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Parallelization of Last Glacial loess-paleosol section of Red Hill with Heinrich events and ice core records

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Abstract

In this paper, I would like to provide refined relative chronological data to loess-paleosol section situated on the IV. and V. terraces of Red Hill (Moravia), based on a comparison with Heirich events, North and South hemispheric ice core records. The last glacial–interglacial loess section is almost complete, all of the interstadial soils can be identified in the series instead of the eroded upper part of the PK I complex.

The onset of the formation of recent soil can be parallelized to H_0 event (~12 000), the double structural soils to H_1 and H_2 events, the eroded soils of PK I to H_3 and H_4, while the lower part of the complex has been correlated with H_5 and H_6 events (~63 ka BP). The loess series above PK I has been classified into Würm-3, the strata between PK I and PK II belong to the Würm-2. The lower part, under PK II is mostly clayey, cannot be regarded as a cold climate deposit. After the Riss/Würm interglacial the climate has changed slowly, and the typical glacial climate has started only after 75 ka BP.

Keywords: Heinrich events, ice cores, loess-paleosol series, chronology, $\delta^{18}O$ values

Introduction

Main aim of this paper is to provide new, refined relative chronological data on the formation of loess-paleosol deposits in Southern Moravia (*Photos 1–2*). The section is located on Devonian red sandstone and pebbles, and Miocene sandstone at the IV–V. terraces of the Red Hill (*Photo 3*). This investigation was based on records of Heinrich events, North and South hemispheric ice core drillings, and on the comparison of these paleoenvironmental proxies with our former loess-studies in the region (Kis, É. *et al.* 2011).

The stratigraphic investigations of the Red Hill section have been made by Kukla, G.J. (1975); Fink, J. and Kukla, G.J. (1977); Smolikova, L. (1982), Zeman, A. (1992) and Demek, J. *et al.* (2005). Loess deposits are important terres-

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Photo 1. The South Czech "Red Hill" (Photo: Kɪs, É.)

Photo 2. Perspective view of the terrace system of Red Hill (*source:* GoogleEarth^{TM})

Photo 3. Devonian red sandstone and pebbles underlying the loess-paleosol section at the IV. terrace (Photo: Kis, É.)

trial archives of climatic changes (Lóczy, D. and Szalay, L. 1995; Lóczy, D. 2008) and these aeolian dust deposits provide insight into the Plio-Pleistocene geomorphological and environmental development of Central Europe (Frechen, M. *et al.* 1997, 2003; Fábián, Sz.Á. *et al.* 2004; Kovács, J. *et al.* 2011).

During the last glacial period, the dust transportation was defined by three prevailing wind-directions: (1) westerlies in the east-west corridor along latitude 50°N, (2) northwesterly winds from the Fennoscandinavian ice sheet, and (3) according to Rozycki, S.Z. (1991) and Rousseau, D.D. *et al.* (2007) the Saharan dust from south was also relevant. This last conception about the role of the Saharan dust was confirmed by the studies of Varga, Gy. (2011) and Varga, Gy. *et al.* (2012).

Methods

The sedimentary and stable isotopic parameters of the investigated, almost complete loess-paleosol section have been compared to the isotopic records of NGRIP (Greenland), EPICA Dome-C and Vostok (Antarctica) ice cores and to the North Atlantic Heinrich layers (*Figures 1–2*). I would like to correlate the

