Volcanic successions and the role of destructional events in the Western Mátra Mountains, Hungary: implications for the volcanic structures / Successions volcanologiques et événements tectoniques dans les Monts Mátra occidentaux : implications pour les structures volcaniques

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Géomorphologie : relief, processus, environnement, Année 2001, Volume 7, Numéro 2
p. 79 - 92

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Successions volcanologiques et événements tectoniques dans les Monts Mátra occidentaux : implications pour les structures volcaniques

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Abstract

The original volcanic edifice of the western part of the mid-Miocene Mátra Mountains, North Hungary, may have been a group of small-scale andesitic centres built upon an ignimbrite sheet of the Middle Rhyolite Tuff of the Pannonian Basin. A previously suggested large caldera is not supported by the available volcanological, structural-geological, and geomorphological data. Late Miocene to Pleistocene tectonic movements resulted in the asymmetrical uplift of the mountains, broken up by NW-SE and NE-SW-trending faults. As a response, long-term tectonic displacements as well as catastrophic debris avalanches and lahars contributed to the rearrangement of volcanic successions and orographic elements probably in the latest Miocene to Pliocene.

Key words: volcanic structure, caldera, geomorphic analysis, debris avalanches, Carpathians.

Résumé

La structure volcanique originale de la partie occidentale des Monts Mátra (Hongrie septentrionale) se compose de nombreux petits centres andésitiques, alimentés par des fissures éruptives et bâtis sur l'ignimbrite des "tufs rhyolitiques moyens" du Bassin pannonien. L'hypothèse de l'existence d'une caldera de grande taille, émise par différents auteurs, n'est vérifiée ni par l'analyse géomorphologique, ni par les données de la géologie structurale. Du Miocène supérieur au Pléistocène, l'ensemble a été basculé, soulevé de manière dissymétrique et fracturé par des failles NO-SE et NE-SO. En conséquence, des glissements de grande ampleur et surtout des avalanches de débris se sont produits et ont remanié les formations volcaniques probablement du Miocène supérieur au Pliocène.

***Mots clés** : structure volcanique, caldera, analyse géomorphologique, avalanches de débris, Carpathes.*

Version abrégée

On considère l'ensemble de l'édifice volcanique des Monts Mátra comme un groupe de petits centres andésitiques alimentés par des fissures éruptives (Noszky, 1927 ; Varga et al.*, 1975). L'hypothèse de l'existence d'une caldera de grande taille, proposée dans la littérature hongroise, n'est vérifiée ni dans la morphologie, ni à travers les dépôts volcaniques observés. Ceux-ci ne sont pas associés à l'effondrement d'une caldera quelconque, mais ils sont dominés par de puissants épanchements d'andésites reposant sur une ignimbrite distale, dénommée "tufs rhyolitiques moyens" dans le Bassin pannonien. En fait, la forme grosso modo circulaire de la masse des Monts Mátra occidentaux peut refléter un groupe de centres éruptifs, qui ont été affectés par les mouvements tectoniques de failles normales et par de grands glissements vers le Sud. L'étude de la répartition des dépôts volcaniques et l'analyse de la géologie structurale indiquent que l'épaisse séquence de laves andésitiques des Mátra occidentaux, construite sur les "tufs rhyolitiques moyens", a été déformée par des mouvements tectoniques intenses de la fin du Miocène au Pliocène.*

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L'ensemble du massif volcanique des Mátra occidentaux, recoupé par des failles orientées ouest-nord-ouest – est-sud-est et perpendiculaires à cette direction, a été soulevé et basculé vers le sud. Une tectonique cassante importante, probablement déclenchée par un soulèvement de la zone septentrionale, s'est produite le long de plans de glissement inclinés vers le sud-est. À la faveur de cette tectonique cassante, de grands glissements et des avalanches de débris ont remanié et re-déposé les matériaux volcaniques antérieurs. Ces avalanches de débris ont également modifié les volumes de relief à petite échelle, en transportant des masses d'andésite des régions septentrionales vers le centre et le sud du massif. L'érosion des régions sommitales a pu atteindre 400 à 500 m depuis le Miocène supérieur (Karátson, 1996). Dans cette hypothèse, des formes de relief côniques, décrites par J. Noszky (1927) comme des "coulées de laves érodées", peuvent être ré-interprétées comme des hummocks (collines côniques), caractéristiques des avalanches de débris. On peut ajouter qu'une partie de ces formes de relief a aussi été déformée et a glissé vers le sud. Enfin, les auteurs proposent une relation génétique entre la tectonique (soulèvement et failles), l'altération hydrothermale et les glissements en masse. Le rôle et l'importance des déformations cassantes et des glissements de grandes dimensions impliquent que la recherche d'appareils volcaniques centrés et individualisés peut s'avérer vaine ou très difficile, d'autant plus que l'état d'altération ne permet pas de distinguer facilement les laves originelles ou en place et les dépôts remaniés et glissés.

Introduction

The mid-Miocene Mátra Mts, belonging to the calc-alkaline Inner Carpathian Volcanic Chain (fig. 1) are the highest volcanic mountains in Hungary (1015 m). The west-east-oriented main range has an arcuate shape in the west, whereas the east range is remarkably linear (fig. 2). Both parts are characterised by steep (15-30°) northern slopes revealing a complete Oligo-Miocene stratigraphy and more gentle (5-15°) undulating southern slopes consisting mostly of thick mid-Miocene andesites.

Either the whole mountains, or at least their arcuated western part, have been considered as remnant of a huge caldera in most of the Hungarian literature since the 1950s (e. g., Baksa *et al.*, 1981). However, the dimensions, localities and even the number of calderas have been differently assessed by each author, while the relationship between the present morphology and the proposed caldera has not been clarified. The main purpose of this paper, publishing results of an interdisciplinary project (volcanology, geomorphology, structural geology, and geochemistry) is to clarify the caldera problem in relation to present-day geomorphology.

Geomorphic features and geological setting

Geomorphic features

Major geomorphic features of the Western Mátra (fig. 2) are the large-scale arcuate form of the main watershed and the presence of quasi-perpendicular, NW-SE and NE-SW-trending valleys and ridges over a large area. Of these, the NW-SE-oriented Kövicses Valley and the parallel ridges in

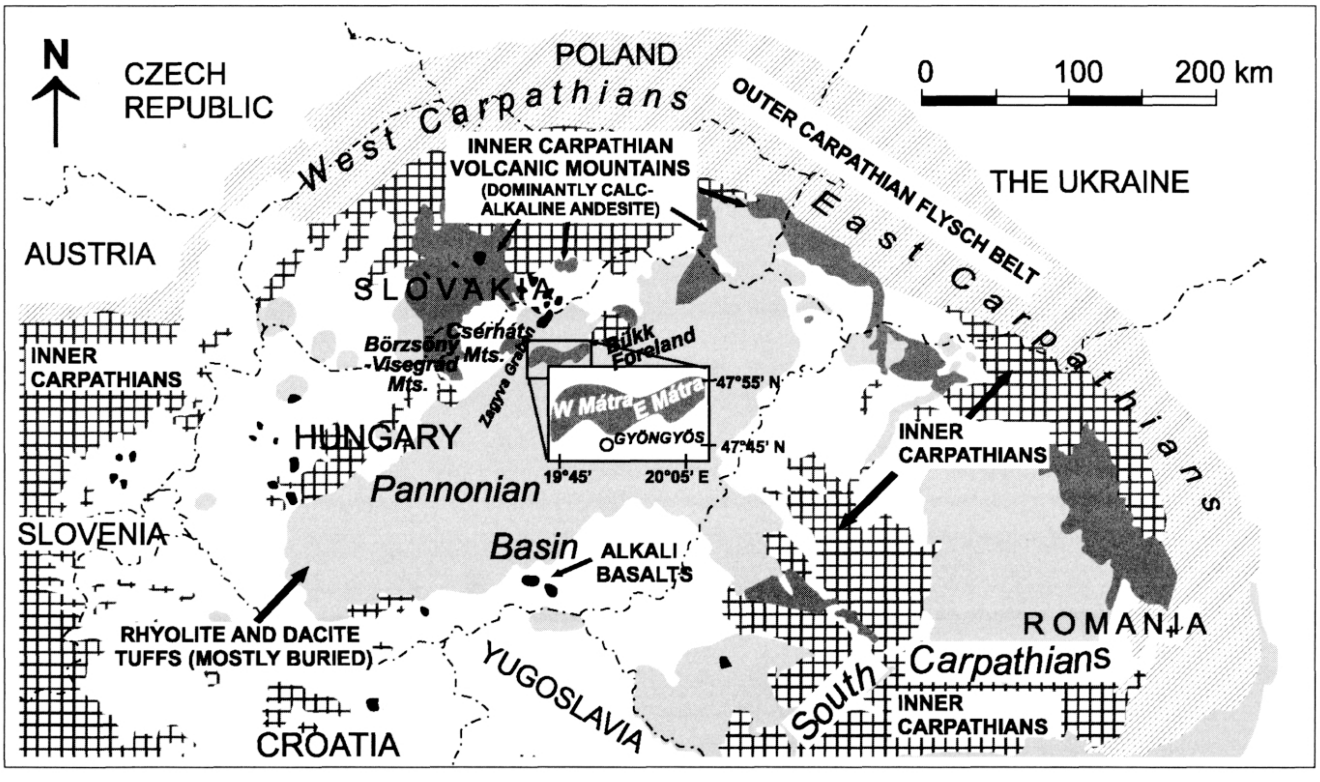

Fig. 1 – **Geological setting of the Mátra Mountains in the Carpathian Basin.**
*Fig. 1 – **Position géologique des Monts Mátra au sein du Bassin Pannonien**.*

