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ON THE ORIGIN AND GEOHISTORICAL EVOLUTION OF THE NATRON LAKES OF THE BUGAC REGION

by

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The natron lakes of the southern Great Hungarian Plain have been studied for more than a decade by a team of geographers, geologists, biologists and hydrochemists. The present paper is to show a few examples of the geological results that have been obtained under the Bugac Lakes Project sponsored by the Szeged Commission of the Academy of Sciences.

LATEST PLEISTOCENE TO HOLOCENE HISTORY OF THE DANUBE—TISZA INTERFLUVE

In the Pleistocene the area of what is now Hungary belonged to the periglacial climatic zone. Thus the Latest Pleistocene to Holocene geohistorical evolution of the country in general and of the Danube—Tisza Interfluve in particular was controlled by two main factors. On the one hand, by the frequent alternation of warm and cold climatic influences due to the Pleistocene periglacial climatic zone and by the subsequent changes of the warmer Holocene climate and the associated accumulations of sediments, respectively. On the other hand, by the basin-modelling effect of differential crustal movements that were crucial in controlling the degree and rate of basin filling and the differentiation of facies in the particular subregions.

In the Quaternary not all parts of the basin did subside at the same rate. For instance, before the Günz-Mindel interglacial the Danube seems to have flowed diagonally across the Danube—Tisza Interfluve towards what is now Szeged. In the Günz-Mindel interglacial, however, the Interfluve subsided at a lower rate as compared to the adjacent regions and, particularly so, to the Tiszántúl (area east of the Tisza river). Eventually, it may even have been uplifted a little. The present-day Danube valley, however, underwent a marked tectonic subsidence which caused the Danube to abandon its earlier diagonal course and to occupy its present-day meridional valley (B. Molnár 1972). In the rest of the Pleistocene the Interfluve area was abandoned by fluviatile accumulation and it developed into a dry land. The westerly winds of the cold period that ushered the glaciations blowed sands out of the flood-plain of the Danube and deposited them as „wind-blown sands" on the surface of the Interfluve. During the glaciations the wind-blown sand surface was overlain by airborne dust giving birth to loess. In the middle part of the Interfluve the resulting sequence of alternating loess and wind-blown sand locally attains even 150 m in thickness, reaching up to the present-day land surface (B. Molnár 1961). Accordingly, the surface of the Danube—Tisza Interfluve is composed predominantly of *these* sediments.

The Holocene saw continue the deposition of gravels that had begun in the Pleistocene. In several places, some allochtonous loess settled on the surface of the

