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Magnetostratigraphic correlation of Quaternary travertine sequences in NE Transdanubia

Északkelet-dunántúli negyedidőszaki édesvízi mészkőszelvények magnetosztratigráfiai korrelációja

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(Figures 10)

Keywords: magnetostratigraphy, North-eastern Transdanubia, Pleistocene, travertine
Tárgyszavak: magnetosztratigráfia, ÉK–Dunántúl, negyedidőszak, édesvízi mészkő

Összefoglalás

Az ÉK–Dunántúlon hét édesvízi mészkő előfordulás mintáin készült magnetosztratigráfiai korreláció, a szelvények helye: Buda, Budakalász, Dunaalmás, Les-hegy, Süttő, Tata és Vértesszőlős. A mágnesezettség iránya 200–300 °C fölött volt stabil. A termikus lemágnesezési diagramok és a röntgendiffrakciós vizsgálatok szerint a mágnesezettség hordozója hematit és magnetit. Az inklináció alapján meghatározott polaritás zónákat radiometrikus korok és őslénytani eredmények segítségével korreláltuk a földmágneses polaritás–idő skálával.

A kísérleti magnetosztratigráfiai korreláció szerint az egyes szelvények az időskála diszkrét szakaszain helyezkednek el. Süttő (Haraszti kőfejtő), Dunaalmás és Les-hegy mészkövei kora-pleisztocén korúak. A budai (ÉK Vár-hegy) és budakalászi rétegsorok valószínűleg az 1,1–0,5 Ma intervallumban képződtek, míg a vértesszőlősi ősember lelőhely és a tatai kőfejtő rétegei a Brunhes kron középső és fiatalabb része idején.

Abstract

Magnetostratigraphic studies were carried out on samples from seven travertine sites in NE Transdanubia: Buda, Budakalász, Dunaalmás, Les-hegy, Süttő, Tata and Vértesszőlős. Stable directions of magnetisation were revealed above 200–300 °C. Thermal demagnetisation diagrams and X-ray diffraction analysis indicate that the magnetisation resides in haematite and magnetite. Polarity zones, defined by inclinations, have been correlated with the geomagnetic polarity time scale employing radiometric ages and results of palaeontological studies. Tentative magnetostratigraphic correlations indicate that the individual sections occupy discrete parts of the time-scale. The travertines in the Haraszti quarry (Süttő), Dunaalmás and Les-hegy quarries are early Pleistocene in age. The NW Vár-hegy (Buda) and Budakalász sequences appear to have accumulated in the interval between 1.1–0.5 Ma, whereas the travertines at the palaeolithic site in Vértesszőlős and Tata quarry were deposited during the middle and younger part of the Brunhes chron.

Introduction

Magnetostratigraphy can be a useful method for dating sedimentary sequences if they are long enough in time. Recent observations and their extrapolations indicate that travertine deposits may form over a period of several thousand years, as summarised by KORPÁS (2003) and FORD & PEDLEY (1996). In this case the magnetostratigraphy is useless, and no study on travertine has been reported yet.

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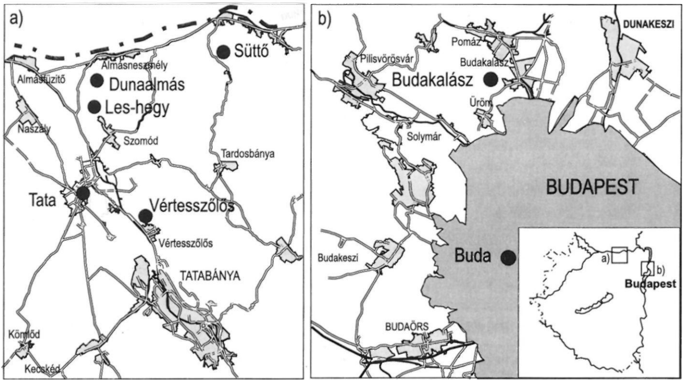