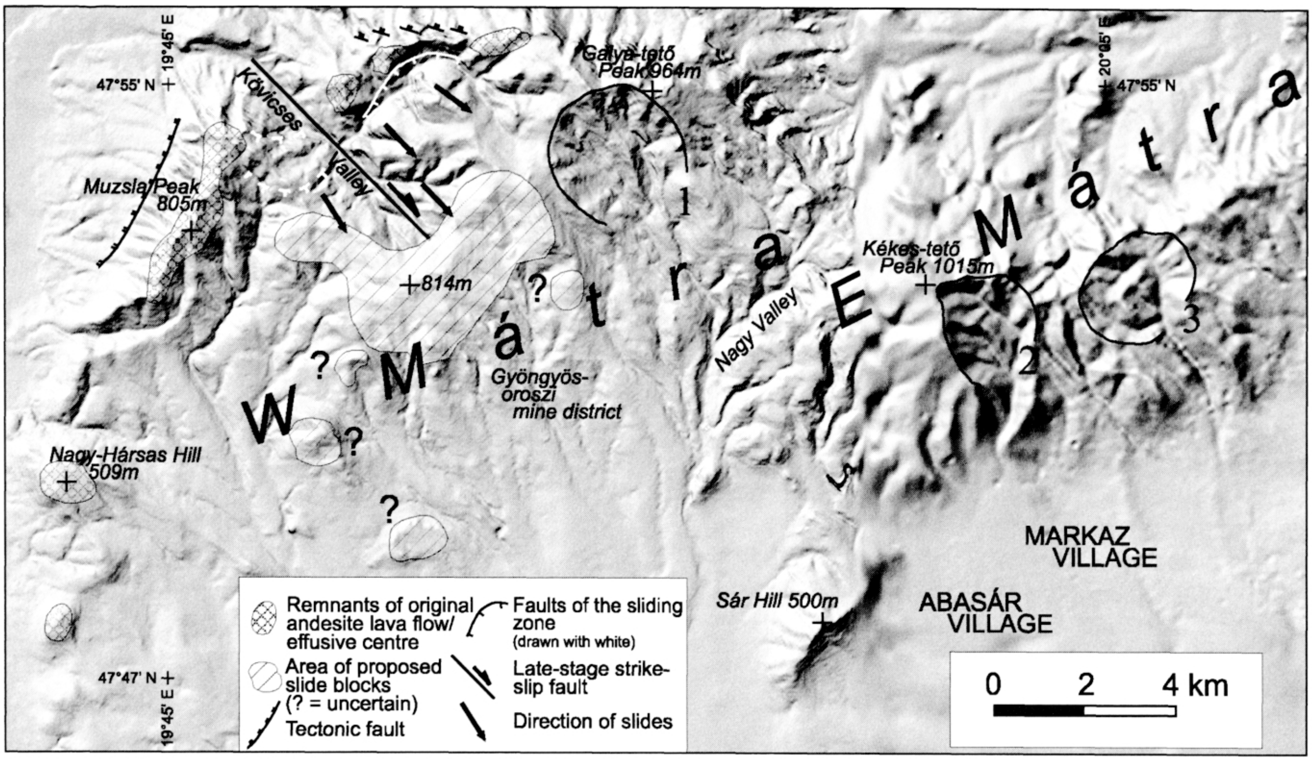

Fig. 2 – **Shaded relief image of the Mátra with proposed, major volcano-tectonic elements for the western part.** 1: Galya Crater; 2: Kékes-tető Peak Crater (Cholnoky, 1937); 3: Nagy-Szár Peak Crater (Kiss *et al.*, 1996).

*Fig. 2 – **Image en relief ombré des Monts Mátra avec les éléments volcano-structuraux proposés.** 1 : cratère du Galya ; 2 : cratère du Mont Kékes (Cholnoky, 1937) ; 3 : cratère du Mont Nagy-Szár (Kiss* et al.*, 1996).*

the NW part are the most characteristic, adjoining major tectonic directions (Czakó and Zelenka, 1981). This system has long been recognised all over the North Hungarian Mts, and was related to late Miocene to early Pleistocene tectonic movements (for the Mátra, Noszky, 1927; Szentes, 1939; Schréter, 1940).

In detail, a DEM-derived ridge map (fig. 3) clearly shows that the linear segment of Muzsla ridge is interrupted by the Kövicses Valley which is bordered by the roughly parallel NW-SE Vöröskő-Hidegkút and Som-tető ridges, respectively. Beyond the valley, the northernmost Mátrabérc ridge is at first sight a continuation of the Muzsla ridge. In fact, however, the Mátrabérc ridge and ridges (1a-b) west of the highest Galya-tető Peak bifurcate. These bifurcated ridges are in lower elevation (700-750 m asl.) than the Galya ridge section (ca. 950 m). Eastward of Galya-tető Peak, descending ridges (2a-b) reach the Nagy Valley (figs. 2 and 4). This valley separates the huge masses of the Eastern Mátra from the Western Mátra. Constituent ridges of the main watershed of the Western Mátra (especially the Muzsla, Mátrabérc and Galya ridge *cf* fig. 3) are steep (15-30°) in their outer northern slopes and gentle (5-15°) to the south, and southward of them, rectangular instead of centrifugal ridge (and drainage) pattern can be observed. These features do not fit with a caldera interior, even if it is tilted.

Geological formations

In the simplified geological map of the Western Mátra (fig. 4, Varga *et al.*, 1975), the first significant volcanic deposit is the Lower Miocene, fine-grained, stratified, up to 40 m-thick "Lower Rhyolite Tuff", the first widespread product of the calc-alkaline volcanic activity throughout the Carpathians (Noszky, 1927; Varga *et al.*, 1975; Hámor *et al.*, 1985). It is separated from the subsequent Lower Andesite by soft-coal beds and fine-grained, up to 200-400 m-thick submarine sedimentary deposits (collectively called "schlier": Noszky, 1927; Varga *et al.*, 1975). The 50-100 m-thick Lower Andesite lava flows and lava breccias are overlain by the continuous, mostly massive, Middle Miocene "Middle Rhyolite Tuff" (MRT), which is up to 30-100 m-thick and dacitic in composition, and by scattered pyroxene-andesite extrusions in the Eastern Mátra. Most of the mentioned volcanic activity occurred in a medium- or shallow-marine to marshy environment, but occasionally (especially in the case of MRT) it may have filled local basins and became subaerial (Varga *et al.*, 1975). The uppermost, youngest, commonly several hundred metres-thick (to 1200 m in boreholes) volcanic successions were grouped into the more extensive Middle Andesite Series (MAS) and the Upper Andesite by Gy. Varga *et al.* (1975), although Z. Balla (1984) saw no reason to split them. All the volcanic rocks are exposed in a complete succession in the north foreland and the steep north slopes. In contrast, only the MAS can be found to the south except for small rhyolitic extrusions. Gy. Varga *et al.* (1975) reported "isolated" tuff exposures in the southern part too, but they considered them as belonging to the MAS. Most of the post-MRT andesites and the small rhyolite extrusions to the south seem to have been emplaced subaerially (Varga *et al.*, 1975).

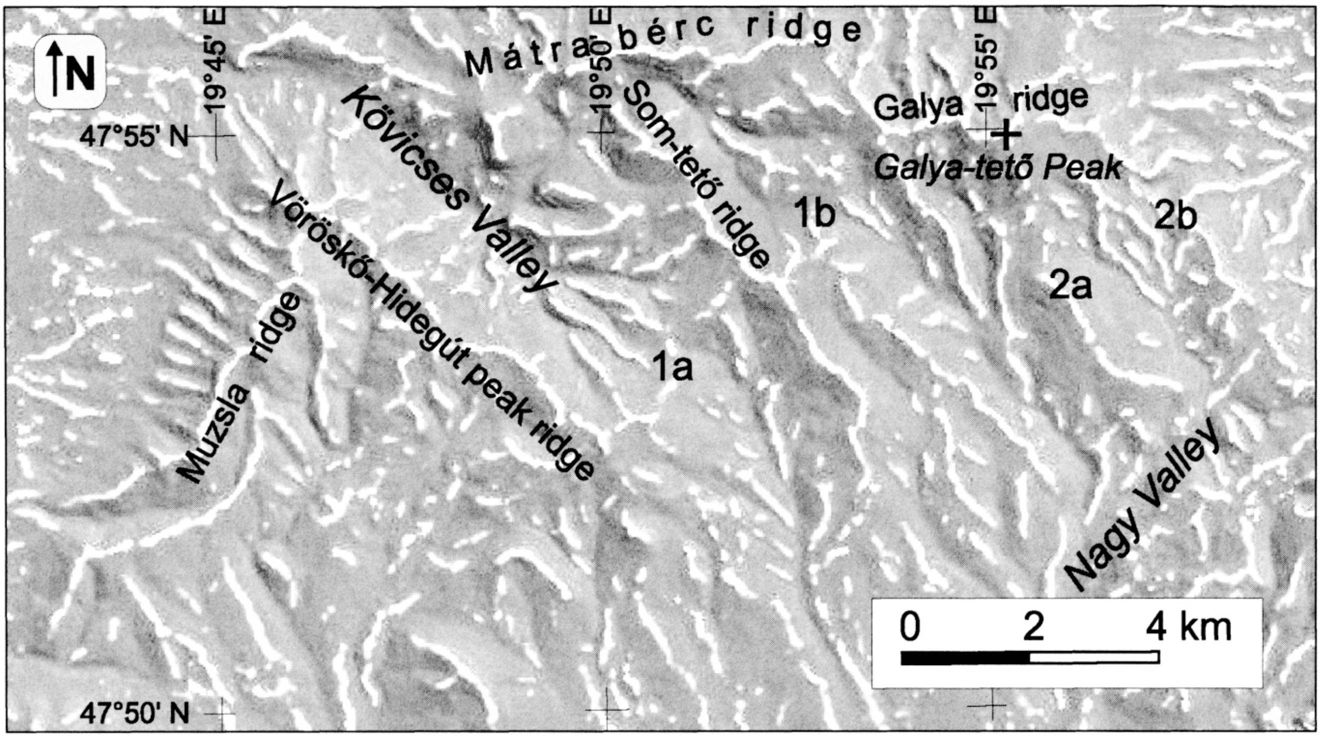

Fig. 3 – **Ridge map of the Western Mátra Mountains derived from a 10-m resolution DEM of the 1:50,000 topographic map of Hungary**. A 25 by 25 pixel local histogram equalization filter and a 5 by 5 pixel median filter were applied in succession to the original elevation data, and the resulting image was stretched to enhance the locally highest points (peaks and ridges). The ridge map was then amalgamated to a shaded low-contrast DEM image.

