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RESCULPTURING OF BASALTIC MOUNTAINS OF THE NORTHWESTERN CARPATHIANS DURING THE PLEISTOCENE

The Intra-Carpathian Volcanic Range was built up during three Tertiary episodes of volcanic eruptions of a highly differing nature. Thus, the sculpture of mountains of differing age, composition and shape depended not only on the duration of the period of denudation, but also on the rates, intensities, and even way and mechanism of erosion. There is much variation in the extent of resculpturing (Székely 1978, 1983, 1983—84, 1985, 1989) which resulted in the present diversity of the landscapes in these mountains.

THREE MAIN PERIODS OF VOLCANIC ACTIVITY

1. Smaller-scale initial volcanism in the Upper Eocene (45 million yrs BP). As a consequence of prolonged denudation, only ruins of these originally composite volcanoes (being buried under a thick Oligocene sedimentary cover now) and subvolcanic bodies (mainly laccoliths) have been preserved. Their remnants are merely colouring elements at Recsk, Mátra Mountains.

2. The principal volcanic activity took place largely in the Middle Miocene (19—22 million yrs BP Hamor *et al.* 1987). This produced the Intra-Carpathian Volcanic Range, 800 km long, of which 250 km lie in Hungary. The volcanics mostly comprise andesite and its pyroclastics (about 80 per cent of all products during the Middle Miocene) and only a small proportion of acidic volcanic material (rhyolite and rhyolitic tuff and dacite).

3. The final basalt volcanism is much younger. In the Intra-Carpathian zone it is dated to the late Pliocene in the north around Salgótarján, Eastern-Nógrád basin (generally 2.5—2 million yrs BP, but 3 million yrs BP at Magyar-bánya on the Medves plateau). Absolute dating has been performed recently by the K/Ar method (Balogh *et*

al. 1986). In the western part of Hungary, in Transdanubia, basaltic volcanoes were active 7—3 million yrs ago. The processes of erosion were similar, but not identical there. The differences are not dealt with in this paper.

As early as the 1930s 47 independent occurrences of basalt were mapped by geologists in eastern-Nógrád and southwestern Gömör (Gemer) (Jugovics 1940, 1940a, 1942, 1944, 1948). Their relief was first investigated by the present author in the late fifties (Székely 1960). This basalt region continues without any interruption on the Czechoslovakian side of the border (Jugovics 1940a, 1944, 1948). Thus, the larger, northern parts of the basaltic hills lie in Czechoslovakia. This statement is especially true of the basalt plateaus (Fig. 1). The number of basalt localities in the volcanic range of the Northwestern Carpathians — in the southern, inner volcanic range (from Visegrad to the Tokaj Mountains) and in the northern, outer range (from the Štiavnické to the Slanské vrchy) — exceeds one hundred. Their areas, volumes, heights and features are highly variable.

This was the most alkalic and weakest stage of volcanism. Therefore, only individual hills of variable size, i.e. basaltic plateaus but mostly cones could form. They are only colouring elements in the neighbourhood of the large andesite mountains. In Nógrád they are, however, decisive in the landscape. Although they were subjected to destruction for the shortest time they are considerably eroded. The erosion period was there only one-sixth to one-eight of that for the andesite mountains, i.e. about 2 million years instead of 12—16 million years.

An important consequence is that in the andesite mountains several climatic changes and the resulting varieties in denudation are. These vary from warm-humid subtropical weathering to destruction under cool-dry periglacial conditions. On the other hand the properties of rocks also play a significant part (Székely 1982). Chemical weathering is usually more efficient on the andesite than on the basalt. The basaltic mountains of Hungary were eroded during the Pleistocene due to strong frost shattering under periglacial climatic conditions.

