JOURNAL OF ENVIRONMENTAL GEOGRAPHY
Journal of Environmental Geography 7 (3–4), 13–19.
DOI: 10.2478/jengeo-2014-0008
ISSN: 2060-467X

MAPPING FRESHWATER CARBONATE DEPOSITS BY USING GROUND-PENETRATING RADAR AT LAKE KOLON, HUNGARY

Eszter Pécsi[1*], Orsolya Katona[1], Károly Barta[1], György Sipos[1], Csaba Biró[2]

[1]Department of Physical Geography and Geoinformatics, University of Szeged, Egyetem u. 2-6, H-6722 Szeged, Hungary
[2]Directorate of Kiskunság National Park, Liszt F. u. 19, H-6000 Kecskemét, Hungary
*Corresponding author, e-mail: pecsi.eszter18@gmail.com

Research article, received 02 March 2014, accepted 13 May 2014

Abstract

Freshwater carbonate deposit, as a special phenomenon in the Danube-Tisza Interfluve, located in the centre of Hungary, is a significant geological heritage in the Carpathian Basin. At present there is not any applicable method to investigate the presence of carbonate layers in an undisturbed way, as neither vegetation nor morphological characteristics indicate unambiguously these formations. Ground-penetrating radar technology is widely used in various earth science related researches, and the number of applications is steadily increasing. The aim of the study was to determine the spatial extension of freshwater limestone using geophysical methods near Lake Kolon, Hungary. The lake, which is now a protected wetland area with opened water surfaces, was formed in the paleo-channel of the River Danube. Measurements were performed with the help of ground-penetrating radar, the results were calibrated by high spatial resolution drillings. Investigations have been made since 2012, and freshwater limestone was detected at several locations determining the more exact extension of the formation. Ground-penetrating radar proved to be an appropriate method to detect the compact and fragmented freshwater limestone layers in such an environment. However, based on the results the method can be best applied under dry soil or sediment conditions while the uncertainty of the results increases significantly as a matter of higher soil moisture. Further control measurements are necessary verified by several drillings in order to give an exact method to determine freshwater limestone.

Keywords: freshwater limestone, ground-penetrating radar, Lake Kolon, drilling

INTRODUCTION

Freshwater limestone is a significant but unique geological formation (Philip, 1987) in the arid and semiarid areas around the World. It can be found in California, where besides geological research it is also used for building purposes (Goodfriend and Stipp, 1983). In Australia a vast amount of freshwater limestone has been formed, here wine is being cultivated on the surface (Johns, 1963). Similar formations have evolved in Iran and in Inner-Anatolia (Thomas et al., 1981; Gail et al., 2014).

In Hungary it has been mined since the Arpad era, it has been used for building purposes, which is being neglected nowadays. The reason may be the artificial improvement of building material, as well as the delivery made easier with the improvement of technology and logistics. Tálasi (1946) pointed out the usage of freshwater limestone during his ethnographical research in Danube-Tisza Interfluve. He emphasized in his study that freshwater limestone is being mined and made use of the same way as two centuries before. Since the 1970’s environment protection has been given more emphasis, and the unique nature of freshwater limestone has been largely recognized as well. As a result, more and more people think that it is essential to gain thorough knowledge of this geological formation, because, it being a unique formation, it is part of our geographical heritage, and by studying it, we are able to understand the details of its formation process (Sümegi et al., 2013).

Despite the fact that the appearance of freshwater limestone is known in Danube-Tisza Interfluve, there is not any applicable method which would be able to prove its presence from either ecological or morphological characteristics.

The aim of this research is to border both the solid, compact and scattered freshwater limestone with help of ground-penetrating radar on two study areas. It was tried to determine the presence and deepness of freshwater limestone both with boreholes and with ground-penetrating radar. The results received by the ground-penetrating radar were calibrated with the drilling data, so it was able to border the extension of freshwater limestone on the study areas.

In order to find out the spatial extension of freshwater limestone, measurements with the help of ground-penetrating radar have previously taken place in Turkey (Selma, 2008). The main aim of this study was to determine the thickness of freshwater limestone with ground-penetrating radar on Turkish study areas, as well as to map the caves and joints in the limestone.

During the research several fissures and caves were located, and an accurate estimate was given about the deepness of freshwater dolomite.

Further ground-penetrating radar research took place in Denmark, but not on freshwater dolomite (Nielsen et al., 2004). During the measurements the geometrical characteristics of limestone structure were mapped. That way it is possible to forecast the possible behaviour of limestone layers, in case of seismic events. As a result, an important evaluation came to existence about contingencies concerning reservoirs on limestone surfaces.