*Fig. 3 – **Carte des crêtes des Mont Mátra Occidentaux, dérivée d'un MNT à 10 m de résolution**. Un filtre d'équilibrage de l'histogramme local de 25x25 pixels suivi d'un filtre médian de 5x5 pixels ont été appliqués aux altitudes et l'image résultante a été étirée afin de montrer les points culminants. La carte des crêtes a été ensuite combinée avec le MNT ombré.*

The caldera hypothesis

The first author to interpret the distribution of volcanic successions was B. Mauritz (1909) who defined the Mátra as a "south-dipping, subsided, large crustal block". The uplift of the North Mátra, its southward tilt and a fault system related to Mio-Pliocene tectonic movements have later been confirmed and widely accepted (Czakó and Zelenka, 1981; Balla and Szabó, 1986). For example, the type locality of the MRT in a quarry of Tar village (350 m asl. in the northern foreland: locality 46 in fig. 4) is obviously disconnected and separated from the same ignimbrite horizon exposed along the northern mountain slopes between 550-700 m asl.

An outstanding researcher of the Mátra, J. Noszky (1927), considered the Mátra Mts "as having a partly downfaulted, partly erosional rim". He concluded that "the apparent surface landforms, parts of cones and peaks, as well as the emerging, steep summit levels and ridges, are none other than eroded, 'polished' details of lava sheets". In the subsequent decades, this view was common (Láng, 1955; Székely, 1960), until E. Szádeczky-Kardoss *et al.* (1959) introduced the caldera hypothesis. They declared the whole Mátra as "a single collapse caldera of Etnean size", without presenting field volcanological evidence or delimiting caldera contours.

Gy. Varga *et al.* (1975) provided the first detailed work including descriptions of key outcrops. These authors saw no reason to reconstruct volcanic edifices other than remnants of deeply eroded effusive centres. Although this conclusion seems to be supported by their field data, they did not discuss structural geology in relation to the caldera model and, therefore, their conclusion has not been accepted by most researchers. In a summary paper, Cs. Baksa *et al.* (1981) outlined the caldera rim along Muzsla, Mátrabérc, Galya and 1b ridge sections (see fig. 3). The "pro-caldera" argumentation has been completed by (i) the existence of the Gyöngyösoroszi ore mineralisation (fig. 4), (ii), its related dyke pattern interpreted as concentric and radial, (iii) the observed steep faults and structural deformation of veins inside the caldera area, and (iv) the southward thickening of the volcanic products in some boreholes (Siklóssy, 1977; Baksa *et al.*, 1981). The caldera model was also favoured by a geophysical work of Z. Balla and Z. Szabó (1986) who interpreted the Bouguer anomaly map as revealing a double caldera, both having a half section. However, neither of these calderas were explained in terms of volcanology, except for a tentatively assumed relationship to the MRT (Baksa *et al.*, 1981; Balla and Szabó, 1986).

The same problem applies to the calderas of A. Székely. Influenced by E. Szádeczky-Kardoss *et al.* (1959) and I. Kubovics (1970), A. Székely (1985) modified his previous view and also proposed a half-caldera, 13 km in diameter, for the Western Mátra (ridges 1a-b, Galya ridge and ridge 2b in fig. 3). Caldera contours were defined on the basis of watershed pattern and satellite image interpretation.

Observing the topographic complications in the northwest sector, he proposed a distinct, small caldera between ridges Mátrabérc and 1a-b (fig. 3). However, these calderas were not supported by volcanological data, either. In the following, we provide our new data and interpretations on the volcanic formations and structures.

Mountain-building volcanic successions

Dacite lapilli tuff

The deposit, which is the apparent base of the mountainous part of the Mátra, is a poorly sorted, massive, subordinately stratified, pumice-rich whitish yellow lapilli tuff, sometimes silicified and greenish/purplish in colour. Pumice is biotite-bearing and commonly less than 5-8 cm in diameter. In the Tar quarry (fig. 4, 46), pumice is larger (up to 10-15 cm), and vertical segregation pipes have been observed. Glass composition of pumice and glass shards (fig. 5) is rhyolitic (SiO_2 = 75.8-76.7 wt %) and potassic (K_2O = 5.1-5.2 wt %; K_2O/Na_2O = 2.0-2.2). Biotites show calc-alkaline characteristics as defined by the classification scheme of J. Abdel-Rahman (1994). Sparsely distributed, cm-sized andesitic lithic clasts (up to 5-10 %) can be common all over the Mátra, but increase in diameter or other near-vent features have not been observed. Sporadically, scoria clasts also occur at the base of the pumiceous lapilli tuff. Bulk rock major-element composition of the lithic clasts indicates high-K calc-alkaline andesitic character and fall in the compositional trend of the lava rocks from the Mátra (fig. 5). Massive facies, abundant pumices and presence of segregation pipes in the lapilli tuff suggest a primary, hot emplacement, and therefore we consider most of the deposit as an ignimbrite. Given the bedded, altered appearance in places (e. g., locality 41b in fig. 4), the overlying, stratified volcaniclastic breccia cover (e. g., locality 46) as well as volcanic mudstone association, a syn-eruptive, shallow-water reworking is also likely (cf. Cas and Wright, 1991; Cole and DeCelles, 1991; in Hungary, Karátson and Németh, in press). As for implications for source of the ignimbrite, (i) the commonly small size of pumices, (ii) the small lithic content with small grainsize, and (iii) no near-vent breccias and other caldera-related features, all indicate a distal deposition, except the Tar quarry which may be nearer the vent. On the basis of eastward thickening and occurence of larger lithic clasts, Gy. Varga *et al.* (1975) and Cs. Baksa *et al.* (1981) proposed a source in the Eastern Mátra or in the SE foreland. Hence, in the Western Mátra, the local origin of a large-scale ignimbrite and its spatial association with a caldera remain unsupported.

Volcaniclastic mudstone/siltstone

These types of deposits have not been distinguished previously from the Middle Rhyolite Tuff (MRT) or the Middle Andesite Series (MAS), although they seem to occur in a close spatial association. The most important exposures (fig. 4, 16 and 20a) are along the western segment of Mátrabérc ridge, part of the "caldera rim" of Cs. Baksa *et al.* (1981) and others. This area was mapped as belonging to the MAS by Gy. Varga *et al.* (1975, fig. 4) and "andesite tuff covered by andesite" by Z. Balla (1984). Instead, the major constituents of the Mátrabérc ridge are the MRT and up to 200-m thick, mostly massive, rarely stratified, silt- and sand-sized volcanic-sedimentary deposits (fig. 6a) capped 20-50 m thick andesite lava flows in places. Although direct contact has not been observed, these deposits seem to be the embedding layers of the MRT and a few platy jointed, pyroxene- andesite dykes (which fused the loose deposits in places). Smaller, sporadic occurrences of pumiceous volcanic mudstone deposits to the south are at the isolated Kis Hill rhyolitic lava dome (fig. 4, 60), at the mountaineering road near Mátrafüred (fig. 4, 72), and around the southwestern end of Muzsla ridge (fig. 4, 38). Although a palaeogeographical reconstruction should be completed by, for example, palaeontological evidence, the coexistence of ignimbrite and volcanic-sedimentary deposits seems to confirm the previous view, i. e. an upfilling medium- or shallow-water archipelago (Varga *et al.,* 1975).

Andesite – basaltic andesite lava flows

Most of these rocks are predominantly pyroxene-andesites. I. Kubovics (1970) and Gy. Varga *et al.* (1975) characterised the Middle Andesite Series as having various texture and degree of alteration, whereas the more uniform upper series is commonly unaltered. The majority of both groups are lava flows, and the MAS includes volcaniclastic rocks too. As for geologic distinction between the two series, the published chemical analyses (Varga *et al.,* 1975) overlap. In fact, the difference seems rather to be related to topographic position (fig. 4). On the other hand, previous (Balogh, 1984; Hámor *et al.,* 1985) and recent K/Ar datings (Pécskay and Zelenka, pers. commun.) have yielded distinct ages, ranging from early Badenian (ca. 15.5 Ma) to Sarmatian (up to 13.0 Ma), so the discrimination between the andesite series is still an open question.

As for sources of the lava flows, Gy. Varga *et al.* (1975) argued generally for fissure vents, whereas, in the central and Eastern Mátra, at least two crater-like depressions were proposed (Cholnoky, 1937; Kiss *et al.,* 1996: fig. 2). We cannot see evidence for original vents of fissures or craters for most of the Western Mátra. However, south of Galya Peak, (i) dip directions of platy jointed lavas (fig. 4), (ii) circular ridges around Csukás-Cseternás streams (figs. 2 and 4), (iii) centrifugal drainage pattern, and (iv) strong hydrothermal alteration in the valley bottom (e. g., Csongrádi, 1982) point to the existence of a deeply eroded, enlarged crater ("Galya Crater"), built up of both the MAS and the upper andesite.

We collected three fresh andesite samples from the middle (fig. 4, 17, 24, 26) and upper (fig. 4, 22, 34, 44b) andesite series, respectively, from the Western Mátra. We also used two published analyses from H. Downes *et al.* (1995). The analysed samples have basaltic andesite to dacite composition and define a narrow linear trend in the SiO_2 vs. K_2O diagram (fig. 5). They can be classified as high-K calc-alkaline rocks as defined by J. Gill (1981). Remarkably, glass composition of the pumice and glass shards from the dacite lapilli tuff also falls in this linear trend. This linear trend may indicate a simple differentiation process in the genesis of volcanic rocks. No clear distinction, however, can be seen between the middle and upper andesitic series.

A rare but characteristic rock type in the Western Mátra is K-trachyte (Kubovics 1970; Varga *et al.*, 1975; Varga, 1992: fig. 4). This rock may have been formed from andesite by potassic metasomatism along structural planes (Kubovics, 1970). Apart from lava rocks, the described occurrences also include volcaniclastics (see below). A typical adularia-sericite alteration in the K-rich rocks resembles that of the Gyöngyöroroszi ore mineralization, indicating a time-space relationship between the two (Gatter *et al.*, 1999; Gatter, pers. comm.)