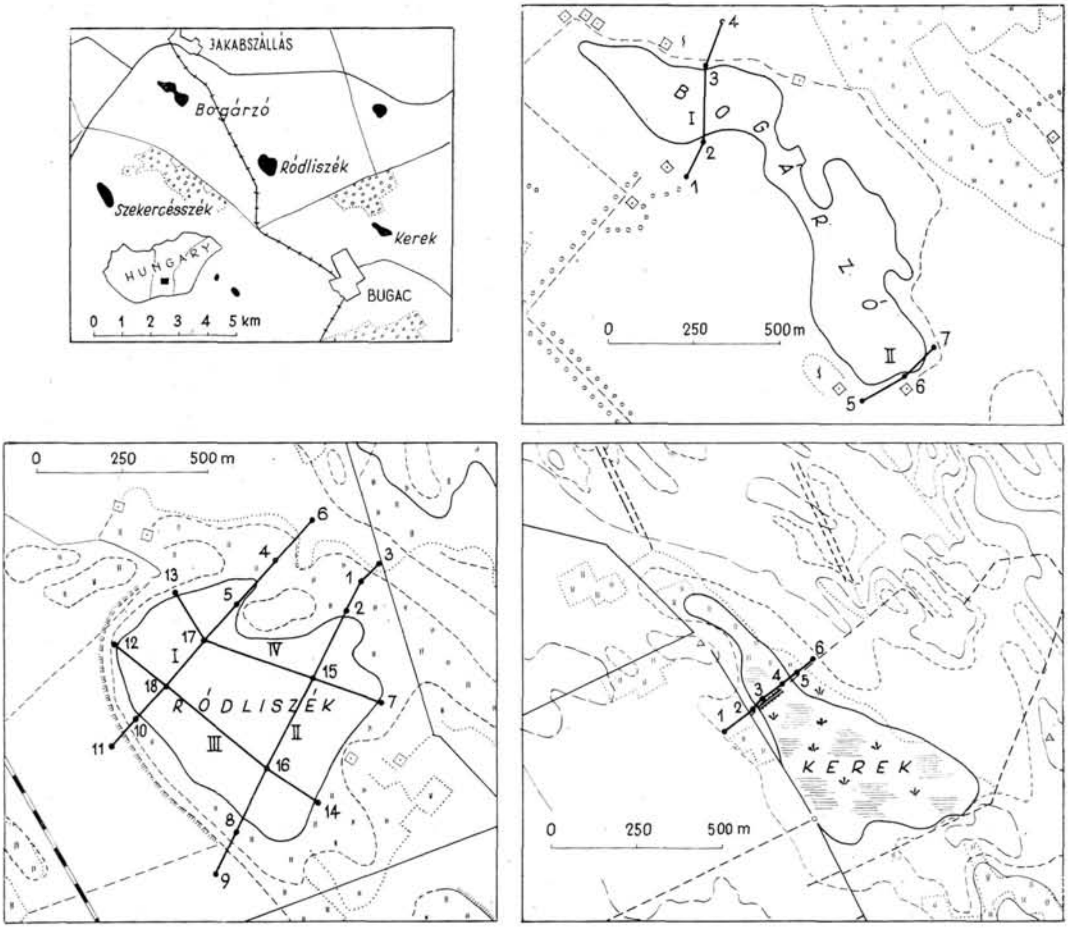

Fig. 1: Layout of the natron lakes of Bugac, and locations of the geological profiles.

gravel sheet; in other places, e. g. in the vicinity of Kecel, a considerable thickness of peat accumulated on it. In the summer half of the year, — especially during the dry hazelnut phase when the ground-water table lay deeper than today on the Danube—Tisza Interfluve Ridge — a surface rising almost 40 m above the alluvium of the Tisza, the predominantly northwest-southeast oriented winds arranged the wind-blown sands so as to form northwest-southeast trending dunes that would be separated by depressions of similar direction (I. Miháltz 1953). On the Ridge it is these depressions that made possible the formation of shallow lakes, that of the Bugac lakes inclusive (Fig. 1).

On account of the higher water table of the more humid post-hazelnut periods, permanent lakes of shallow water could be formed which would not dry out but in exceptionally few cases, and most of which have been aligned in northwest-southeast direction corresponding to the trend of the dune ranges.

The stratigraphy of the Latest Pleistocene and Holocene sediments of the Danube—Tisza Interfluve was studied and discussed, inter alia, by M. Mucsi and M. Faragó

(M. Mucsi 1963, 1965, 1966; M. Faragó 1966, 1968; M. Faragó—M. Mucsi 1971). Relying on their own investigations of gastropods and pollen grains, respectively, M. Mucsi and M. Faragó gave the generalized profile of the Pleistocene and Holocened epositsof the Danube—Tisza Inerfluve (Fig. 2). The stratigraphic subdivision of the Latest Pleistocene and of the Holocene can be readily seen on the profile as well as the sedimentary types of the various climati cphases have been illusztrated.

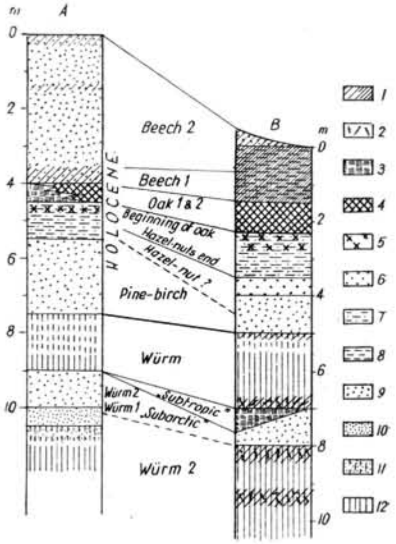

Fig. 2: Subdivision of the latest Quaternary and Holocene sediments of the Danube—Tisza Interfluve according to M. Mucsi.

Type sections A—B from the Danube—Tisza Interfluve

1. Heavily and slightly humic strata
2. Plant remains
3. Peat
4. Calcareous silt
5. Calcareous carbonate-silty layers
6. Wind-blown sand accumulated in standing water
7. Lacustrine, finesandy, unsorted silt
8. Coarse—silty fine silt
9. Small-grained wind-blown sand
10. Fine sand
11. Loessic fine sand and fine-sandy loess
12. Loess

The results of the afore-mentioned authors have also shown that teh basement of one group of the lakes occurring on the Danube—Tisza Interfluve Ridge, e. g. that of Lake Kunfehér by Kiskunhalas, is represented by Latest Pleistocene loess (Würm$_3$). In another group the Latest Pleistocene loess is first overlain by the wind blown sands of the Holocene pine-birch and of the dry hazelnut phases. Accordingly, it was not until the next, more humid period that lacustrine sediments could be deposited. A lake of this kind is e. g. Lake Petőfi near Soltvadkert which has been studied, too.

GEOLOGICAL FORMATIONS OF THE BUGAC LAKES

The Bugac lakes to be shown here lie north of the natron lakes studied earlier, on the side of the Ridge sloping towards the Tisza (Fig. 1). Of the lakes selected for study, Lake Bogárzó and Lake Ródliszék dry out once in every 7—8 years. In Lake Kerek, open water, if any, is available in entirely humid years only. Its area is covered by reeds and sedges. Therefore the process of filling up is more advanced here as compared to the former two. Lake Kerek is of narrower shape with regard to its size, and its immediate vicinity is uplifting in every direction more rapidly than the surroundings of the other two lakes are. Because of the different environment the geological history of Lake Kerek developed in a different way, too.

