Susak, a loess island in the Adriatic – a geochronological overview[1]

Introduction

This article contains the achievements of the investigations carried out in the framework of a research project launched in 1997 and supported by the Hungarian Academy of Sciences and Hungarian National Science Fund. The project entitled 'Reconstruction of past changes in global climate and environments through the correlative analysis of type localities of loess in the Mediterranean (Susak Island) and in the Carpathian Basin (Paks) yielded achievements of international interest.

The research project has been aimed at an overview of paleoecological and paleogeomorphological transformation in the Carpathian Basin and its southern surroundings as a result of climatic change during the Pliocene and Pleistocene epochs. The research primarily focused on those events in the physical environment, which controlled geomorphic evolution leading to the emergence of landforms and sediments over the time period in concern.

One of the fundamental tasks of geomorphological research in the region of the Alps and in the Carpathian Basin is clearing up Pliocene landform evolution and the time scales involved. The Quaternary sequence of the Alps and of the Po Plain were studied by Cremaschi, M. (1987, 1991) in detail. He has dealt with loess-like sediments of the Mediterranean; their distribution and types were identified in a map (*Figure 1*).

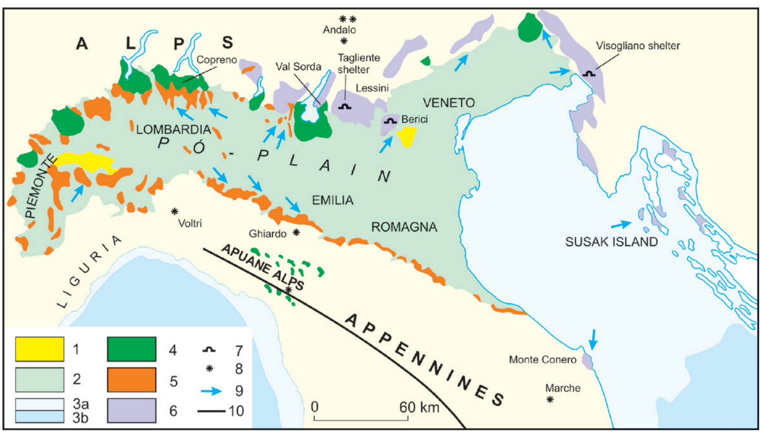

Fig. 1. The distribution of loess deposits in Northern Italy (by Cremaschi, M. 1987 and modified in 1991). – 1 = Pre-Quaternary rocks; 2 = Late Pleistocene and Holocene alluvial plain; 3 = present day sea extent: a<100 m; b>100 m; 4 = Pre-Alpine and Appennine moraine system; 5 = loess deposits on fluviatile, fluvioglacial terraces and moraine ridges; 6 = loess deposits on karstic plateaus; 7 = loess in caves or shelters; 8 = loess on erosional surfaces; 9 = directions of dominant winds during loess sedimentation; 10 = possible south–west boundary of loess sedimentation during Upper Pleistocene

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The author classified genetically the sediments on Susak Island (*Figure 2, Photo 1*) studied by our team in detail into the category of loesses developed on karst plateaus and their deposition he put in late Pleistocene. He draws attention to the variability of Quaternary formations on Susak: apart from loess pockets of eolian origin fossil sand dunes and terraces of marine abrasion could be traced, based on previous investigations.

Results of complex mineralogical, lithological, geochemical, geological and geomorphological analyses were published by Bognar, A. (1979), Bognar, A. *et al*. (1989), further by Bognar, A. and Zámbó, L. (1992), according to which the most important stratigraphical features are the followings.

– Red clay as infillings in cracks of Cretaceous limestone of so called rudist facies could have formed in Csarnótan (4–3 million years BP); it should be considered the weathering product of subtropical karstification. Reddish clay covering this rudist facies (with a marked reversal in paleomagnetism) might have formed in Villányian–Villafranchian (3–1.8 million years BP).
– Formation of various sandy silts, sandy loesses and sands overlying red clays reaches back to the second half of Middle Pleistocene and Late Pleistocene, when several phases of sedimentation can be traced. These deposits bear character of floodplains and/or alluvial cones. Typical loess is completely missing from the island.
– Based on the occurrence of paleosols and semipedolites superimposing red clays three humid-warm intervals can be identified, while the occurrence of loessy sand, sandy loess and wind-blown sand refers to drier and warmer climatic phases.
– Micromineralogical studies revealed a similarity between the heavy metal spectrum of the sediments overlying red clays on Susak and that of Middle and Upper Pleistocene fluvial and fluvioglacial sequences of the Po Plain, which suggests a common source of origin.
– It should be stated that only pilot studies were carried out concerning carbonate and clay mineral paragenesis of sediments. As far as their carbonate content is concerned, deposits on Susak Island and in the Po Plain differ between one another.