A third important aspect is areal extension. The andesitic mountains are larger than the basaltic ones by an order of magnitude. Consequently, if for instance 20—25 per cent of an andesite mountain is removed this means the loss of a vast amount of material. However, the transformation of the mountain is less than that of a much smaller basaltic mountain. Although erosion of a similar scale means the loss of lesser amounts from the basaltic mountains, the reduction of area and features is more striking. The basic landforms change, however, little. A basaltic mantle remains a mantle and a cone is conical for a long time. It only becomes reduced in size.

My investigations indicate that mechanical weathering has been decisive in the erosion of the basaltic hills. This is explained first of all by the structure of the basalt.

The eruption of basalt usually began with an explosion and opening up of the channel for the main volcanic activity to be followed by lava flows. Consequently, as opposed to the andesitic volcanoes the basaltic volcanoes are built up mostly of lava and subordinately of pyroclastics. Naturally, the basaltic lava flowed toward the valleys. Since the Lower Miocene the land surface has been eroded heavily and dissected by valleys, more than 10 m deep. The late Pliocene surface became dissected but this articulation cannot be compared to the present situation. Lava streams flowing down the basaltic volcanoes and filling up the valleys partly planated the surface and partly produced basaltic mantles of highly variable thickness, e.g., on the Medves plateau ranging from 10—100 m. The basaltic caps being harder and more resistant than the sedimentary rocks were eroded at a slower rate and preserved as ridges. As the basalt tongue rose above its environment, its free sides became exposed to erosion. This is a good example of geomorphological inversion being represented by the Bucsony and other sites beyond the national border. The inversion is also reflected in the present-day features. In the andesitic mountains mechanical weathering was most extensive, where the andesite was thinly bedded and cut across by vertical joints, e.g., in the eastern Mátra Mountains. In these places erosion was intensive in the periglacials during which the original surface was resculptured. Here periglacial features are characteristic (Székely 1973, 1973a, 1978, 1982).

The plateaus formed of basaltic mantles are often covered by felsenmeere the best example of which is found at Pogányvár in Czechoslovakia. Slopes bear talus mantles. At the feet of cliffs, and even more characteristically of cones thick screes have accumulated. These consist of large angular blocks. Consequently, the retreat of the basaltic slope was considerable, and the area occupied by basaltic mantles became reduced, although they usually decreased very little in height.

Erosion was almost exclusively lateral since the felsenmeere on the summit levels, some 3—4 m thick, virtually preserved the surface. Only slow in situ mechanical weathering could continue. On the marginal slopes the removed blocks disintegrated more easily, generally into 30—60 cm particles, while they became more and more rounded. This mechanism of cliff retreat was accompanied by the accumulation of an even more extensive and thicker debris slope of unsorted basalt fragments of various sizes (20—90 cm in diameter).

Slope retreat brought about the development of local pediments — crypediments, some 10 m wide, with still wider (100—200 m) cryo-