The aim of the study of the Bugac lakes was to explore the history of evolution of the lakes and to get acquainted with their sedimentary sequence. In the case of

Lake Kerek, the authors have intended to explore and demonstrate a peat-laden lake that had not yet been investigated geologically in detail in this region.

In the vicinity of the Bugac lakes, field observations were undertaken and rock samples were collected. By the lakes, 5- to 10-m-deep holes were drilled. The grain size composition of the samples was analyzed in the laboratory, where their carbonate content was also determined.

The resulting lithological logs have been grouped as shown in Figures 3 to 6. These profiles show up three main types of sediment.

(1) The lower part of the profiles is composed of Pleistocene loess or loessic fine sand.

(2) The loess is overlain, in Lake Bogárzó and Lake Ródliszék, by Holocene wind-blown sand.

(3) In the same lakes, the wind-blown sand is overlain by lacustrine sediment which, at Lake Kerek, has been deposited immediately upon the loess.

Let us have a look at these sediments and examine them in further detail.

1. In the investigated area the oldest formation reached by drilling is *loess and loessic fine sand* lying at 5.5 to 7.0 m by Lake Bogárzó and Lake Ródliszék and at 3.0 to 3.5 m by Lake Kerek. The loess is fine-sandy, of porous composition and mostly of grey colour throughout the area. The loess is situated below the ground-water table, so that reduction processes may take place at that depth the grey colour of the loess, instead of the comonly yellow one.

In the loess, the predominant 0.02 to 0.5 mm fraction characteristic of the loess averages 46% as a rule. The quantity of the fine material finer than the predominant fraction is 28% on the average, that of the coarser one being 26%, of which 22% is the share of the 0.05 to 0.1 mm, i. e. of the fine sand, fraction. Part „D" of Figure 7 shows a few characteristic loess curves of the area. The carbonate content of the loess is on the average around 25%; consequently, it is rather significant.

At Lake Bogárzó and Lake Ródliszék the loess on the western side of the lakes grades into fine sand upwards in the profile. This loessic fine sand will wedge out in eastern direction beneath both lakes. In the profile Ródliszék I the loessic fine sand continues westwards with fine-sandy small sand (Fig. 4). Consequently, starting from the loess, the sedimentary sequence will grow coarser in both vertical and horizontal directions.

The permeability of the loessic fine sand and of the fine-sandy small sand is better than that of the loess underneath, being worse than that of the overlying smallgrained wind-blown sand. The lakes receive their recharge predominantly from the ground-water, but this is certainly of importance for the development of the lakes. For the time being, we are still unaware of the size of this influence, however.

It is a generally acknowledged fact that the uppermost loess occurring in the Danube—Tisza Interfluve represents the last glaciation of the Ice Age, probably the Würm$_3$ glacial. Accordingly, the investigated loess and loessic fine sand of the Bugac region would be of similar age, having been deposited in the Würm$_3$.

2. At Lake Bogárzó and Lake Ródliszék, the loess and loessic fine sand are overlain — under the lacustrine sediments — by 3 to 4 m of *small-grained loose, unconsolidated wind-blonw sand*, a deposit attaining a thickness of 5 to 6 m farther away from all three lakes. The predominant fraction of the wind-blown sand is, between 0.1 and 0.2 mm, present on the average in 43% in the samples. The finer fraction atta-

