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Paleomagnetic correlation of Miocene pyroclastics of the Bükk Mts and their forelands

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Paleomagnetic measurements were carried out on 163 independently oriented samples from 19 sites of the Bükk Mts and their northern, western and southern forelands. The aim was to correlate the sites with one of three Miocene rhyolite tuff horizons using the combination of paleomagnetic marker horizons (rotational events) and traditional magnetostratigraphy.

In contrast to the results of earlier studies in the southern Bükk foreland, which yielded only reversed polarity magnetizations, nearly half of the presently obtained paleomagnetic directions are of normal polarity. By their declinations they mostly belong to the middle tuff horizon, and only one belongs to the upper.

The paleomagnetic age assignment of the studied sites sometimes supports one or both of the classifications of Balogh (1964) and Pelikán et al. (2005). However, about one-third of the sites classified by these authors as upper or lower tuffs were shown to belong to the middle tuff complex.

Key words: pyroclastics, Miocene, paleomagnetism, Bükk Mts

Introduction

Around the Bükk Mts, which are built up from predominantly Mesozoic sediments, pyroclastics of Miocene age are widespread. The pyroclastics, deposited on land or in water, were first studied by Schréter (1913) who correlated them with those occurring in three stratigraphic horizons in the Salgótarján Basin. In the southern foreland of the Bükk Mts he also discovered

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sheet-like massive igneous rocks of rhyolitic or dacitic composition and suggested that the first was coeval with the lower, and the second with the middle tuff horizons of the Salgótarján Basin. Balogh (1964) in his monograph and map adopted Schréter's subdivision of the Miocene pyroclastics, but following Pantó (1962), he used the modern terminology ignimbrite for the sheet-like, massive igneous rocks. Eventually, Balogh (1964) distinguished a lower (rhyolitic) and an upper (dacitic) ignimbrite horizon in the southern foreland of the Bükk Mts, both containing hardly welded to highly welded varieties.

A systematic paleomagnetic study on a large number of geographically distributed ignimbrite sites from the southern foreland of the Bükk Mts (Márton and Márton 1996) found that while all studied sites had reversed polarity natural remanent magnetizations, there were considerable differences in declinations between sites belonging to the lower and to the upper ignimbrite horizons of Balogh (1964), respectively. The declinations suggested that the area rotated twice, first after the eruption of the lower, the second time after that of the upper ignimbrites. The rotations were later dated as 18.5–17.5 Ma and 16–14.5 Ma, respectively (Márton and Pécskay 1998). In the paleomagnetic data set, there were two distinct groups corresponding to the lower and upper ignimbrites and just one site without significant declination deviation from expected declination in a stable European reference system, thus clearly post-dating the counter-clockwise rotations of the area.

The map compiled by Balogh (1964) was partly revised by Pentelényi and Pelikán (see Pelikán et al. 2005) and several outcrops (which were not studied earlier paleomagnetically) were shifted stratigraphically upward. Thus, it was a new challenge for paleomagnetism to decide if the old or the new age assignment was more plausible. In addition, recently published petrological and volcanological studies pointed out that the ignimbrite horizons were composite, the products of several eruptions (Szakács et al. 1998; Póka et al. 1998) or suggested the existence of more than two ignimbrite horizons in the southern foreland of the Bükk Mts, some of them welded, some unwelded (Lukács et al. 2002; Harangi et al. 2005). In the context of several eruptions during a time span of a few million years with quite frequent polarity reversals (Cande and Kent 1995) the absence of ignimbrites with normal polarity in the Bükk foreland (Márton and Márton 1996) was peculiar. The question therefore was whether the repeated eruptions were really all confined to reversed polarity intervals. These were the main reasons why paleomagnetic studies in the Bükk Mts and their foreland were resumed.