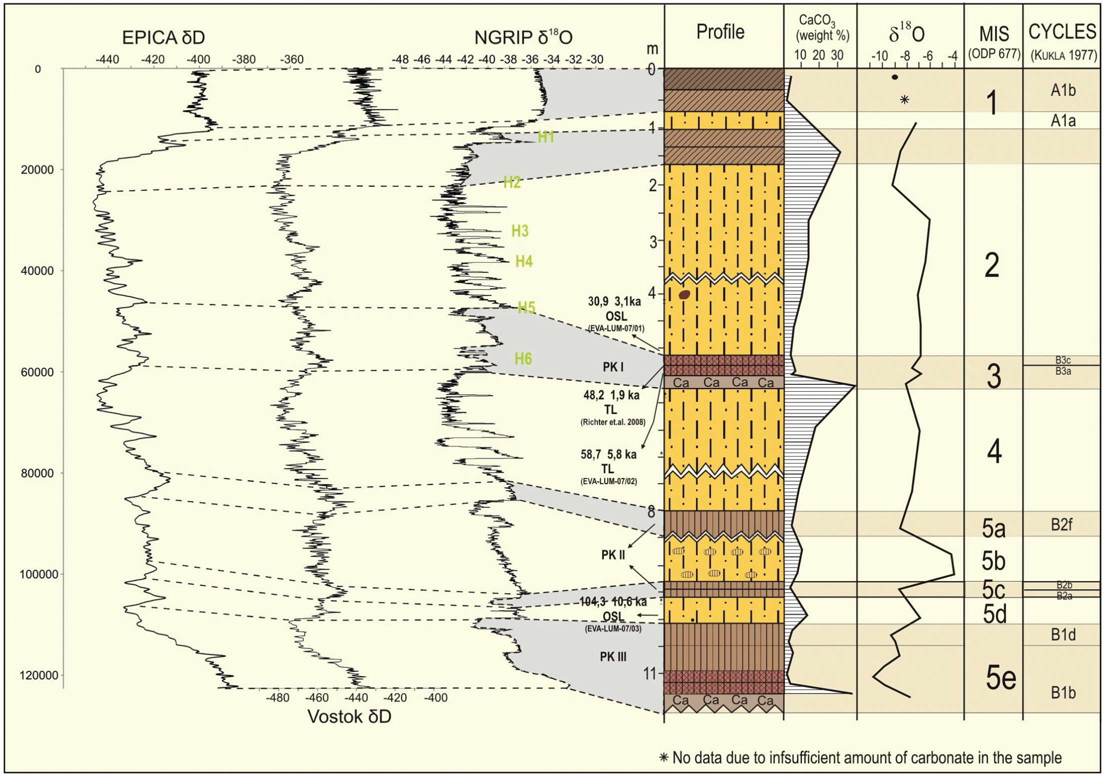

Fig. 1. Possible correlation of the last glacial/interglacial loess-paleosol series of the Red Hill with Heinrich events, Antarctic EPICA and Vostok δD, and Greenlandic NGRIP δ^{18}O records (Kis, É.). Sedimentary parameters: Kis, É. Stratigraphic analysis: Schweitzer, F., Kis, É., Balogh, J. and Di Gléria, M. Oxygen isotope measurements: Futó, I. and Vodila, G. Grain-size analysis: Di Gléria, M. (Data sources of ice core records and Heinrich events: Petit, J.R. *et al.* 1999; EPICA Community members 2004; NGRIP Community members 2004; Hemming, S.R. 2004)