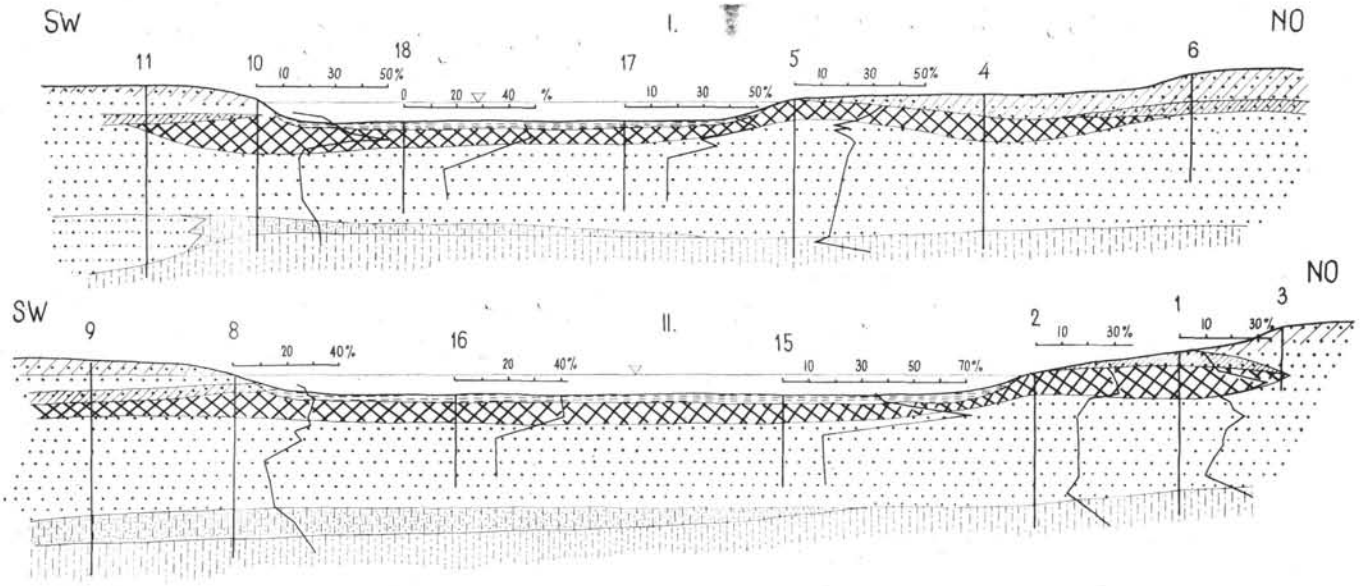

Fig. 3: Geological profiles of Lake Bogárzó (for the legend, see Fig. 5).

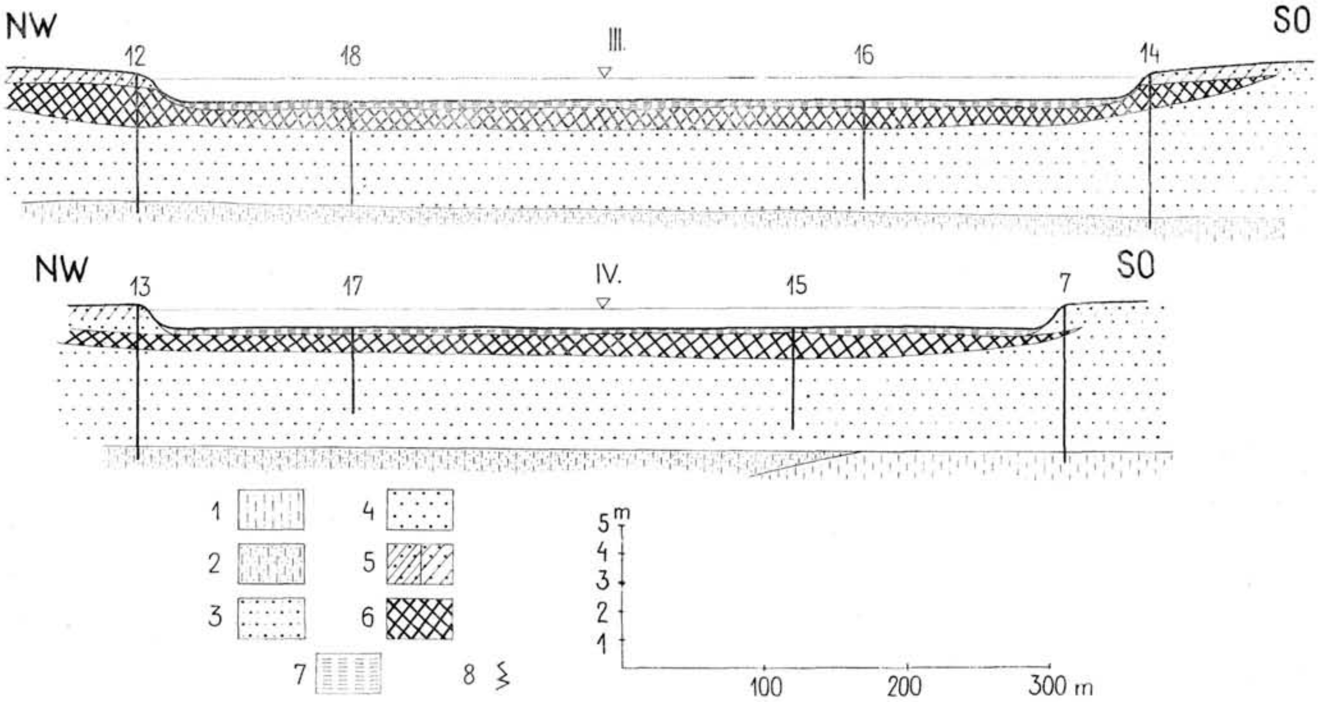

Fig. 4: Southeast-northwest profiles of Lake Ródliszék (for the legend, see Fig. 5).

ins an average of 35% in the samples. The share of the so-called mediumgrained sand, coarser than the fine sand, 0.2 to 0.5 mm in diametre, is 22%.

In accordance with the eolian origin, the sand grains are rounded and dull on their surface. The average carbonate content of the sand samples is about 15%. As shown by earlier analyses of heavy minerals, the sands occurring here had been blown out of the flood-plain of the Danube in the west, thus being of Danubian origin (B. Molnár 1961).

The wind-blown sand surface is humic in many cases. This means that in these places the wind-blown sand has been already fixed up in part and on its surface the process of humification has begun. In the southwest part of Lake Kerek the earlier soil level has been buried by a new wind-blown sand layer. In the dry hazelnut phase the sand movement was particularly intensive. Much of the wind-blown sand must thus have been deposited that time. In smaller measure, however, wind-blown sand movements took place in both the pre- and post-hazelnut periods, too. The aforementioned buried soil level is the result of the last-mentioned movement.