Paleomagnetic sampling and laboratory measurements

From the northern, western and southern forelands of the Bükk Mts a total of 153 samples were drilled from 18 sites, and 10 samples from an additional site, from an outcrop sitting directly on the Mesozoic sediments of the Bükk Mts (Fig. 1, site 14). The rocks at the sites are ignimbrites and tuffs, representing a wide

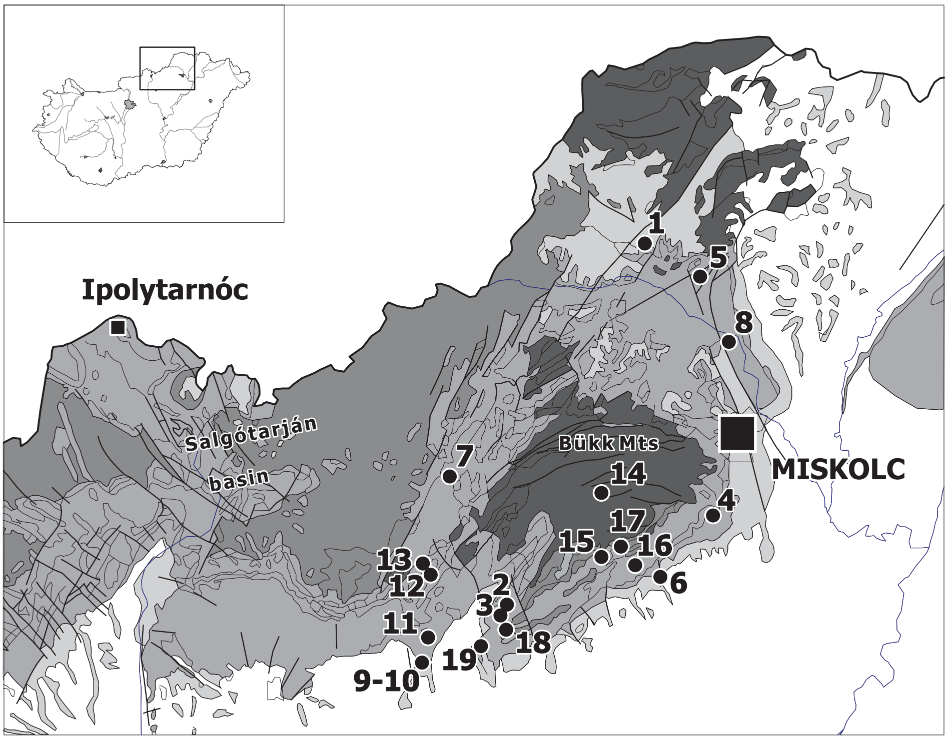

Fig. 1
Bükk Mts and their foreland with the paleomagnetic sampling sites (numbered). The location of the study area is shown on the insert. Key to geology: from darkest to lightest gray: Mesozoic–Paleozoic, Paleogene, Miocene, Pannonian

range of lithology (Table 1). The drill cores were oriented in situ with magnetic and sometimes also with sun compass.

The cores were cut into standard-size specimens. The natural remanent magnetization (NRM) and the magnetic susceptibility of each specimen were measured in the natural state. Pilot specimens were demagnetized in a large number of steps by alternating field (AF). As a rule, NRM was fully demagnetized by maximum 0.1 T AF field (Fig. 2). Sometimes, however, the NRM was very hard, thus demagnetization had to be continued by thermal method (Fig. 3). Based on the behavior of the pilot specimens, the remaining samples from each group were demagnetized in several steps so that the remanence direction characteristic of each sample could be obtained. The characteristic remanences were identified as linear segments of the demagnetization curves (Kirschvink 1980) and evaluated statistically on site level. The results are summarized in Table 1.

