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Geophysical exploration of Quaternary formations in the area of the DANREG project

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It was striking for the DANREG project's Geophysics Team that in the area of the Danube's thick Quaternary detrital cone (especially between Bratislava and Győr) not more than a dozen wells penetrated the detrital cone of about 3000 km^2 surface extension. Therefore an effort was made to fill the gaps with common Hungarian-Slovak VES and IP measurements. The results are presented as three apparent resistivity maps for different penetration depths, a thickness map of the coarse gravel sequence and a map of the thickness of the complete Quaternary sequence. An attempt was also made to carry out lithological classification on a smaller area.

The Quaternary sequence in the Vienna Basin was investigated along a single profile consisting of a few transient soundings.

Keywords: VES, transient methods, resistivity, water storage, grain size, DANREG

1. Introduction

A map of the Quaternary formations has been constructed for the whole area covered by the DANREG project. In the central Danube Basin this map is based first of all on geophysical data because only three drillings have penetrated the whole Quaternary sequence in the Hungarian part of this area and nine drillings on the Slovak side. It is for this reason that it is necessary to present and explain the geophysical maps for regions of thickest Quaternary formations separately, in addition to the Quaternary map for the whole DANREG area. These items of information have been obtained mostly by

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vertical electrical soundings (VES). The maximum separation of current electrodes was up to 4 km. Soundings were located along profiles on the Slovak side, as opposed to a quasi-grid on the Hungarian side. This survey was performed in Hungary and Slovakia only because the large basin in question terminates at about the Austrian border. The general objective of the electrical survey was to recognize the horizontal and vertical extent of the Quaternary sequence and its approximate lithology as well. This thick Quaternary sequence is the largest and most valuable drinkwater resource in Central Europe, thus the importance of the survey needs no explanation.

Due to the lack of sufficient geological information, an additional VES survey was also performed. Field measurements at the Slovak and Hungarian sides have been processed using agreed principles and a model of the same character. Consequently, unified maps for the area of clastic sediments deposited by the Danube could be constructed. Correct selection of processing principles and steps has been proven by the fact that unification of the maps was feasible in spite of the lack of data in the border region of several kilometres' width.

From the survey results, the simplified geological structure of the Quaternary sediments for the area in question is as follows: Below a thin (up to several m) and *strongly variable overburden* the highest resistivity (the coarsest grain size) section of the Quaternary sequence, the *gravel layer,* can be found. Below this, a *sandy sequence* of lower resistivity but also of considerable porosity follows which is of Quaternary age as well. The bottom of the water-bearing sequence in the whole area consists of low resistivity, probably *Upper Pannonian fine grained formations*. Results of the common work of Slovak and Hungarian geophysicists are illustrated by several *apparent resistivity maps* compiled for different AB separations (for different penetration depths), by the thickness map of the whole Quaternary sequence and that of the gravel section. In addition to these, a simplified polarizability sketch and, as a matter of methodological interest, a lithologic sketch (practically a hydrogeological zoning) constructed from the resistivity and polarizability values — for the Hungarian side only — are presented. The partial application can be explained by the fact that for instrumental reasons the two teams were able to perform the IP measurements only by using slightly different equipment parameters.

2. Apparent resistivity maps

In a reconnaissance survey of larger areas, construction of such maps is always of practical value. These particular maps show the resistivity distribution at the depth of about one quarter of the actual current electrode (AB) distance. The main advantage of apparent resistivity maps is that on the one hand, they make it easy to recognize the structural lines, faults and other geological features which — if they exist — could result in considerable deviations from the horizontally layered model. And on the other hand, in cases when sharp layer boundaries traceable for long distances are missing, a series of apparent resistivity maps for different penetration depths gives a good qualitative image of the lateral and vertical extent of formations of different resistivities. Apparent resistivity maps have been constructed for current electrode separations AB=200 m, 600 m and 1000 m.

All three apparent resistivity maps *(Figs. 1* to *3*) clearly indicate coarse-grained sediments accumulated in the central part of the basin. The resistivity highs are only slightly elongated in the flow direction, their shapes are practically isometric.