3. The youngest deposits of the area are represented by *lacustrine sediments.* These can be divided into two groups.

(a) At Lake Kerek calcareous silt (chalk)settled down directly upon the loess, at Lake Bogárzó and Ródliszék, on the wind-blown sand. This layer contains 35 to 80% carbonate, being white to greyish-white, just very slightly humic if at all, unconsolidated, crumbling, when dry, in one's hand. As shown by earlier investigations, $CaCO_3$ is associated with $CaMg(CO_3)_2$ in its composition (P. Kriván 1953, M. Mucsi 1963).

Its thickness varies between 0.6 and 1.2 m. At Lake Kerek the carbonate has impregnated, imbibed, the loess surface in 0.6 to 0.8 m thickness, so that carbonate content of the loess underlying the calcareous silt (chalk) attains 30 to 40% (Fig. 7). At Lake Bogárzó and Ródliszék the calcareous silt is transgressive, reaching beyond the present-day lake area (Fig. 3—5). This certifies that the lakes must have been larger than today. In fact, the calcareous silt can be deposited only in case of permanent water coverage. However, in the meantime a part of the area of the lakes was buried by wind-blown sand.

The composition of the transgressive calcareous silt is different from the composition available within the present-day boundaries of the lakes.

As shown by the curves „A" of Fig. 7, the predominant grain size in the calcareous silt layers occurring outside the present-day lake areas is about the limit between the fine and small sands. Finer fraction is available in 25 to 35% only, of which 15 to 20% is the share of clay (fraction below 0.005 mm in diametre). The carbonate content of the strata is between 31 and 54%.

The calcareous silt available within the present-day boundaries of the lakes is very poorly sorted. Its grain size composition is finer than the former. As a contrast to the previous 25 to 35%, the fraction lower than the fine sand's (lower than 0.06 mm in diametre) attains 50 to 70%, of which the share of the clay fraction is considerable, about 40 to 60% (Fig. 7, „B"). The carbonate content of these strata too is hihger and more unsteady. It varies between 39.6 and 72.8%. The calcareous silt of Lake Kerek belongs to the latter type, as far as both its extension with regard to the lake's and its composition are concerned (Fig. 6, 7, „B").

The cause of the differences in grain composition is that nowadays a calcareous silt of higher clay content and of finer grain composition is being deposited in the territory of the lakes, as compared to that which was deposited in the hazelnut and

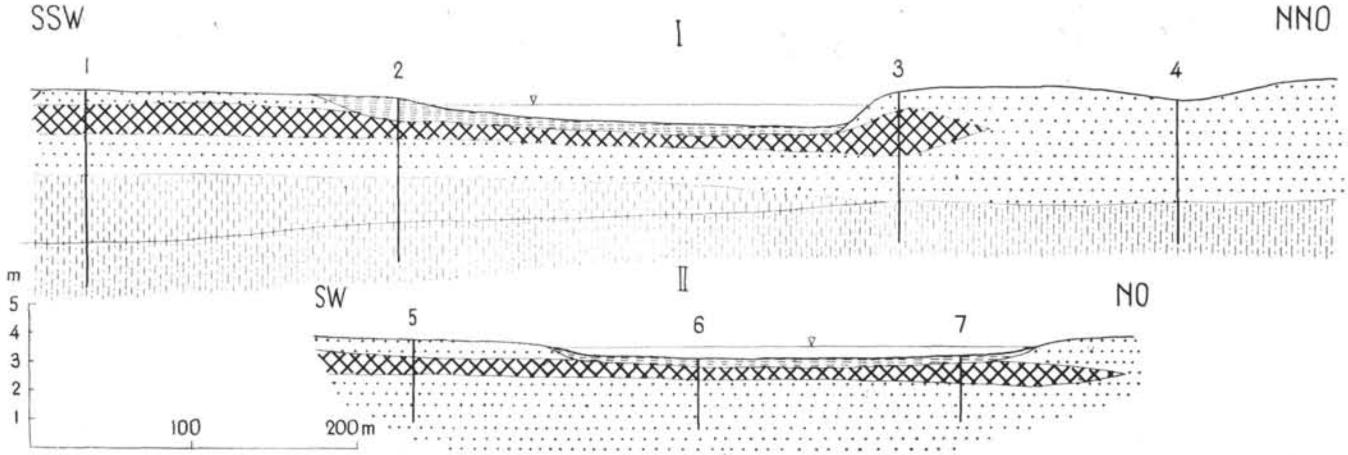

Fig. 5: Northwest-southeast profiles of Lake Ródliszék.
1. Fine-sandy loess. 2. Loessic fine sand, 3. Fine-sandy, small-grainred, wind-blown sand, 4. Small-grained, wind-blown sand, 5. Heavily (left side) and slightly (right side) humic, small-grained, wind-blown sand, 6. Calcareous silt, 7. The youngest carbonate-silty sediment, 8. Carbonate content