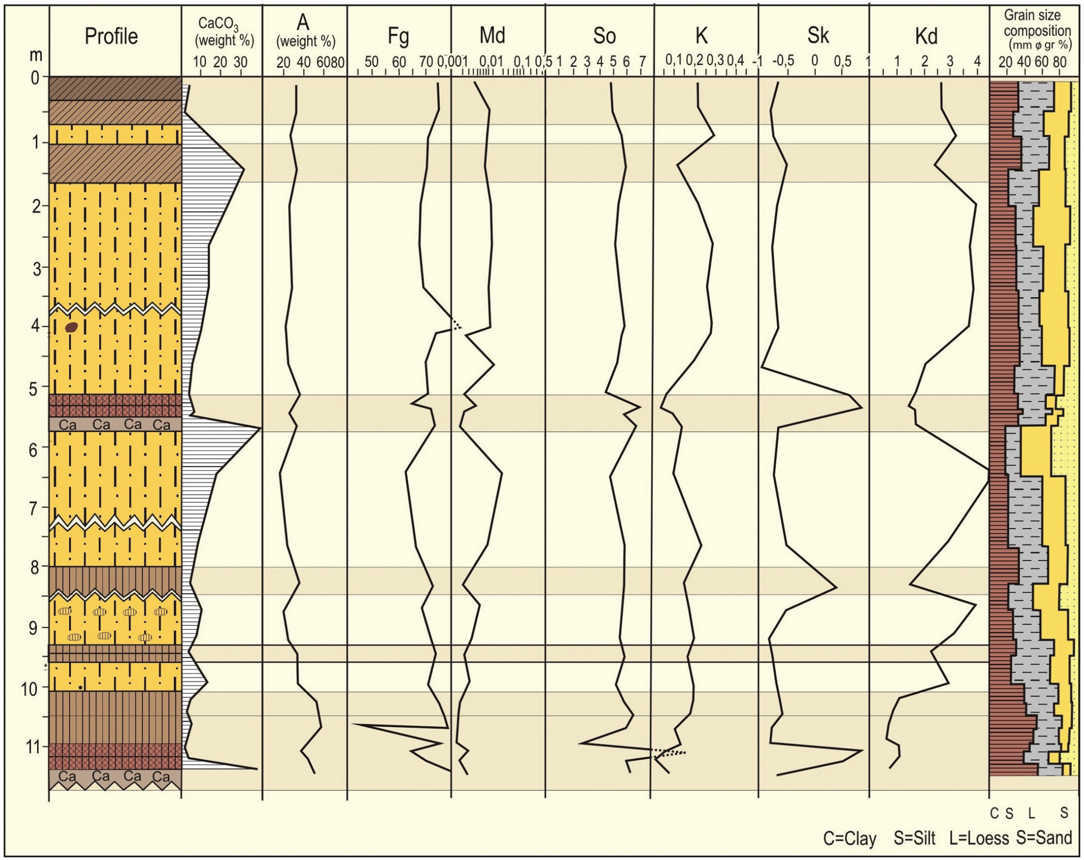

Fig. 2. Variations of sedimentary parameter values in the Red Hill loess-paleosol series (source: Kis, É. *et al.* 2011). Sedimentary parameters: Kis, É. Stratigraphic analysis: Schweitzer, F., Kis, É., Balogh, J. and Di Gléria, M. Grain-size analysis: Di Gléria, M.

δD and $\delta^{18}O$ values of ice cores with the measured $\delta^{18}O$ values of the analysed loess-paleosol deposits to refine the chronological framework of the section.

The sedimentary parameters of the Red Hill section have been determined by environmental-discrimination proxies (Kis, É. 2003; Schweitzer, F. and Kis, É. 2003; Kis, É. *et al.* 2011, 2012). These are traditional sedimentary parameters and our newly introduced indices (fineness grade: F_g and degree of weathering: K_d), and $\delta^{18}O$-values. The detailed description of the applied methods can be found in Kis, É. *et al.* (2011).

The NGRIP ice core (Greenland)

The ice core provides information on the climatic changes and anomalies during the last glacial period of the North Atlantic domain (*Figure 1*). According to the North GRIP Community Members (2004), the analytical data represent 25 Dansgaard-Oeschger (D/O) events; abrupt, large amplitude climate fluctuations (often within several decades).

These events show us the rapid changes of cold and warm periods of the region. The D/O events can be correlated well with other North Atlantic paleotemperature proxies (e.g. benthic foraminiferal isotope records of VM23-0.81, DSDP 609, VM30-101k deep sea cores – Bond, G.C. *et al.* 1993; Ziegler, M. *et al.* 2008) or with terrestrial aeolian dust deposits (Varga, Gy. 2010). The stable isotope values and gas content of ice cores suggest the occurrence of abrupt 8–16°C temperature fluctuations during the last glacial period.

EPICA Dome Concordia (DOME C) ice core (Antarctica)

The EPICA DOME C ice core contains information on the climate changes of the last 800 kyr, the only one ice core which could have provide climate data on cyclic changes from the Brunhes/Matuyama Boundary (*Figure 1*). Beside the stable isotopes, the greenhouse gas content trapped in bubbles can be used as proxy of climatic fluctuations. Based on the detailed analyses of the sequence, eight glacials and interglacials (and their durations) have been distinguished during the last 800 kyr. Earlier Antarctic ice cores provide data only on the climate of the last 400 kyr (e.g. Vostok – Petit, J.R. *et al.* 1999).

The ice core records can be correlated with the benthic foraminiferal records and $\delta^{18}O$ values of deep sea deposits (e.g. ODP 659 Tiedemann, R. *et al.* 1994; Lisiecki, L. and Raymo, M.E. 2005), confirming the eight glacial cycles of the last 800 kyr.

Vostok ice core (Antarctica)

The more than 3700 metres deep ice core represent the climatic cycles of the last 440 kyr (*Figure 1*). (The third deepest lake of the Earth, Lake Vostok subglacial lake can be found beneath the Vostok Station.) Various measurements provide data on local paleotemperature, humidity, wind speed, atmospheric O_2, CO_2 and CH_4 content, lithic material of ancient volcanic eruptions. Based on the correlation of δD values of the ice core with $\delta^{18}O$ values of GRIP core (Jouzel, J. *et al.* 1997), all of the 25 D/O events of the last glacial periods can be found in the sequence. However, the relationship between the two regions is asynchronous; the warming phases had been occurring earlier in the Vostok cores compared to the Greenland ice cores. The northern ice cores have ~1,500 years lag behind the southern hemispheric climatic variations, but the global changes can be well correlated with statistical analyses of the phase-lag relationships.