Fig. 1 Location maps of travertine sites in North-eastern Transdanubia

1. ábra. A travertínó előfordulások helyszínrajzai

However, extrapolation included the assumption that the depositional environment did not change during the entire formation of travertine. This assumption is invalid for the relatively thick sequences in NE Transdanubia, because the travertines are divided by discontinuity surfaces and interlayered with fine clastics and palaeosols related to subaerial exposures (e.g. see KORPÁS 2003). These horizons have great lateral continuity. The length of break in deposition is unknown but the time of accumulation of interlayered beds can be estimated. The 0.5 m-thick, weakly-developed palaeosol within the Buda section (BAJNÓCZY et al. 2003) may have formed over 10 ka, considering that 30 m thick Pleistocene red clay formed over 700 ka based on magnetostratigraphic correlation (KOLOSZÁR et al. 2001). Thus the travertine below and above the palaeosol may have formed in two (or more) different oxygen isotope stages. The period-time of the oxygen isotope cycles ranges from 40 to 100 ka in the Pleistocene (e.g. SHACKLETON et al. 1990), hence the formation of the entire travertine sequence is of the order of 100 ka.

Magnetostratigraphic studies were carried out on seven inactive travertine sites in NE Transdanubia (Fig. 1). The sites chosen were as follows; Vár-hegy, (Fortuna u. 25 and Táncsics u. 5), Buda; Monalovác-hegy (southern part of the quarry), Budakalász; Roman quarry and quarry no. 4; Dunaalmás, quarry on the topof Les-hegy (near Szomód); Új Haraszti and Diósvölgyi quarries, Süttő; Tata quarry (below the high school) and Vértesszőlős (palaeolithic site). The object was to develop geomagnetically controlled time-lines that could serve to place the travertine sections in the time-scale. The basic pattern of the travertine sequences is described in KORPÁS (2003). This paper presents the results of the magnetostratigraphic studies and gives atentative correlation of the polarity zones with the time-scale.

Sampling and laboratory procedures

Oriented hand samples were collected from undisturbed and unaltered rocks at ~0.5 m vertical intervals. The palaeomagnetic samples were cut into cubic shapes with a bronze-diamond saw. The usual practice was to obtain two samples from the same stratigraphic level. The interlayered, fine-clastic and palaeosol layers were also sampled. The loose and wet samples were placed in cubic plastic boxes which then were sealed. Altogether, 400 oriented samples were collected from 240 stratigraphic levels.

The samples were processed in the joint laboratory of the Geological Institute of Hungary and the Eötvös Loránd Geophysical Institute. Magnetisation of samples was measured in a CCL two-axis cryogenic magnetometer. The samples were demagnetised in a Schoenstedt thermal demagnetiser or in a one-component Schoenstedt alternating field demagnetiser.

Following measurements of the natural remanent magnetisation (NRM), a series of pilot samples representing various types of rock and different magnetic directions were selected for progressive demagnetisation. Initially both thermal and alternating field (AF) demagnetisations were carried out. AF demagnetisation was less efficient in the limestone, therefore later the travertines were only thermally demagnetised. All loose samples were progressively demagnetised in an alternating field, and the soft, secondary magnetisation disappeared at 15–20 mT.

Thermal demagnetisation diagrams indicated that secondary magnetisations disappeared at 200–300 °C (*Fig. 2*). Stable directions of magnetisation were revealed above 450 °C. Remaining samples were demagnetised in two (three) stages in the range of 200–350 (450) °C; the intensity decreased near the noise level of the magnetometer at higher temperatures. Most samples displayed no changes in polarity with demagnetisation. Samples that did not contain stable original directions were discarded.

Stable directions above 575 °C on the thermal demagnetisation diagrams suggest the presence of haematite (*Fig. 2*). X-ray diffraction analysis revealed haematite in all sequences and magnetite across the Tata section and at the top of Les-hegy (KOVÁCS-PÁLFFY & FÖLDVÁRI 2004, in press). Goethite was observed in only 20% of samples. As seen on the demagnetisation diagram in *Fig. 2a*, the influence of goethite on stable inclination does not appear to be important. In addition, inclinations of samples containing goethite are commonly similar to inclinations from adjacent samples lacking goethite. Maghemite was identified by X-ray diffraction analysis only in two sections, in two samples from Tata and many samples from Les-hegy (KOVÁCS-PÁLFFY & FÖLDVÁRI 2004, in press). Maghemite is a secondary mineral, therefore many samples in the Les-hegy section may display secondary directions.