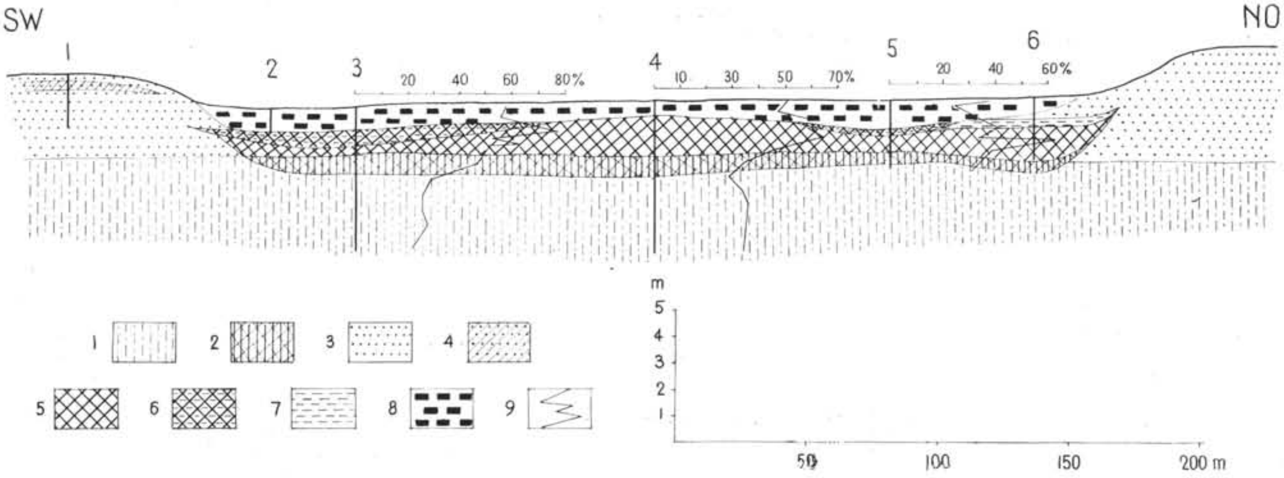

Fig. 6: Southwest-northeast profile of Lake Kerek

1. Fine-sandy loess, 2. Carbonate-silty loess, 3. Small-grained, wind-blown sand, 4. Humic, small-grained, wind-blown sand, 5. Calcareous silt, 6. Peaty calcareous silt, 7. Sandy silt, 8. Peat, 9. Carbonate content