Table 1
Paleomagnetic site-mean directions with statistical parameters. Site numbers refer to Fig 1. and used throughout the paper. Key: n/no: number used/collected samples (the samples are independently oriented cores); D°, I°: declination, inclination; k and a95°: statistical parameters (Fisher, 1953). Lithological characterization of the sites (under the heading "rock type") is based on thin section evaluation

	Site	Rocktype	n/n_0	D°	I°	k	α_{95}°
1	Felsőnyárád 9188-193	accretionary lapilli bearing dacite tuff (with biotite and pyroxene)	5/6	18	+50	20	18
2	Felnémet, quarry 9398-407	slightly welded dacitic ignimbrite (with biotite)	10/10	206	–71	494	2
3	Felnémet, Bajusz-völgy 9408-416	slightly welded dacite-rhyolite ignimbrite (with biotite)	8/9	173	–75	210	4
4	N. of Harsány 7721-728	non-welded dacite-rhyolite ignimbritie (with biotite)	7/8	145	–70	103	6
5	Edelény, Csisztapuszta 9182-187	accretionary lapilli bearing dacite tuff (with biotite and piroxene)	4/6	344	+41	79	10
6	Tibolddaróc 8902-911	slightly welded rhyolitic ignimbritie with lapilli (with biotite and amphibole)	8/10	313	+55	71	7
7	Egercsehi 9093-103	accretionary lapilli bearing rhyolite tuff (with biotite)	10/11	343	+30	268	3
8	Sajószentpéter 9174-181	dacite tuff with lithoclasts (with biotite and piroxene)	8/8	340	+39	56	7
9	Verpelét, Castle hill 9417-420	hyaloclastic andesite tuff (with pyroxene)	4/4	155	–56	337	5
10	Verpelét, Castle hill outer rim, 9421-432	hyaloclastic andesite tuff (with pyroxene)	10/12	143	–58	171	4
11	Tarnaszentmária 9104-112	welded ignimbrite of dacitic composition (with pyroxene)	9/9	165	–51	213	4
12	Sirok, South 9433-446	welded ignimbrite of dacitic composition (with amphibole, pyroxene and biotite)	14/14	177	–51	215	3
13	Sirok, Castle hill 9447-458	welded ignimbrite of dacitic composition (with amphibole, pyroxene and biotite)	12/12	174	–48	288	3
14	Fehérkút, Bükkzsérc 9344-353	slightly welded ignimbrite (with biotite)	10/10	74	–38	80	5
15	Bükkzsérc, Oldalföld 7828-837	non-welded rhyolite tuff (with biotite)	6/10	328	+48	185	7
16	Cserépváralja Törökréti-patak 7809-817	slightly welded ignimbrite (with biotite)	5/9	329	+46	178	6
17	Cserépfalu, Karácsony tisztás 7843-850+7838-842	welded rhyolitic ignimbrite (with biotite)	11/13	105	–46	97	5
18	Eger, Tihamér quarry 7818-827	non-welded rhyolitic ignimbrite (with biotite and amphibole)	0/10	large scatter			
19	Egerszalók 9113-115	non-welded rhyolitic ignimbrite (with biotite)	0/3	large scatter			

