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On the Origin and Age of the Nepheline Syenite Massif of Ditro (Transylvania, Rumania)

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With 2 figures and 1 table in the text

Abstract

The paper records the geological facts, discusses the origin of the massif, and presents results on its age. A magmatic origin, accompanied by widespread hybridization phenomena and metasomatic changes, is assumed. According to K-Ar determinations the intrusion occurred in Jurassic time (around 160 m. y.).

The nepheline syenite massif of Ditro (= Ditrău) is situated on the inner margin of the Eastern Carpathians. It rises from the alluvial plain of the Mureş (= Maros) River (700 m) and culminates in the Pricske (= Piricske) Mt. (1545 m).

The massif was discovered in 1859 by F. Herbich and soon visited by many eminent geologists. A large number of workers have been concerned with its investigation: A. Koch (1877–1880), F. M. Berwerth (1905), B. Mauritz and co-workers (1910–1925), V. Ianovici (1932–1968), A. Codarcea and co-workers (1958), and also one of the present authors (A. S.) has studied the massif.

The massif consists of rocks of extremely varied mineralogy, chemistry, and texture and presents a particularly complicated structure. Therefore, it may be understood that its history is far from being elucidated. The present contribution records the geological facts, discusses the origin of the massif and presents some results on its age.

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GEOLOGICAL DATA

The massif is emplaced in the pre-Permian crystalline schists of the Eastern Carpathians (Fig. 1), against which it has developed a marked thermal aureole. At a peneplain it is covered by the Pliocene (Dacian) lacustric deposits (with lignites) of the Orotva (= Jolotca) basin (Jekelius 1923) and by Upper Pliocene or Lower Pleistocene gravels and torrential deposits (Streckeisen 1952, p. 281–283). These are succeeded by the Quaternary volcanic formations of the Călimani-Harghita chain, which show a distinct calc-alkaline character. They consist mainly of volcanic agglomerates and tuffs with some interbedded lavas of basalt andesite and andesite, which are, in turn, overlain by a volcanic-sedimentary complex (Ianovici 1934, Savul et Kräutner 1936a, Rădulescu et al. 1973).

Crystalline Schists

The crystalline core of the southern part of the Eastern Carpathians is formed of 3 distinct metamorphic series: 1. the epizonal Tulgheș, series, 2. the mesozonal Bistrița-Bărnar series, and 3. the high-grade Rarău gneiss series (Hăghimaș).

1. The epizonal *Tulgheș series* has been described in detail by Atanasiu (1928, p. 386–406) and recorded by Streckeisen (1932, p. 408f.; 1952, p. 268f.; 1968, p. 757). It consists mainly of phyllitic sericite and chlorite schists and contains frequent intercalations of metamorphosed porphyritic rocks (usually described as porphyroids: quartz porphyries, hälleflintas, etc.) and tuffaceous rocks (rhyolitic and some subordinate basic metatuffs; Mureșan et Mureșan 1972, Kräutner 1972, Kräutner et Popa 1973); the metamorphosed acid tuffaceous series of Sărmaș occurs in the north-western part of the area below a band of black quartzites. Furthermore, the Tulgheș series contains frequent