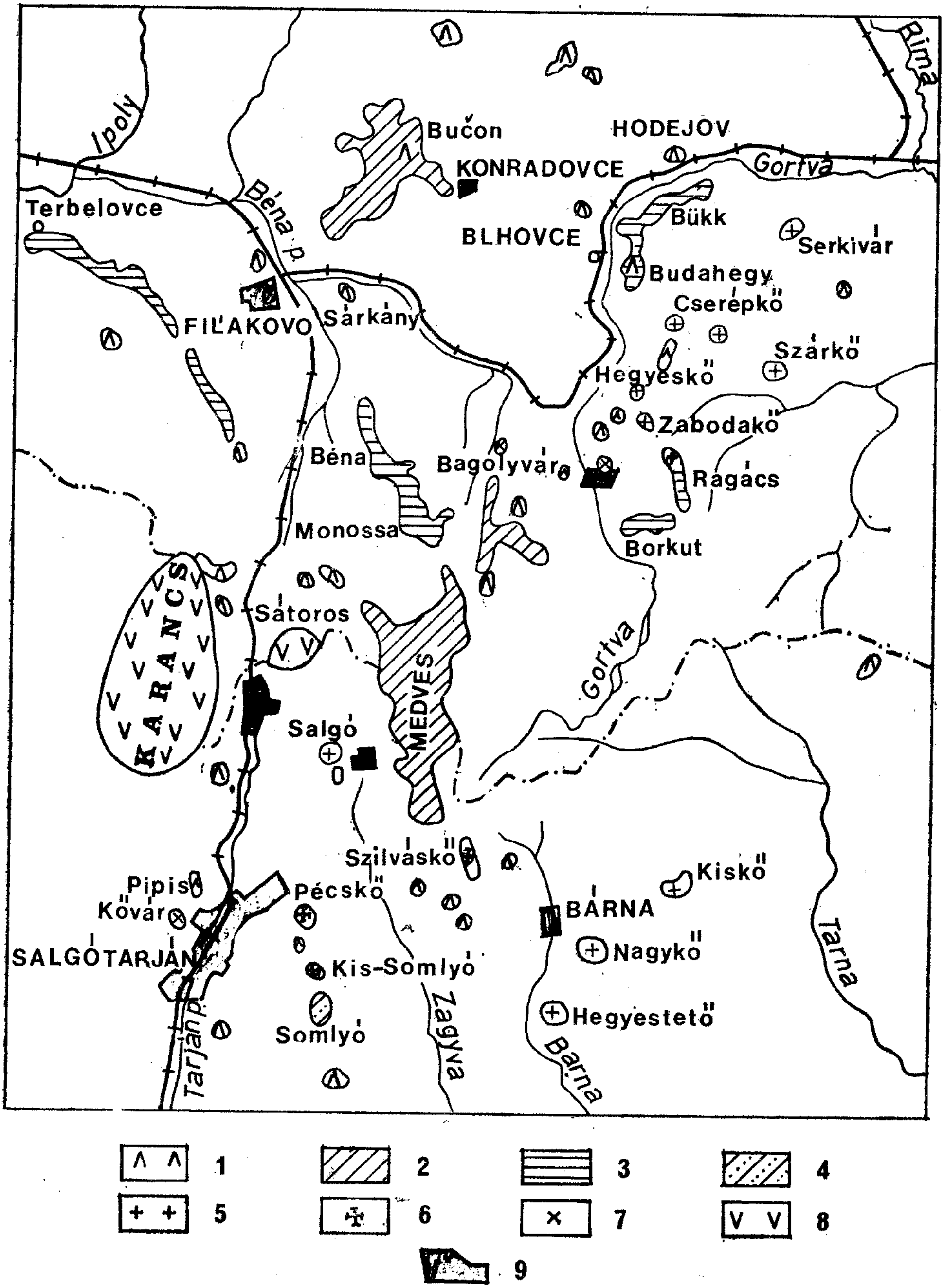

Fig. 1. Geomorphological sketch to show the Intra-Carpathian basalt country in eastern Nógrád and southwestern Gemer (Gömör) (by A. Székely using the geological sketch map by L. Jugovics): 1 — basaltic hills undifferentiated, 2 — basaltic plateus, broader relic or denuded mantle, 3 — basaltic ridge, relic or denuded narrow basalt stream, 4 — remnant of basaltic mantle, 5 — basaltic

glacis on the underlying Oligocene—Lower Miocene strata in their neighbourhood.

A large number of basaltic cones are conduit cones (Fig. 1 and 2), i.e. only the cylindrical basaltic body solidified in the former lava conduit was retained. This was the core of the lava that broke through the exploded pyroclastics and vaulted it locally. The less resistant pyroclastics are more easily eroded and the basaltic conduit is increasingly exposed and eroded. Parallelly, the basalt cliff became

