40/2, pp. 131–139. (In Hungarian.)

Kovács-Láng, E., Gy. Molnár, S. Kröel-Dulay, S. Barabás (Eds) 1999: Long Term Ecological Research in the Kiskunság, Hungary. Institute of Ecology and Botany, Hungarian Academy of Sciences, Vácrátót, 64 p. (In Hungarian.)

Kuti, L. 1977: Az agrogeológiai problémák és a talajvíz kapcsolata az Izsáki térképlap területén (Relation between agricultural problems and groundwater in the area of the Izsák map sheet). – Magyar Állami Földtani Intézet Évi Jelentése az 1977. évről, Budapest. pp. 121–130. (In Hungarian.)

Kuti, L., L. Kőrössy 1989: Az Alföld Földtani Atlasza: Dunaújváros-Izsák (The geologic atlas of the Hungarian Great Plain: Dunaújváros-Izsák). – Magyar Állami Földtani Intézet, Budapest. (In Hungarian.)

Mádl-Szőnyi, J., J. Tóth 2009: A hydrogeological type section for the Duna–Tisza Interfluve, Hungary. – Hydrogeology Journal. DOI: 10.1007/s10040-008-0421-z

Mészáros, E. 2005: Hidrogeológiai célú szeizmikus értelmezés a Duna-völgy északkeleti részén (Seismic interpretation for hydrogeological purposes at the NE part of the Danube Valley). – MSc Thesis, Eötvös Loránd University, Department of Applied and Environmental Geology, Budapest. 84 p. (In Hungarian.)

Molnár, B., l. Kuti 1978: A Kiskunsági Nemzeti Park III. sz. területén található Kisréti-, Zabszék-, és Kelemenszék-tavak környékének talajvízföldtani viszonyai (Shallow groundwater conditions around Lakes Kisrét, Zabszék, and Kelemenszék in area No. III of the Kiskunsági National Park). – Hidrológiai Közlöny, 58/8, pp. 347–355. (In Hungarian.)

Molnár, B., A. Iványosi-Szabó, J. Fényes 1979: A Kolon-tó kialakulása és limnogeológiai fejlődése (The origin and limnogeological evolution of Lake Kolon). – Hidrológiai Közlöny, 59/12, pp. 549–560. (In Hungarian.)

Nagymarosy, A. 1990: Paleogeographical and paleotectonical outlines of some Intracarpathian Paleogene basins. – Geologica Carpathica, 41/3, pp. 259–274.

Nemcok, M., Gy. Pogácsás, L. Pospišil 2006: Activity timing of the main tectonic systems in the Carpathian–Pannonian Region in relation to the rollback destruction of the lithosphere. – In: Golonka, J, F.J. Picha (Eds): The Carpathians and their foreland: Geology and hydrocarbon resources. American Association of Petroleum Geologists Memoir, 84, pp. 743–766.

Pogácsás, Gy., L. Lakatos, A. Barvitz, G. Vakarcs, Cs. Farkas 1989: Pliocén kvarter oldaleltolódások a Nagyalföldön (Pliocen and Quaternary strike-slips in the Great Hungarian Plain). – Általános Földtani Szemle, 24, pp. 149–169. (In Hungarian.)

Royden, L., F. Horváth (Eds): 1988: The Pannonian Basin: A Study in Basin Evolution. – American Association of Petroleum Geologists, Memoir, 45, pp. 1–394.

Rumpler, J., F. Horváth 1988: Some Representative Seismic Reflection Lines and Structural Interpretation from the Pannonian Basin. – American Association of Petroleum Geologists, Memoir, 45, pp. 153–170.

Sigmond, E. 1923: A hidrológiai viszonyok szerepe a szikesek képződésében (The role of hydrological conditions in the genesis of saline soils). – Hidrológiai Közlöny, 3/1, pp. 5–9. (In Hungarian.)

Simon, Sz. 2003: Tó és felszín alatti víz közötti kölcsönhatás vizsgálata a Duna–Tisza közi Kelemen-szék tónál (Study of the interaction between lake water and groundwater at Kelemen-szék Lake of the Danube–Tisza Interfluve). – MSc Thesis, Eötvös Loránd University of Sciences, Hungary. (In Hungarian.)

Tessedik, S. 1804: A tiszavidéki szikes földek műveléséről, hasznosításáról (About the agricultural use and beneficiation of saline soils in the Tisza region). – Patriotisches Wochenblatt für Ungarn 27, 6 p.

Tóth, T. 1999: Dynamics of salt accumulation in salt-affected soils. – In: E. Kovács-Láng, Gy. Molnár, S. Kröel-Dulay, S. Barabás (Eds): Long Term Ecological Research in the Kiskunság, Hungary. Institute of Ecology and Botany, Hungarian Academy of Sciences, Vácrátót pp. 25–26. (In Hungarian.)

Tóth, J., I. Almási 2001: Interpretation of observed fluid potential patterns in a deep sedimentary basin under tectonic compression: Hungarian Great Plain, Pannonian Basin. – Geofluids, 1/1, pp. 11–36.

Treitz, P. 1924: A sós és szikes talajok természetrajza (Nature study of the saline and salt-affected soils). – Stádium, Budapest 311 p. (In Hungarian.)

Várallyay, Gy. 1967: A Dunavölgyi talajok sófelhalmozódási folyamatai (Salinization processes of the Danube Valley soils). – Agrokémia- és Talajtan, 16/3, pp. 327–349. (In Hungarian.)