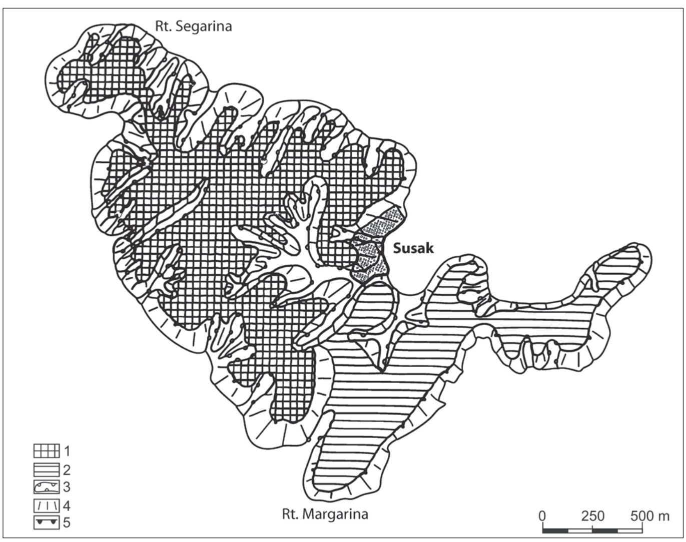


Fig. 2. Geomorphological map of the island (ed. by Kis, É. and Schweitzer, F. 2000). – 1 = the higher level (60–98 m a.s.l.); 2 = the lower level (30–50 m a.s.l.) of the plateau; 3 = valleys; 4 = slopes; 5 = loess bluffs with landslide

Photo 1. A panoramic view of Susak Island (Photo by Kɪs, É.)

Origin and description of the samples

Bay of Bok was designated as the place of the establishment of profiles and sampling for subsequent analyses (*Photo 2*). Exposures including a complete sequence of loess and loess-like sediments overlying reddish clays (SAV) were cut with soil steps, followed by a general description of the profile and collection of samples (*Photos 3* and *4*).

Field works and laboratory analyses permitted to compile a geomorphological cross-section (*Figure 3*) also making possible identification of the set of samples using data of depth from the sea level. A generalized profile Susak 1997 is shown on *Figure 4*.

Chronological issues

The Pliocene spans a time interval with duration of 2.5–3.0 million years; during this period a 200–700 m thick sequence of series was deposited in the innermost areas of the Carpathian Basin. At the same time the basin margins and less peripheral areas became covered by terrestrial sediments of 10–250 m thickness (constituting formations such as the so called Gödöllő sand, red clays, travertines of considerable thickness, the oldest terraces etc.).

One of the sediments formed in the Pliocene is a terrestrial sequence figuring in the literature as the Levantan stage. Its further subdivision (Piacenzan, Astian), however, was carried out using data from the Mediterranean. Perhaps this is the reason why *Pliocene sediments from the Carpathian Basin cannot be correlated completely with the originally described Levantan sediments and levels.*

That is why the denomination 'Levantan' has been abandoned recently and this interval initially became called Upper Pliocene (with the Miocene–Pliocene boundary placed between the Sarmatian and Pannonian stages), later it was simply referred to as *Pliocene stage* (with the *Miocene–Pliocene boundary drawn at 5.5 million year BP*).

These figures point to highly *diverse* and controversial *concepts* on landform evolution during the Pliocene. Formation of sediments

Photo 2. Bay of Bok at Susak Island (Photo by Kis, É.)

Photo 3. Upper part of the loess exposure with Bay of Bok in the background (Photo by Schweitzer, F.)

Photo 4. Lower part of the loess exposure at Susak (Photo by Kis, É.)

and landforms belonging to various stages was assigned to this epoch by the different authors.

In the Hungarian stratigraphical practice the *lower and upper boundaries of Pliocene vary, therefore it is necessary to specify in what a sense they will be used below*.

The *lower boundary* is drawn, in accordance with the international recommendations, between the Messinian and Zanclean at *5.3 million year*, which corresponds to the limit between zones MN 13 and MN 14 in the mammal scale by Mein (*Table 1*).

This was the time of a considerable drop of the level of the Pannonian brackish inland sea considered to be a remnant of the Paratethys.

This in turn can be correlated with the lowering level of the Mediterranean Sea during the Messinian (6.8–5.3 million year) with the formation of evaporites in that basin ('Messinian Salinity Crisis').

The triggers of this intense evaporite formation have not been cleared yet. At that time there was a change in faunal succession and ecosystems in the Carpathian Basin. Pannonian inland sea had dried out; warm-dry and hot-dry climatic conditions prevailed evidenced by desert pan and varnish.

The upper boundary of the Pliocene does not coincide with the internationally accepted 1.8 million year BP.

In the present paper the boundary between the Matuyama–Gauss paleomagnetic epochs, i.e. ca. *2.4 million year is adopted* as the Pliocene-Pleistocene boundary, in accordance with the recommendation of the Hungarian Commission on Stratigraphy from 1988.

The middle phase of Pliocene in the Carpathian Basin was characterised by a warm-humid climate between 4 and 3 million year BP (Csarnótan), in some places with south and southeast Asian faunal elements. This environment changed into a grassy steppe ecotype between 3 and 1.7 million year BP (Villányian).