The foregoing observations indicate that haematite and magnetite are the principal carriers of stable magnetisation in the travertine sequences and also indicate a minor alteration of the minerals in the samples except for the Les-hegy section. Therefore, the stable directions are considered to reflect original magnetisation acquired during deposition. However, some shallow negative inclinations, one-sample normal polarity reversals and a large part of the Les-hegy section may be related to a secondary magnetisation.

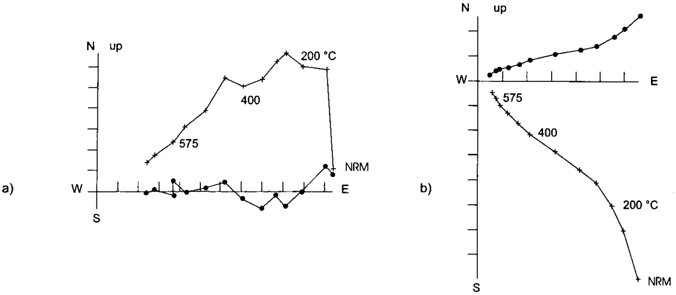

Fig. 2 Orthogonal demagnetisation diagrams for samples a) Vértesszőlős 3.3 m, b) Tata 8.4 m. + = vertical plane, ·● = horizontal plane

2. ábra. Ortogonális lemágnesezési diagramok a) Vértesszőlős 3,3 m, b) Tata 8,4 m. + = vertikális sík, ·● = horizontális sík

The polarity zones have been defined by the inclinations excluding one-sample normal polarity intervals. Interpretation of declinations is difficult because the secular variation is not averaged-out in the samples. Plots of inclinations and polarity zones of the individual sections are shown in *Figures 3–9*.

Magnetic susceptibility in the travertine

During recent decades many loess, lacustrine and marine sections have been studied for magnetic susceptibility (MS), and it was found that changes in MS reflect climatic changes. A close correspondence between the MS and the marine oxygen isotope record was also found in Pleistocene fluvial sediments in the eastern part of the Pannonian Basin (Nádor et al. 2000, 2003).

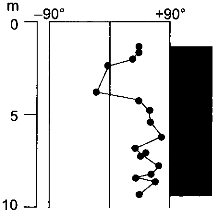

Fig. 3 Plots of inclinations and polarity zones versus depth of the section in Tata quarry

3. ábra. A tatai kőfejtő szelvényének inklinációja és polaritása a mélység függvényében

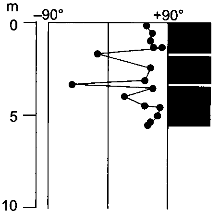

Fig. 4 Plots of inclinations and polarity zones versus depth of the Vértesszőlős section. The profile is adjacent to hominoid site marker in the palaeolithic site

4. ábra. A vértesszőlősi szelvény inklinációja és polaritása a mélység függvényében. A szelvény az ősember lelet táblája mellett húzódik

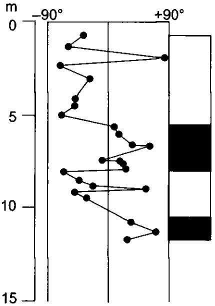

Fig. 5 Plots of inclinations and polarity zones versus depth of the composite section at Buda, Vár-hegy (Fortuna u. 25 and Táncsics u. 5)

5. ábra. A Buda, Vár-hegy (Fortuna u. 25. és Táncsics u. 5.) kompozit szelvény inklinációja és polaritása a mélység függvényében

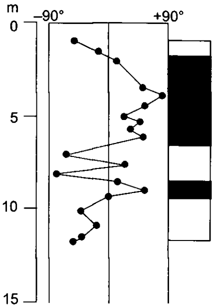

Fig. 6 Plots of inclinations and polarity zones versus depth of the Budakalász section

6. ábra. A budakalászi szelvény inklinációja és polaritása a mélység függvényében

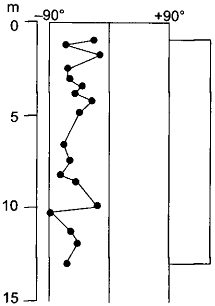

Fig. 7 Plots of inclinations and polarity zones versus depth of the quarry no. 4 at Dunaalmás