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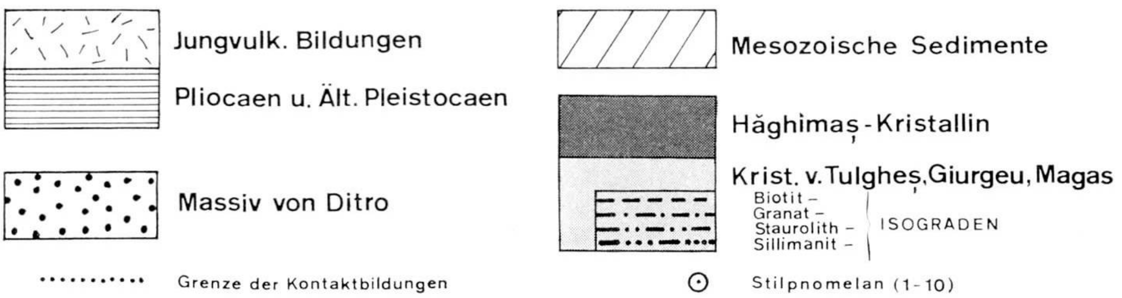
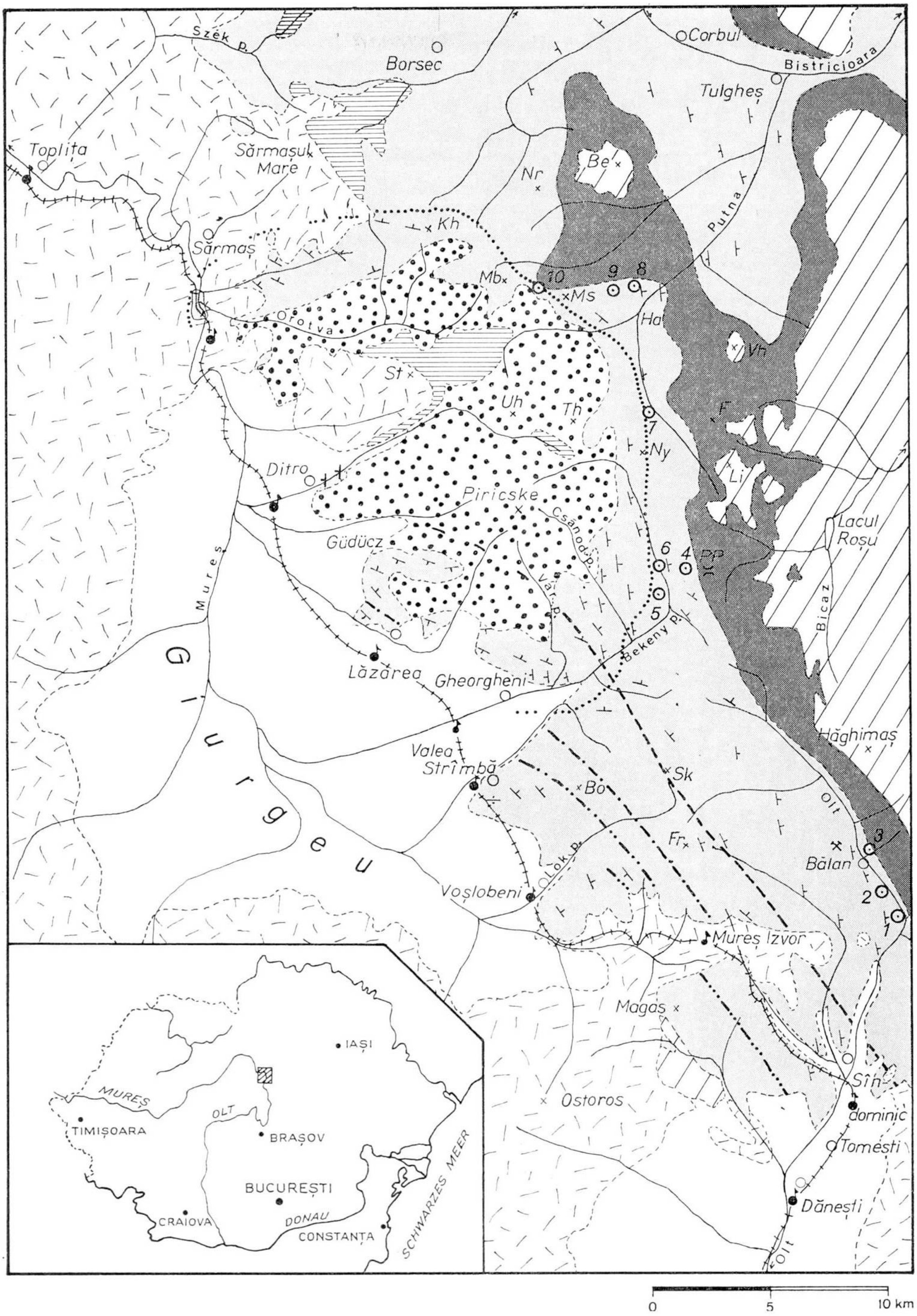
Fig. 1. Geological sketch map of the southern part of the Eastern Carpathians (reproduced from Streckeisen 1968, p. 755).

Abbreviations: Be Nagy Benes (= Beneșul Mare), Bo Borzoka tetö, F Fügés tetö, Fr Fekete rész, Ha Hagota (= Hágótöalja), Kh Nagy Közrezhavas, Li Likas, Mb Magasbükk, Ms Melegmezösarka, Nr Nagyrész patak, Ny Nyerges, PP Pongrácz-Pass (= Pasul Pingărați), Sk Siposkö, St Sóza tetö, Th Tatárhavas, Uh Ujhavas, Vh Vithavas.





