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LANDFORM EVOLUTION IN MOUNTAIN AREAS

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# WAS THERE DESERT CLIMATE IN THE CARPATHIAN BASIN, OR NOT?

**Abstract.** The desert theory of the basin evolution was first sounded by L. Lóczy Sen. (1913) and J. Cholnoky (1918). Their hypothesis was based primarily on geomorphological features indicating desert conditions. Several geomorphologists, geologists and paleontologists set up working hypothesis on geomorphologic evolution during this desert period. Recently it has been held that the desertification of Pannonian Basin corresponds to the Messinian Salinity Crisis. Until the end of the '90s only geomorphological features and mammal fossils had been known as evidence to the long-debated dry-warm semidesert climate in the Carpathian Basin following the filling up of the Pannonian Lake. A comparison of samples with desert varnish collected NE of Budapest (Mogyoród site), Tapolca Basin, Keszthely Hills and Hassi Zegdou (Algeria), Maktar (Tunesia) supports the desert theory. Our investigation methods on desert varnish were X-ray fluorescence (XRF) analyses and thermal analyses (TG, DTG). Our opinion is that during drier climatic periods i.e. Late Miocene, Early Pliocene desert climate as well as Pleistocene glaciations the material transport of the winds played an important role. When relief energies became greater in the basin the mass movement process became very effective. Typical areas of mass movements are Szigliget Hill and Szent-György Hill. In the cold periods of Pleistocene the cryofraction of basalt mesas was significant.

**Keywords:** Hungary, desert crust, XRF, Miocene

## INTRODUCTION

Between Hungarian geomorphologists and geologists one of the most frequented question is the regression and discontinuance of Pannonian Sea that coincide with Messinian Salinity Crisis in the course of the investigation of landscape evolution of the Carpathian Basin. One of the most significant area of the debate is Tapolca Basin. The problem is: on the 260–300 m a.s.l. high surface of the basin basaltic lava had erupted. The K/Ar ages of alkali basalt on Balaton Highland are between 2.8 Ma and 7.5 Ma (Budai et al. 1999). The bed of the basalt is Upper

Pannonian clay and sand. The eruptions are mainly freatomagmatic, which suggests the presence of the Pannonian Lake. The recent surface of the basin is 106–160 m a.s.l. high, excluding the bed of the basalt. It means approx. 100–180 m thick sediment eroded from the end of the basaltic eruption. The question is: what kind of weathering was involved and when the basin was formed.

The new results as pediments, desert varnish and crusts refer to warm and arid climate period at the end of Miocene and beginning of Pliocene. We investigated various sites (Fig. 1) and used XRF method on desert crusts to give further result about the arid, semiarid climate interval of the border of Miocene and Pliocene.