7. ábra. A dunaalmási 4. sz. kőfejtő szelvényének inklinációja és polaritása a mélység függvényében

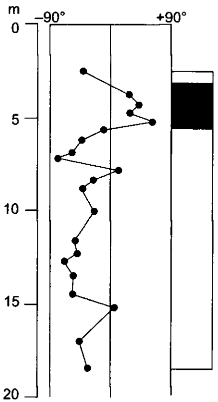

Fig. 8 Plots of inclinations and polarity zones versus depth of the section in the quarry on Les-hegy

8. ábra. A Les-hegy kőfejtőjének inklinációja és polaritása a mélység függvényében

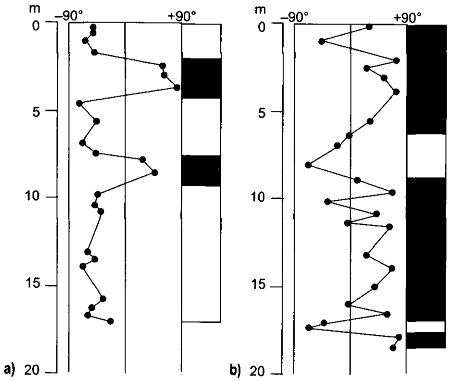

Fig. 9 Plots of inclinations and polarity zones versus depth of the Süttő sections . a) Új Haraszti quarry, b) Diósvölgyi quarry

9. ábra. A süttői szelvények inklinációja és polaritása a mélység függvényében. a) Új Haraszti kőfejtő, b) Diósvölgyi kőfejtő

Magnetic susceptibilities of the samples were measured with a Sapphire Instrument SI-2. Many samples show low negative and rather uniform susceptibilities. Significant fluctuations have been found within and near the interlayered detrital strata where the amount of calcium carbonate decreases.

The travertines consist of almost pure, very low-magnesian calcite with a small amount of clay minerals, quartz and very little haematite and magnetite (KOVÁCS-PÁLFFY & FÖLDVÁRI 2004, in press). The susceptibility of calcium carbonate and quartz is a very low negative value, the clay minerals have low positive MS, whereas the haematite and magnetite have a high positive MS. The measured susceptibility is dependent upon susceptibilities of all grains in the sample. The negative MS is due to the almost pure calcium carbonate, and a positive MS indicates a higher abundance of clay minerals. The haematite and magnetite play a minor role in the susceptibility of travertine because of their very small quantities. Changes in susceptibility of the travertine sequences appear to reflect mainly differences in clay content, and it is controlled not only by climate but also by local depositional conditions. Consequently, the relation between the susceptibility record and climate in the travertine sections is not as straightforward as in the detrital sequences.

Correlation of polarity zones and polarity time-scale

The polarity zones have been correlated with the time-scale of BERGGREN et al. (1995), employing radiometric ages and the results of palaeontological studies. The Tata section shows a normal polarity zone (*Fig. 3*). Radiometric ages of 101±10 and 98±8 ka were determined by HENNIG et al. (1983) and 120±6 ka by SCHWARCZ (1980) for the travertine. Therefore the normal polarity interval correlates with the younger part of the Brunhes chron (*Fig. 10*).

The Vértesszőlős site has a special importance because a part of a hominid skull and human artefacts were found here. Several palaeomagnetic samples from the quarry had been measured earlier and all displayed normal polarity (LATHAM & SCHWARCZ 1990). The recent inclination record near the hominid site marker shows a predominantly normal polarity interval with two brief reversed polarity zones (*Fig. 4*). Samples were also collected and processed from another profile (N of the covered area) and the two records are similar. The two sections can be correlated by means of palaeomagnetic inclinations, mineralogical composition and stratigraphy. Reliable U/Th and ESR data range from 250 to 475 ka (CHERDINTSEV & KAZACHEVKSI 1990, HENNIG et al. 1983, BLACKWELL, personal communication). For this reason the predominantly normal polarity interval at Vértesszőlős correlates with the middle part of the Brunhes chron (*Fig. 10*).

The Castle Hill (Vár-hegy) on the Buda side of Budapest is covered by travertine. The entire sequence was not accessible in one cellar, and the individual sections are shown in KORPÁS et al. (2004, in press). The base of the composite section exhibits normal polarity, the overlying reversed polarity interval is followed by a normal polarity zone and the top of the section is reversed again (*Fig. 5*).