In the present publication Pliocene is subdivided into three time intervals. MN

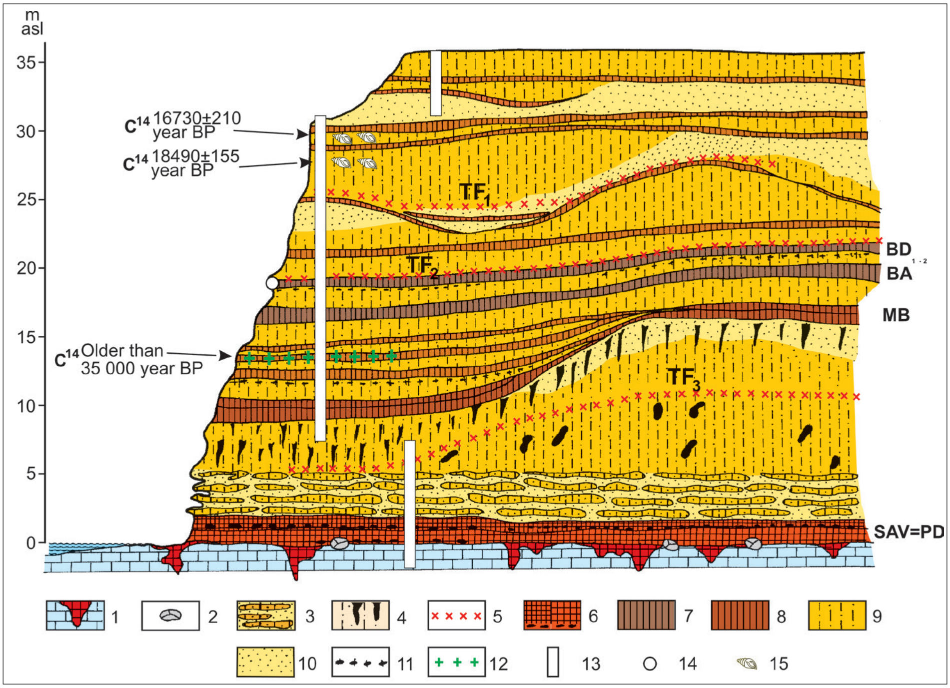


Fig. 3. A geomorphological cross-section of Susak (compiled by Schweitzer, F. 2000). – 1 = Mesozoic (rudist) limestone, with infillings of typical red clay in the karstic depressions (see *Photo 6*); 2 = ventifact (see *Photo 10*); 3 = sandstone bench; 4 = old loess with loess dolls; 5 = tephra horizons (TF_1, TF_2, TF_3); 6 = reddish clays with horizons of $CaCO_3$ accumulation; 7 = chernozem paleosols; 8 = reddish brown forest soil; 9 = sandy loess; 10 = sand; 11 = charcoal horizon; 12 = charcoal horizon with ^{14}C dating; 13 = sampling sites along the Susak 1997 profile; 14 = Paleolithic artefact finds; 15 = ^{14}C datings of Mollusc fauna

zones are taken for the basis with a tripartite Pliocene with lower (MN 14), middle (MN 15) and upper (MN 16) sections.

Pliocene events

Lower Pliocene; possibilities for the correlation of Bérbaltavarian with Messinian

The end of Upper Miocene and the advent of Lower Pliocene were marked by the end of Messinian Salinity Crisis which culminated in an almost total desiccation of the Mediterranean Sea (Rögl, F. and Steininger, F.F. 1978).

In the area what is now the Carpathian Basin it was the era when the Pannonian inland sea was filling up gradually, indicated by carbonate evaporites, sand formations and desert varnish (Schweitzer, F. 1993; Schweitzer, F., Szöőr, Gy. 1997).

The expansion of mainland in the Carpathian Basin toward the end of Pannonian is also supported by borehole and geophysical data (Pogácsás, Gy. *et al.* 1989), sand sequences locally reaching 100–200 m (e.g. Gödöllő sand) and indicated by pediment formation as geomorphic features (Pécsi, M. 1967, Schweitzer, F. 1993).

Pedimentation was an active factor in landform evolution during dry and warm periods in the foreland of Hungarian Mountains; pediment surfaces formed along the Dalmatian shore of the Adriatic (e.g. Velebit