Volcaniclastic breccias

Evaluating field and borehole data, half of the post-Middle Rhyolite Tuff (MRT) andesites in the whole Mátra were termed 'agglomerates', 'lava agglomerates' and 'tuff breccias' by Gy. Varga *et al.* (1975; fig. 4). In contrast, at least in the Western Mátra, we have found the surface distribution of coarse-grained volcaniclastic deposits to be very limited, and there is no convincing evidence that borehole sequences differ significantly. No features of pyroclastic breccias (e. g., monolithologic composition, prismatic jointing of angular and/or vesiculated clasts, segregation pipes, significant amount of matrix in the breccia) have been found in the field. Most of the 'agglomerates' exhibit features of autoclastic lava flows (high clast/matrix ratio or no matrix, monolithologic composition, transition from fractured lava to lava breccia: e. g., 64 Hársas Hill in fig. 4). Monolithologic debris-flow deposits have also been found (e. g., 19: Óvár

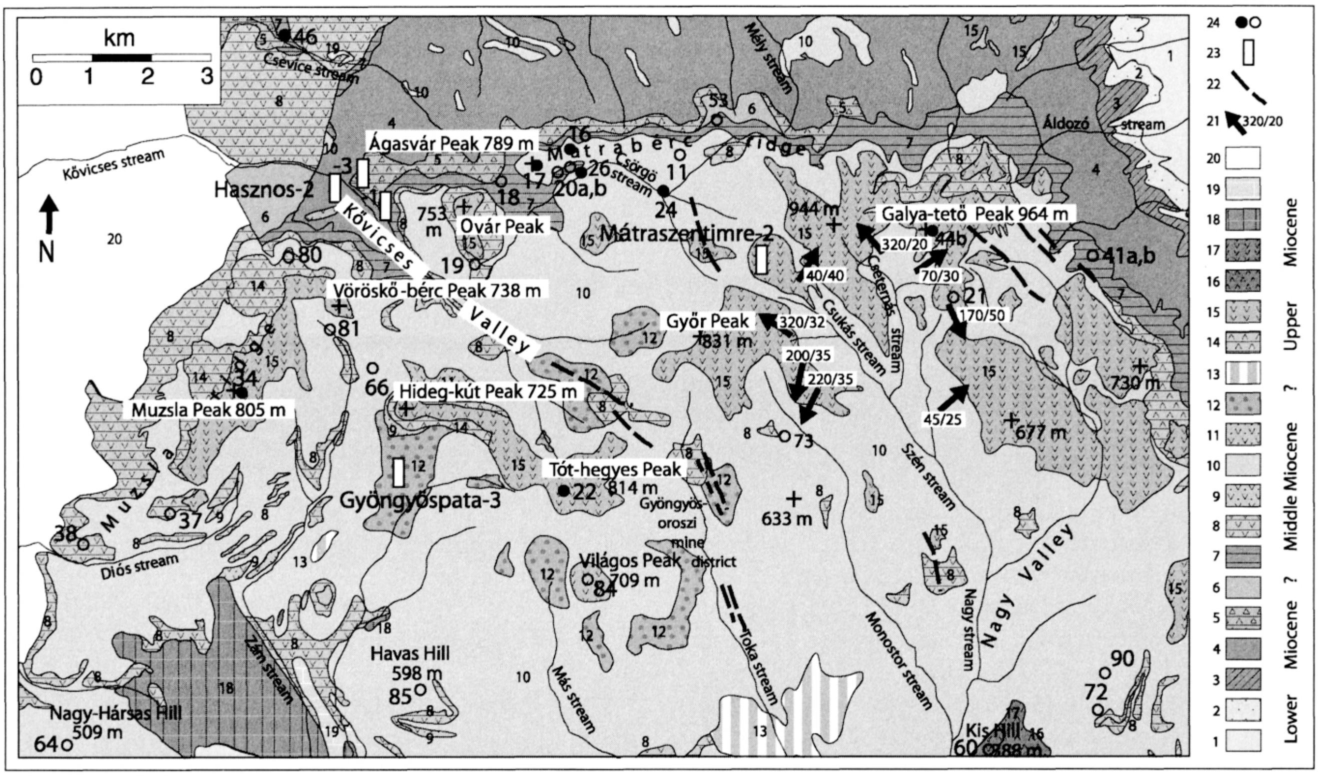

Fig. 4 – **Simplified geological map of the Western Mátra (after Varga *et al.*, 1975).** 1: submarine sandstone, clay, conglomerate; 2: continental sand, sandstone, gravel; 3: Lower rhyolite tuff; 4: silstone,silty clay marl ("schlier"); 5: Lower pyroxene-andesite tuff and breccia; 6: Lower("submarine") pyroxene andesite; 7: pumiceous dacite tuff (Middle rhyolite tuff); 8: Middle pyroxene-andesite tuff and other volcanoclastic deposits, rhyodacitic tuff; 9: Middle pyroxene-andesite "lava agglomerate"; 10: Middle ("stratovolcanic") pyroxene-andesite; 11: potassic trachyte tuff; 12: potassic trachyte and other potassium-rich rock; 13: limnoquartzite, opal, opalo-breccia, geyserite; 14: Upper pyroxene-andesite tuff and breccia; 15: Upper ("cover") pyroxene-andesite; 16: rhyolite tuff; 17: rhyolite, rhyodacite; 18: diatomaceous sequence; 19: Lajta (Leitha) limestone; 20: sand,clay, soft brown coal with organic remains; 21: dip and orientation of platy jointing in selected lava flows; 22: major hydrothermal veins; 23: selected borehole; 24: outcrop locality quoted in the text (filled=geochimical analysis).

*Fig. 4 – **Carte géologique simplifiée (d'aprés Varga** et al., **1975**). 1 : grès, argile, conglomérats marins ; 2 : sable, grès, graviers continentaux ; 3 : tuf rhyolitique inférieur ; 4 : siltite,marne limono-argileuse ("schlier"); 5 : tufs et brèches (andésite à pyroxènes inférieure); 6 : andésite à pyroxènes inférieure ("marine") ; 7 : tuf dacitique à ponces (tuf rhyolitique moyen) ; 8 : tuf andésitique à pyroxènes moyen et autres dépôts volcanoclastiques ; 9 : "agglomérat de lave" (andésite à pyroxènes moyenne) ; 10 : andésite à pyroxènes moyenne (strato-volcan) ; 11 : tuf potassio-trachytique ; 12 : trachyte potassique et autres roches riches en potassium ; 13 : limnoquartzite, opale, brèche d'opale, geysérite ; 14 : tufs et brèches (andésite à pyroxènes supérieure) ; 15 : andésite à pyroxènes supérieure ("couverture") ; 16 : tuf rhyolitique ; 17 : rhyolite, rhyodacite ; 18 : gisements à diatomées ; 19 : calcaire de Lajta (Leitha) ; 20 : sable, argile, lignite avec restes organiques ; 21 : inclinaison et orientation des diaclases dans un choix de coulées de lave ; 22 : principaux filons hydrothermaux ; 23 : forages sélectionnés ; 24 : affleurements mentionnés dans le texte (ronds pleins = analyses géochimiques).*

peak in fig. 4). Heterolithic, fine- to coarse-grained (up to 50 cm), stratified volcaniclastic mass-flow deposits, interbedded with the pumiceous mass-flows of MRT have been found in two exposures (38: SW base of Muzsla ridge, 46: Tar quarry top level, fig. 4). However, these cannot be linked to the overlying andesite sequence. Given the high lava/breccia ratio, it can be inferred that effusive activity dominated the post-MRT andesitic volcanism of the Western Mátra, unlike in other North Hungarian volcanic mountains characterised by significant explosive lava dome activity (e. g., Karátson *et al.*, 2000; Karátson *et al.*, 2001).

Sporadic previous data and suggestions (Varga *et al.*, 1975) for voluminous debris-flow (lahar) and debris-avalanche deposits have nevertheless been confirmed by our survey, and further occurrences have been found. Three principal areas which seem to be important from a volcanostructural viewpoint are described below. Due to very limited exposure conditions, uncertainties in interpretation should be emphasized.

Vöröskő-bérc – Hideg-kút peaks western slope

A forest road cut, not described before, reveals a peculiar deposit in a ca. 500 m-long section (locality 66 in fig. 4). In its west half, a varicoloured, fine-grained tuff alternates with highly fractured lava bodies (figs. 6b, 6c). The different lithological composition of the matrix and the embedded lava and scoriaceous clasts was already mentioned by Gy. Varga *et al.* (1975). Reddish, scoriaceous, basaltic andesite bombs can be found on the slopes of Muzsla to Hideg-kút peaks too (e. g., 81). Eastward on the road cut, in the same level, the fine matrix is replaced by highly fractured andesite (lava flows, dykes or megablocks) with various jointing pattern. Features of the road-cut deposits (i. e. contrasting clast size and lithology, jigsaw-fit of broken clasts, heavily fractured andesite) are typical of a debris avalanche. The described characteristics conform with the description of other outcrops around Hideg-kút peak (fig. 4) by Gy. Varga *et al.* (1975): "strongly silicified potassic trachyte tuff, whitish or purplish in colour, having a 'false' breccia structure and sandstone inclusions". Recently, J. Kiss *et al.* (1996) noted that this K-rich rock may have accumulated in shear zones of tectonic movements.

The Mátrafüred – Sás Lake mountaineering road cut

This outcrop (locality 90 in fig. 4) was described by Gy. Varga *et al.* (1975) during their geological survey in the 1960s, when the road was constructed. Unfortunately, most of the outcrop has disappeared to date. They mentioned a 10-m thick isolated occurrence of a white pumiceous biotite-bearing dacitic lapilli tuff mixed with an "andesite agglomerate", on which they presented a photo (fig. 6d). They explained this mixing by a "lahar or a debris avalanche" origin. Moreover, they noted that similar "mixture rock" can be found at the north end of Abasár village (fig. 2). At present, only a small spot of biotite-bearing tuff crops out at 90 locality, suddenly replaced in the same level by an andesite breccia southward along the road. In addition, there is an accretionary lapilli-bearing part of the tuff. The lapilli up to 1 cm in size consist of fine-grained white tuff. They have never been found in the Western Mátra, except for the north end of Abasár, where Gy. Varga *et al.* (1975) described similar accretionary lapilli in "tuff of various appearance". Due to the lack of exposures, we cannot evaluate the origin of the accretionary lapilli.

The Abasár – Markaz foothill area (fig. 2)

The slopes north of Abasár village and a multiple quarry at its northern end reveal fine-grained, varicoloured tuff with lava clasts of different texture and colour. The colour and textural pattern strongly resembles that of the roadcut outcrop of Vöröskő-bérc Peak (66 in fig. 4). In one of the quarries, highly fractured, broken andesite lava flow- or dyke bodies, several metres in length, in fine- to medium-grained, slightly stratified lapilli tuff have been observed.