A similar study took place in Germany; it’s about to map limestone’s structure (Asprion et al., 2000). The measurements proved that the ground-penetrating radar is particularly suitable for analyzing limestone, defining its geomorphological structure, and it provides help in defining the individual facies in the limestone structure.

The aim of this study is to prove that ground-penetrating radar is suitable to determine where this geological formation can be found and regardless of whether the freshwater limestone is compact or fragmented.

Dolomite formation in the Danube-Tisza Interfluve

The process of dolomite formation is probably most thoroughly described by Morrow (1982). The formation process is the thermodynamical transformation of dolomite, lasting from calcite to dolomite (Morrow, 1982; Jenei, 2007). It is pointed out that the two main influencing factors are the velocity of crystallization and the proportion of Ca/Mg. This lattest one can help the process if it is higher than 1.

Carbonates in the Danube-Tisza Interfluve have been given attention since the 1930’s (Faragó, 1938). Formations and sedimentary rocks from the ice age and from the Holocene have been studied in the area and as part of these geological researches freshwater limestone has also been examined (Miháltz, 1938, Miháltz and Faragó, 1945). Besides the formation process the spatial extension of this phenomenon has also been pointed out. It was stated that carbonate rocks had been formed in loess and in small patterns near blown sand forms and in lakes’ deeper carbonate sludge layers (Mucsi, 1963). It was also pointed out that the water level of several lakes is found lower than the groundwater level of the neighbouring territories, so the groundwater with different solute minerals inside is leaking towards the lakes helping the carbonate accumulation (Miháltz and Mucsi, 1964).

Later geochemical, paleontological and sedimentological research was made on this formation (Molnár and Kuti, 1978a). During the research the evolution conditions of freshwater limestone have been defined, the environmental conditions determining the evolution of freshwater limestone have been presented, the time interval, during which under the given environmental conditions this significant geological formation evolved, was restricted. Besides, they proved that during the evolution process evaporation is of immense importance, as the solute minerals can move closer to the surface of the soil (Molnár and Kuti, 1978b). They stated that sodic lakes include a vast amount of calcium, so the conditions are given to the formation of freshwater limestone. Via collected water samples it has been established that the proportion of CO_3/Ca is always higher than one, therefore the formation of dolomite can take place in the investigated area (Molnár and Jenei, 2006).

Several further publications can be found about pollen analytical, malacological, and sedimentological researches about the Kiskunság (Sümegi et al., 1991; Molnár and Botz 1996; Sümegi et al., 2005; Jenei et al., 2007; Sümegi et al., 2011).

These publications also mention several aspects of freshwater limestone around Lake Kolon. During these researches the picture about environmental conditions and their changes has been clarified as well. At the end of the ice age, a significant climate change took place, which induced several further changes, and thus enabled the formation of freshwater limestone in Kiskunság. The local accumulation of blown sand started at this period as well, this is today’s bedrock level in Kiskunság (Sümegi et al., 2013). Eolic forms like hummocks, and parabolic dunes evolved in this period. Besides, they stated that the accumulation of chemical components necessary for the formation on freshwater limestone, like Ca and Mg, took place in sedimentary basins, and hollows between hills (Iványosi, 2013). The accumulation of carbonate sludge is very typical in the soils of the Danube-Tisza Interfluve and several carbonate resources are worth mentioning in this area (Fügedi et al., 2008; Molnár, 1980). One of them is the organic resource originated from fossil remains like snails and shells, which plays a significant part during formation. Another carbonate resource determining process is the changing ground water level and the capillary water lifting that is also an influential factor. In warm periods, the salts in the groundwater approach the surface with the steaming water, then they are evaporated. The rock hardening takes place in this period, along with the cementation of the accumulated carbonate sludge, which in this case, is a fast process, in which the periodical water cover is a determining factor. If there is a permanent water cover, then there is no possibility to dry surface and subsurface layers, so compact freshwater limestone is unable to be formed, only uncompacted carbonate sludge remains in the area (Sümegi et al., 2013).

STUDY AREA

Lake Kolon is located in the middle of Hungary, in the Danube-Tisza Interfluve (Fig.1); it is the greatest and most significant freshwater swamp of the region. It is situated in north-western direction from the settlement Izsák, it is approximately 7 kilometers long and it is found 5-6 kilometers eastwards from the western border of Kiskunság Sand Back.