If one examines the three maps together, vertical and horizontal extensions of the gravel sequence can clearly be seen. Although unambiguous numeric values cannot be given, the values above 200 Ωm approximately indicate the coarse gravel section. The largest and highest resistivity maximum can be found on the map of smallest penetration depth (about 40–50 m, AB=200 m) which is evident, knowing the model. Maps for larger depths indicate that the grain size decreases continuously downwards.

Each map shows that the main carrier of sediments was the main branch of the Danube. The peak values of the anomalies are located at the main branch; sedimentary sequences deposited by the Moson Danube and mostly by the Little Danube in Slovakia are of less importance. Sediments deposited by the river Lajta are insignificant.

Definite termination of resistivity anomalies (i.e. that of the sediments) to the north and west can obviously be explained by the surrounding mountains because they bound the young basin. Termination to the southeast is of a different character. The present relief does not provide any reason for it in the vicinity of the city of Győr. Thinning of clastic sediments is supported by the polarizability sketch (*Fig. 4*) as well. It is well-known that in a sedimentary environment the polarizability highs are associated with the fine sand–silt fraction located between sands and clays. This fraction probably

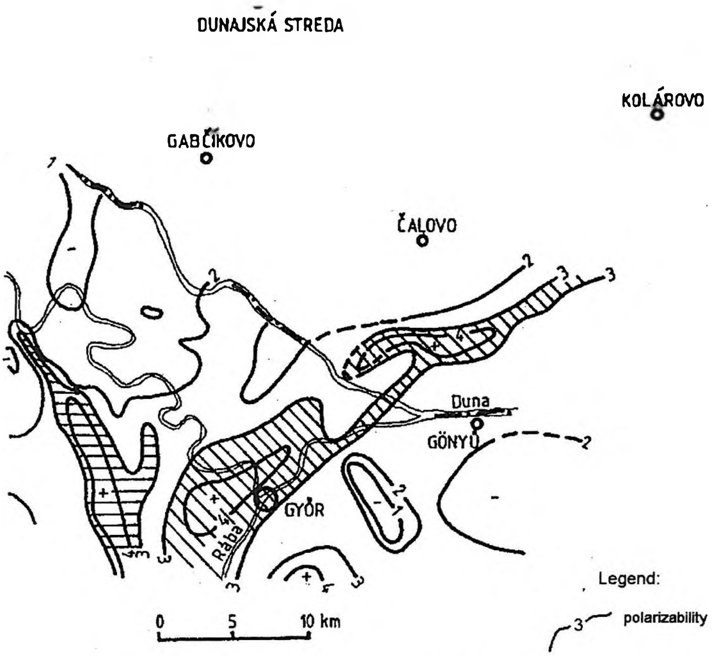

Fig. 4. Polarizability sketch
4. ábra. Polarizálhatósági vázlat

occurs at the edges of coarse grained sequences; the maps prove this expectation. In our interpretation the polarizability highs indicate the borders (fine grained edge zones) of the coarse grained sequence. It is striking that the southeastern border of the thick Quaternary sediments approximately coincides with the Rába-Hurbanovo line. Although the causal relation has not been proven yet, the fact of coincidence suggests that the tectonic lines affecting the Tertiary basement possibly renewed later and this therefore underlines the importance of neotectonic investigations.

Finally, a further interesting fact: east of the city of Győr, where the Danube turns towards the west-east direction, young sediments can hardly be found. A few kilometres north and south of the Danube nearly every anomaly disappears.

3. Thickness map of the whole Quaternary sequence and that of its coarse gravel section

Despite apparent resistivity maps being very reliable, experts using the geophysical results require maps to be interpreted more easily. Since the same geological model can be used for the whole area, the thickness map of the whole Quaternary sequence and that of its coarse gravel section were constructed. In spite of the integrating and approximating nature of geophysical methods, the importance and novelty of these maps should be underlined. Prior to the DANREG project there was only very limited geological information about the whole Quaternary sequence; in fact the paucity of information did not allow one to draw spatial conclusions. This could be done solely on the basis of geophysical results.

The lack of sharp boundaries, consequently the uncertainties about the thicknesses were overcome in the following way:

- Actual depth (thickness) values obtained from several wells, based partly on fossils, were considered as initial information. The 1-D VES inversion started from these several basic points;
- Although the 3-layer structure of the Quaternary sequence is a highly simplified version of the geological reality, the thickness values obtained in this way are more reliable and the constructed thickness maps provide qualitatively correct information.