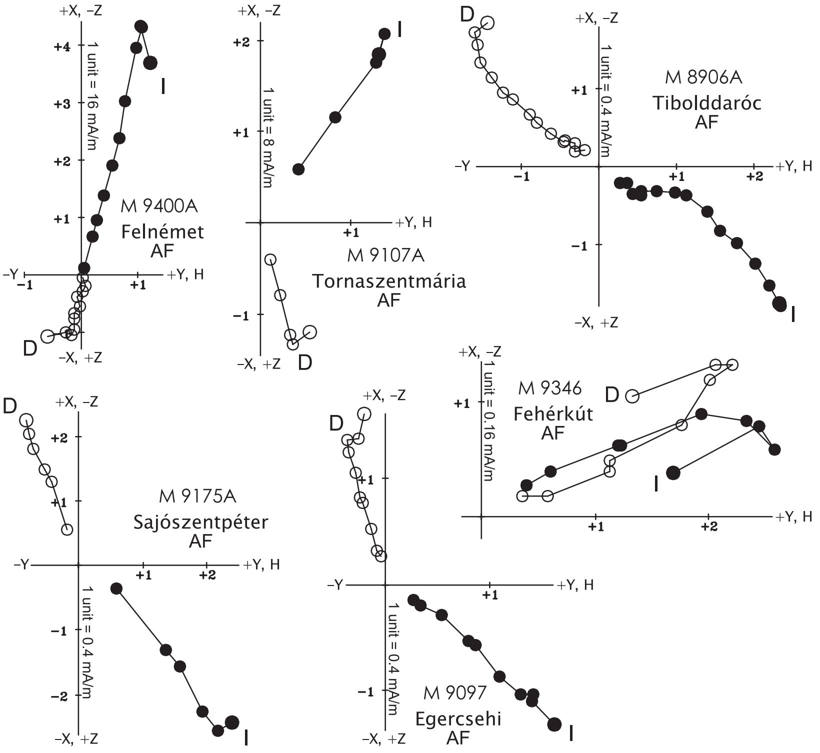

Fig. 2
Bükk Mts and their foreland. Typical demagnetization curves (Zijderveld diagrams) showing basically one-component NRM decaying towards the origin on AF demagnetization

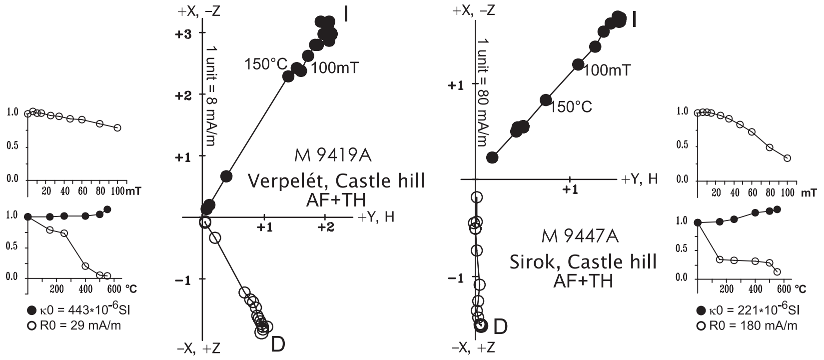

Fig. 3
Foreland of the Bükk Mts. Examples of hard magnetic signal: the demagnetization, after AF method up to 100 mT, had to be continued with the thermal method. The NRM signal became lost before 600 °C, indicating magnetite as the carrier of the NRM. Larger diagrams are Zijderveld plots, smaller diagrams are intensity versus demagnetizing field (upper diagrams) and intensity (circles) / susceptibility (dots) versus temperature curves

Results and discussion

As the demagnetization curves document, the NRM is practically single component regardless of the composition or welding degree at a site. The site mean statistical parameters (Table 1) are excellent or good, except for site 1, where the radius of confidence circle (95) somewhat exceeds the internationally accepted 15°, and sites 18 and 19, where the scatter within the site is so large that paleomagnetic directions for these sites cannot be defined. Among the tabulated paleomagnetic directions both normal and reversed polarity remanences occur (inclinations are positive and negative, respectively). Concerning declinations, the sites cluster around three values, two of them indicating counter-clockwise rotations of different degrees and one a slight clockwise deviation from the present north (Fig. 4). These three values are the overall-mean declinations earlier measured for the three tuff (ignimbrite) complexes of the Salgótarján Basin and of the southern foreland of the Bükk Mts. As the separation of paleomagnetic directions by their declination is the consequence of important geodynamic events taking place between main phases of eruptions, we regard it as the principal correlation tool. Thus, the sites of the present study are distributed among the three tuff (ignimbrite) complexes in the following way. Sites 14 and 17 belong to the lower, sites 4, 5, 6, 7, 6, 9, 10, 15, 16 to the middle, sites 1, 2, 3 to the upper complexes, respectively, while sites 11, 12 and 13 seem to be transitions between the middle and upper complexes. The age estimation can be further refined when polarities are taken into account and the sites are tied to the standard polarity time scale (Fig. 5). Unfortunately, magnetic parameters, like susceptibility or initial NRM intensity are so varied within the main groups that they have no correlation value. It is interesting that they