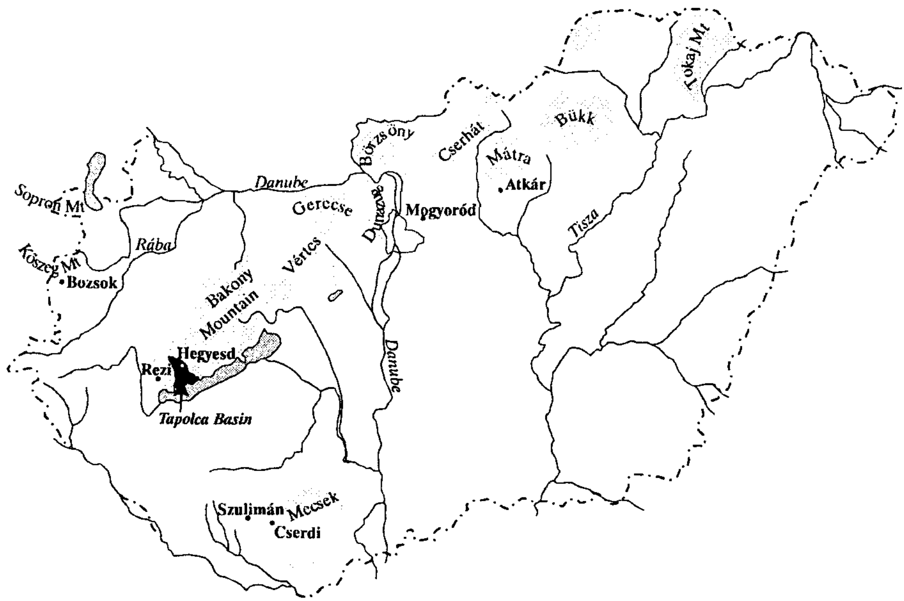


Fig. 1. Location of the investigated sites in Hungary

## HISTORY OF RESEARCH

For about 100 years there has been a long-lasting debate on turning into desert of Carpathian Basin. The problem was examined by L. Lóczy Sen. (1890, 1913) and J. Cholnoky (1918) in detail, the 'Pannonian–Pontian desert theory' was first sounded by them. Their hypotheses was based on geomorphological features indicating desert environment. They laid special stress on origin of deflation of Tapolca Basin. Cholnoky mentioned dreikanters (ventifact) as evidence of deflation.

As P. Treitz (1904) has it in the overlying of Upper Pannonian strata there are limestones, sandstones cemented by carbonates and marls the remains of dried up shotts under desert conditions. According to F. Pávai-Vajna (1941) this evaporites with $CaCO_3$ are the remains of the filling up Pannonian Sea.

B. Bulla (1943) accepted the 'desert theory' suggested by Lóczy and Cholnoky, but he shifted it into the Pleistocene. He precluded the possibility of the desert climate period at the end of the Pannonian–Pontian stage as in his opinion there was tropical peneplanation till Pleistocene (Bulla 1962). In view of him the 'desert theory' was forgotten. The data of new investigations about palaeontology, sedimentology, geomorphology and geochemistry emphasise the problem of climate of the late Pannonian and the Pliocene (Schweitzer 1997).

## HOT AND ARID (SEMIARID) CLIMATE SPELLS IN THE SECOND PART OF NEOGENE

Four characteristic hot or warm and dry or semidry climate spells can be distinguished in the second part of the Neogene in the Carpathian Basin.

1. The first was the end of the Sarmatian stage about 12 Ma. After the Carpathian–Badenian interval became bigger desiccation than it was in the former stages. We can find omission of the sequence on the margin of the basin and sapropelic solidification inside the basin. The marine-brackish fauna extinction shows the final stage of the Sarmatian (Sarmatian limestone).
2. The second interval with warm and dry ecological conditions was the Sümegian (8 to 7 Ma). In the fauna the Meriones turned up and there was no species at all bantered water or wood. All species of fauna was replaced with European southern elements (Kretzoi 1987). This period was the beginning of pedimentation.
3. The third hot and dry period was the Bérbaltavarian. The fauna characterised by *Hipparion*, *Gazella*, *Ophisaurus*, *Meriones* and *Epimeriones*. All of them verify the arid climate in the basin (Hir 1989, Kordos 1992, Kretzoi 1952). Vegetation was shrubs and sparse grass under semidesert condition. This interval is dated from 6.3 to 5.0 Ma BP (MN zone 13). During this period layers of grey sand with considerable thickness and high mica contents accumulated and were subsequently cemented by carbonates under arid climate. The fauna-free thick sand justifies climate changing into drier conditions. This period corresponds to the Messinian Salinity Crisis in the Mediterranean region. Because of the character of climate it was principal period of pedimentation. Pediments, the sharpest geomorphological features were developed intensive in Bérbaltavarian stage (Fig. 2). Besides, there is no travertine at all for the lack of precipitation on the surface of limestone mountains of Hungary. We can find data on hot dry climate in boreholes. In the 930 m deep Jászladány-1 borehole there is a segment with pollens indicated desert environment (Rónai 1985). TG/DTA of desert crusts found nearby Mogyoród (NE of Budapest) also indicate hot desert conditions in this interval (Schweitzer 1997).
4. The fourth and last interval was Villanyian stage (3.0 to 1.8 Ma BP, MN zone 16 and 17). It is characterised by poorly developed pediments and alluvial funs;