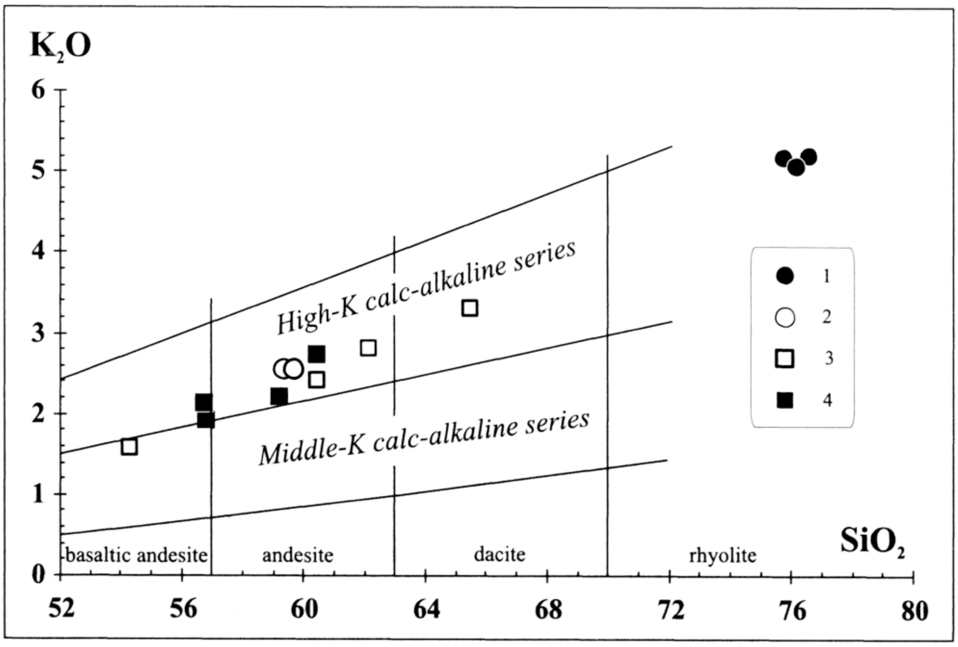

Fig. 5 – **SiO_2 vs. K_2O diagram for the volcanic rocks of the Western Mátra, based on classification by J. Gill (1981).** 1: glasses from the pumiceous lapilli tuff (Tar village, outcrop 46); 2: lithic clasts from the pumiceous lapilli tuff (n° 46); 3: Middle andesite series; 4: Upper andesite series. For sample locality, see fig. 4.

*Fig. 5 – **Diagramme SiO_2/K_2O pour les roches volcaniques des Mont Mátra Occidentaux, fondé sur la classification de J. Gill (1981).** 1 : verres du tuf à ponces et lapilli (Tar, affleurement 46) ; 2 : débris du tuf à ponces et lapilli (46) ; 3 : série des andésites moyennes; 4 : série des andésites supérieures. Pour la localisation des échantilons voir la fig. 4.*

Their presence can be explained by a lahar or debris avalanche transport mechanism. North of Markaz village, at a small, abandoned quarry and in a gully branching out of it, a complex lahar deposit was described by Gy. Varga *et al.* (1975) who also mentioned an interbedded "acid" tuff layer. This lahar deposit, apart from stratified, finer-grained basal parts, is a pyroxene-andesite breccia with broken, heavily fractured clasts up to 8-10 m in diameter. According to Varga *et al.* (1975), the deposit is "result of a big lahar or a debris avalanche"; based on the size and amount of oversized clasts, this interpretation is acceptable.

Structural geology

On the basis of the geomorphological evaluation, the distribution of debris avalanche deposits, and previous results

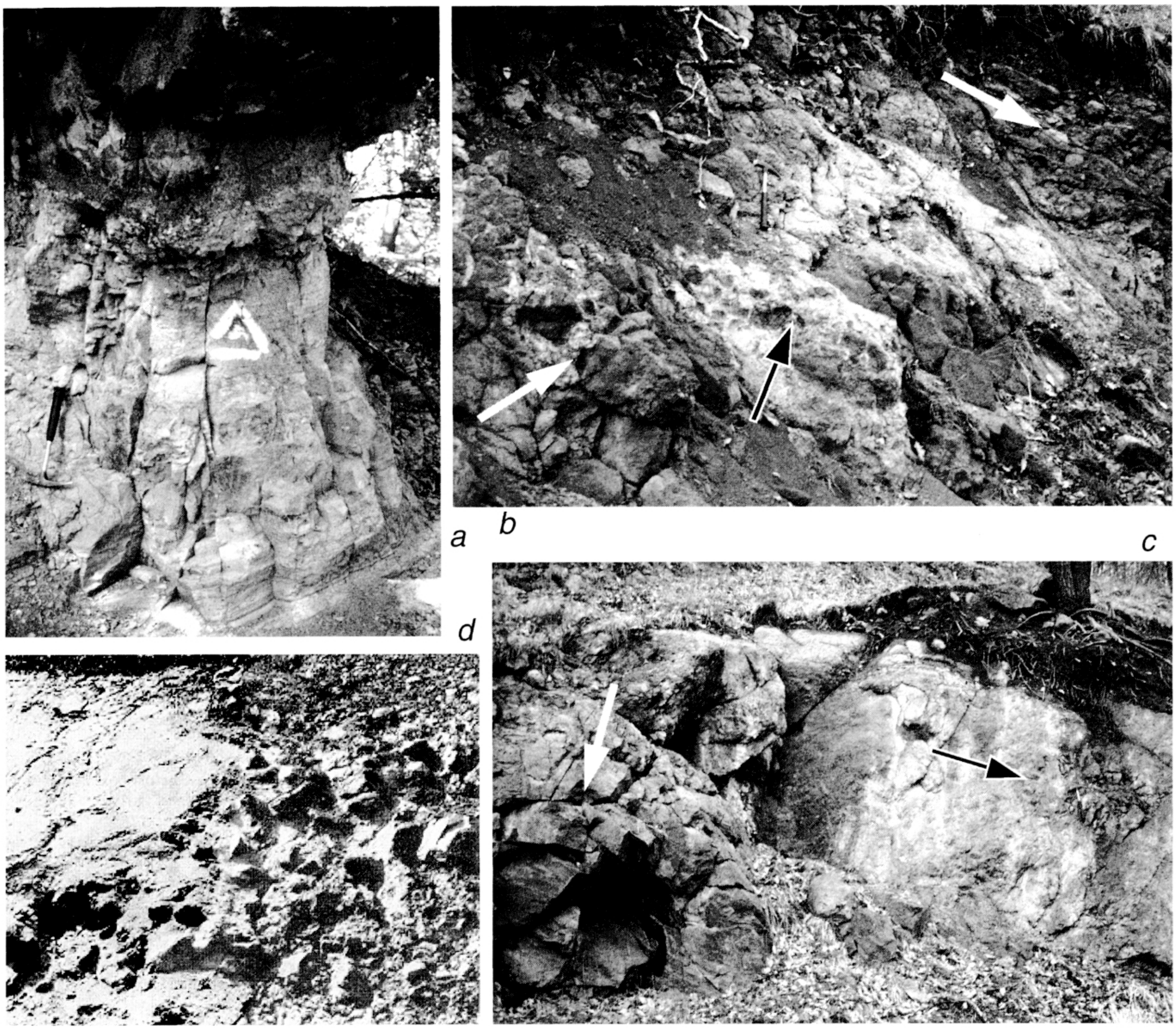

Fig. 6 – **Photographs of selected outcrops. a: massive and slightly bedded volcanic mudstone and siltstone sequence.** Mapped earlier as pyroclastics, it composes a major part of Mátrabérc ridge (locality 16, fig. 4). **b: debris-avalanche deposit northwest of Hideg-kút Peak** (locality 66, fig. 4). Reddish and yellowish tuff with pumiceous matrix alternate with altered pyroxene-andesite lava boulders (upper right and left bottom: white arrows). In the lower central part, fragments of disrupted lava blocks (black arrow) can be seen. **c: the west part of outcrop n° 66.** A fractured lava boulder (left, white arrow) and a fine-grained, pumice-free, altered tuff with an embedded, heavily broken andesite clast (black arrow: hammer for scale). **d: original photo of part of the "disappeared" locality 90, taken by Gy. Varga (1975).** "contact of acid tuff and andesite agglomerate", intepreted as a debris-avalanche deposit.

*Fig. 6 – **Photos de quelques affleurements. a : séquence de siltites et pélites volcanogéniques massives et peu stratifiées** (localité 16, fig. 4). La séquence, cartographiée auparavant comme des pyroclastites, constitue la majorité de la crête de Mátrabérc. **b: dépôt d'avalanche de débris au NO du Mont Hideg-kút** (localité 66, fig. 4). Un tuf jaunâtre-rougeâtre à matrice de ponces alterne avec des blocs de lave d'andésite à pyroxénes altérée (coins droit supérieur et gauche inférieur). Dans la partie centrale inférieure, on observe des fragments de blocs de lave. **c : partie occidentale de l'affleurement n° 66.** Un bloc de lave fracturé (à gauche) et un tuf fin altéré, sans cinérite, avec un bloc d'andésite trés fracturé (le marteau sert d'échelle). **d : photo originale de l'affleurement n° 90 (en partie détruit), prise par Gy. Varga (1975).** "contact d'un tuf acide et d'un agglomérat d'andésite", interprété maintenant comme un dépôt d'avalanche de débris.*

on the tectonics of the Mátra, the present orographic features do not suggest a direct relationship to original volcanic structures. Rather, orography seems to be strongly controlled by tectonic deformation. In order to verify this assumption, we have performed investigations on structural geology to measure fault directions and infer the structural history of the mountains. We also evaluate the previously described dyke pattern and a new gravimetric map.

Fault measurements

We visited a number of exposures in non-welded ignimbrite and volcanic mudstone/siltstone along the Mátrabérc ridge in order to find traces of movements along tectonic surfaces. The detected faults offset the observed layering in the deposits and quite often slickenslide lineations and fault-related microstructural features could be measured and determined. The most remarkable detected faults are NE-SW striking, flat (ca. 45° dip angle) faults with normal downthrow towards the SE (fig. 7a), observed close to the main valley that separates the central andesite masses from the northern watershed (Mátrabérc ridge in figs. 3 and 4). The measured faults were numerically treated by the method of J. Angelier (1979) to infer the palaeo-stress-field directions.