Figure 5 shows the thickness of the coarse gravel sequence. This is the most important sequence from the viewpoint of water storage. Its greatest thickness — more than 300 m — can be found in the central part of the basin. The sequence is unambiguously associated with the main branch of the Danube. Its thickness is only about 50 m at the Little Danube. Around Bratislava and below Győr both the thickness and extension of this sequence are insignificant.

Figure 6 shows the thickness of the complete Quaternary sequence. In the central part it exceeds 600 m which is a new piece of information in relation to the earlier geological concept. At several points VES up to AB=4000 m was not enough to reach the relatively low resisitivity formations: here they must lie deeper than 700 m. For the time being, though it has been proven indirectly only, — because in the central part no borehole has as yet been drilled down to 600–700 m — the 300 m thickness of the coarse grained formations and thus the correctness of the model and reality of its numerical parameters have already been justified. In the southern–southwestern part of the map having almost circular character the effect of sediments deposited by the river Old Rába can be seen, similarly to every other map. At the southeastern edge the Quaternary sediments suddenly become rather thin, this feature can be seen on all the maps. As has already been mentioned, this change coincides with the Rába-Hurbanovo line.

If one compares all the maps it can be seen that the greatest thickness of the Quaternary sediments (the deepest part of the Quaternary basin) coincides with the resistivity highs. It means that the coarsest sediments have been deposited in the deepest (most intensively sinking) regions.

It should be noted that the whole area can generally be characterized by the lack of surface on near-surface clayey protecting overburden (or at least a layer of poor hydraulic conductivity). Thus, the valuable drinkwater reservoir shown in the previous figures is not protected against surface contamination. It is very vulnerable. This must be kept in mind when planning or carrying out any infrastructural, land use, agricultural, water production, traffic, etc. activities.

4. Hydrogeological zoning

In a sedimentary environment both resistivity and polarizability strongly depend on the average grain size of the sediments; this grain size dependence of both parameters is, however, of different character. This gives us a more realistic image if we examine both parameters simultaneously than on the basis of one parameter alone. Nomograms have been constructed where the axes of the coordinate system are the resistivity and polarizability, and the parameter of the nomogram curves is the dominant grain size (*Fig. 7*). With the help of these nomograms, apparent grain diameters were determined from the measured resistivity and polarizability values. The procedure can be performed for different separations between current electrodes (for different penetration depths), thus a series of lithological sketches were obtained. From these, the sketch for the depth interval from 0 to 200 m is presented (*Fig. 8*; from the water storage point of view, the key to the areas is: 1—best; 2—good; 3—medium; 4—poor; 5—disadvantageous).

The average grain size increases from the clay fraction to the coarse gravel as indicated from green across yellow to brown. This map indicates the coarsest formations in the central part of the young basin as well.

This sketch could be constructed for the Hungarian side only because of the different IP measurements already mentioned. Considering, however, the identical character of the resisitivity maps at the two sides of the Danube and the similar behaviour of polarizability, a considerably different lithological image on the Slovak side cannot be expected.

Summarizing: The centre of the young basin — which is filled with clastic sediments from the Danube — can be found at about half way between Bratislava and Győr, at the Old Danube. Here the greatest thickness of the Quaternary sediments reaches 600–700 m, and that of the coarse gravel sequence exceeds 300 m (at the same site). Thickness isolines and resistivity anomalies are practically of circular shape. Consequently, the sedimentation process on the Slovak and Hungarian sides must have been the same or very similar. The southeastern edge of the thick Quaternary sequence coincides with the Rába–Hurbanovo line. East of Győr young sediments occur only in a zone of several kilometres width; their thickness is insignificant. In general, there is no proper protecting layer above the water-bearing formations.

5. Geophysical investigations in the Vienna basin

No financial resources were available for systematic geophysical investigations of the Quaternary formations in the Vienna basin. At the closing stage of the DANREG project, however, a magnetotelluric profile of northwest-southeast orientation was measured in the basin. Although the uppermost several hundred metres could not be investigated by magnetotellurics, this depth interval should also be known in order to be able to interpret the MT measurements. Therefore transient electromagnetic soundings were carried out along the profile (*Fig. 9*).