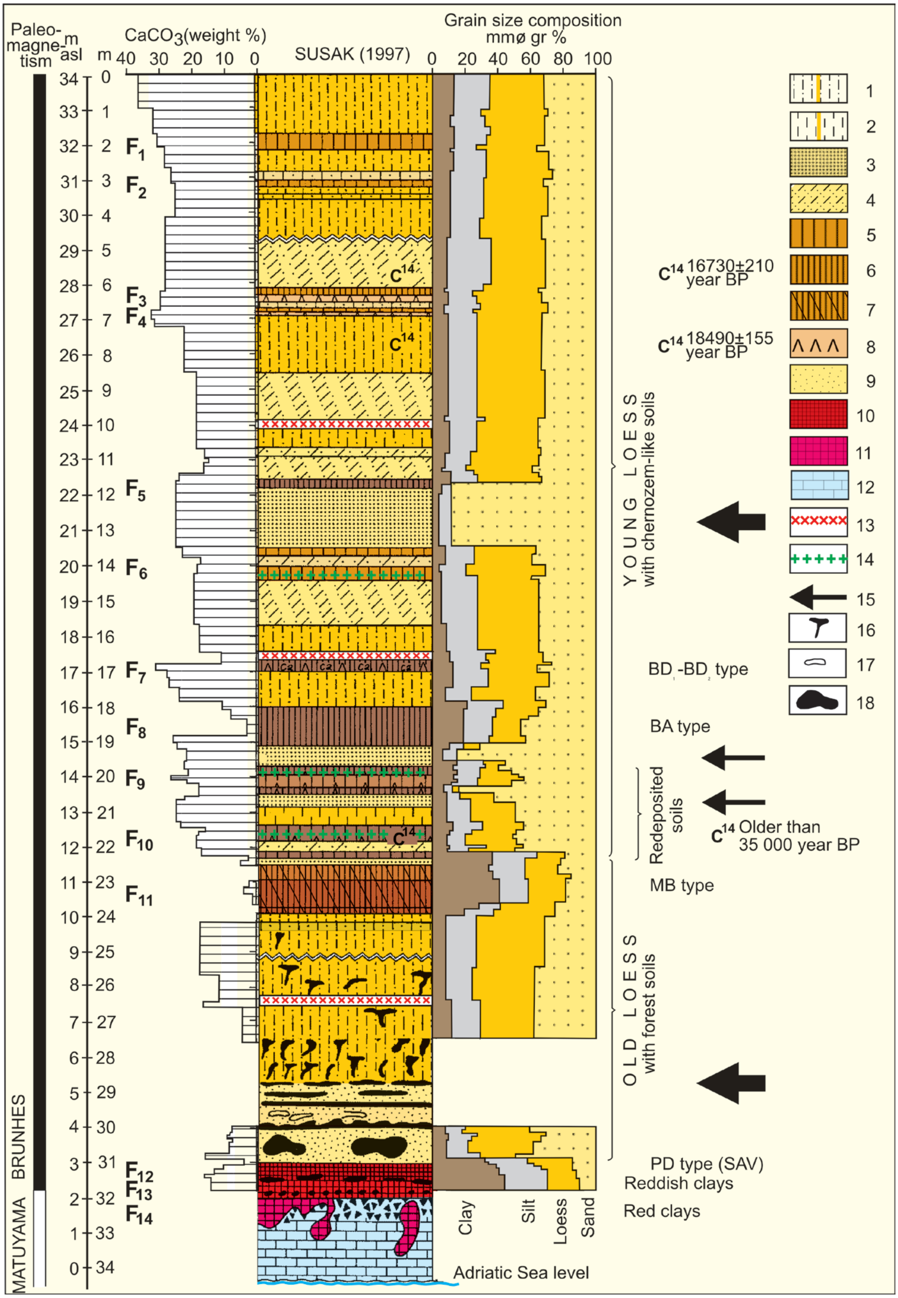


Fig. 4. The generalised Susak profile with carbonate content and grain size distribution (by Schweitzer, F., Bognar, A., Szöőr, Gy., Kis, É., Balogh, Di Gleria, M. 1997). – 1 = sandy loess; 2 = unstratified loess; 3 = sand; 4 = loessy sand; 5 = slightly humified horizon; 6 = chernozem paleosols; 7 = reddish brown forest soil (MB); 8 = horizon of calcium carbonate accumulation; 9 = fine-grained loessy sand formed on sandstone bench; 10 = reddish clay; 11 = red clay; 12 = rudist limestone 13 = tephra horizon; 14 = charcoal horizon; 15 = erosional hiatus; 16 =loess doll; 17 = rhyzolith; 18 = sandstone bench

Table 1. Correlation of the Central and Eastern paratethys (after K*RETZOI*, *M. 1987)*

Approximate age (m yr)	Mediterranean biochronology: Codes: Foraminifer zones	Codes: Nannonplankton zones	Stage[1]	European terrestrial biochronology[2]: Group	Age / Stage*	MN Zone-Codes: POMEL 1853	GANDRY 1878	CRUSAFONT 1971	C-F-F 1972	CRUSAFONT 1974	MEIN 1975	Central Paratethys, Lithostratigraphy, Carpathian Basin: KM[3]	RB[4]
5	N-18	NN-13	(Tabianium-Zancleum)	Barótium	Ruscinium		14	22	11	23	MN 14	Danubian	
6	N-17	MN-12	Messinium	Battavárium*(=Turolium etc.)	Bérbaltavárium*						MN 13		
7		MN-11	Tortonium (s. Str.)		Hatvanium*						NN 12		Transdanubian
8					Sümegium	6	13	21	10	22		Pannonian	
9	N-16				Csákvárium						MN 11		
10		MN-10		Eppelcheimium* (=Vallesium)	Rhenohassium*		12	20b	9	21b	NN 10		Premartonian
11	N-15	NN-9	Serravallium		Bodvaium*			20a		21a	MN 9		
12	N-14				Monacium*	5	11	19b	8	20b	MN 8		
13	N-13	NN-8			(Oeningium)*							(Mediterranean)	(Sarmatian)