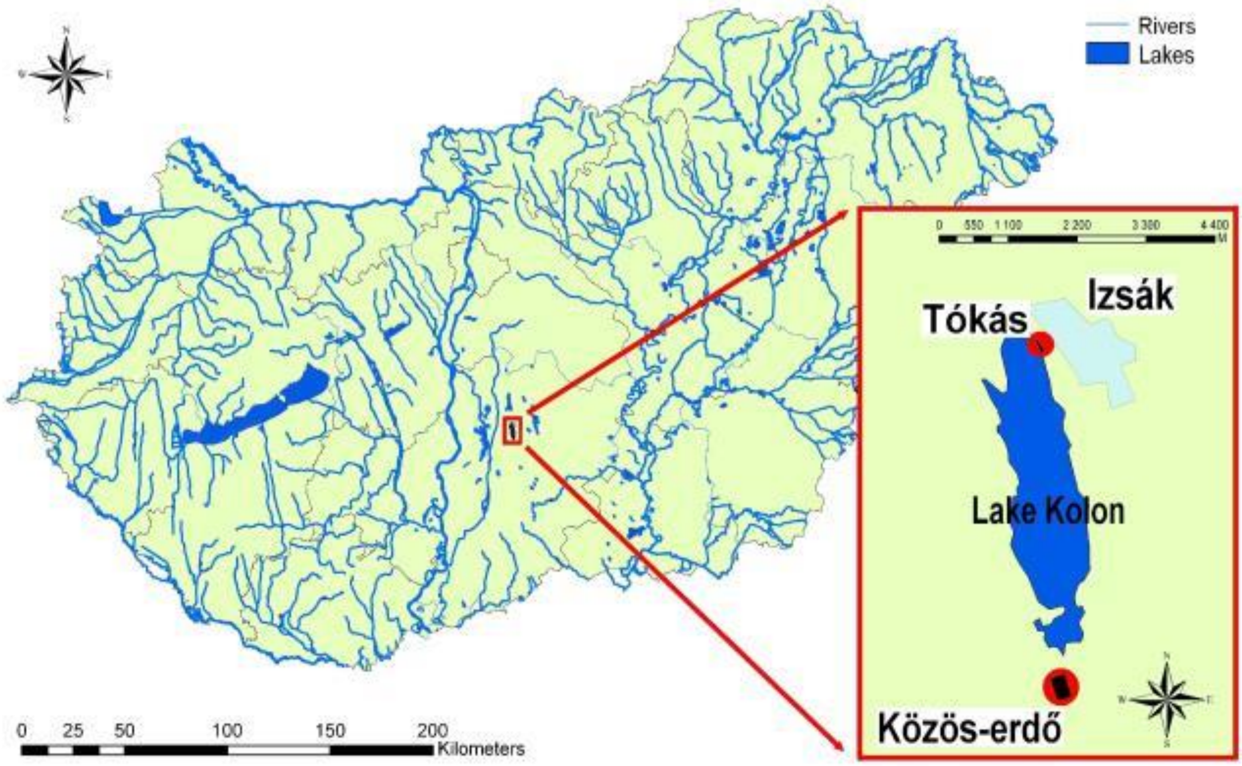

Fig. 1 Location of Lake Kolon in Danube-Tisza Interfluve and the two sample sites

The lake and its environment are found in an excessively fragmented area. The area is divided into three geomorphological units:

- Bikatorok Hill and its environment (W from the lake) were formed by aeolian processes, elder fluvial sediments are buried by sand. The highest point of this area is Revecke Hill with height 120 m.
- Lake Kolon and its near environment are in the ancient Danube riverbed. Its shape's direction is north-south, the bed is gradually rising from west to the east.
- Sandy loess back near Izsák is a little bit higher surface formed by wind but with lower relief than Bikatorok.

Lake Kolon is part of the Kiskunság National Park and the marshlands and surrounding areas are strictly protected. The extension of the National Park exceeds 48.000 hectares, the lake itself is 2962 hectares from it.

Two sample sites have been appointed in the lake basin. The northern one so called "Tókás" (Fig. 1.) is located in the direct neighbourhood of Izsák, in the south-western direction, the north-eastern shore of Lake Kolon; as a natural meadow. The height difference between the highest and lowest points is 1.2 meter.

The second study area is situated on the southern part of Lake Kolon, near the ash-oak bog forest called "Közös-erdő". The study area is located on its margin as a swamp meadow with variable hydrological and ecological conditions from permanent water cover until steppe-like grasslands.

MATERIALS AND METHODS

In order to map the freshwater limestone on the sample sites, first hand drill and the Pürkhauer sticking rod was applied. When it has reached the freshwater limestone, its deepness was measured from the surface, as well as its appearance (hooked, compact, etc.). Guessing from the occurrence of freshwater limestone based on its formation process, it was mapped with denser drilling network, but at the same time there were several control points on higher surfaces as well; so altogether on the northern area was made more than 100, while at Gulya-kút about 140 boreholes.