Szék p.
Borsec
Corbul
Bistricioara
Tulgheș
Toplița
Sărmașul Mare
Be
Nr
Putna
Kh
Sărmaș
Mb
10
9
8
Ms
Orotva
Ha
Vh
St
Uh
Th
F
7
Ny
Ditro
Li
Piricske
Csánod p.
Güdücz
Lacul Roșu
6
4
PP
Vár p.
5
Bicaz
Mureș
Bekeny p.
Lăzărea
Gheorgheni
Giurgeu
Hăghimaș
Valea Strîmbă
Sk
Bo
Olt
3
Fr
Bălan
Lok p.
Voșlobeni
2
1
Mureș Izvor
Magas
IAȘI
MUREȘ
OLT
TIMIȘOARA
BRAȘOV
Ostoros
Sîndominic
Tomești
SCHWARZES MEER
BUCUREȘTI
Dănești
CRAIOVA
DONAU
CONSTANȚA
Olt
0
5
10 km

intercalations of black quartzites and graphitic schists, and more subordinate beds and small lenses of crystalline limestones (not shown in Fig. 2). A Lower Cambrian age for the Tulgheş series has been determined by palynological evidence (ILIESCU et MUREŞAN 1970, 1972). The regional metamorphism of the epizonal series is considered to be Baikalian (end of Lower Cambrian) on the basis of K-Ar determinations which gave 570 m. y. (GIUŞCĂ et al. 1969, ILIESCU et MUREŞAN 1972).

2. The Tulgheş series grades towards the south-west into the mesozonal *Biştrita-Bărnar series* (described as Magas series by STRECKEISEN 1952, p. 270; 1968, p. 758–760). This series consists mainly of micaschists with biotite, garnet, staurolite, and sillimanite, frequently with transverse biotite porphyroblasts. The progressive isograds of biotite, garnet, staurolite, and sillimanite have been traced by STRECKEISEN (1968), see Fig. 1. In the lower part of the series, interbedded in the micaschists, thick bands of crystalline limestones and dolomites appear which frequently contain tremolite and talc. These marbles are exposed on the western margin of the massif in the surroundings of Lăzarea. They are widespread in the Bistriţa area (SAVUL 1938). The Bistriţa-Bărnar series is considered as Infracambrian (Upper Precambrian) by ILIESCU et MUREŞAN (1972), as Lower Middle-Precambrian by KRÄUTNER (1972).

3. In the eastern part of the area appears a high-grade metamorphic series, the *Rarău gneiss series* («série des gneiss de Rarău (Hăghimaş)» in Note expl. 1968, p. 18). It has been described as Hăghimaş series by STECKEISEN (1931, p. 616; 1932, p. 409; 1940, p. 299–302; 1952, p. 269; 1954, p. 386–388; 1968, p. 760–763). The series was treated in detail by ATANASIU (1928, p. 406–424) who suggested that granito-dioritic bodies had intruded into the Tulgheş series. The high-grade series consists of garnet micaschists, some amphibolites, and widespread migmatites and anatexites with garnet, cordierite (replaced by pinite), and sillimanite (STRECKEISEN 1940). At the contact with the epizonal series, the Rarău gneiss series grades into the Tulgheş series across the short distance of about 100 m (STRECKEISEN 1932, p. 410; BĂNCILĂ 1941, p. 48). Along the contact frequently appear flaser and augen gneisses of type Rarău (ATANASIU 1928, p. 421–426). The Rarău gneiss series approaches the massif on its north-eastern margin (Magasbükk).

The relation between the Rarău gneiss series and the Tulgheş series has been debated a long time. ATANASIU (1928) favored mushroom-like granito-dioritic intrusions that should have developed a thermal contact against the Tulgheş series[1]). It is now generally accepted that the Rarău gneiss series was

[1]) In this connection it may be observed that the late Professor Ion Atanasiu kindly conveyed us a section of a chlorite schist from Piatra Roşie, Tulgheş area (see ATANASIU 1928, p. 413). This rock shows porphyroblasts of an olive biotite that appear partly to be sheared subsequently. Although this rock could favor Professor Atanasiu's interpretation, we cannot consider it decisive and recommend a further study.

thrusted over the Tulgheş series. The age of the overthrust was assumed to by Alpine by VOITEŞTI (1929), whereas a pre-Permian age was suggested by STRECKEISEN (1932, p. 410), BĂNCILĂ (1941, p. 49 and 113); and Note expl. (1968, p. 63). Recently, MUREŞAN (1968) and KRÄUTNER (1972) are in favor of an Alpine age, whereas SĂNDULESCU (1967, 1972) considers the overthrust to be pre-Triassic (probably Hercynian).