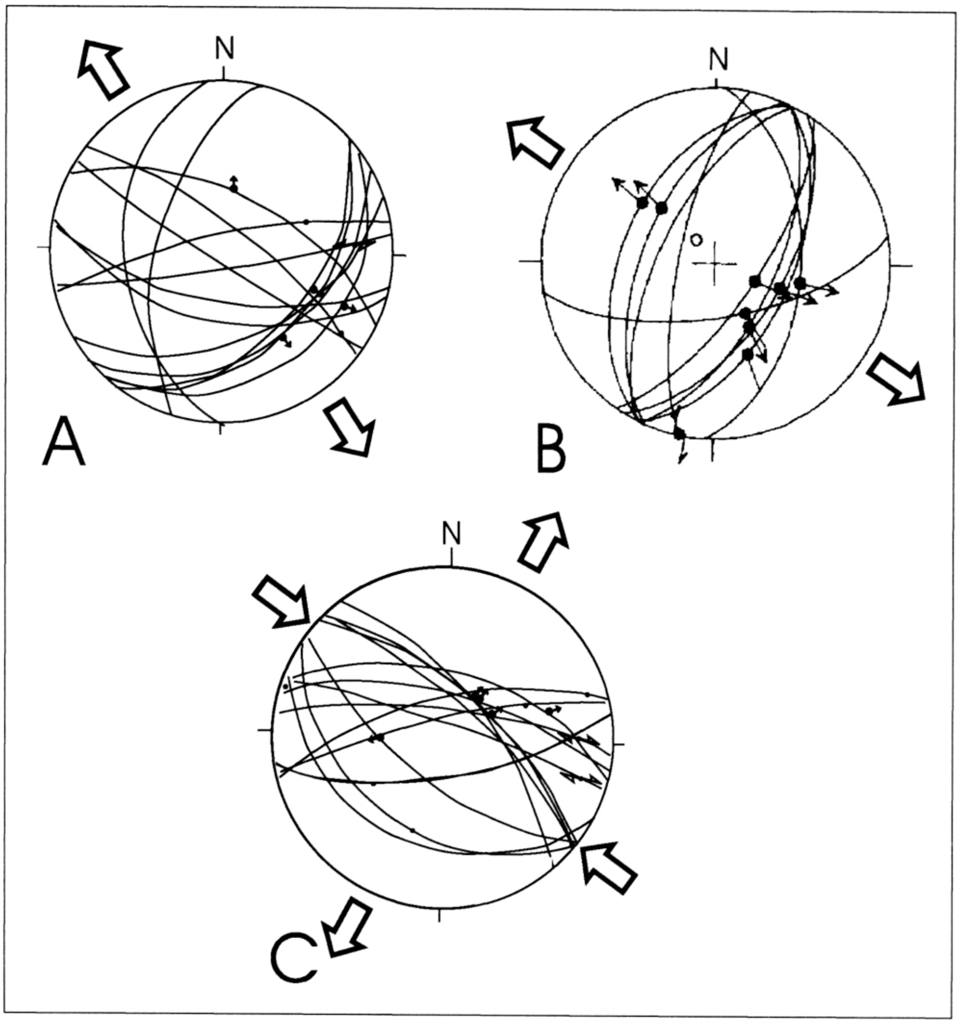

Fig. 7 – **Stereographic plots of fault measurements in and around the Mátra Mounts. A: NW-SE extension-related faults measured in mid-Miocene volcanic-sedimentary rocks at the northern watershed (Mátrabérc ridge) of the Mátra; B: normal faults measured in Sarmatian diatomite, Szurdokpüspöki (north of Hársas Hill, fig. 4), by F. Bergerat and L. Csontos (1987); C: NE-SW extension measured in Middle Miocene volcanic-sedimentary rocks at the northern watershed (Mátrabérc ridge) of the Mátra**. All plots on lower hemisphere Schmidt projection. Faults are represented by traces, slickenslides by dots. Arrow pointing outwards indicates normal faulting, shear arrows indicate right and left lateral motion. Thick arrows indicate compression and extension directions.

*Fig. 7 – **Projections stéréographiques des failles mesurées dans la région des Monts Mátra. A: failles jouant en distension NO-SE mesurées dans les sédiments volcaniques du Miocène moyen sur la crête septentrionale (Mátrabérc ridge) des Monts Mátra ; B: failles normales mesurées dans les diatomites sarmatiennes, à Szurdokpüspöki (au N du Mont Hársas, fig. 4), par F. Bergerat et L. Csontos (1987) ; C: distension NE-SO mesurée dans des roches volcano-sédimentaires du Miocène moyen sur la crête septentrionale de Mátrabérc des Monts Mátra**. Toutes les projections sont sur l'hémisphere inférieur de Schmidt. Les failles sont représentées par des lignes, les stries par des points. Les flèches vers l'extérieur indiquent un mouvement normal, les doubles flèches en cisaillement indiquent des mouvements dextres et senestres. Les grandes flèches à l'exté-*

Two palaeo-stress tensors at right angles could be determined. The first is characterised by a NW-SE compression and a NE-SW extension. The NW-SE-oriented normal faults and the WNW-ESE-oriented dextral faults could operate under the influence of this stress-field. The second tensor is characterised by a NW-SE extension with compression direction close to the vertical. All the flat NE-SW striking normal faults would operate under this stress-field.

The chronology of stress fields is hard to assess. No syn-formational structures have been observed; hence, the measured faults could form theoretically at any time since the mid-Miocene. A large number of measurements exists for the regions surrounding the Mátra, especially at its western margin (Benkovics, 1991). Fault data collected by F. Bergerat and L. Csontos (1987) have also been taken into account. Summarising these, the mid-Miocene volcanic formations recorded both stress fields. Fault data (Bergerat and Csontos, 1987; fig. 7B) from a Sarmatian diatomite quarry (north of Nagy Hársas Hill, fig. 4) show conjugate normal faults with a NW-SE extension. Similar observations in Sarmatian sediments around the Mátra (Benkovics, 1991) also support a syn-post Sarmatian age for the NW-SE oriented extension. A detailed study (Fodor *et al.,* 1999, their fig. 3) also shows a first inversion phase corresponding to a NE-SW compression direction in the late Sarmatian, followed by tilt and a late Miocene (9-6 Ma) NW-SE-directed extension. The last recorded structural phase has been a Pliocene-Quaternary NNW-SSE-directed compression.

Seismic section analysis of the Zagyva Graben (fig. 1; Benkovics, 1991) indicated that the graben opened in the Sarmatian-lower Pannonian (late Miocene) due to NW-SE extension. A later structural event caused erosion of the deposited strata with southward tilting. This erosion has been attributed to a late-stage compression. The most intense erosion, at least in the western margin of Mátra, is observable very close to the north crest of the mountains. The axis of the uplifted and eroded region is approximately WNW-ESE, fitting with the N-S-oriented compression. Because the Pannonian (late Miocene) strata are also deeply eroded, the uplift must be post-Pannonian in age.

Remote sensing was also used to define structural directions and their relative chronology (Czakó and Zelenka, 1981). In the Mátra, two sets of regional fracture zones were defined: a linear NW-SE-trending and a more disrupted NE-SW-directed fault family. The authors recognised that the former is younger than the latter. The younger, linear faults were considered as strike-slip or normal faults, while the older, more curved fault lines were thought to be of compressional origin. We note that flatter extensional faults may also have curvilinear trends. The proposed age for the older, NE-SW oriented set is late Miocene, whereas for the younger, NW-SE oriented one, Plio-Pleistocene (Czakó and Zelenka, 1981). This latter direction is best seen in the Kövicses Valley (figs. 3 and 4).

Borehole data

Most of the boreholes in the Mátra were drilled in the 1940s to 1960s for coal and ore prospecting purposes (see Hungarian Geological Institute Open-File Reports). Unfortunately, little information can be obtained for volcanology but some notes on structural geology seem very useful.

Around the mouth of Kövicses Valley, the most important structural observation in a number of coal prospecting boreholes (e. g., Hasznos-1 in fig. 4) is the presence of sliding planes. According to S. Vitális (1942) who wrote the borehole reports, "the fact that the Hasznos-1 borehole is drilled in a fault line is evidenced by the great number of steep sliding planes with oil remains (...)". Most of these planes occur in clay or tuffaceous clay, a few in lava rock.

The Mátraszentimre-2 borehole (fig. 4), in contrast, was drilled in a thick andesite sequence. This 1200-m deep borehole aimed to reach the gently southward-dipping Middle Rhyolite Tuff (MRT) at ca. 560 m. asl. as inferred from boreholes in the northern vicinity. However, since the bottom of the drilling (as low as 376 m below sl.) did not reach the tuff, E. Csillag-Teplánszky (1966) concluded that "the gentle southward dip of the basement is disrupted by a graben-like collapse zone".

The Gyöngyöspata-3 ore prospecting borehole was located on the southern slopes of the Vöröskő-bérc - Hideg-kút peaks region (fig. 4), i. e. within a proposed debris-avalanche area. A complex volcaniclastic sequence, intercalated with highly fractured andesite lava bodies, has been identified from the borehole, exhibiting a great number of steep fractures, crumbled structures, fault planes and fault gouges.

Relationship between dyke pattern and structure

The Western Mátra hydrothermal ore veins (fig. 4) and andesite dykes were described as a NW-SE, a NE-SW and minor, intersecting N-S trending dyke swarms (Vidacs, 1958; Siklóssy, 1977), not affecting the Upper Andesite (Vidacs, 1958). Hydrothermal veins used either pre-existing NE-SW oriented zones or NW-SE faults, formed during ore genesis. The ore veins were later offset and "crumbled" by NW-SE and NE-SW oriented strike-slip faults (Czakó and Zelenka, 1981). A youngest generation of NNW-SSE faults cuts finally the whole complex. These fractured veins as well as andesite dykes form neither a cylindrical pattern nor a radial one, as suggested later (e. g., Baksa *et al.,* 1981); therefore, their spatial distribution itself does not confirm the existence of a caldera.

Residual anomaly map

Gravity anomalies of the Mátra have been filtered to intensify the short wavelength anomalies (less than 10 km) and to suppress those having longer wavelength. As a result, the so-called residual anomalies are largely determined by small-sized bodies, i. e. intrusions or thick lava flows.

The residual anomaly map (fig. 8) does not suggest caldera structures. The slightly arcuated westernmost segment of the Western Mátra (dashed line around Muzsla peak) appears as a narrow, somewhat elongated positive anomaly zone starting from the Hársas Hill concentric maximum area (heavily dashed circle). This western segment corresponds to the thick andesite sequence of Muzsla ridge. Northward, along the morphological continuation of this segment (Mátrabérc ridge), the positive anomaly disappears and is characterised by a negative anomaly zone (also see dashed pattern). This feature fits with the mapped low-density volcanic-sedimentary material of that area, and is in contradiction with the notion of a uniform caldera rim encircling the Western Mátra. More eastward (east of Galya-tető Peak), the positive anomalies are found in the north foreland of the main ridge of the Eastern Mátra, possibly related to the scattered andesite extrusions there (see section on geological formations).