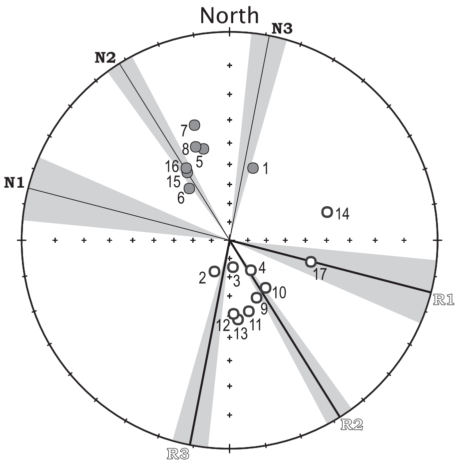

Fig. 4
Bükk Mts (site 14) and their foreland. Site-mean paleomagnetic directions on a stereonet. For comparison, overall-mean paleomagnetic declinations are plotted as lines (normal and reversed polarity segments are distinguished as N and R, respectively). The statistical error of the declination lines is shown by the shaded area, 1) for the lower tuffs (ignimbrites) of the southern foreland of the Bükk Mts and the Salgótarján Basin (line 1, all paleomagnetic site means were of reversed polarity); 2) for the middle tuffs (ignimbrites) of the southern foreland of the Bükk Mts (line 2, all paleomagnetic site means were of reversed polarity); 3) for the upper tuffs (ignimbrites) for two sites (line 3); one is Tar Quarry (earlier type locality for the Tar Dacite Tuff Formation: for revision see Zelenka et al. 2005), the other is Demjén Nagyeresztvény Quarry (earlier mapped as lower tuff, for revision see Márton and Pécskay 1998)

do not correlate with lithology either (Table 2).

Among the sites of the present study normal polarities occur only in the groups which are younger than the first Miocene rotation event. Based on geologic considerations (e.g. direct field observation of the sequence of ignimbrites, such as site 6, which follows welded typical upper ignimbrite of reversed polarity of the southern foreland of the Bükk Mts), some sites belonging to the middle tuff (ignimbrite) complex with normal polarity can be somewhat older, and some slightly younger than the dominant reversed polarity bulk of the complex (Fig. 5). Concerning the upper complex, site 1 with normal polarity seems to be younger than the reversed polarity sites of this and of earlier studies (Márton and Márton 1996; Zelenka et al. 2005).

As Table 3 shows, there are sites where the paleomagnetic results support either the age assignment of Balogh (1964) or that of Pelikán (2005). To the first group belong site 14, to the second sites 2 and 3. The paleomagnetic age assignment for sites 1, 8, 9, 10 and 17 is in harmony with the classification of both authors. Concerning the rest, they have mean declinations typical for middle rhyolite tuff (sites 4, 5, 6 and 7, which are shown on the geologic maps as "upper rhyolite tuff", and sites 15 and 16 as "lower rhyolite tuff") or transition between middle and upper tuffs (sites 11–13). While the latter are not problematic, those with typical "middle rhyolite tuff" declinations and different geologic age assignments are. The solution can be what is shown in the last column of Table 3, which distributes the critical sites with normal polarity between a group which is younger, and another one which is older, than the andesite tuffs. The older group can then be regarded as coeval with the first and second eruption level of Ipolytarnóc, which have similar declinations and also normal polarities (Márton et al., in prep).

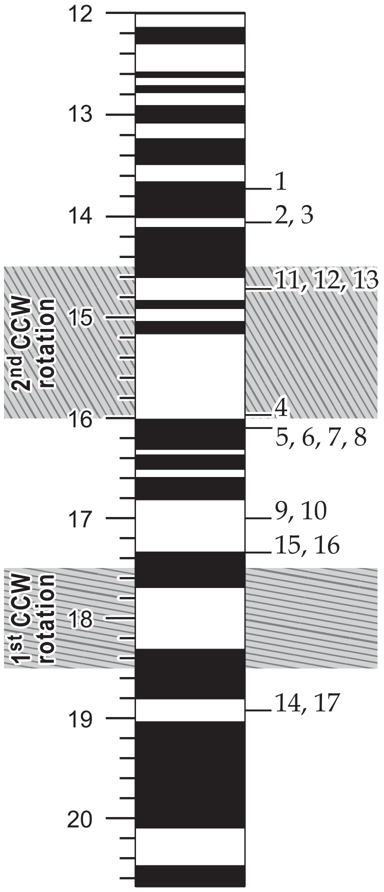

Fig. 5
Age estimation of the studied sites using declinations in comparison with paleomagnetic marker horizons (gray fields at both sides of the standard polarity time scale) and polarity information