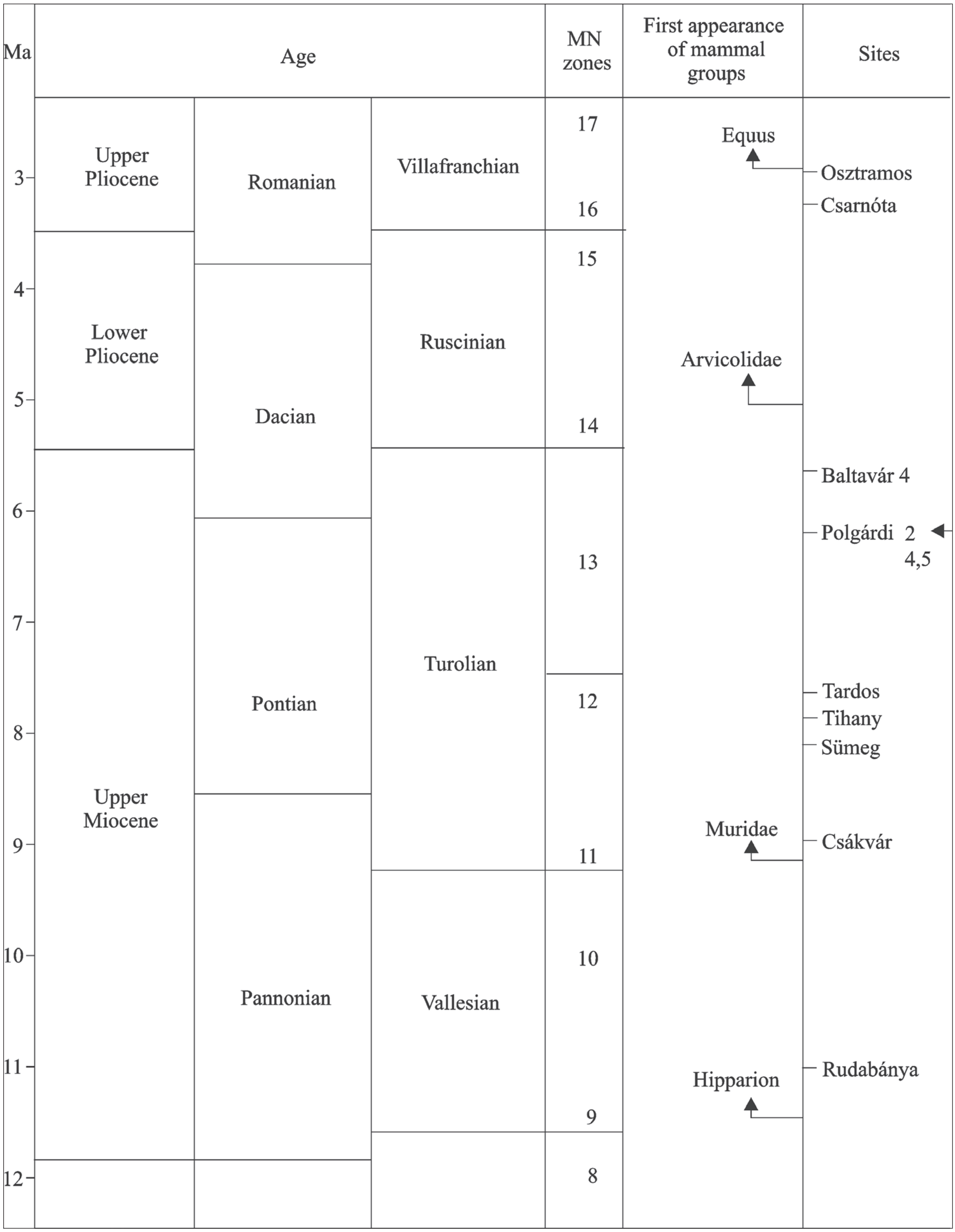
[1]Traditional, so called mixed (bio-litho) taxa. [2]Biochronological units; of them* with lithostratigraphic significance as well. [3]Author's proposal. [4]Recommendation of the Pliocene Subcommission of Hungarian Commission on Stratigraphy.

Mountains), starting with Sümegium and lasted until Csarnotanum and Ruscinium, when it was succeeded by red clay formation. For the latter Bérbaltavárian was an essential phase (*Table 2.*).

Geomorphological position and age of typical red clays and reddish clays

Typical red clays and reddish clays have a high relevance for the identification of paleo-

Table 2. Fauna of the classic site Polgárdi (N2) evidencig to the regression the Pannonian Lake, at least in this region of the Transdanubium***



*After Kormos, T. (1911), Kretzoi, M. (1952) and Kordos, L. (1992). **According to Kordos, L. (1992) vertebrate fauna at Polgárdi can be correlated with vertebrate fossils found in terrestrial deposits at Crevillente N6 site (Spain) where Messinian marine and terrestrial sediments are intercalated.

geographic periods and phases of tectonic movements. However, no adequate attention has been paid so far to the main interval of their formation.

There is a controversy about the age and formation of red clays proper, which are younger than Upper Miocene formation (previously referred as Upper Pannonian) and superimpose them. They were put in the Pliocene or in early Pleistocene. (Kretzoi, M. *et al*. 1982; De Bruijn, H. 1983; Pécsi, M. 1985). Based on the recent geomorphological investigations and sedimentological and paleomagnetic analyses of deep boreholes it can be stated that the appearance of typical red clays is confined to the time interval following pediment formation in the late Miocene (Pontian) and early Pliocene.

The oldest generation of red clays can be found on foothills of Bérbaltavarian age situated in a higher position than the Pleistocene terraces, in karstic dolines or on abrasional terraces. In certain partial basins of the Great Hungarian Plain, however, (e.g. in the Vésztő and Dévaványa boreholes in the Körös Basin) several red clay horizons occur at a depth of 800–1,100 m (Rónai, A. 1985a); they evidence to their character as sediment traps.

Typical red clays

Typical red clays (based on an analogy with Csarnóta-2 site) are chemostratigraphic markers of the Pliocene (Csarnotanum and Ruscinium), while fossil reddish clay (terra rossa), sediments and lime tuffs (based on the sample from the Villány-3 type locality) are markers of the Lower Pleistocene (Villányian). Their distinct mineral paragenesis is an indication of varied climatic conditions. The product of weathering under warm (subtropical) and humid climate is kaolinite–halloysite, whereas moderately warm, humid and arid climates had resulted in formation of illite-montmorillonite and various carbonate paragenesis. These two sediments of distinct type might be separated along several geochemical parameters. A good example is the total amount of uranium and thorium (U_{ekv}) and changes in the rate of ferric oxide (Fe_2O_3) (*Figure 5*). This regularity can be associated with weathering and solution processes influencing mineral paragenesis.