The digital elevation model (DEM) of the study areas was prepared in ArcGIS. With the help of DEMs it was possible to locate the territories more effectively, where freshwater limestone might have been formed with more probability. It can be found in lower relief, closed hollows, and under their concave slopes. That way it is possible to make impoundment on both sample sites, with combining drilling data with the ground-penetrating radar results.

In the sections between the point-like drillings it's possible to map freshwater limestone with the help of ground-penetrating radar. Ground-penetrating radar consists of a transmitter, a receiver and a control unit (Katona et al., 2013). Its operation is based on the transmitter emitting electromagnetic impulses, which has strong reflection from even surfaces and depending on electromagnetic characteristic of the investigated surface diffraction can occur (Jol, 2009). Electrical permittivity, magnetic permeability and electrical conductivity determine the reflection of electromagnetic waves from objects in the investigated material. The reflected wave is being received by the receiver, after the registration the data, stored in digital form (Cardimona et al., 2000). Because of the measurement area of the ground-penetrating radar, it is not possible to give the locality with absolute precision, because the ground-penetrating radar transmits electromagnetic impulses in the subsurface layers forwards and backwards in 60° angle, sideward in 90° (Casa et al., 2000). The differences in the measured material can be determined based on the reflected signal amplitudes, frequency and phase.

The measurements were completed with 400 MHz antenna, in central frequency. On the northern shore of Lake Kolon altogether 7 ground-penetrating radar cross sections were registered and 6 ones on the southern sample site. Ground-penetrating radar segments were planned mainly through points, where during the previous drillings freshwater limestone has been found. Recording these points has been important because of the calibration with ground-penetrating radar.

First static correction was applied on the registered segments. After that, band pass filter was applied to remove noise. Migration steps were used to determine the velocity of electromagnetic wave in the different part of the investigation area. By analyzing the magnitude and frequency, it was possible to allocate the presence of freshwater limestone on the ground-penetrating radar map.

Ground-penetrating radar was used for the determination of limestone amounts on the previously allocated points based on samples taken from the soil. Altogether 5 segments and 25 soil samples have been collected. The carbonate content in the samples was determined with Scheibler calcimeter. In light of the results it is possible to border the territories where there is a high carbonate capacity in the soil. That way the ground-penetrating radar measurements can be calibrated with pedological properties, because both soil conditions and its physical characteristics influence the results of ground-penetrating radar measurements.

RESULTS AND DISCUSSION

At "Tókás" freshwater limestone was found in 45 cases between 35 and 100 cm deep in the soil, while at 60 boreholes the presence of the formation is not detected. Besides at "Gulya-kút" freshwater limestone was found at 64 points, between 60 and 120 cm deep; at 55 points it was not detected the presence of freshwater limestone with drilling. Where its presence was not obvious, in these cases it is due to the soil being full of pieces of limestone and this condition inflicts same received signal like dolomite on the ground-penetrating radar map. These cases occurred 5 times on the north, and 10 times on the south. Based on the drillings, one can state that freshwater dolomite is not a continuous strata, but a fragmented phenomenon on the study areas (Fig. 2).

In order to eliminate the uncertainty, ground-penetrating radar measurements were calibrated with drilling results. On the deeper reliefs the drilling results unanimously proved, how the freshwater limestone might have been formed; this has been supported by the ground-penetrating radar research, according to which a more dominant signal can be detected on these points. Here the signal is stronger on the ground-penetrating radar map, but probably not because of the