We favor a pre-Permian (probably Hercynian) age of the overthrust for the following reasons: 1. The overthrust is directed towards the west, whereas the overthrusts of the Alpine orogeny are generally directed towards the east. 2. Along more than 100 km of thrust plane, no wedges of mesozoic rocks have been observed. 3. The limit between the Rarău gneiss and the Tulgheş series is gradational across a short distance (about 100 m); this could be explained by a later, slight recrystallization of the tectonic contact (STRECKEISEN 1932). 4. In the Rarău flaser gneisses on the north-eastern margin (Magasbükk) of the massif, andalusite appears as a contact mineral (Nr. 1257). Therefore, the contact aureole post-dates the thrust plane.

Massif of Ditro

The massif of Ditro (Fig. 2) is of intermediate size and presents an elliptical shape (14 km × 19 km diameter), with some irregular indentations. The massif, including the part covered by younger volcanic rocks, comprises an area of about 170 sq. km[2]).

The massif is situated in a mountain area and its center is covered by thick forests. Except in the younger Orotva Valley in the north and some other valleys, it presents few exposures, particularly on the crests. Mapping frequently has to be done according to rocks that appear loose on the surface, with all possible associated errors[3]).

The massif has the shape of a dome with an imperfect ring structure. At the margins frequently appear granitic rocks, which have a larger distribution in the Laposbükk region to the north. Toward the center of the massif, they are generally followed by syenites, partly massive but more commonly foliated. In the interior appear two complexes of dioritic rocks: the complex of the

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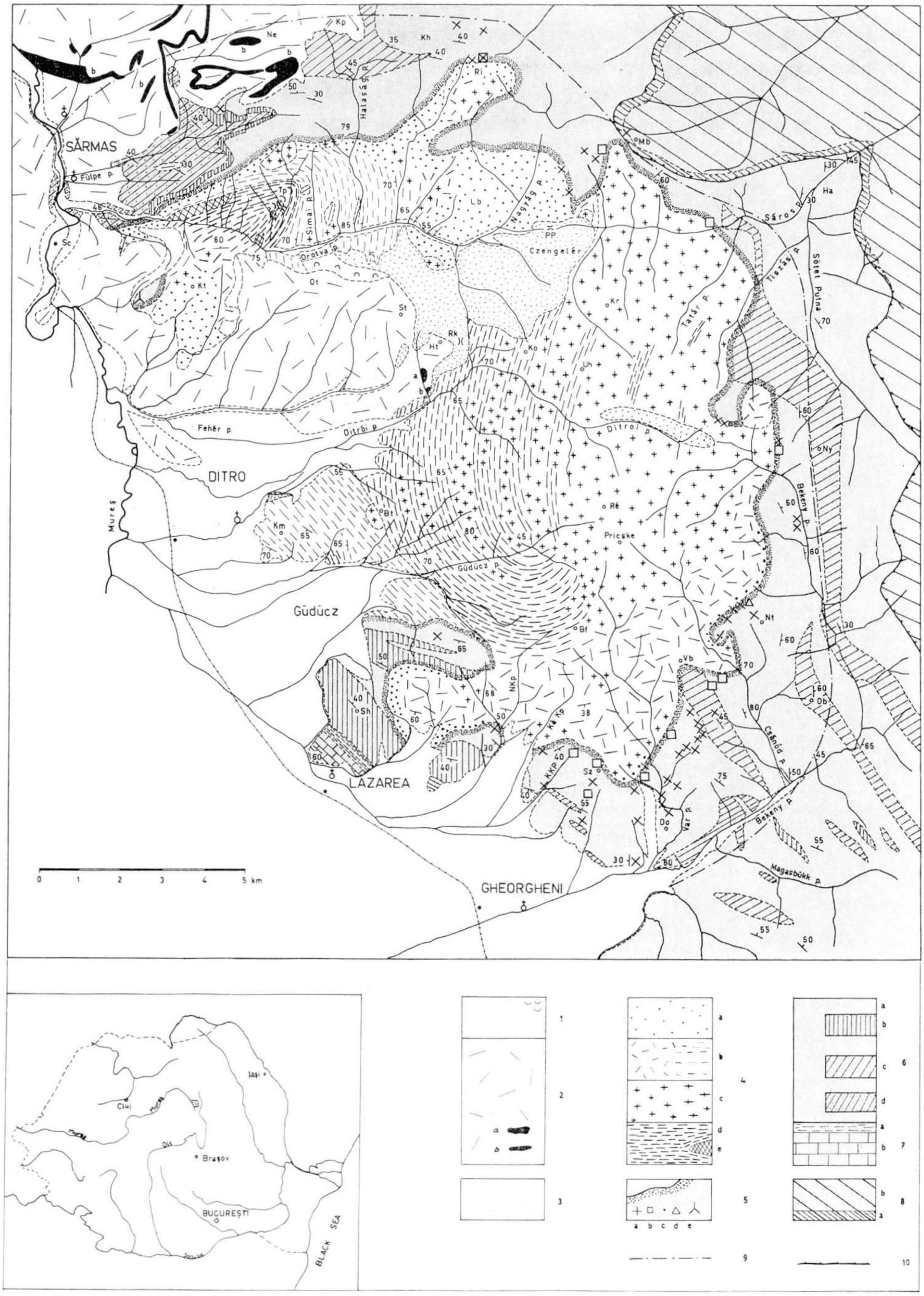
[2]) A general picture of the massif has been presented by STRECKEISEN (1952, p. 272 to 275; 1960, p. 228–232), CODARCEA et al. (1958, p. 1–64), and IANOVICI et al. (1968, p. 10–25).