The most prominent maximum zone of the whole Mátra is found in the west-central part, around the Gyöngyösoroszi mine district (heavily dashed pattern east of Tóthegyes Peak). The narrow maximum zone of Muzsla ridge turns to the E-SE and runs into the large Gyöngyösoroszi maximum area, in accordance with the analysed ridge pattern (fig. 3). From this maximum towards Galya-tető Peak, lava flow successions are the thickest (up to 2000 m) and hydrothermal ore mineralisation is the most prominent (Siklóssy, 1977; Baksa *et al.,* 1981). Thickening of massive volcanics to the south cannot be inferred from the residual gravimetric map.

Discussion: a model for the volcanic structure

On the basis of previous work and our study, the starting points for an interpretation of the volcanic structures of the Western Mátra are as follows. 1) There is little evidence, if any, for the spatial relationship between the Middle Rhyolite Tuff and subsequent andesites. 2) The andesite sequence forms the most voluminous part of the Western Mátra. Significant explosive activity can be excluded, but voluminous lahar or debris-avalanche deposits, possibly associated with hydrothermally altered and K-metasomatised areas, have been found. 3) The present-day orography has been strongly controlled by intense, large-scale tectonic movements. These movements must have rearranged the primary volcano-structural elements since no original volcanic landforms have been preserved except for a highly eroded crater remnant (Galya-tető Peak south). In turn the preservation of the Galya Crater and other craters to the east indicate no significant horizontal break-up of the volcanic masses eastward.

The proposed volcanic structures are presented in figure 2. We suggest that the present-day volcanic structures of the Western Mátra are controlled by large, gently SE-dipping, arcuate normal fault planes that crosscut the mountains in a NE - SW direction. The proposed downfaulting may have

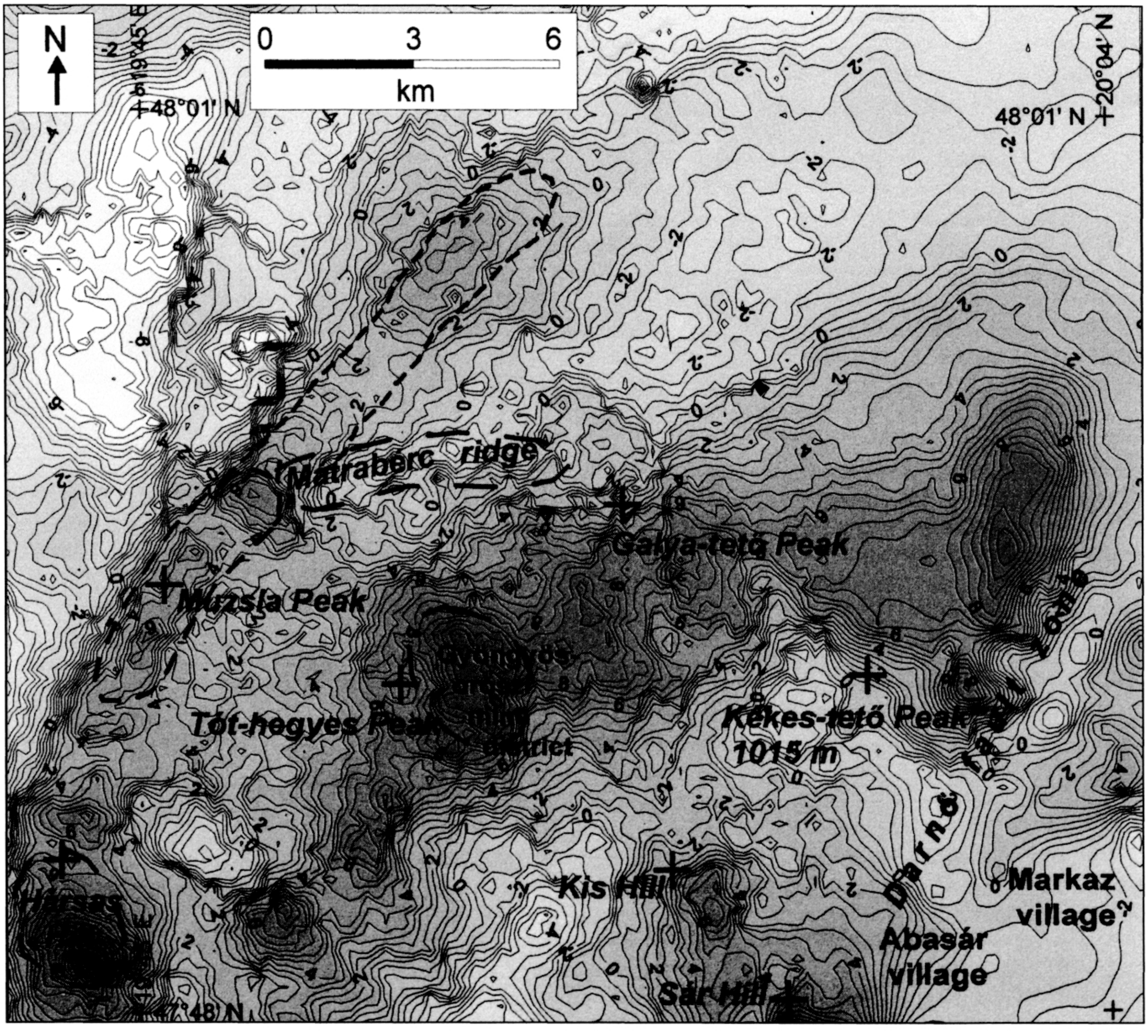

Fig. 8 – **Residual gravity map of the Mátra Mountains using the gravity data base of Eötvös Loránd Geophysical Institute of Hungary**. Density for correction: 2400 kg/m³. Values are in mgal.

*Fig. 8 – **Carte d'anomalie gravimétrique résiduelle des Monts Mátra d'après les données gravimétriques de l'Institut de Géophysique Eötvös Loránd de Hongrie**. La densité de correction est de 2400 kg/m³. Les valeurs sont en mgal.*

been triggered by the late Miocene - Pliocene tectonic uplift of the northern part. The distribution of large-scale debris-avalanche and lahar deposits, mapped in a large area, seems to correlate with the direction of the downfaulting. The slide events are proposed as factors redepositing the volcanic successions and reshaping the morphology from the NW Kövicses Valley to as far SE as the villages of Abasár or Markaz (fig. 2). The most proximal occurrence of the debris avalanche(s), the area of Vöröskő-bérc – Hideg-kút peaks (see fig. 4) seems to be linked spatially to the Gyöngyösoroszi hydrothermal ore mineralisation and neighbouring K-metasomatism (fig. 2). Weak slide zones could form in the altered rocks and, therefore, we propose a genetic relationship between tectonism (uplift and faulting), alteration, and slide events (cf. López and Williams, 1993). The volcanic mudstone deposits of Mátrabérc ridge, which exhibit slide-related fault planes and are intruded by dykes, are envisaged as the root zone of the proposed displacements and slides. This uplifted root zone seems to have lost the majority of its volcanic cover due to the debris-avalanche events, as supported by field data and the residual anomaly map. The allochtonous status of part of the "cover" andesite lava flows in ridges to the south (e. g., remnants of possible slide mounds: Havas Hill, Világos and Tóthegyes peaks and their surroundings, figs. 2 and 4) seems to fit with the displacement directions, areal distribution of upper andesites in the geological map (fig. 4) and bifurcating, anastomosing ridge pattern in the NW (fig. 3). Sudden thickening of the andesite sequence in the Mátraszentimre-2 borehole (fig. 4), interpreted earlier as result of caldera collapse, may also fit with the downfaulting-sliding hypothesis.

The pronounced NW-SE geomorphic elements, particularly the Kövicses Valley, must be the result of NW-SE-oriented faulting as already suggested by J. Noszky (1927) and T. Czakó and T. Zelenka (1981). Since these faults seem to crosscut the ridges of the proposed slide area, they should be younger (Plio-Pleistocene). The linear trends and observed offsets (Czakó and Zelenka, 1981) suggest a left lateral strike-slip fault set, which would fit into a late-stage compression of the whole area.

The proposed geomorphic rearrangement of the original volcanic landforms as well as existing field volcanological data are in contradiction with the presence of a caldera in the Western Mátra. Apart from the Middle Rhyolite Tuff (MRT), there are no deposits or structures (e. g., lag breccia, megabreccia, ring faults, caldera rim morphology, etc.) that can be associated with caldera-forming mechanisms. For the MRT, we have shown that its association with a large, local caldera is unlikely. We propose that the MRT is a tectonically uplifted, distally emplaced ignimbrite sheet along the whole Mátra, originating from either a single large or a number of small-scale vents. Even if there was a caldera or small calderas in an early stage, these have not been preserved due to the late Miocene break-up of the whole volcanic mass and to the late Miocene to Pleistocene tectonic faults and slides. For instance, the apparent arcuate shape of the Muzsla-Mátrabérc main watershed, generally linked to a caldera in the literature (cf. Baksa *et al.*, 1981; Székely, 1985), has various origins. The westernmost Muzsla ridge may represent, or belong to, the remnant of a fissure vent with a thick andesite sequence. This sequence is cut by a NE-SW-trending late Miocene normal fault toward the Zagyva Graben, which means that the apparent direction of the ridge is controlled by tectonic instead of volcanic structures. In contrast, the geomorphic continuation, i. e. the Mátrabérc ridge, consists mostly of volcanic-sedimentary rocks and has been deformed by subsequent, north-directed Quaternary slumping (Noszky, 1927; Szabó, 1996).

Conclusions

We consider the majority of volcanic edifice of the Western Mátra as a group of small-scale andesitic centres fed originally by individual or fissure vents (Noszky, 1927; Varga *et al.*, 1975). An early caldera is not seen in the morphology and not suggested by the observable volcanic deposits. Instead, the present-day, largely "circular" mass of the Western Mátra may reflect a cluster-like association of vents, enhanced by a southward-directed rearrangement of original geomorphic elements by large-scale downfaulting and sliding.