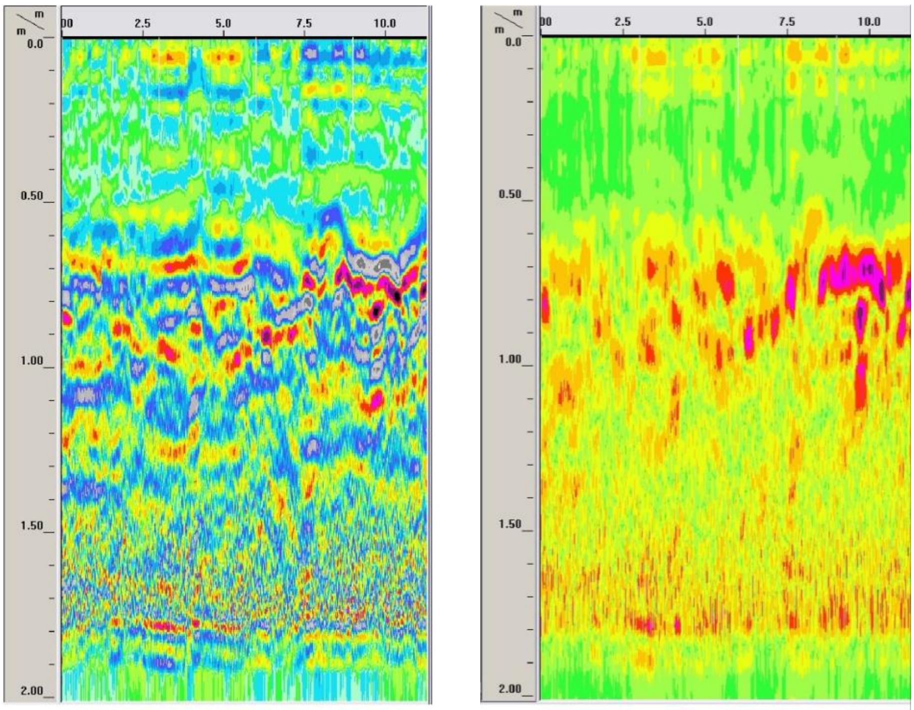

Fig. 2 Ideal case: detection of freshwater limestone's presence based on the electromagnetic wave magnitude
Left: compact limestone, right: fragmented limestone (2012)

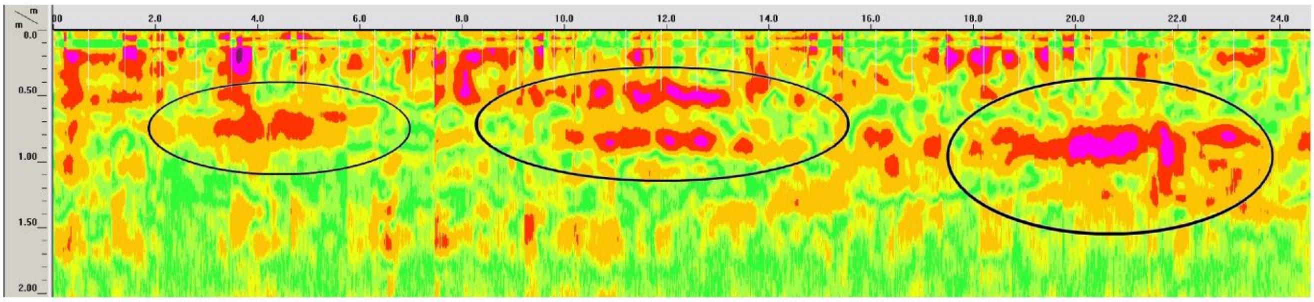

Fig. 3 Calibrated on the basis of drilling data, ground-penetrating radar cross section recorded in dry period. There is fragmented formed limestone between compact layers (marked in black) (2012)

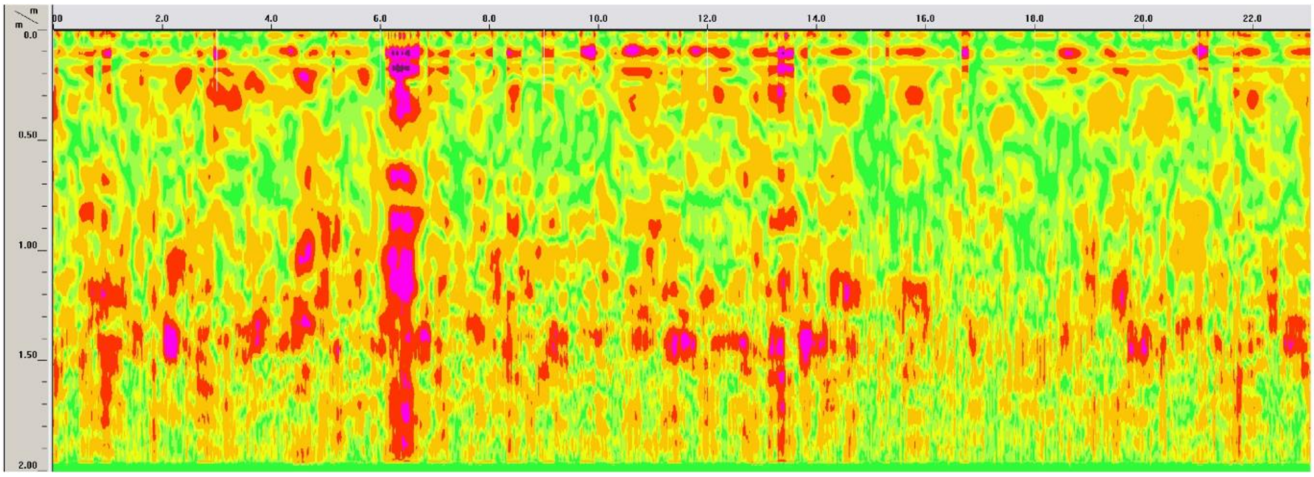

Fig. 4 A ground-penetrating radar image received after rainfall in October 2013. Existence of freshwater limestone is not clear