[3]) STRECKEISEN (1952, 1960) assumed that the center of the massif be formed by fresh white nepheline syenites and concluded at a distinct ring dike strukture. Galleries that since have been trenched in the upper Ditro Valley have revealed that the dioritic rocks of the Czengelér-Güdücz zone have a considerably larger distribution than hitherto was assumed, and are intricately penetrated by bands and veins of syenite and nepheline syenite.



Correction: Note that the occurrences of andalusite are indicated in Fig. 2 by × instead of +.

lower Orotva Valley in the north-west, and the north-south trending Czengelér-Güdücz complex in the central part. The rocks of these complexes, for which STRECKEISEN (1952, 1954, 1960) used the comprehensive term "Ditro-essexites", are particularly heterogeneous. They are more rarely massive, commonly foliated, at places even distinctly schistose. They are intricately intermingled with bands and veins of syenite and nepheline syenite. CODARCEA et al. (1958) have shown that the original rocks of the dioritic complexes have undergone widespread metasomatic changes and hybridization phenomena. In the eastern and north-eastern parts of the massif, nepheline syenites appear, some white and particularly fresh, others reddish and affected by thorough hydrothermal alteration, with all possible transitions. The white nepheline syenites are accompanied by tinguaites and are frequently penetrated by veins and veinlets of sodalite that appear along fissures, diaclases, and at intergranular boundaries. Lamprophyres (mainly càmptonites), with sharp limits, are widespread, especially in the complexes of dioritic rocks, but occur also in the other parts of the massif and in its nearer and farther surroundings. Xenoliths with hornfels texture and bands and lenses of contact metamorphosed crystalline schists appear at many places in the interior of the massif. The massif is surrounded by a thermal contact aureole: hornfelses at the immediate contact, followed by spotted and knotted schists more distant from the contact.

The nepheline syenites of Ditro show the miaskitic character as defined by SØRENSEN (1960). The index of agpaicity, Na+K/Al (molecular ratio), varies between 0.8–1.0, while in agpaitic rocks it exceeds 1.0. The Ditro rocks are alkaline but not peralkaline. The most important minerals are microcline, microcline-perthite and -antiperthite, albite and oligoclase, Fe- and Ti-rich biotite (lepidomelan) and amphibole (basaltic hornblende), aegirine-augite,

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Fig. 2. Geological sketch map of the massif of Ditro and its surroundings, according to the mapping done by A. Streckeisen 1928–1935 and the maps presented by CODARCEA et al. (1958).

1 Quaternary deposits. 2 Pyroclastics and Volcanic-sedimentary complex; a) Andesite, b) Basaltic andesite. 3 Gravels and torrential deposits (Upper Pliocene or Lower Pleistocene). 4 Massif of Ditro: a) Granitoid rocks, b) Syenites, c) Nepheline syenites, d) Dioritic rocks (Ditro-essexites), e) Hornblendites. 5 Thermal contact aureole; contact minerals: a) andalusite, b) corindon, c) spinel, d) alkali amphibole, e) chloritoid. 6 Epizonal series (Tulgheş series): a) Phyllites, b) Black quartzites and graphitic schists, c) Metamorphosed porphyritic and tuffaceous rocks, d) Metamorphosed tuffaceous series of Sårmaş. 7 Mesozonal series (Bistriţa-Bărnar series): a) Micaschists, b) Crystalline limestones and dolomites. 8 High-grade metamorphic series (Rarău gneiss series): a) Flaser and augen gneisses of Rarău type, b) Garnet micaschists, migmatites and anatexites. 9 Outer limit of contact aureole. 10 Thrust plane of the Rårau gneiss nappe.