Oxygen isotope values of the ice cores

Dansgaard, W. has established that the isotope ratio of $H_2{}^{18}O/H_2{}^{16}O$ of precipitation is constantly decreasing into the direction of higher latitudes, implying a strong relationship between temperature and stable isotope content. The temporal changes of isotopic composition of the precipitation provide information on the temperature changes. This relationship can be used to determine the paleotemperature from the ice cores oxygen isotope values. The values have been different during glacial and interglacial periods (Dansgaard, W. *et al.* 1983).

Oeschger, H. measured similar differences between cold and warm phases in the sequence of the Grenzensee deposits in Switzerland (Dansgaard, W. *et al.* 1993). These climatic fluctuations are not only typical for Greenland and Switzerland, however represent the whole northern hemispheric changes. The early measurements were confirmed by the recent NGRIP drillings and measurements (NGRIP Community Members 2004). The abrupt warming episodes and the longer cooling phases have determined the last glacial period.

Heinrich events

Heinrich events provide valuable information to recognition of paleoenvironmental, paleoclimatic and principally global climate changes. These events caused relatively rapid changes on a global paleoclimatic temporal scale. To recognize the causes of climate changes, the complex effects of terrestrial, oceanic and atmospheric components should be investigated together. The deep sea deposits and ice cores provide the most comprehensive and complex picture on climate changes. These proxies reflect the variability of climatic stages and the variations of components on various temporal scales, even the seasonal changes. Heinrich events correlate with the destruction of the Arctic ice-sheets, and with the consequent release of vast volume of icebergs to North Atlantic. Signs of the events can be observed in the deep sea deposits after periodic major, mainly longer cold episodes.

These last glacial events were first reported by Heinrich, H. (1988) and by Bond, G.C. *et al.* (1992). The deep sea sediments of North Atlantic consist several layers rich in ice rafted terrestrial material and with decreased foraminiferal abundance. These, so called Heinrich layers can be correlated with cooling periods of marine and terrestrial environments, and also with decreased oceanic salinity. Investigations have confirmed that the cooling events can be connected to the presence and drifting of freshwater reservoir icebergs even at lower latitudes. The trails of the icebergs could be tracked trough 3000 km, following the melted detrital carbonate deposits. The deep sea sediments prove the abrupt cooling episodes in the last glacial period and the presence of vast volume of drifting icebergs.

Heinrich layers provide important sedimentary information on the short term, abrupt climate fluctuations by the repeated occurrence of ice rafted debris. The terrestrial material was eroded by glaciers and the calving icebergs transported it to the Atlantic Ocean. The melting and drifting icebergs dropped the embedded material onto the sea floor. The freshwater content of melted ice has changed significantly the oceanic and atmospheric circulation patterns.

Based on deep sea drillings, the Heinrich events were dated as the following: H_0: ~12 ka (Hemming, S.R. 2004); H_1: ~16.8 ka (Hemming, S.R. 2004), ~14 ka (Vidal, L. *et al.* 1999); H_2: ~24 ka (Hemming, S.R. 2004), ~22 ka (Bond, G.C. and Lotti, R. 1995; Vidal, L. *et al.* 1999); H_3: ~31 ka (Hemming, S.R. 2004), ~29 ka (Bond, G.C. and Lotti, R. 1995); H_4: ~38 ka (Hemming, S.R. 2004), ~37 ka (Bond, G.C. and Lotti, R. 1995), ~35 ka (Vidal, L. *et al.* 1999); H_5: ~45 ka (Hemming, S.R. 2004; Vidal, L. *et al.* 1999); H_6: ~60 ka (*Figure 1*).

The orientation of the H_1, H_2, H_4 and H_5 layers on the sea floor is north-south (from Labrador Sea into southern direction), while H_3 and H_6 deposits has west-east orientation (from North America into the direction of Europe, around the 40° northern latitude).