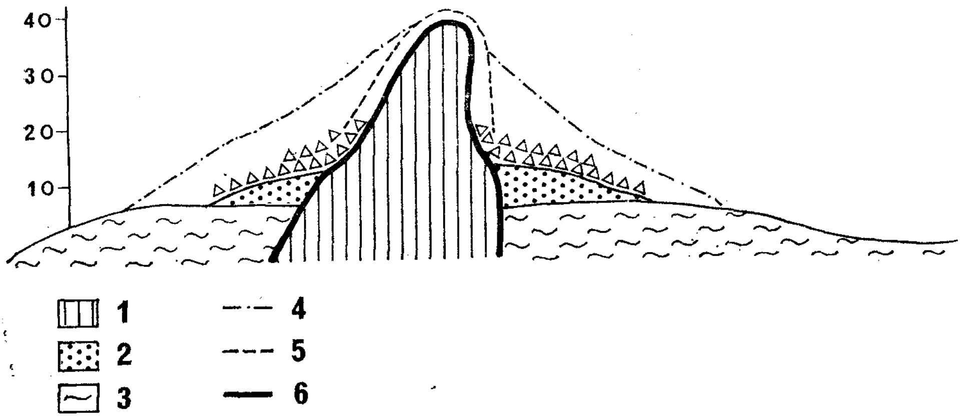

Fig. 2. Resculpturing of basaltic cones during the Pleistocene: 1 — Upper Oligocene-Lower Miocene sedimentary rocks, 2 — basalt pyroclastics, 3 — columnar basalt lava, 4 — reconstructed surface of pyroclastics, 5 — reconstructed surface of basalt lava, 6 — present-day surface

Ryc. 2. Zmiany kształtu stożków bazaltowych w plejstocenie: 1 — skały osadowe wieku górnooligoceńskiego — dolnomioceńskiego, 2 — bazaltowe utwory piroklastyczne, 3 — lawa bazaltowa o ciosie słupowym, 4 — odtworzona powierzchnia utworów piroklastycznych, 5 — odtworzona powierzchnia lawy bazaltowej, 7 — obecna powierzchnia

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cone, relic or denuded former lava conduit, 6 — remnant of a basalt or agglomerate cone altered by human intervention (mainly by quarrying), 7 — exposed remnant of former vent Schlotkegel, 8 — exposed Middle Miocene andesite laccolith, 9 — settlement, 10 — national border

Ryc. 1. Szkic geomorfologiczny śródkarpackiej krainy bazaltowej, wschodni Nógrád i południowo-zachodni Gemer (Gömör) (opracował A. Székely na podstawie mapy geologicznej L. Jugovicsa): 1 — wzniesienia bazaltowe nierozdzielone, 2 — plateau bazaltowe, rozległa ostańcowa lub zdenudowana pokrywa, 3 — grzbiet bazaltowy, ostańcowy lub zdenudowany wąski potok bazaltowy, 4 — pozostałość pokrywy bazaltowej, 5 — stożek bazaltowy, ostańcowy lub zdenudowany rdzeń wulkaniczny, 6 — pozostałość stożka bazaltowego lub aglomeratowego przeobrażonego w wyniku działalności człowieka (głównie kamieniołomy), 7 — odsłonięte dawne wypełnienie komina, 8 — odsłonięty lakkolit andezytowy wieku środkowomioceńskiego, 9 — osada, 10 — granica państwowa higher and higher. Off the vertical cliffs blocks toppled instead of being transported slowly downslope.

As the basalt is mostly of columnar structure, the basaltic columns were increasingly isolated from the cylinder of the lava conduit. They became more and more slender and finally collapsed. In this manner the cliff retreated preserving its vertical slope. The collapsed columns broke into large fragments. In this case large blocks are scattered along the footslope. They are naturally smaller, and angular because they have not been transported downslope gradually. In short, the talus slope material is unsorted. Wearing down of the angular blocks occurred only on the surface of the talus slope due to rolling over and bouncing. However, this was insufficient to round the sharp edges considerably. As a consequence, the latter survived until now.