The age of typical red clays – apart from some exceptions – cannot be identified exactly by radiometric and paleomagnetic measurements for the time being. Nevertheless, an indirect correlation with paleontological finds seems to be possible. Based on faunistic evidence provided by Kretzoi, M. (1969), Jánossy, D. (1972), Kordos, L. (1988), De Bruijn, H. (1984) and especially on fossils of the European Pliocene *Spalax* (*Micro spalax*), it is considered probable by Kordos, L. (1992) that material of red clay site Csarnóta I (*Photo 5*) and that of red clay site Maritsa I formed between 3 and 4 million year BP, while red clay containing Odessa *Spalax* is somewhat older (ca. 4 m year, by Pevzner M.A. *ex verbis* 1989). (In China red clay formation span the period between 5.0–2.4 million year BP.) Red clays found on Susak Island in cavities of karstified Mesozoic limestone are supposed to be of the same age (*Photo 6*).

The occurrence of warm periods necessary for the formation of red clays are corroborated by paleoclimatic reconstructions by Koppány (1997) covering the time interval between 4 and 2 million year BP. It is well known that

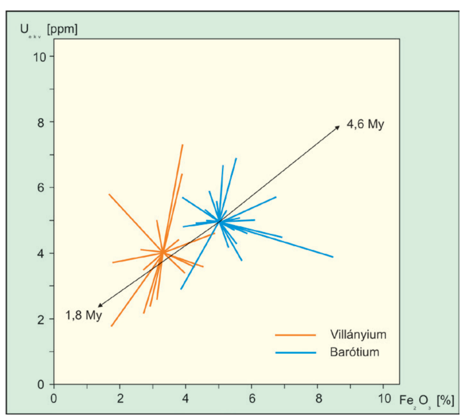


Fig. 5. Chemostratigraphic characteristics of Villányium with changing content of uranium, thorium (U_{ekv}) and ferric oxide (by Schweitzer, F. and Szöőr, Gy. 1993).

Photo 5. Type locality of Csarnotan fossil fauna in South Hungary (Photo by Schweitzer, F.)

Photo 6. Infillings of typical red clay in karstic depressions of Mesozoic limestone on Susak (Photo by Schweitzer, F.)

a decisive factor in fluctuations of global climate is the variation of solar irradiation as a result of secular oscillations of the Earth orbit.

Based on values of total insolation obtained through calculations the following phases could be identified during the 2 million years in concern:

$2.00 \cdot 10^6 – 2.16 \cdot 10^6$ year WARM
$2.16 \cdot 10^6 – 2.26 \cdot 10^6$ year COLD
$2.26 \cdot 10^6 – 2.50 \cdot 10^6$ year WARM
$2.50 \cdot 10^6 – 2.66 \cdot 10^6$ year COLD
$2.66 \cdot 10^6 – 2.90 \cdot 10^6$ year WARM
$2.90 \cdot 10^6 – 3.04 \cdot 10^6$ year COLD
$3.04 \cdot 10^6 – 3.14 \cdot 10^6$ year WARM
$3.14 \cdot 10^6 – 3.17 \cdot 10^6$ year COLD
$3.17 \cdot 10^6 – 3.51 \cdot 10^6$ year WARM
$3.51 \cdot 10^6 – 3.61 \cdot 10^6$ year COLD
$3.61 \cdot 10^6 – 3.96 \cdot 10^6$ year WARM

Such an exact delimitation of boundaries is purely theoretical and it serves only for fixing the dominant climate type during the studied period.

Between 3 and 2 million year BP:
WARM ca. 640,000 year;
COLD ca. 360,000 year;
Between 4 and 3 million year BP:
WARM ca. 790,000 year;
COLD ca. 210,000 year;
Over the two periods combined (ca. 2 million year):
WARM ca. 1,430,000 year (72%);
COLD ca. 570,000 year (28%).

These results corroborate information gained from other (paleontological, paleobotanic, sedimentological, geological and geomorphological) sources that this interval of 2 million yr duration was predominantly warm but, due to possible miscalculations nothing else can be concluded.

Reddish clays

The other group of formations is highly varied genetically. Fossil soils and pedosediments of purplish and reddish colour, and silty clays and clayey silts of pink tint are classified here. Reddish clays are as a rule intercalated in old loesses. None of them is typical red clay; rather they are steppe soils formed under warm and dry or subhumid climates. They have a lower plasticity than red clays proper and a higher carbonate content (between 10% and 70%), frequently with carbonate veins and grains. Samples are characterised with clay mineral of illite-montmorillonite (smectite) type and the carbonate association is highly varied: calcite, dolomite calcite (magnesite calcite) and dolomite occur. In the samples quartzite reoccurs frequently.

Formation of reddish clays is put to the Villányian, Villafranchian, sometimes to Calabrian; they represent lower or the lowermost Pleistocene (*Photos 7* and *8*) They might have formed between 3.0 and 1.7 million year BP.

Ventifacts polished by wind

These gravels are frequently encountered in the central part of the Carpathian Basin. They occur in alluvial fans and in clastic sediments. Along with its transportation function, polishing and scouring are also typical of wind action. In areas with frequent sand storms even the hardest rocks are being worn down. Desert and semidesert landforms bear traces of this process and this is the case with Susak Island as well.

Here surfaces with ventifact occurrences in sediments transported by torrents and cemented by calcium carbonate are overlain by reddish clays (*Photos 9* and *10*). In the Carpathian Basin they can be found both in older alluvial fans and debris and on younger (mainly Pleistocene) terrace surfaces.