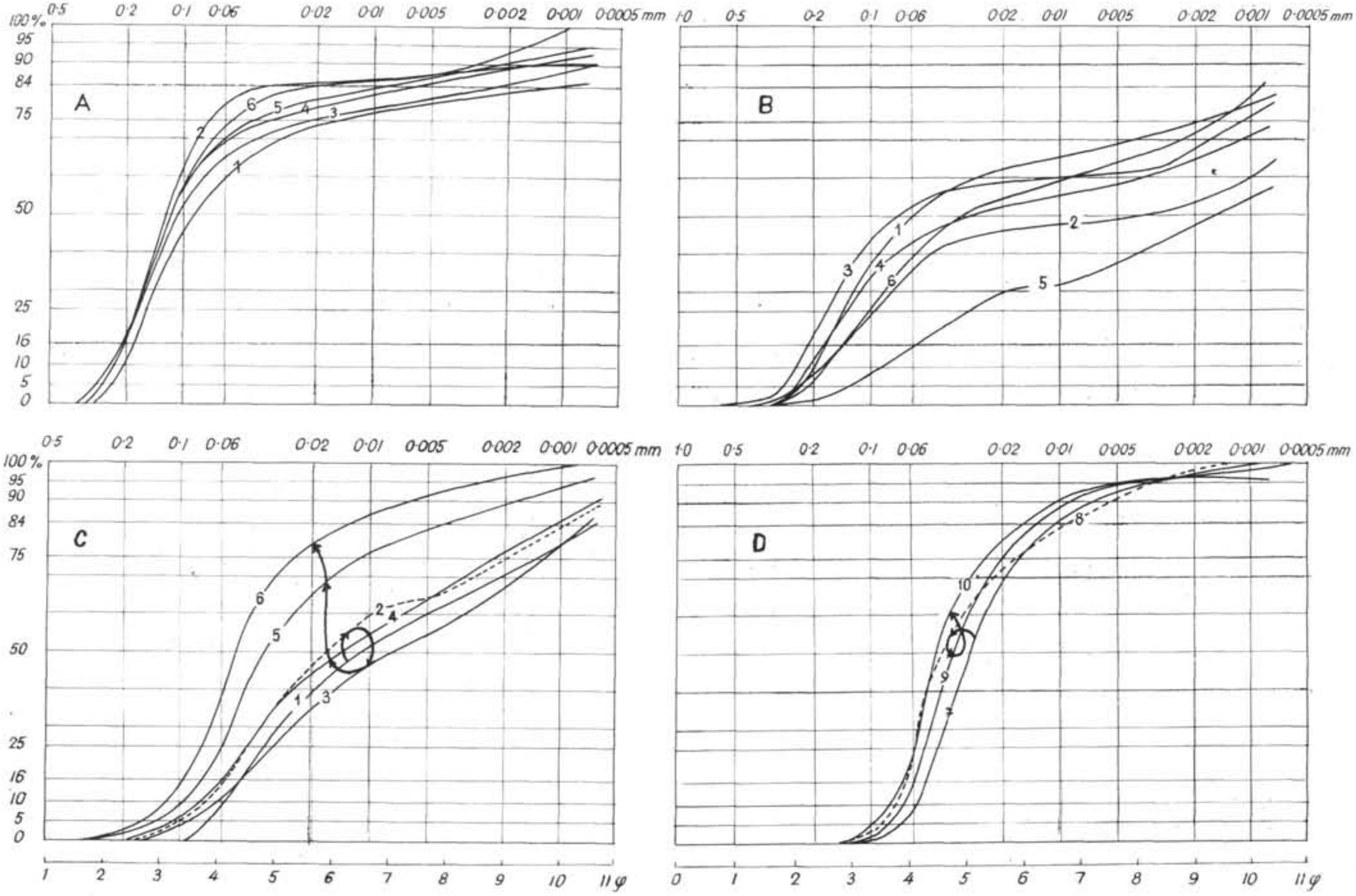

Fig. 7: A—B: Granulometric curves of the sediment types deriving from the area of Lake Ródliszék.

A: Curves of the calcareous silt layers extending beyond the present-day boundary of the lake: (the percentage values indicate the carbonate content of the sample)

1 2 sz. f. 0.4—0.6 m: 31.2%
2 2 sz. f. 0.6—0.8 m: 31.0%
3 10 sz. f. 0.5—1.0 m: 31.1%
4 10 sz. f. 1.0—1.2 m: 36.8%
5 10 sz. f. 1.2—1.5 m: 34.6%
6 10 sz. f. 1.5—2.0 m: 54.0%

B: Curves of the calcareous silt layers deposited within the present-day area of the lake:

1 15 sz. f. 0.3—0.7 m: 72.8%
2 16 sz. f. 0.0—0.3 m: 40.0%
3 16 sz. f. 0.3—0.7 m: 39.6%
4 17 sz. f. 0.3—0.6 m: 42.3%
5 18 sz. f. 0.0—0.3 m: 46.8%
6 18 sz. f. 0.3—0.6 m: 46.8%

C—D: Sequence underlying the peat deposit as exposed by the borehole No 4 at Lake Kerek.

C: 1 0.6—0.7 m: 55.0%
2 0.7—0.8 m: 59.1%
3 0.8—1.0 m: 63.7%
4 1.0—1.5 m: 49.6%
5 1.5—2.0 m: 45.0%
6 2.0—2.8 m: 33.0%

D: 7 2.8—3.2 m: 28.0%
8 3.2—3.8 m: 33.0%
9 3.8—4.2 m: 36.4%
10 4.8—5.8 m: 33.7%

oak phases. After the frequent dessiccations of the lakes their bottom silt layer is heavily cracked and fractured. The fissures reach down to very significant depths, 10 to 25 cm, so that the contemporary finer-grained, more clayey sediment is washed into the deeper strata by meteoric waters, to enrich the finer fractions there.

The differences in carbonate content are, in their turn, due to the fact that the carbonate matter of the strata derives from the ground-waters flowing towards the lakes: the local depressions. Nota bene, the ground-water dissolves high amounts of carbonate from the sands and loesses of Danubian origin. Crossing the carbonate layers available beyond the present-day boundaries of the lakes, it can exsolve from the soil a carbonate quantity that is higher even than that mentioned previously. The carbonate in solution will then be precipitated in the lakes, to enrich on their bottom the carbonate content of the lacustrine sediment which is considerable even without that. It is true, by the way, that this process will diminish the carbonate content of the carbonate silts occurring beyond the present-day lake area.

(b) At Lake Kerek the calcareous silts on the southwest and nordeast sides of the Lake are overlain by peat of loose structure, 0.6 to 1.0 m thick, grading progressively from the calcareous silt into the peat composition, though with a rather sharp boundary in the middle. The material of the peat consists of fibres of water-dwelling plants, predominantly reeds and sedge, still covering the water body of the lake. Its carbonate content too is very significant, attaining 50 and sometimes even 60%. Beside the vegetal and carbonate matter some wind-blown sand is also frequently present in the peat. Consequently, the peat is only partly organic in origin, the inorganic part being in many cases equal to the organic one.

Among the Bugac lakes, Lake Kerek and the other two lakes, Bogárzó and Ródliszék, differ from one another in their geohistorical evolution.

The lacustrine sediment of *Lake Kerek* overlies, as already shown, the loess directly. No wind-blown sand is available between the loess and the lacustrine sedimentary sequence. Consequently, the lake seems to have been formed in early Holocene time, some 10 to 15 thousand years ago. In the case of Lake Kunfehér at Kiskunhalas, a lake of similar development, M. Faragó, relying on pollen analytical results, has concluded that that lake already existed at the end of the Pleistocene and that the Holocene epoch must have inherited it. In Lake Kunfehér, however, the surface of the loess lies deeper in the axis of the lake than it does to the southwest and northeast of it, so that at the end of the Pleistocene this already represented a local depression in which the lake could develop.