In their majority the large blocks remained immediately at the foot of the hill. They could be transported only on slopes inclined 4—5° at the minimum. On slopes exceeding 15° they travelled over longer distances. Consequently, most of the eroded correlative material rests at the foot of the basaltic hill or in its close vicinity. It can be mapped accurately. Its amount can be measured. My observations show that generally more than 90 per cent of the basalt is retained in the immediate environs and this allows reliable reconstructions to be made. The difficulty lies in the measurement of the thickness of the basaltic debris cover since the underlying rock is located several metres below the debris heap. It can neither be reached nor seen nor drilled. Therefore, in most cases only estimations are possible.

Another way of reconstructing the basalt volcanoes is the hypothetical recharge of this correlative material onto the volcano. The methods of drainage network analysis and evaluation which were applied successfully in the reconstructions of the andesite volanoes (Székely 1983, 1985a) can be used for basalt volcanoes in a limited extent and in an indirect manner only. The small extension of the basaltic hills does not allow a drainage network even of intermittent streams to develop. For this reason, in the research on basaltic hills other indirect methods of analysis had to be elaborated in order to reconstruct the original extent of the basalt volcano. This method is usefully supplemented and partly checked by the computation of the amount of correlative material.

The diversity of periglacial features is much less than in the andesitic mountains. In fact, a single continuous series due to effective frost action during the periglacial stages may be recognized: felsenmeere — stone flows — debris sheets — talus slopes. This again is a consequence of the limited extent of the basaltic hills. There was no room available for the development of cryoplanation terraces, fields of stone polygons, rock bars and other phenomena. There was even less opportunity for valley broadening and narrowing of the interfluves, since true valleys could not develop on the basaltic hill slopes. The above processes were most important in the andesitic mountains. They led not only to the formation of new landforms but also to a substantial modification of the original land surface (S z é k e l y 1978a, 1987).

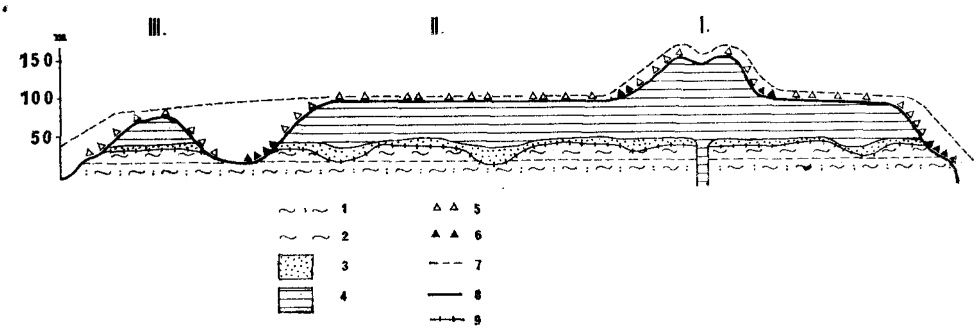

Fig. 3. Generalized profile of basaltic mantles (by example of the Medves): 1 — Upper Oligocene sandstone, 2 — Lower Miocene variegated clay, rhyolitic tuff, locally with coal measures protected by the basaltic mantle, 3 — basalt pyroclastics, 4 — layered basalt, often showing columnar jointing, 5 — disintegrated blocks: felsenmeere, debris sheets, stone-flows, 6 — talus slope at footslope, 7 — prebasaltic surface of erosion, 8 — reconstructed postbasaltic surface, 9 — present-day surface; I — relic cone of eruption centre of basalt lava or composite volcano, II — relic basaltic plateau or mantle, III — marginal residual hill isolated by erosion

Ryc. 3. Uogólniony profil pokryw bazaltowych (na przykładzie Medves): 1 — górnooligoceński piaskowiec, 2 — dolnomioceńskie iły, tufy ryolitowe, miejscami pokłady węgla zachowane pod pokrywą bazaltową, 3 — bazaltowe utwory piroklastyczne, 4 — warstwowany bazalt często o ciosie słupowym, 5 — rozpadające się bloki: gołoborza, pokrywy rumowiskowe, jęzory gruzowe, 6 — stok usypiskowy u podnóży wzniesień, 7 — przedbazaltowa powierzchnia erozyjna, 8 — odtworzona powierzchnia pobazaltowa, 9 — obecna powierzchnia; I — ostańcowy stożek — erupcja centralna lawy bazaltowej lub złożony wulkan, II — ostańcowe plato bazaltowe lub pokrywa bazaltowa, III — brzeżny pagór ostańcowy odcięty wskutek erozji