The problem of Tertiary–Quaternary boundary and of other possible boundaries

As far as the Neogene–Quaternary boundary is concerned, experts on Late Neogene and Quaternary have always been strongly divided. According to the recommendations of the International Geological Congress (London, 1948) the Pliocene-Pleistocene boundary

Photo 7. Displacements along faults in Mesozoic (rudist) limestone with thermal spring occurrences (Photo by Schweitzer, F.)

Photo 8. Crater of a thermal spring breaking through rudist limestone occurring in several places on Susak (Photo by Schweitzer, F.)

Photo 9. 10–30 cm thick debris cemented by carbonate on the surface of Mesozoic limestone and covered by reddish clay with ventifact occurrences on Susak (Photo by Kɪs, É.)

Photo 10. Ventifacts embedded in reddish clay on Susak (Photo by Sᴄʜᴡᴇɪᴛᴢᴇʀ, F.)

should be drawn at the bottom of the Calabrian layers where cold tolerant foraminifers appear in marine sediments. Later these layers were dated ca. 2 million year BP by Arias, C. *et al*. (1980) with paleomagnetic analyses.

Earlier the Neogene–Quaternary boundary was drawn at 600,000 year BP based on the climatic calendar by Milanković, M. (1930) and Bacsák, Gy. (1942)[2] and on the Alpine glaciation stages by Penck and Bruckner and coincided with the first significant glacial as the advent of the Ice Age proper. However, through the study of the Günz glacial several previous stages (such as Donau /Eburon/, Biber /Praeteigelen) were traced, consequently the duration of the Pleistocene was extended (initially back to 1.8 million year, then by some to 2.4 million year and even to 3 million year BP).

This extension of the Quaternary was corroborated by the tendency to correlate the appearance of Early Man with the advent of this epoch. The sites at Olduvai are 1.7–1.8 million years old and the age of Coobi Forai (sites on the eastern shore of Lake Turkana) is 2.2–2.0 million year BP.

The arid and warm steppe fauna of the Villafranchian (3.0–2.5 million year) had deteriorated (Kretzoi, M. 1954, 1969; Jánossy, D. 1979; Kordos, L. 1992) then disappeared and between 2.4 and 2.0 million year a new faunistic event followed with an enrichment of fauna.

Probably this event starting from 2.4 million year could be an adequate boundary between the Pliocene and Pleistocene in the Carpathian Basin. According to Rónai, A. (1972, 1985b) the borehole sediments in the Great Hungarian Plain evidence to a climatic change that had a general trend to cool down but not continuously. Beside an uneven deterioration of climate the alternation of arid and humid phases was a typical feature of fluctuations. Borehole samples from the Hungarian Great Plain have revealed five longer cycles between 2.4 and 1.8 million year BP.

There are, however, several authors (Evans, P. 1972; Shackleton, N.J., Opdyke, N.D. 1973; Ruggieri, G., Sprovieri, R. 1977; Azzaroli, A. 1982; De Giuli, H. *et al*. 1987; Nikiforova, K.V. *et al.* 1984) suggesting the *lowermost boundary* of the Pleistocene to be drawn at the 22nd stage of the oxygen-isotope scale. This coincides with the coldest peak of the Pleistocene with an age of 0.8 million year BP. In the Russian Quaternary literature this is the Pleistocene-Eopleistoceneboundary.

In Hungary the Pliocene-Pleistocene boundary coincides with the Matuyama–Gauss paleomagnetic boundary (2.4 million year) while in the Mediterranean this is 1.8–1.7 million year. The former is associated with significant structural, paleogeographic and environmental changes in the Carpathian Basin.

Quaternary events

When overviewing the geological events over the past 4 million years, five cycles of climatic fluctuations can be distinguished that had brought about significant geomorphic–lithological changes in the Carpathian Basin and in northern Adriatic (Susak and Krk islands).

1. The time interval between 4 and 3 million year BP was a period of humid and warm climate with a high diversity of species of mammal fauna. As a result red clays formed in considerable thickness and there was a significant karstification in the limestone regions. It was a period of formation of typical red clays in the Carpathian Basin (see *Photo 5*) and also on Susak Island (see *Photo 6*). Tectonic events induced activities of thermal springs (*Photos 11* and *12*).

2. The second climatic cycle started ca. 3 million years ago, when a warm and humid

[2] As it is known global climate change is regulated by solar radiation. The impact of fluctuations in cycles of insolation during the Pleistocene first was calculated by Milanković, M. (1930). Later this theory on the relationship between glaciations and solar irradiation was criticised repeatedly but recently it has come to the fore again. The calculations by Milanković were checked by several experts and found correct within a time period back to 1 million year BP.

Photo 11. 0.5–1.0 m wide fissures formed as a result of tectonic displacement filled with minutely broken limestone and reddish clay on Susak (Photo by Schweitzer, F.)

Photo 12. Reddish clay filling up tectonic fissures in Villányi Mountains (Hungary) and containing Villányian fossil fauna (Photo by Schweitzer, F.)

environment had been succeeded by a warm and drier climate lasting between 3.0 and 1.8 million year BP. The contemporary rivers deposited coarser sediments. Pediment surfaces in lower position were formed at that time. Based on marine stratigraphy the 1.8 million year BP marker is considered the boundary both between the Pliocene and Pleistocene and between the Neogene and Quaternary in the northern Mediterranean, contrary to the Matuyama–Gauss paleomagnetic boundary of 2.4 million year adopted as the Plio-Pleistocene boundary in Hungary.