Our results on the type and distribution of volcanic deposits as well as on structural geology indicate that the thick andesite sequence of the Western Mátra, built upon the Middle Rhyolite Tuff, has been substantially affected by intense late Miocene to Pleistocene tectonic movements. The whole structure, crosscut by generations of WNW-ESE-trending and perpendicular faults, was uplifted asymmetrically, and significant downfaulting occurred along SE-dipping planes. This downfaulting could be associated with huge slides, mostly debris avalanches, contributing to the redeposition of volcanic successions, and even to the reshaping of large-scale orographic elements. Relative erosion of summit regions in the Hungarian volcanic mountains since the late Miocene has been up to 400-500 m in total (Karátson, 1996). In this way, the interpretation of Noszky (1927) about the cone-like landforms as "polished, eroded lava sheets" seems to be correct, adding that a part of them has not only been eroded, but also tilted and removed to the south. This tectonic deformation as well as geochemical similarities of lava rocks and various subsequent alteration imply that searching for original, individual volcanic centres is difficult.

Acknowledgements

Research work has been funded by Hungarian National Grants OTKA T032774 and FKFP 0175/00. Additional computer work by B. Korbély, helpful discussions with T. Zelenka, J. Kiss, and constructive reviews by L. Korpás, K. Németh and J.-C. Thouret are acknowledged.

References

Abdel-Rahman J. (1994) – The nature of biotites in igneous rocks. *Journal of Petrology* 37, 125-141.

Angelier J. (1984) – Tectonic analysis of fault slip data sets. *Journal of Geophysical Research,* 8, B7, 5835-5848.

Baksa Cs., Csillag J., Földessy J., Zelenka T. (1981) – A hypothesis about the Tertiary volcanic activities of the Mátra Mountains, NE Hungary. *Acta Geologica Acad. Sci. Hung.*, 24 (2-4), 337-349, Budapest.

Balla Z. (1984) – Geological structure of the main ridge of Western Mátra. *Annual Report of the Eötvös Loránd Geophysical Institute of Hungary,* 33-43, Budapest (in Hungarian with English figure caption).

Balla Z., Szabó Z. (1986) – Regional volcano-structural analysis of the Mátra. *Annual Report of the Eötvös Loránd Geophysical Institute of Hungary,* 32-60, Budapest (in Hungarian with English figure caption).

Balogh K. (1984) – *Introducing the K/Ar age determination method to Hungarian geology: results of application.* Unpublished PhD dissertation, Nuclear Institute of Hungarian, Academy of Sciences, Debrecen, 235 p (in Hungarian).

Benkovics L. (1991) – *Microtectonic investigations in the Zagyva Trench and their relationship to seismic sections.* Eötvös University, unpublished Master Thesis, Budapest, 95 p (in Hungarian).

Bergerat F., Csontos L. (1987) – Présence de failles hydroplastiques de compaction dans les lignites miocènes et pliocènes des massifs de Mátra et du Bükk (Hongrie). Interprétation dans le contexte extensif du Bassin Pannonien. *C. R. Académie des Sciences Paris*, t. 305, Série II, 791-796.

Cas R. A. F., Wright J. V. (1991) – Subaqueous pyroclastic flows and ignimbrites: an assessment. *Bulletin of Volcanology,* 53, 357-380.

Cholnoky J. (1937) – *Magyarország földrajza (Geography of Hungary).* Danubia Kiadó, Pécs, 167 p. (in Hungarian).

Cole R. B., DeCelles P. G. (1991) – Subaerial to submarine transitions in early Miocene pyroclastic-flow deposits, southern San Joaquin basin, California. *Geological Society of America Bulletin,* 103, 221-235.

Csillag-Teplánszky E. (1966) – Complete documentation of the Mátraszentimre-2 borehole *Archives of the Hungarian Geological Institute,* 1568/2, Budapest (in Hungarian).

Csongrádi, J. (1982) – Ore geological reambulation of the 1:10 000 sheet of Mátraszentimre village. *Archives of the Hungarian Geological Institute* (in Hungarian).

Czakó T., Zelenka T. (1981) – New data about the neotectonics of Mátra Mountains, Northern Hungary. *Advances in Space Research, COSPAR,* 1, 289-298, London.

Downes H., Pantó Gy., Póka T., Mattey D. P. & Greenwood P. B. (1995) – Calc-alkaline volcanics of the Inner Carpathian arc, Northern Hungary: new geochemical and oxygen isotopic results. *In* Downes H. & Vaselli O. (Eds.): Neogene and related magmatism in the Carpatho-Pannonian Region. *Acta Vulcanologica,* 7, 29-41.

Fodor L., Csontos L., Bada G., Györfi I., Benkovics L. (1999) – Tertiary tectonic evolution of the Pannonian Basin system and neighbouring orogens: a new synthesis of paleostress data. *In* Durand B., Jolivet L., Horváth F., Séranne M. (Eds.): *The Mediterranean Basins: Tertiary extension within the Alpine orogen.* Geological Society London, Spec. Publ., 156, 295-334.

Gatter J., Molnár F., Földessy J., Zelenka T., Kiss J., Szebényi G. (1999) – High- and Low-Sulfidation Epithermal Mineralization of the Mátra Mountains, NE Hungary. *In* Thompson T. B. (Eds.): *Epithermal mineralization of the West Carpathians.* SEG Guide Book, 31, 155-179.

Gill J. B. (1981) – *Orogenic andesites and plate tectonics.* Springer Verlag, Berlin-Heidelberg-New York, 390 p.

Hámor G., Ravasz-Baranyai L., Halmai J., Balogh K., Árváné-Sós E. (1985) – Dating of Miocene acid and intermediate volcanic activity in Hungary. *Proceedings of the 8th RCMNS Congress, Annals of the Hungarian Geological Institute,* 149-154.

Karátson D. (1996) – Rates and factors of stratovolcano degradation in a continental climate: a complex morphometric analysis of nineteen Neogene/Quaternary crater remnants in the Carpathians. *Journal of Volcanology and Geothermal Research,* 73, 65-78.

Karátson D., Márton E., Harangi Sz., Józsa S., Balogh K., Pécskay Z., Kovácsvölgyi S., Szakmány Gy., Dulai A. (2000) – Volcanic evolution and stratigraphy of the Miocene Börzsöny Mountains, Hungary: An integrated study. *Geologica Carpathica,* 51, 5, 325-343.

Karátson D., Németh K., Józsa S., Borbély E. (2001) – An ancient volcanic debris avalanche initiated the river loop? The mystery of the Danube Bend, Hungary. *XI EUG Congress, Strasbourg, Abstract Volume, Section EVO2*, 181.

Karátson D., Németh K. (2001) – Lithofacies associations of an emerging volcaniclastic apron in a Miocene volcanic complex: an example from the Börzsöny Mountains, Hungary. *International Journal of Earth Sciences*, (in press).

Kiss J., Síkhegyi F., vetö-Ákos É., Zelenka T. (1996) – Volcanic structures, Alpine metallogeny and tectonics in the SE Mátra Mts, NE Hungary. *Plate Tectonic Aspects of the Alpine Metallogeny in the Carpatho-Balkan Region,* IGCP Congress Proceedings, Sofia, 145-155.

Kubovics I. (1970) – Mineralogical-petrological study of the NE and W Mátra. *In* Kubovics I. & Pantó Gy. (1970): *Volcanological studies in the Mátra and Börzsöny Mountains, Akadémiai Kiadó,* Budapest, 7-160 (in Hungarian).

Láng S. (1955) – *Physical geography of the Mátra and Börzsöny Mountains. Akadémiai Kiadó,* Budapest, 512 p. (in Hungarian with German and Russian abstracts).

López, D. L., Williams, S. N. (1993) – Catastrophic volcanic collapse: relation to hydrothermal processes. *Science,* 260, 1794-1796.

Mauritz, B. (1909) – *A Mátra hegység eruptív kőzetei (Eruptive rocks of the Mátra Mts). Bulletin of Mathematics and Natural Sciences,* 30, Budapest, 114 p. (in Hungarian).

Noszky J. (1927) – A Mátra hegység geomorphologiai viszonyai (Geomorphological features of the Mátra Mts). *Tisza I. Tudományos Társulat Honismereti Bizottság Kiadványa,* Karcag, 149 p. (in Hungarian with German figure caption).

Schréter Z. (1940) – A mine geological survey in the vicinity of the village of Nagybátony. *Annual Report of the Hungarian Geological Institute on the year 1933-35,* 1163-1179 (in Hungarian with German abridged version).

Siklóssy S. (1977) – Structural evaluation of Gyöngyösoroszi and its vicinity. *Bulletin of Hungrian Geological Society,* 107, 348-357 (in Hungarian with English abstract).

Szabó J. (1996) – *The role of landslides in the geomorphological evolution of Hungarian landscapes.* Kossuth University Press, Debrecen, 223 p. (in Hungarian with English abridged version).

Szádeczky-Kardoss E., Vidacs A., Varrók K. (1959) – Neogene volcanism of the Mátra Mountains. *Geochemical Conference Issue,* Hung. Acad. Sci., 35 p.

Székely A. (1960) – Genesis and landforms of the W part of the Mátra Mts. *Bull. Hung. Geogr. Soc.,* VIII/3 (LXXXIV), 251-278 (in Hungarian with English abstract).

Székely A. (1985) – Recent research achievements and a typology of volcanic mountains in Hungary. *In* Pécsi M. (Ed.): *Environmental and Dynamic Geomorphology, Akadémiai Kiadó,* Budapest, 157-170.

Szentes F. (1939) – Report on the geological survey in the northern part of the Mátra Mountains in 1933-34. *Annual Report of the Hungarian Geological Institute on the year 1933-35,* 621-652 (in Hungarian with German abridged version).

Varga Gy. Csillag-Teplánszky E., Félegyházi Zs. (1975) – *Geology of the Mátra Mountains.* Annual Report of the Hungarian Geological Institute, LVII, 1, 575 p.

Varga Gy. (1992) – Potassium trachyte and potassium-rich rocks of the Mátra Mts. *Annual Report of the Hungarian Geological Institute on the year 1990,* 240-276.

Vidacs A. (1958) – Hydrothermal veins of the Gyöngyösoroszi mine district. *Annual Report of the Hungarian Geological Institute on the year 1957-58,* 25-70.

Vitális S. (1942) – Report on the Hasznos-1, -2 and –3 boreholes. *Archives of the Hungarian Geological Institute,* 300/1-3, Budapest.

Article reçu le 30 octobre 2000, accepté le 22 mai 2001