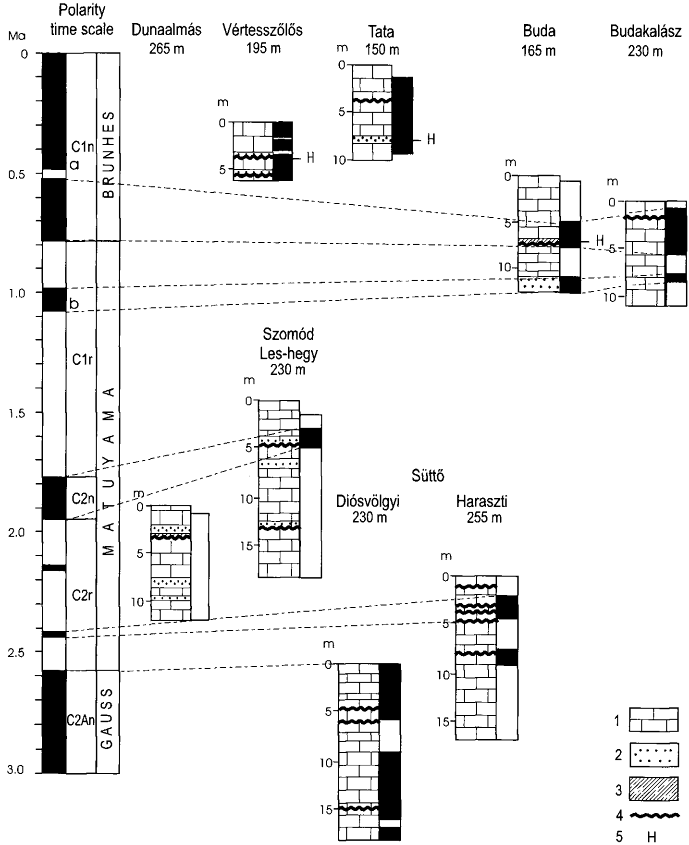

Fig. 10 Lithology, elevation and magnetic polarity zones of the travertine sections in NE Transdanubia and their correlation with the polarity time scale. The polarity time scale is from BERGGREN et al. (1995), modified after CANDE & KENT (1995). The C2n is the Olduvai chron. Legend: 1 travertine, 2 sand, 3 palaeosol, 4 discontinuity surface, a – cryptochron C1n-1, b – Jaramillo subchron, 5 – human remain or artefact, black – normal polarity, white – reversed polarity.

10. ábra. Az ÉK-dunántúli édesvízi mészkő szelvények rétegsora, tengerszint feletti magassága, mágneses polaritása és korrelációjuk a polaritás–idő skálával. A polaritás–idő skála BERGGREN *et al. (1995) munkájából, kiegészítve* CANDE *&* KENT *(1995) adataival. A C2n az Olduvai kron. Jelmagyarázat: 1. édesvízi mészkő, 2. homok, 3. paleotalaj, 4. üledékhiány, 5. ősemberi lelet, a – C1n-1 kriptokron, b – Jaramillo szubkron, fekete – normál polaritás, fehér – fordított polaritás*

A radiometric age from the travertine close to our sections was determined as >350 ka, at the limit of the Th/U method (HENNIG et al. 1983). The vertebrate data suggest an age range from 1.0 Ma to 600 ka for the base of the travertine complex and the underlying clastic sediments (KORDOS, personal communication), and 400–350 ka for its middle part (KORDOS 1994). Therefore the normal polarity interval at the base of the Buda section can be correlated with the Jaramillo subchron (0.99–1.07 Ma). Since the youngest reversed polarity interval in the polarity time scale of BERGGREN et al. (1995) is the Matuyama chron, the correlation of the reversed polarity interval at the top of the Buda section raises problems. In the polarity time scale of CANDE & KENT (1995), a single brief reversed interval has been identified in the Brunhes chron, between 504 and 493 ka, and it is called cryptochron C1n-1. Thus the upper reversed polarity interval at the Buda section thus has been assigned to this cryptochron (*Fig. 10*).