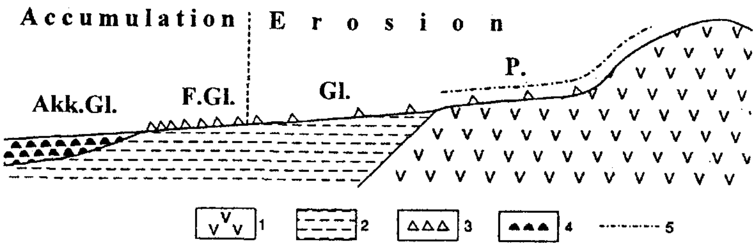


Fig. 2. The main types of pediments (Székely 1993). 1 — bedrock, 2 — younger sediments, 3 — derasional mass movement, rubble and blocks, 4 — bed load of torrent, 5 — presumed abrasion platform and cliff, P — pediment, Gl — glacis, F.Gl — covered glacis, Akk.Gl — accumulation glacis

the formations contain the Kislangian fauna with ostrich and camel. The oldest 'warm loess' horizons and reddish clays with carbonate veins and concretions in desiccation cracks belong here (Schweitzer 1997).

These dry periods link up with the curve of marine oscillation by Haq et al. (1987). In the period in question there are four characteristic regression can be found: 10.9, 7.8, 6.3, 5.3 Ma BP (Pogácsás et al. 1989).

## EXAMINED SITES

1. Atkár site (sand pit). Atkár lies on the southern remnants of the Mátra pediment. The sand pit deepens 20–25 m into the surface. The exposure shows the Late Miocene–Early Pliocene sequence where we can investigate easily the landscape evolution through geological time. Its bottom is made up of 5–10 m thick greyish-yellow, mica-rich, cross-bedded sand. The lower part of the sand bed bears different fossils (animal, plant), sometimes between sandstone benches. There are particularly lots of brown coloured gastropod internal clasts in this strata. Many bone fragments can be found like teeth, jaws, costae from *Hipparion* sp., *Mastodon* sp. and *Rhinoceros* sp. (ex verbis Kordos). In the upper part can be seen many fossil torrent. These torrents bear allochtonous nodules which have 1–3 mm thick reddish-brown, hard Fe, Mn encrustation. The cross-bedded sand is overlain with 2–4 m thick red clay horizon. The red clay horizon has relevance for the identification of palaegeographic periods and phase of tectonic movements. It is covered by a 2–3 m thick loamy loess and recent soil. The age of the recovered fossils are 6 Ma, but unfortunately they are only facies indicators and not a persistent stratigraphic markers.
2. Szulimán site. It is located in Southern Transdanubia, north from the town of Szigetvár, in Szulimán village. The lower part of the exposure has horizontal stratification. This sandy sequence bears a number of sand bench fragments and on the top, there is a limestone bench. The red clay sequence to-

gether with its well-expressed horizon of lime accumulation overlaying the limestone bench.

3. Cserdi site. The exposure is situated on the western part of the Mecsek foothills between Cserdi and Boda settlements at 160 m a.s.l. Interesting in these sequences are the 20–25 m wide and 5 m deep double fossil river beds. Under the river beds can be seen 20–30 cm thick, horizontal bedded, highly cemented, limonite sandstone, between the Upper Miocene stratas. Eastern from the fossil riverbed, the sandy sequence bears 1–10 cm thick, white, horizontal bedded, evaporite-lenses with reddish-brown encrustation. The left side of the riverbeds is a red clay tongue, which is eroded by the second river stream. The infilling sediments in the upper fossil riverbed are horizontal-bedded, sand, bentonite and gravel (fossil bed load). The overlaying bed is Pliocene red clay.