Twenty soundings with 4–6 km separation can by no means result in surprising new discoveries. The profile is, however, so characteristic that it is worth presenting here as well.

It is striking that the profile of the depth interval from the near-surface down to about 800 m can be divided into three parts (Fig. 9). In the southern part, high resistivity Quaternary clastic sediments (gravel) of the Danube practically do not occur or are only a few metres thick, thus they cannot be detected by our measurements. Below them lies a sequence of 40–80 Ωm resisitivity and about 30 m thickness which is probably a continuation of the lower (sandy) section of the Quaternary formations obtained at the Slovak and Hungarian sides of the Danube. Northwards along the profile, the situation considerably changes at the Danube. We consider the resistive sequence reaching even a thickness of 600 m to be very similar to the large alluvial fan below Bratislava. Coarse gravel of resistivity above 100 Ωm can be found near the surface. This is underlain by finer grained sandy formations with continuous transition to the Pliocene clayey sequences (decreasing resistivity, decreasing grain size downwards). At the last two points to the north, flysch formations of Upper Cretaceous and Paleocene age can be found on the surface. Consequently, the electrical image obtained from the transient measurements changes completely.

This little example suggests that geoelectric methods can play an important role in the survey of the alluvial fan of Quaternary age in several parts of the Vienna basin.

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A negyedkori összlet geofizikai kutatása a DANREG területen

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1. Bevezetés

Ez a kutatási tevékenység nem terjed ki a DANREG terület egészére. A maximálisan 4 km-es tápelektróda távolságokkal végzett vertikális elektromos szondázások (VESz) elsősorban a Pozsony és Győr közötti medence központi részén voltak jelentősek, ahol korábban csak alig tucatnyi fúrással harántolták a kvarter korú összletet. (A Szigetköz területén mindössze három fúrásban fúrták át a teljes kvarter összletet és a Duna szlovák oldalán sem sokkal többen). A szlovák és magyar geofizikusok egyeztetett mérési és feldolgozó programok alapján dolgoztak és így mód nyílt arra, hogy a Duna hordalékkúpjának vertikális és horizontális elterjedéséről egységes képet nyerjenek.

A hordalékkúp negyedkori összletének földtani felépítése nagy vonalakban a következő: a legfeljebb néhány méter vastag fedőképződmények alatt a rétegsor legnagyobb fajlagos ellenállású, durva-kavicsos összlete települ, majd alatta a finomabb szemcséjű homokos összlet. Ez utóbbi kettő a legfontosabb víztároló. A kvarter feküje a finomhomokos felső pannon. Az egyes összletek között az átmenet folyamatos, éles réteghatárok nincsenek. Ez az oka annak, hogy az összlet jellemzésére látszólagos ellenállás térképeket is szerkesztettünk és ahol a GP méréseket is felhasználhattuk, ott egy kisebb területen kísérletet tettünk litológiai térképvázlat szerkesztésére is.

2. A látszólagos ellenállás térképek

Három térképet szerkesztettünk, a három tápelektróda távolsághoz (AB=200 m, 600 m és 1000 m) tartozó térképek (*1.*, *2.* és *3. ábra*) jól tükrözik a dunai hordalékkúp vízszintes és horizontális elterjedését. Behatolási mélységnek durván az AB/4 értékeket tekinthetjük. A durvakavics fajlagos ellenállása 200 Ωm-nél nagyobbra becsülhető. A három térképet együtt szemlélve látszik, hogy a mélység növekedésével a durvakavics elterjedése egyre kisebb és egyre nyilvánvalóbb, hogy az Ős-Duna hordalékkúpjáról van szó. Érdemes azonban megfigyelni, hogy míg a hordalékkúp elterjedését általában a mély medence központi részével definiálhatjuk, a délkeleti elvégződés kissé meglepő: a Rába-vonal zónájával esik egybe. Ezt a határt rendkívül szemléletessé teszik a GP maximumok, amelyek a durvaszemcsés összlet elterjedésének határán lépnek fel (*4. ábra*). Eredményeink a neotektonikai folyamatok vizsgálatának szükségességére hívják fel a figyelmet.