Table 2
Summary of the average susceptibilities and initial intensities of the NRM for the studied sites, complete with WGS 84 co-ordinates either read from GPS or from maps (the latter marked with stars)

	Site	Susceptibility [10-6SI]	NRM intensity [mA/m]
1	Felsőnyárád * E 20.59897°, N 48.33447°	46.1	0.8
2	Felnémet, quarry E 20.38319°, N 47.93353°	2156.5	61.6
3	Felnémet, Bajusz-völgy E 20.39128°, N 47.93472°	1702.3	47.3
4	Harsány * E 20.75490°, N 47.99570°	97.0	50.0
5	Edelény, Csisztapuszta * E 20.70747°, N 48.32386°	47.5	0.1
6	Tibolddaróc E 20.63267°, N 47.92675°	90.4	1.3
7	Egercsehi * E 20.26834°, N 48.04250°	59.1	0.6
8	Sajószentpéter * E 20.71533°, N 48.21009°	70.1	1.7
9	Verpelét, Castle hill E 20.20772°, N 47.86025°	447.6	40.5
10	Verpelét, Castle hill, outer rim * E 20.20710°, N 47.85931°	678.6	108.9
11	Tarnaszentmária * E 20.20420°, N 47.88180°	134.8	14.0
12	Sirok, South E 20.19733°, N 47.92733°	397.4	151.6
13	Sirok, Castle hill E 20.19931°, N 47.93317°	226.5	157.8
14	Fehérkút, Bükkzsérc E 20.51586°, N 48.02206°	419.7	0.6
15	Bükkzsérc, Oldalföld * E 20.49913°, N 47.94629°	90.4	3.6
16	Cserépváralja, Törökréti-patak * E 20.56851°, N 47.93711°	119.3	4.2
17	Cserépfalu, Karácsony tisztás * E 20.55101°, N 47.96870°	151.4	43.4
18	Andornaktálya * E 20.39729°, N 47.88790°	201.3	11.3
19	Egerszalók * E 20.33001°, N 47.86998°	70.3	4.36

Table 3
Summary table of geologic and paleomagnetic correlations. Earlier correlations are from Balogh (1964). New correlations are from Less et al. (2002) 1:50 000 Geologic map of the Bükk Mts. and items with stars from Less et al. (2004) 1:100 000 Geologic map of the Gemer-Bükk area. Locality 6 is a special one, being situated at the boundary between middle and upper tuffs on the 1:50 000 Geologic map (Less et al. 2002). Proposed correlation based on rotation angle, polarity and geologic consideration