In the case of Lake Kerek, however, the surface of the loess lies at an almost uniform hypsometrical elevation above the sea level. Consequently, the deeper position of the lake area with regard to its environment is due to the appearance of the wind-blown sand accumulations around the lake; in other words, Lake Kerek seems to have been formed simultaneously with the appearance of the sands.

The surrounding of Lake Kerek rise rapidly morphologically within a short distance, 200 to 300 m, so that the difference in altitude between the lake bottom and the surroundings of the lake attains a figure of 4 to 5 m.

It is well-known that the ground-water table, which lies here at very small depth, about 2 m below the surface, will adjust itself to the surface relief. Accordingly, the ground-water table must intensively slope lakewards, following the morphology of the surface. Here is a guarantee for the lakeward flow of the ground-water which is still the rule as it was earlier the case. Therefore, the rapid evaporation of the water of the lake can be recharged by ground-waters whenever such a recharge is needed. This factor, however, has increased the quantity of the carbonate introduced into the lake. Hence the result that in the calcareous silts of the lake the carbonate content is higher and the development is thicker than in the other two lakes.

In the periods of higher humidity of the climate the growth of vegetation was always granted by the more permanent recharge due to higher difference in water level. This is how the coverage of the lake with plants could begin, first on the two sides of the lake, then in its centre as well. This fact is also proved by the grading of calcareous silts on the two sides of the lake into peats (Fig. 6).

When the youngest sediments richer in clay fraction, but poorer in carbonates, are deposited in the other two lakes, Lake Kerek is already grown up with water-dwelling plants. Consequently, the peat and the uppermost layer of the other two lakes are heteropical facies replacing each other. As shown above, large amount of carbonate is precipitated together with the peat. At violent storms, smaller or larger amounts of wind-blown sands may also be introduced from the surroundings into the lake area of Lake Kerek. Its area is only in small measure buried by theses sands which settle mainly along the shore.

The calcareous silts of *Lake Bogárzó and Lake Ródliszék* follow after the wind-blown sand intercalation of 3—4 m thickness overlying the loess. According to M. Mucsi and M. Faragó M., the wind-blown sands in the Danube—Tisza Interfluve were deposited in the pine-birch and hazelnut phases of the Holocene (Fig. 2) (M. Mucsi 1965, 1966; M. Faragó M. 1966, 1969). Consequently, the two lakes could not develop before this event; in absolute terms, they seem to have been formed

5 to 7 thousand years ago. Morphologically, the surroundings of the two lakes emerge to higher elevation onyl at great distances. Hence the resutl that, unlike in the case of Lake Kerek, the ground-water table here will sink much below the level of the lake bottom in extremely dry years. In such cases the lake area runs dry. Accordingly, the plants requiring a permanent water body or constant humidity (moisture) can settle in it only temporarily, to die and decay after words. This temporary vegetation, however, is not sufficient for peat formation. Therefore, not peat, but a fine-grained sediment with calcareous silt is now being deposited in Lake Bogárzó and Lake Ródliszék.

Since the hazelnut phase the wind-blown sand fill of the lakes has decreased the lake area considerably.

A common characteristic of the two lakes is their shallow, not more than a few decimetres deep, water body. It is recharged from ground-water and meteoric waters. It is particularly the rechargint effect of the ground-water flow that is significant. The precipitations falling into the lake and the waters flowing in from surface water-courses are of smaller quantity than the annual amount of evaporation (M. Andó 1966, I. Miháltz—M. Mucsi 1964). The resulting water surplus can onlyderive from ground-waters.

Because of the heavy evaporation in summer time, the water of the lakes is alkaline, a phenomenon also due to the shallow depth and relatively large surface of the water body. The water-covered parts of the lakes will consequently change their areal extension. All these circumstances, will largely enhance the alkalization, the development of „szik"-soils, in their surroundings.

The most heavily alkalized areas always occur in the immediate vicinity of the lakes, where the largest quantity of water evaporates. In these places the downward percolation of meteoric waters is impeded to a great extent by the fact that the sediments of lowest permeability are usually localized here.

The alkalization of the vicinity of the lakes is provoked, beside the given hydrogeological characteristics, by the inreasing concentration of the salts of the ground-waters and meteoric waters. The salts are dissolved from the sediments of the surrounding areas. Because of the presence of sediments of high $CaCO_3$ content, lime-richer alkaline soils, „szik"-soils, have been formed in the Danube—Tisza Interfluve, so in the regions of the two lakes as well.

It can thus be concluded that, despite the many features that are the same in both the Bugac lakes and in the other lakes of similar development of the Danube—Tisza Interfluve, the former show a number of specific individual features. It is therefore desirable to continue the investigations in order to get acquainted with the individual characteristics of each lake: a knowledge that may allow a better understanding of the general laws and regularities.

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