3. A durva-kavicsos összlet és a teljes kvarter összlet vastagságának térképei

A geológusok, hidrogeológusok egyszerűbben értelmezhető eredményeket, például vastagság térképeket vártak a geofizikusoktól. A korábban említett vastagság bizonytalanságokat úgy enyhítettük, hogy a VESz kiértékelést néhány fúrásban ősmaradványok alapján megállapított vastagság adatokra alapoztuk.

Az *5. ábra* a durvakavicsos összlet vastagság térképe. Vastagsága Lipót község térségében eléri, sőt meghaladja a 300 m-t. Egyértelműen a Duna mai főágának területéhez köthető és feltűnő, hogy a Győr alatti szakaszon sem vastagsága, sem elterjedése nem számottevő.

A *6. ábra* a teljes kvarter korú összlet vastagságát mutatja. A központi részeken 700 m-nél is nagyobb értékeket találunk. Szembetűnő, hogy a Duna hordalékkúpján kívül a délnyugat felől benyúló Rába hordalékkúpnak van még nagyobb jelentősége (vastagsága). A Rába-vonalnál a teljes összlet hirtelen kivékonyodása is megfigyelhető, csakúgy, mint valamennyi kvarter térképünkön.

Megfigyelhető, hogy a központi medence területén gyakorlatilag hiányzik a felszínről egy rossz vízvezető képességű, kisellenállású, agyagos fedő. Így a térképeinken ábrázolt értékes ivóvízbázis felülről védtelen.

4. Hidrogeológiai (litológiai) osztályozás

Mint ismeretes, a kőzetek fajlagos ellenállása és polarizálhatósága is függ a szemcsemérettől, de nem egyformán. A két paraméter együttes mérésével a tapasztalati úton szerzett, *7. ábrán*kon látható diagram segítségével a tápelektródák által definiált kutatási mélységig meghatározhatjuk az átlagos szemcseméretet. Ilyen térképet a behatolási mélység függvényében többet is szerkesztettünk. Példaként itt a felszíntől 200 m mélységig előforduló összlet átlagos szemcseméretének horizontális változását láthatjuk (*8. ábra*). Sajnos, csak a magyar oldalon, mert a szlovák és magyar GP műszerek által mért paraméterek nem azonosak. Erről a térképről is megállapíthatjuk, hogy a legdurvább frakció a mai Duna közelében található és attól távolodva egyre agyagosabb ez az összlet.

5. Geofizikai kutatások a Bécsi medencében

A DANREG program befejező szakaszában került sor a Bécsi-medencében egy 80 km hosszú magnetotellurikus vonal lemérésére. A 20 mérési ponton a felső (mintegy 800 méteres vastagságú) összlet tanulmányozására tranziens elektromágneses szondázásokat végeztünk. Az eredmények a *9. ábrán* láthatók. Az ábra felső részén a látszólagos ellenállás szelvény, az alsó részén a geoelektromos rétegszelvény látható.

Feltűnő a szelvény északnyugati és délkeleti felének különbözősége. A Dunától északnyugatra megjelenő nagyellenállású képződményeket durvakavicsnak, homokos kavicsnak értelmezhetjük. Ez minden bizonnyal a Duna hordalékkúpjával azonosítható, mert fizikai tulajdonságai feltűnően egyeznek a Pozsony–Győr közötti hordalékkúpon mért adatokkal, noha mélyfúrási és őslénytani adatok hiányában nem állíthatjuk, hogy bármelyik réteghatárunk egyértelműen azonosítható a kvarter feküjével. A kvarter–felsőpannon átmenet itt is folyamatos, ugrásszerű szemcseméret és más fizikai paraméterhatár nincs.

Érdekes még, hogy a szelvény északi része, a felsőkréta paleogén flis képződmények területén milyen határozottan különül el a szelvény többi részétől. A Dunától délkeletre pedig érzékelhető, hogy itt gyakorlatilag nincs kvarter, a kisellenállású agyagos összlet alatt a nagyellenállású lajtamészkő és annak kristályos aljzata egyetlen geoelektromos réteg. E zónától a magyar területek felé a Kisalföld medencéjének szegélyét láthatjuk, még finomszemcsés, vastagodó kvarterével és pannon képződményeivel.