physical characteristics caused by the high amount of limestone in the soil, but because of the presence of freshwater limestone. Nevertheless, on points, where based on the drillings, no dolomite can be found, the ground-penetrating radar still measured under surface discrepancies, this is due to the fragmented nature of the formation, along with the aforementioned high amount of carbonate, which on the northern sample ground collected from the given deepness, is 28,8%, while on the southern sample grounds 53%.

Previously, in autumn 2012 ground-penetrating radar research was conducted. This year it was examined after a long dry period, with deep groundwater. At this time it was possible to unequivocally determine the compact and fragmented limestone, it was not necessary to take into consideration the disturbing effect of high carbonate-content of the soil on the ground-penetrating radar maps (*Fig. 3*).

A year later measurements were made after a rainfall period with high groundwater (Autumn 2013). Although the high soil moisture content enhances the amplitude of the electromagnetic waves, it causes signal loss. Due to the signal loss interpreting the ground-penetrating radar segments proved to be difficult, therefore it wasn't possible unequivocally to determine the presence of limestone. In the deeper layer, during the set fortifications in the measurements the formations close to the surface are not reflected, so it is not possible to unequivocally border the freshwater limestone (*Fig. 4*).

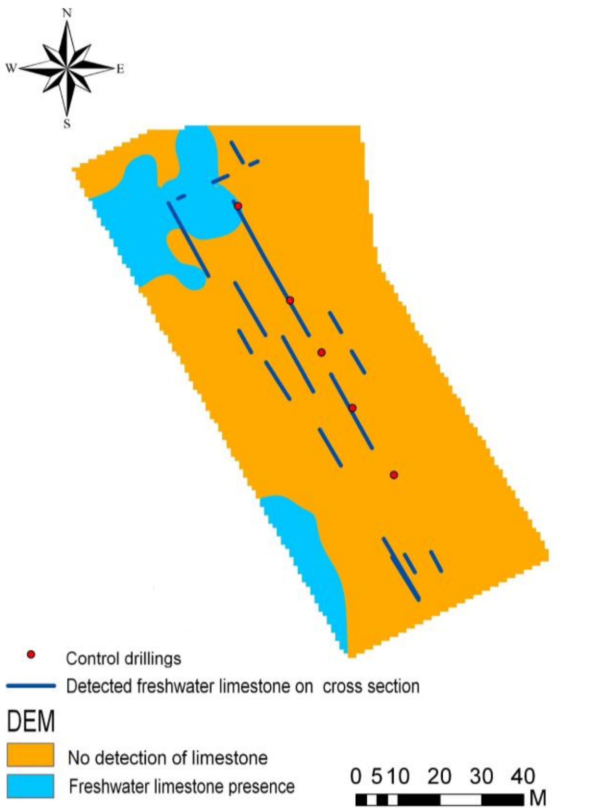

Fig. 5 Results of the investigation in the northern study area (Tókás)

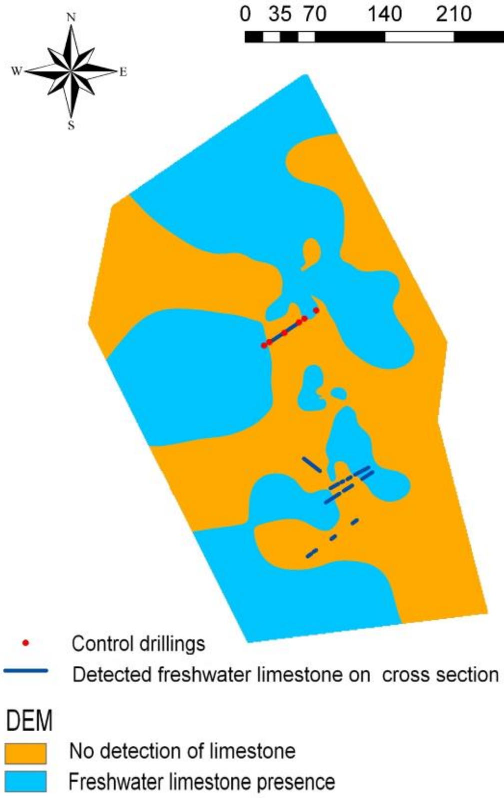

Fig. 6 Results of the investigation in the southern study area (Gulya-kút)