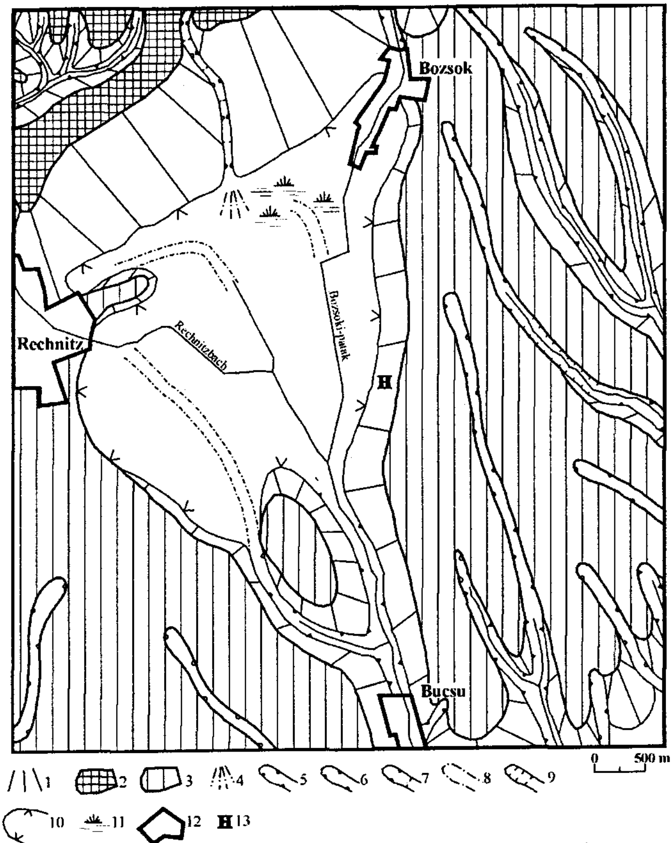


Fig. 3. Geomorphic map of Bozsok sand pit and surroundigs (drawn by Sz. Á. Fábián and G. Varga). 1 — slope, 2 — rounded ridge, 3 — pediment, 4 — talus cone on basin bottom, 5 — erosion valley, 6 — derasional valley, 7 — erosion-derasion valley, 8 — abandoned channels of smaller watercourses, 9 — stream-bed with steep banks, 10 — denudation basin, 11 — waterlogged areas, 12 — settlement, 13 — sand pit

4. Bozsok site (sand pit). The sand pit lies on the slope of Kőszeghegyalja, 2.5 km south from Bozsok settlement and some hundreds of meters from the Hungarian-Austrian border at 300 m a.s.l. The whole area around is a huge pediment surface of the Kőszeg Mountain (Fig. 3). The exposure is a 10 m high sand sequence with some torrent infilled metamorphic stone fragments from the Kőszeg Hills and desert crusts.
5. Rezi site (sand pit). It is located on the pediment of the Keszthely Hills, next to Rezi village at 180–320 m a.s.l. The lower part of the sequence is made up of grey, cross-bedded, fine sand. The upper part is composed of 5–15 cm thick, medium-grained, well-sorted, reddish sand bearing desert crusts like we have found in Mogyoród site. These desert crusts are dark brown or black coloured, polished by wind and oolitic forms.
6. Hegyesd site (sand pit). This little sand pit is situated on the NE margin of the Tapolca Basin, next to the main road between Veszprém–Tapolca, close to Hegyesd. Its lower part is made up of yellow and grey, cross-bedded, mica-rich sand overlain by torrents infilled with basalt fragments and gravels. The bed load bears a 4–8 cm thick, white evaporite lens with basalt fragments and reddish-brown nodules.

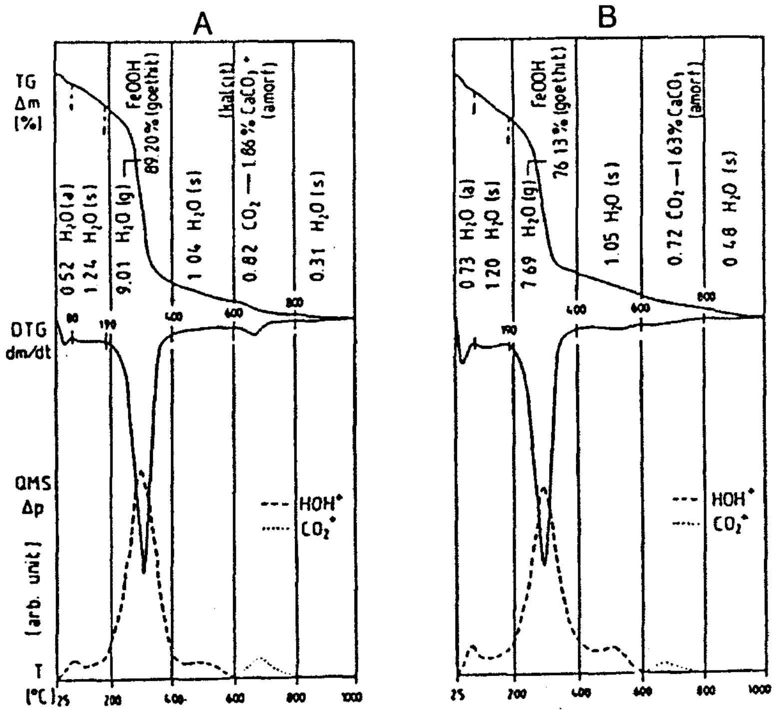


Fig. 4. TG/DTG analysis of carbonatic-ferric-siliceous concretion from (A) Mogyoród (Hungary) and (B) Algeria (Schweitzer and Szöőr 1992). $H_2O$ (a) — adhering water, $H_2O$ (s) — structurally bound water, $H_2O$ (g) — water content of geothite