3. The third significant change started between 1.8 and 1.7 million year and terminated at ca, 700,000 year BP when, after a nearly 1 million year of relative stability, a considerable subsidence started in the area what is now the Great Hungarian Plain and in the northern Adriatic. The first spell of cooling occurred at that time but it had not resulted in tundra environment over these regions. Stratigraphically this is the Lower Biharian stage (*Figure 6).*

4. In the beginning of the fourth phase (ca. 1 million–800,000 year BP) the expansion of Alpine mountain glaciation and of the advancement of European inland ice sheet could be felt for the first time. Eastern and northern faunal species penetrated in the Carpathian Basin and proceeding through the desiccated northern Adriatic they reached the Appennine Peninsula. Under dry and cold climate loess formation started and subsequently it had become general during the cold periods of the Pleistocene (see *Figure 1*).

5. The last regional climatic event took place ca. 400,000 years ago as a consequence of a glacial stage of long duration. The vertebrate fauna had changed fundamentally and a process of the emergence of the present-day species began. In the Adriatic sandy loess accumulated in a vast thickness whereas in the Carpathian Basin typical loess developed. Generally, it is held that continental drift was primarily responsible for changes in the global climate and for the recurrence of glaciations, but rhythmic oscillations of the latter probably were controlled by cosmic factors.

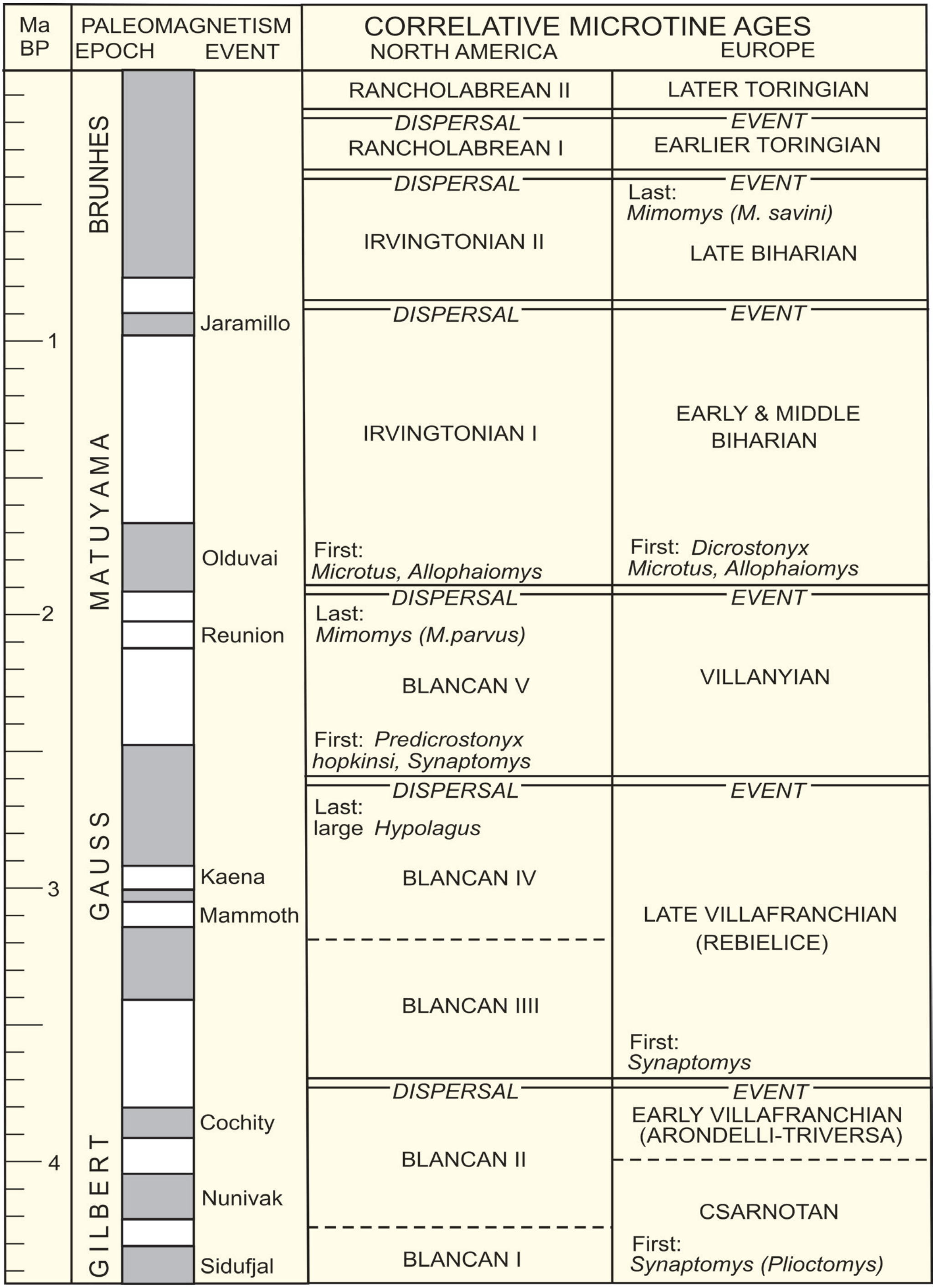


Fig. 6. Correlation of Late Pliocene events in North America and Europe (after Repenning, C.A. 1987)

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