Different rock properties were responsible for effective gelisolifluction only on the underlying sedimentary rocks in the neighbourhood of the basaltic hills. On the clayey sediments slopes were considerably refashioned, and both valleys and basins widened. Similarly, frost wedges and frost sacks could develop only outside the basalt occurrences.

The above facts may suggest that the rates of periglacial resculpturing were smaller on the basaltic hills. In reality, frost action was so strong that it became more significant there. Landforms became reduced in size and the cones were reshaped to various degrees. In spite of their young age, they are mostly relic or denuded volcanoes which are more ruined than those in the andesitic mountains. These young volcanoes even changed to relic volcanoes (the Somlyó, 584 m a.s.l., situated east of Salgótarján) and to denuded volcanoes as a result of intensive destruction. Such are the originally subsurface agglomerate cones of the former vent remnants being exposed on the surface now: Baglyaskő, Salgótarján, and beyond the state border the Šurice (Sőreg) Castle hill and Hajnačka (Ajnacskő) as well as the Fil'akovo (Fülek) Castle hill. They were exposed mainly by stream and rain erosion during the interglacials and by gelisolifluction in the periglacials when the surficial part was removed. The margins of the basaltic plateaus became dissected and locally indented into a lace pattern by erosion, e.g., the western margin of the Medves and in Czechoslovakia (Pogányvár, Bucsony etc.).

The present landforms of the Intra-Carpathian basaltic mountains of the Northwestern Carpathians developed during the Pleistocene by resculpturing the late Pliocene primary volcanic features, but first of all during the periglacial stages due to intensive frost shattering and the resulting mass movements (falls and slides). Therefore, frost-riven cliffs and columns as well as debris (eluvium, deluvium and coluvium) of variable grain size are common phenomena. During the interglacials erosion further modified the forms and led to the present complex set of landforms with the predominance of periglacial features produced by frost action.

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STRESZCZENIE

A. S z é k e l y

PLEJSTOCEŃSKIE PRZEKSZTAŁCENIE GÓR BAZALTOWYCH W PÓŁNOCNO-ZACHODNICH KARPATACH

W Karpatach wulkany bazaltowe powstały w najmłodszej, końcowej fazie działalności wulkanicznej przypadającej 2,5—2 miliony lat BP (późny pliocen). W celu odtworzenia etapów ich niszczenia i określenia rozmiarów przekształcenia w plejstocenie autor zbadał ponad 100 stanowisk bazaltu na północy, we wschodnim Nógrád i w południowo-zachodnim Gemer (Gömör). Poszczególne wzniesienia bazaltowe różnią się wielkością, kształtem i wysokością, różnią się także mechanizmem denudacji od starszych gór andezytowych. Proces niszczenia wulkanów bazaltowych, głównie wskutek wietrzenia mrozowego i degradowania stoków, przebiegał w warunkach klimatu peryglacjalnego plejstocenu. Doprowadził on do powstania gołoborzy, jęzorów gruzowych, pokryw rumowiskowych, stoków usypiskowych, skałek, kriopedymentów itd. Autor podejmuje próbę rekonstrukcji pierwotnej powierzchni i określenia rozmiarów jej przekształcenia. Mimo młodego wieku, wśród wulkanów bazaltowych przeważają formy ostańcowe lub zdenudowane. Spotyka się także odsłonięte wypełnienia kominów. Obecne kształty gór bazaltowych rozwinęły się w plejstocenie, zwłaszcza w okresach o klimacie peryglacjalnym.