CONCLUSIONS

Ground-penetrating radar can be used to map freshwater limestone. It was established that high soil moisture content is not optimal environment for taking measurements; therefore it is worth taking into consideration the given environmental factors. The electromagnetic wave applied by the ground-penetrating radar, due to its characteristics, easily shows freshwater limestone on records on dry soil. The moisture content of the environment largely influences the measurements made by ground-penetrating radar. The moisture content reduces the penetrating deepness, as well as enhances value of the reflected electromagnetic wave's amplitude. Accordingly, although the reflected electromagnetic wave's amplitude is higher, it cannot be applied with such soil conditions, due to the quick absorption of the sign. Dry weather and deep ground water are preferable when making measurements. Therefore, it is advisable to conduct research in early autumn, or in summer, after a long rainfall free period, in order to avoid signal loss. In case of wet, clayey soil the signal loss might be significant.

With the help of ground-penetrating radar both compact and fragmented freshwater limestone can be traced, if the measurement took place during a dry period. Otherwise the ground-penetrating radar cannot clearly distinguish between freshwater limestone and high carbonated soil because of its characteristics. In this case it is worth combining research data with other methods, in order to specify the final results. It means that ground-penetrating radar can open new perspectives for mapping freshwaters limestone: the former point based mapping can be changed to linear mapping (*Fig. 5-6*) that gives us more adequate and faster method for determining its spatial extension.

References

Asprion, U., Aigner, H., Aigner, T. 2000. An initial Attempt to Map Carbonate Buildups Using Ground-Penetrating Radar: an Example from the Upper Jurassic of SW-Germany. Erlangen (2000) 42, 245–252.

Cardimona, S., Webb, D. J., Lippincott, T. 2000. Ground Penetrating Radar. Department of Geology and Geophysics, University of Missouri-Rolla, Rolla, MO., 2–9.

Casa, A., Pinto, V., Rivero, L. 2000. Fundamentals of ground penetrating radar in enviromental and engineering applications. Annali di Geofisica, Vol. 43, N. 6, December 2000. Department of Chemistry, Petrology, and Geologycal Prospecting, Faculty of Geology, Univerity of Barcelona, Spain, 1091–1097.

Faragó, M. 1938. Nagykőrös környékének felszíni képződményei. *Földtani Közlöny* 68, 144–167.

Fügedi, U., Pocsai, T., Kuti, L., Horváth, I., Vatai J., 2008. A mészfelhalmozódás földtani okai Közép-Magyarország talajaiban. *Agrokémia és talajtan* 57/2, 239–260.

Gail, M. A., Carol, B., Manuel, D-R., Alyssa, M.K., Theresa, M.O., Rodinell, B. 2014. Freshwater Limestone In An Arid Rift Basin: A Goldilocks Effect. *Journal of Sedimentary Research* 84, 988–1004. DOI: 10.2110/jsr.2014.80

Goodfriend, G.A., Stipp, J.J. 1983. Limestone and the problem of Radiocarbon Dating of Land Snail Shell Carbonate. *Geology* 11, 575–577.

Iványosi Szabó, A. 2013. Csólyospálosi Földtani Feltárás Természetvédelmi Terület. In: Kustár, R., Balázs, R. (eds.) Talpalatnyi kő - elveszett emlékeink nyomában. A darázskő. Kiskunsági Nemzeti Park Igazgatóság, 13–22.

Jenei, M. 2007. Tavi karbonátképződés a Duna-Tisza közén. Doctoral (PhD) Theses. Szegedi Tudományegyetem Földtani és Őslénytani Tanszék

Jenei, M., Gulyás, S., Sümegi, P., Molnár, M. 2007 Holocene lacustrine carbonate formation: old ideas in the light of new radiocarbon data from a single site in Central Hungary. Radiocarbon 49/2, 1017–1021.

Johns, R.K., 1963. Limestone, dolomite and magnesite resources of South Australia. South Australia. *Geological Survey. Bulletin*, 38.

Jol, H. M., 2009. Ground Penetrating Radar Theory and Applications. *Elsevier Science*, 13–24.

Katona, O., Sipos, Gy., Fiala, K., Mezősi, G. 2013. A georadar működése és felhasználási területei, különös tekintettel a vízügyi gyakorlatra I. rész: működési elv, fontosabb alkalmazások. *Hidrológiai Közlemények* 93/ 4, 4–7.