The polarity record at Budakalász exhibits mainly normal polarity in the upper part and predominantly reversed polarity in the lower part (*Fig. 6*). The vertebrate and mollusc fossils from the upper part of the quarry are indicative of the Günz–Mindel interglacial (JÁNOSSY 1986; KROLOPP 2004, this volume). For this reason the long normal polarity interval can be correlated with the Brunhes chron and the lower, short normal interval with the Jaramillo subchron (*Fig. 10*). It is noteworthy that several samples from clastic sediments of two vertical fissures exhibit normal polarity.

An interval of reversed polarity has been recorded at Dunaalmás (*Fig. 7*), and a second section from a nearby quarry also exhibits a reversed polarity interval. An age of about 1.8 Ma was estimated for vertebrates from a 70 cm-thick palaeosol layer within the same travertine section (JÁNOSSY 1986). The re-interpretation of the fauna suggests an age of about 2.4 Ma (KORDOS 1988). Therefore the reversed polarity interval may correlate with the older part of the Matuyama chron (*Fig. 10*).

The inclination recorded at Les-hegy displays a predominantly reversed polarity (*Fig. 8*). As mentioned above, many samples in the section could have secondary directions. The reversed directions may have occurred during the Matuyama chron because this is the youngest reversed polarity interval. No radiometric age or palaeontological data are available for the travertine in Les-hegy. This site is close to Dunaalmás, and their morphological features are similar. It is very likely that the Les-hegy section is not older than the Dunaalmás sequence, thus the original inclinations were probably negative as well. The normal polarity interval in the Les-hegy section has been assigned to the Olduvai chron (C2n) and the reversed polarity intervals to the Matuyama chron (*Fig. 10*).

Samples from two different quarries were measured at Süttő, and the polarity records of the sections are different (*Fig. 9*). Palaeontological data indicate that the travertine deposits in the Süttő area are older than at Dunaalmás, and suggest an age of, at the lowest, Pleistocene (JÁNOSSY & KROLOPP 1981). Therefore the upper normal polarity interval in the Haraszti section (Fig. 9a) may correlate with the brief normal polarity cryptochron of 2.43 Ma in the polarity time-scale of CANDE & KENT (1995). The shallow normal inclinations around 8 m in the Haraszti section may reflect secondary magnetisation rather than real reversal. The predominantly normal polarity record from the Diósvölgyi quarry (*Fig. 9b*) may correlate with the upper part of the Gauss normal polarity chron, and therefore the sequence is late Pliocene in age (*Fig. 10*).

Conclusions

Correlations with the time-scale indicate that the individual sequences occupy discrete parts of the time-scale and record discrete episodes of deposition (*Fig. 10*). The travertines in the Haraszti quarry, Süttő , Dunaalmás and Les-hegy are early Pleistocene in age, whereas the Diósvölgyi sequence, Süttő, may be late Pliocene. The Buda (NW Vár-hegy) and Budakalász sequences appear to have accumulated in the interval between 1.1–0.5 Ma, but a 100 ka break in deposition cannot be excluded. The travertines at the palaeolithic site in Vértesszőlős and Tata quarry were deposited during the middle and younger part of the Brunhes chron. As seen in *Figure 10*, travertine deposits older than 2 Ma are at an elevation higher than 230 m but the ages are not in close relationship with the elevation.

Magnetostratigraphic correlations can only be nade tentatively because the lack of accurate time control. In addition, correlations have to be based on the assumption that no break in deposition was longer than 150–200 ka. Moreover, the geomagnetic polarity time scales based on the marine magnetic record (e.g. BERGGREN et al. 1995; CANDE & KENT 1995) are incomplete. During recent decades a large number of papers have reported brief (<20 ka) reversed polarity zones in the Brunhes chron and also brief normal zones in the Matuyama chron. More than 20 brief reversals occurred during this time (e.g. SINGER et al. 2002), and only a few of them are found in the polarity time scales. Several polarity intervals in the travertine sections may correspond to some brief reversals, but their correlation is impossible now because of the lack of precise radiometric ages. The accuracy of many radiometric ages does not usually make it possible to distinguish the brief reversals one from another. Reliable and precise ages would allow the brief reversals to be identified in the travertine sequences, and would also change the present correlations.

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