	Site	**Earlier correlation**	**New correlation**	**Paleo-magnetic correlation**	**Proposed correlation**
1	Felsőnyárád 9188-193	λ Ms Upper rhyolite tuff	M14 (MsP) Upper Rhyolite Tuff*	Upper	Upper most
2	Felnémet, quarry 9398-407	λ Mb Lower rhyolite tuff	fM (Mb-s) Felnémet Rhyolite Tuff Formation	Upper	Upper
3	Felnémet, Bajusz-völgy 9408-416	λ Mb Lower rhyolite tuff	fM (Mb-s) Felnémet Rhyolite Tuff Formation	Upper	Upper
4	Harsány 7721-728	λ Ms Upper rhyolite tuff	hN (Mb-Pa$_1$) Harsány Rhyolite Tuff Formation	Middle?	Top of middle
5	Edelény, Csisztapuszta 9182-187	λ Ms Upper rhyolite tuff	M14s (Ms-P) Upper Rhyolite Tuff*	Middle	Top of middle?
6	Tibolddaróc 8902-911	λ Ms Upper rhyolite tuff	hM (Mb-Pa$_1$) Harsány Rhyolite Tuff Formation ?	Middle	Top of middle
7	Egercsehi 9093-103	λ Ms Upper rhyolite tuff	fM (Mb-s) Felnémet Rhyolite Tuff Formation	Middle	Top of middle
8	Sajószentpéter 9174-181	λ Mt Middle rhyolite tuff	Mg (Mb) Middle Rhyolite Tuff*	Middle	Middle
9	Verpelét, Castle hill 9417-420	α Mt Andesite	M10 (Mb) Andesite tuff*	Middle	Middle
10	Verpelét, Castle hill outer rim, 9421-432	α Mt Andesite tuff	M10 (Mb) Andesite tuff*	Middle	Middle
11	Tarnaszentmária 9104-112	λ Mt Middle rhyolite tuff	Mg (Mb) Middle Rhyolite Tuff*	Middle?	Transition between middle and upper
12	Sirok, South 9433-446	λ Mt Middle rhyolite tuff	Mg (Mb) Middle Rhyolite Tuff*	Middle?	Transition between middle and upper
13	Sirok, Castle hill 9447-458	λ Mt Middle rhyolite tuff	Mg (Mb) Middle Rhyolite Tuff*	Middle?	Transition between middle and upper
14	Fehérkút, Bükkzsérc 9344-353	λ M$_{1\text{-}2}$ Rhyolite tuff (lower?)	fM (Mb-s) Felnémet Rhyolite Tuff Formation	Lower	Lower
15	Bükkzsérc, Oldalföld 7828-837	λ M$_{1\text{-}2}$ Rhyolite tuff (lower?)	gM (Mb) Gyulakeszi Rhyolite Tuff Formation	Middle	Bottom of middle
16	CserépváraljaTörökréti-patak 7809-817	λ Mt Lower rhyolite tuff	gM (Mo) Gyulakeszi Rhyolite Tuff Formation	Middle	Bottom of middle
17	Cserépfalu, Karácsony tisztás 7843-850+7838-842	λ Mh Lower rhyolite tuff	gM (Mo) Gyulakeszi Rhyolite Tuff Formation	Lower	Lower
18	Andornaktálya 7818-827	λ M$_{1\text{-}2}$ Lower rhyolite tuff	gM (Mb-s) Gyulakeszi Rhyolite Tuff Formation	–	–
19	Egerszalók 9113-115	λ M$_{1\text{-}2}$ Lower rhyolite tuff	gM (Mb-s) Gyulakeszi Rhyolite Tuff Formation	–	–

Conclusions

Among the sites of the present study, there are several with normal polarities, while the earlier published results from the Bükk Foreland had only reversed polarity paleomagnetic signals. In a way, they "fill the gaps" between the main eruptions, which took place during reversed polarity times. Nevertheless, the paleomagnetic directions of the normal polarity sites do not form transitions between reversed polarity groups (with about 80°, about 30° counter-clockwise and about 10° clockwise rotated declinations, respectively), but cluster around the second and the third.

It follows that the existence of two main distinct and well-dated geodynamic events of Miocene age in the area of the North Hungarian Paleogene Basin gains support from the new results. Thus, we further conclude that the paleomagnetic declinations are the best guidelines in distinguishing between the three tuff (ignimbrite) complexes; they are far more reliable than correlation by composition (rhyolitic or dacitic), by K/Ar isotope ages (which often overlap), or by the ages of stratigraphically poorly controlled intercalated sediments, if these exist at all.

Age assignment can be refined by correlating the sites by their magnetic polarity to the standard polarity time scale and by some geologic considerations (such as field evidence for the relative position of reversed and normal polarity sites).

The integrated application of paleomagnetic marker horizons (geodynamic events), polarities tied to the standard magnetic polarity time scale and geologic considerations result in a chronostratigraphic classification of the studied sites, which sometimes supports one or both of the classifications by Balogh (1964) and Pelikán (2005). However, about one-third of the sites classified as upper or lower tuffs by these authors were shown to belong the middle tuff complex.

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