The main causes of Heinrich events are still a matter of scientific debate and there are several competing explanations about the processes leading to abrupt climatic fluctuations. The calving icebergs of the Laurentide ice sheet and the huge freshwater input could have major effect on the thermohaline circulation of the ocean, and causing southward (and westward) migration of North Atlantic Current. Consequently, the northward heat transport decreases, leading to the increase of Laurentide ice sheet. According to the EPICA Community Members (2004), the main causes can be traced back to changes of greenhouse gas concentration of the atmosphere. Even small-scale fluctuations of oceanic circulations (especially at Arctic regions) have major impact on the atmospheric CO_2 concentrations. The most important reservoir of CO_2 is the ocean, where fiftyfold of the atmospheric CO_2 can be stored. (The natural CO_2 concentration of the atmosphere was 200 ppm during the cold and 280ppm during the warm episodes).

Other investigations suggest various explanations on the causes; e.g. instability of West Arctic ice sheet; intensifying iceberg calving after cold winters; collapses of ice sheets due to backward erosion (Tiedemann, R. *et al.* 1994). The abrupt and large sea-level rises could have eroded the ice sheets leading to collapses. These explanations were also confirmed by model calculations (Arz, H.W. *et al.* 2007).

Generally, the Heinrich events occurred after a longer (7–10 kyr) cold period, which was terminated a massive release of calving and drifting icebergs. The H-events have been followed by an abrupt warming climatic phase. These cold-warm fluctuations of oceanic-atmospheric system between 20 and 80 ka BP were confirmed by the pioneering works of Bond, G.C. *et al.* (1993). Typical global environmental consequences of the Heinrich events are: decreased $\delta^{18}O$ content of deep sea deposits and decreased oceanic salinity related to the colder climate and to the increased influx of freshwater; increased grain-size of loess deposits indicating stronger winds due to the changing patterns of oceanic currents; increased sedimentation rate of lithic terrestrial fragments at the sea floor; palynological records show the replacement of oak by pines; and decreased foraminiferal abundance.

Results

This research is dealing with the last glacial period's (~100 kyr) stratigraphic features in a South Czech loess-paleosol section. I would like to compare the almost complete series of Moravian aeolian dust deposits to North and South hemispheric ice core records, Heinrich events and sea level changes. The aim of this paper is to complete the chronological framework of the investigated strata, based on the data contributed by Kis, É. *et al.* (2011).

The newest ice core and deep sea drillings provide new insight into dynamics of Plio-Pleistocene paleoenvironmental and paleoclimatic changes. These new databases of ice cores and deep sea sediments allow us to correlate the climatic fluctuations and the terrestrial, oceanic and atmospheric relationships with various proxies from different environments (e.g. loess deposits). In this case, the almost complete South Czech "Red

Hill" loess-paleosol sequence has been compared with the last glacial oscillations. With this comparison, the main aim is to refine the chronological properties of the section. The known intensity, duration and absolute age data of deep sea Heinrich events provide ground for relative dating and correlation of the investigated deposits. Based on these parallelization, the controversial stratigraphic position and ^{14}C data of thin, humic horizons above (and between) thick, well-developed paleosoils (e.g. in the Hungarian Tápiósüly–Dunaújváros loess series) can also be explained. The sedimentary parameters and oxygen isotope data of the series have been used during this comparison.

The investigated 120–130 kyr comprise the paleoenvironmental properties of the last glacial and interglacial periods. During the last interglacial the arctic summers were warmer by 5°C than the later epochs. All of the glaciers have been melted, only the inner part of Greenland remained covered by ice. As a result of the huge amount of melted ice, the sea level has been increased by 5 metres. The temperature of the last glacial maximum (21 ka BP) was colder by 20°C than present conditions (Miler, G.H. *et al.* 2010). The Heinrich events had various intensity and duration. Based on the deep sea records, the H_3 and H_6 events were fairly different than the others; the spatial distribution of the ice-rafted debris of these events is also different.

The investigated section consist of loess and intercalated soils of the last 100 kyr, however the lower part (between 100 and 80 ka BP) cannot be regarded as typical loess, these layers are sandy loess deposits (*Figure 1.; Photos 1 and 4–6.*). The loess section is generally intercalated by interstadial soils instead of the PK III., which is the last interglacial soil-series. The uppermost pedogenic complex consists of the recent (upper) and a redeposited paleosoil (lower). The onset of the soil-formation can be dated from 12 ka BP (preboreal oscillation), the preceding colder period is represented by the underlying loess layer.

The next thick soil is a double, weakly developed humic soil or structural paleosoil and can be correlated with the H_1 and H_2 events. The age of the upper pedogenic horizon is ~16.8 ka BP (Hemming, S.R. 2004), similarly to other loess sections in Central Europe (e.g. Paks: 16730±400 years; Dolní Vestonice). Loess between the two soil horizons cannot be found at the Red Hill, it was eroded or redeposited. The lower structural soil has been formed ~22–24 ka BP.