Miháltz, I., Mucsi, M. 1964. A kiskunhalasi Kunfehértó hidrogeológiája. *Hidrológiai Közlöny* 44, 463–471.

Molnár, B. 1980. Hiperszalin tavi dolomitképződés a Duna-Tisza közén. *Földtani Közlöny* 120/1, 45–64.

Molnár, B., Botz, R. 1996. Geochemistry and stable isotope ratio of modern carbonates in natron lakes of the Danube–Tisza Interfluve, Hungary. *Acta Geologica Hungarica* 39, 153–174.

Molnár, B., Jenei, M. 2006. A Kiskunsági Nemzeti Park talaj- és felszíni vizek hidrodinamikai és hidrokémiai változásainak összefüggése a tavi karbonát képződéssel. *Hidrológiai Tájékoztató* 45, 57–59.

Molnár, B., Kuti L. 1978a. A Kiskunsági Nemzeti Park III. sz. területén található Kisréti-, Zabszék- és Kelemenszék-tavak keletkezése és limnogeológiai története. *Hidrológiai Közlöny* 58/ 5, 216–228.

Molnár, B., Kuti L. 1978b. A Kiskunsági Nemzeti Park III. sz. területén található Kisréti-, Zabszék- és Kelemenszék-tavak keletkezése és limnogeológiai története. *Hidrológiai Közlöny* 58/ 8, 347–355.

Morrow, D.W. 1982. Diagenesis I. Dolomite – Part 1. The geochemistry of dolomitisation and dolomite precipitation. *Geoscinece Canada* 9, 5–13.

Mucsi, M. 1963. Finomrétegtani vizsgálatok a kiskunsági édesvízi karbonát-képződményeken. *Földtani Közlöny* 93, 373–386.

Nielsen, L., Boldreel, L.O., Surlyk, F. 2004. Ground-penetrating radar imaging of carbonate mound structures and implications for interpretation of marine seismic data. American Association of Petroleum Geologists, *Bulletin* 88, 1069–1082.

Philip, D. ,Gingerich ,1987. Early Eocene Bats (Mammalia, Chiroptera) and other Vertebrates in Freshwater Limestones of the Willwood Formation, Clark's Fork Basin, Wyoming. Contributions from the Museum of Paleontology. The University of Michigan, 27/11, 275–320.

Selma, K. 2008. Photographing layer thicknesses and discontinuities in a marble quarry with 3D GPR visualisation. *Journal of Applied Geophysics* 64, 109–114. DOI:10.1016/j.jappgeo.2008.01.001

Sümegi, P., Gulyás, S., Törőcsik, T. 2013. A kiskunsági édesvízi mészkő és dolomitképződés folyamata a geológiai, a geokémiai és a környezettörténeti elemzések tükrében. In: Kustár, R., Balázs, R. (eds.) Talpalatnyi kő - elveszett emlékeink nyomában. A darázskő. Kiskunsági Nemzeti Park Igazgatóság, 25–86.

Sümegi, P., Molnár, M., Jakab, G., Persaits, G., Majkut, P., Páll, D. G., Gulyás, S., Jull, A.J.,T., Törőcsik, T. 2011 Radiocarbon-dated paleoenvironmental changes on a lake and peat sediment sequence from the central part of the Great Hungarian Plains (Central Europe) during the last 25.000 years. Radiocarbon 52, 85–97.

Sümegi, P., Mucsi, M., Fényes, J., Gulyás, S. 2005. First radiocarbon dates from the freshwater carbonates of the Danube–Tisza Interfluve. In: Hum, L., Gulyás, S., Sümegi, P. (eds.): Environmental Historical Studies from the Late Tertiary and Quaternary of Hungary. University of Szeged. 103–117. Szeged

Sümegi, P., Szöőr, Gy., Hertelendi, E. 1991. Palaeoenviromental reconstruction of the last period of the Upper Würm in Hungary, based on malacological and radiocarbon data. Soosiana, 19, 5–12.

Tálasi, I. 1946. Az Alföld néprajzi kutatásának kérdései és problémái In: Bartucz L. (ed) *Az Alföldi Tudományos Intézet Évkönyve* 1/1944-45, 1–35.

Thomas N. T., Robert M. O., Bruce H. W. 1981. Sr/Ca and Mg/Ca ratio sin polygenetic carbonate allochems from a Michigan marl lake. *Geochimica et Cosmochimica Acta* 45, 439-445. DOI: 10.1016/0016-7037(81)90252-0