7. Mogyoród site (sand pit). It is located NE from Budapest, next to the Hungaroring. The yellowish-grey, fine-coarse, cross-bedded sand sequence bears fragments of red and reddish-brown varnish-coated desert crusts. The fragments have several square centimetres of surface. The desert varnishes from our sites look very similar to those samples were collected in Algeria and Tunesia.

Table 1

Major element compositions (wt%) of desert crust samples from Hungary and Tunisia (recalculated on a volatile-free basis)

| Samples | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | MnO | $K_2O$ | $Na_2O$ | $P_2O_5$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Szent-György Hill | 20.4 | 4.45 | 62.9 | 0.170 | 0.42 | 0.55 | 0.150 | 0.71 | 0.470 | 0.130 | 9.21 |
| Zalaszántó | 24.0 | 5.30 | 57.1 | 0.190 | 0.32 | 0.72 | 0.101 | 0.86 | 0.470 | 0.560 | 9.71 |
| Mogyoród | 16.3 | 4.05 | 65.0 | 0.200 | 0.79 | 1.39 | 0.043 | 0.75 | 0.170 | 0.460 | 9.99 |
| Várvölgy | 6.0 | 1.48 | 80.3 | 0.111 | 0.26 | 0.58 | 0.037 | 0.32 | 0.015 | 0.071 | 10.1 |
| Rezi | 8.6 | 3.02 | 76.2 | 0.127 | 0.15 | 0.42 | 0.050 | 0.26 | 0.009 | 0.220 | 10.6 |
| Szekszárd | 15.6 | 4.80 | 66.0 | 0.210 | 0.31 | 0.87 | 0.180 | 0.63 | 0.064 | 0.250 | 10.7 |
| Hegyesd | 24.2 | 5.40 | 57.5 | 0.230 | 0.68 | 0.95 | 0.072 | 0.89 | 0.440 | 0.170 | 9.07 |
| Bozsok | 9.7 | 2.28 | 75.0 | 0.127 | 0.64 | 0.49 | 0.250 | 0.40 | 0.074 | 0.260 | 10.1 |
| Tunesia | 45.4 | 2.15 | 43.4 | 0.280 | 0.34 | 0.45 | 0.500 | 0.65 | 0.084 | 0.280 | 5.71 |
| UCC | 59.1 | 15.8 | 6.6 | 0.700 | 6.40 | 4.40 | 0.100 | 1.88 | 3.200 | 0.200 | — |

UCC — Upper Continental Crust, data adapted from S. R. Taylor and S. M. McLennan (1995)

Table 2

Trace element compositions (ppm) of desert crust samples from Hungary and Tunisia (recalculated on a volatile-free basis)

| Samples | V | Cr | Co | Zn | Rb | Sr | Y | Zr | Ba | Pb |
|---|---|---|---|---|---|---|---|---|---|---|
| Szent-György Hill | 0.7 | 9.1 | 19 | 4 | 2.4 | 3.3 | 0.4 | 4.4 | 6 | 7 |
| Zalaszántó | 16.0 | 36.0 | 21 | 9 | 1.9 | 2.5 | 1.7 | 4.0 | 3 | 17 |
| Mogyoród | 76.0 | 66.0 | 14 | 20 | 1.7 | 4.6 | 8.5 | 4.2 | 22 | 14 |
| Várvölgy | 1.0 | 19.0 | 14 | 42 | 1.3 | 1.1 | 0.7 | 1.0 | 7 | 7 |
| Rezi | 5.9 | 7.5 | 16 | 21 | 0.7 | 1.1 | 0.5 | 2.1 | 4 | 6 |
| Szekszárd | 33.0 | 41.0 | 16 | 9 | 1.0 | 3.2 | 2.8 | 5.0 | 7 | 18 |
| Hegyesd | 14.0 | 27.0 | 19 | 4 | 2.8 | 4.3 | 1.5 | 8.4 | 9 | 4 |
| Bozsok | 34.0 | 62.0 | 18 | 10 | 1.4 | 3.8 | 3.9 | 2.4 | 13 | 8 |
| Tunesia | 39.0 | 47.0 | 13 | 35 | 1.3 | 6.2 | 1.4 | 50.0 | 51 | 12 |
| UCC | 60.0 | 35.0 | 10 | 71 | 112.0 | 350.0 | 22.0 | 190.0 | 550 | 20 |