The thick Würm-3 loess series (*Photo 4*) represents well the cold glacial climate; while the upper part of the underlying PK I soil-complex is eroded. These missing horizons could be parallelized to the H_3 and H_4 events. The middle part of the PK I complex is related to the H_5 and H_6 events, the ages of these events are 45 and 60 ka BP (Vidal, L. *et al.* 1999; Hemming, S.R. 2004). The hiatus at the top of PK I is ~10 kyr.

Photo 4. Würm-3 loess series in the upper part of the section (Photo: Kɪs, É.)

Similarly to Dolní Vestonice, the Würm-2 loess stratum is well-developed and fairly thick. Beneath the PK II soil-complex the section shows us that the climate has changed slowly after the last interglacial, the Würm-1 period was not a real cold stadial and cannot identified in the loess series; the temperature has decreased and the typical steppe environment was formed slowly.

This interpretation of the Red Hill loess section could also be confirmed by several evidences from the discussed ice core and deep sea records (*Figure 1*).

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Photo 5. Periglacial features in young loess (Photo: Kɪs, É.)

Photo 6. The PK I soil series with notable hiatus in the upper part (Photo: Kɪs, É.)

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AVAILABLE!

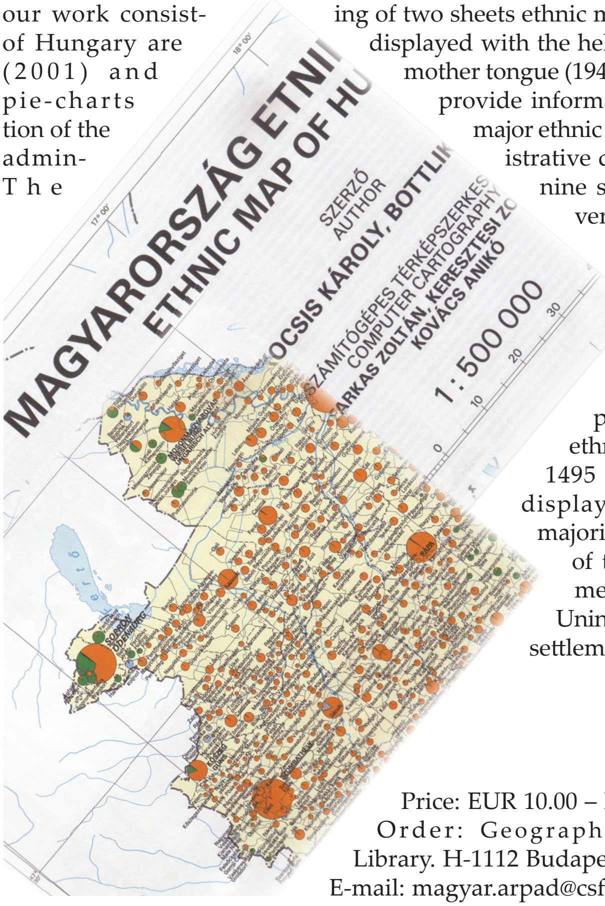
Ethnic map of Hungary 1941 + Ethnic map of present territory of Hungary 2001

Scale 1:500 000

Authors: KOCSIS, K. and BOTTLIK, ZS.

Geographical Research Institute, Hungarian Academy of Sciences, Budapest, 2009

The latest (eighth) piece of ethnic map series of the Carpathian Basin was an attempt to draft the changes that have taken place in the ethnic structure during the past five hundred years as well as to display its present state with the help of ethnic maps and a chart - in our case referring to the present-day territory of Hungary. On the front pages of our work consisting of two sheets ethnic maps of the present-day territory of Hungary are displayed with the help of pie-charts, based on ethnic (2001) and mother tongue (1941) data. Population-proportional pie-charts provide information on the territorial distribution of the major ethnic groups and on the contemporary administrative division. The nine supplementary maps on the reverse show the lingual-ethnic composition of the present-day territory of Hungary in 1495, 1715, 1784, 1880, 1910, 1930, 1941, 1990 and 2001 respectively. The chart here explores the quantitative and proportional changes of the main ethnic groups' population between 1495 and 2001. The series of maps displays absolute or relative ethnic majorities only in the inhabited areas of the settlements which had been mentioned in the source referred. Uninhabited areas with no permanent settlements are shown as blank spots.



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