UCC — Upper Continental Crust, data adapted from S. R. Taylor and S. M. McLennan (1995)

The thermal analyses (Fig. 4) provided almost identical curves for samples from Algeria and Hungary. The comparative geochemical analyses (Table 1, 2) on Tunisian and Hungarian samples also show similarity. The major elements in the samples are the red iron oxide ($Fe_2O_3$: 72 wt%), ($SiO_2$: 15–25wt%) and ($Al_2O_3$: 2–4wt%). As a minor element, manganese oxide (MnO: 0.1wt%) is important. The Al, Si, K, Fe ratios are almost the same in all samples. Siliceous desert crusts form even today under climate with a mean annual precipitation under below 130 mm and a mean annual temperatures 16–24°C. The similarity of crusts fragments from Hungary and North Africa evidence on a hot and dry interval. The cross-bedded sand is overlain by red clay horizons and on the top recent soils.

## DISCUSSION

Was there a desert climate in the Carpathian Basin? It seems to be easy to answer this question, because the geomorphological evidences, like pediments, debris, alluvial fans and desert varnish etc.; and of course the palaeontological evidences, the fossils show the relationship between the study area and the development of the surface in the recent zonal and local desert. The main question generate more new ones. When was this desert climate in the Carpathian Basin and how many times was it, and how long was it?

During the Messinian Salinity Crisis the Mediterranean Sea almost totally dried up, in the Carpathian Basin must have occurred simultaneously. The end of Miocene (ca 6.3 to 5.3 Ma BP) the Bérbaltavarian stage shows the correlation with the Messinian. The desert climate conditions are reconstructed from the fossils (*Meriones* sp. etc.) and the carbonate evaporates, pebbles covered by desert varnish, which can be found W Hungary and Pest Plain. Dry period at the and of the Miocene was not the first and not the last. The Miocene stratigraphy gives evidences for two other earlier stages (12 Ma and 8 to 7 Ma), which represent arid and semiarid climate in the Carpathian Basin. But the Bérbaltavarian arid climate was formed the significant parts of recent relief. Thus we consider to interpret this period as the most important, because it helps us to understand and reconstruct the climate changing and the origin of relief.

We have to study more sites, collect more fossils and desert pebbles etc., and to use new methods (remote sensing, XRD, Mössbauer spectroscopy and ICP-MS for the rare earth elements) to identify exactly palaeoclimate in the Carpathian Basin.

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STRESZCZENIE

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CZY KLIMAT PUSTYNNY ISTNIAŁ W KOTLINACH KARPACKICH?

Na pytanie postawione w tytule pracy autorzy dają odpowiedź pozytywną. Istnieją dowody geomorfologiczne w postaci pedymentów, pokryw gruzowych, stożków aluwialnych, polew pustyniowych, oraz dowody paleontologiczne wskazujące na istnienie klimatu pustynnego w kotlinach karpackich conajmniej kilkakrotnie. Takie warunki mogły istnieć podczas messyńskiego kryzysu solnego, gdy Morze Śródziemne prawie zupełnie zanikło. Koniec miocenu (około 6,3 do 5,3 mln lat BP) zwany stadium Bérbaltavarian jest korelowany z tym zdarzeniem. Warunki klimatu pustynnego są rekonstruowane na podstawie skamielin, ewaporytów węglanowych i żwirów z polewami pustyniowymi, które występują na Równinie Węgierskiej i Równinie Pest. Suchy okres na końcu miocenu nie był pierwszym i ostatnim. Stratygrafia mioceńska dostarcza argumentów za istnieniem dwóch wcześniejszych stadiów (12 i 8–7 mln lat BP). Jednak stadium Bérbaltavarian było największe i wywarło piętno na rzeźbie kotlin karpackich na terenie Węgier.