Abbreviations: Bf Bükkfa t., Bt Bükk teteje, Do Domokos, Ha Hagota (= Hágótöalja), Ho Hodosa, Hp Hájnal patak, Ht Hegyes tetö, Kh Közrezhavas, KKp Kis Kürücz patak, KöKp Közep Kürücz patak, Km Kerek mogyoros, Ko Komarnik tetö, KP Közrez-Pass, Kr Kecske rész, Kt Kerek magas tetö, Lp Laposbükk, Mb Magasbükk, Ne Neagra, NKp Nagy Kürücz patak, Nt Nyárád tetö, Ny Nyerges, Ob Olahbükk, Ot Orotvái tetö, PP Putna-Pass, Ré Réz tetö, Ri Rivó tetö, Rk Reznyak, Sc Subcetate, Sh Szármány hegy, St Sóza tetö, Sz Szent Ana (= Sfînt Ana), Th Tatárhavas, Tp Tászok patak, Uh Ujhavas, Vb Várbükk.

titanaugite, titanite, cancrinite, sodalite, zircon, and apatite; besides aegirine in tinguaites and kaersutite in camptonites. Thus, the rocks show enrichment in Fe, Ti, P, Zr, CO_2, Cl, while F is lacking almost completely. Complex zirconium and titanium silicates, such as eudialyte, etc., have not been recorded in the Ditro massif, which, again, indicates its miaskitic character. Chemical analyses of rocks and minerals of the Ditro massif are compiled, and the chemistry of the association is discussed in STRECKEISEN (1954, p. 349–408).

We present a short description of the most important rocks, which, however, does not provide a true picture of the extreme variability of the rock types encountered in the area.

The *granitic* rocks are usually fine- to medium-grained, of reddish color and massive texture. They contain but few dark constituents. Quartz, microcline and microcline-perthite, albite and acid oligoclase predominate. The dark constituents are commonly replaced by other minerals: biotite by chlorite and limonite; amphibole by aggregates of green biotite, chlorite, epidote and titanite. Alkali amphibole and aegirine-augite occur occasionally. Epidote is frequent, muscovite more subordinate. Accessories are: zircon, titanite, apatite, magnetite. Quartz frequently appears in larger masses among the more fine-grained feldspar aggregates with aplite texture, from which may be concluded at assimilation of country rock (IANOVICI 1932a).

The *syenitic* rocks, usually of reddish color, occur in coarse-, medium- and fine-grained varieties of massive or foliated texture. Microcline-perthite and acid oligoclase (An 15–25) commonly form larger tabular grains oriented parallel to the foliation, in addition to smaller grains of microcline and albite. Mafic constituents are dark-brown biotite (lepidomelan), greenish-brown basaltic amphibole (sometimes replaced by aggregates of green biotite, epidote and titanite), more rarely aegirine-augite. Epidote and muscovite are frequent. Accessories: zircon, apatite, titanite, magnetite.

Fresh white nepheline syenites are coarse- to medium-grained and occur in massive (granitoid) or foliated (trachytoid) varieties, with all possible transitions. Large tabular grains of feldspars (microcline-perthite and -antiperthite, albite and acid oligoclase) occur with large isometric grains of nepheline (slightly corroded, frequently bordered by cancrinite, sometimes even replaced by cancrinite and, more rarely, sodalite), in addition to smaller grains of microcline and albite. Mafic constituents are more subordinate: dark-brown biotite (lepidomelan), basaltic amphibole (zoned with green-brown core and brownish-green margin), and more rarely aegirine-augite. Cancrinite is frequent, primary calcite (occasionally surrounded by titanite and biotite) more subordinate. Occasionally muscovite and epidote appear. Accessories: zircon, titanite, apatite. Frequently, veinlets of sodalite penetrate along fissures, diaclases, and intergranular boundaries.

The fresh white nepheline syenites grade into *reddish altered nepheline syenites* which obviously have been affected by intense hydrothermal processes. The feldspars (microcline-perthite and -antiperthite, albite and acid oligoclase) are remarkably fresh, but nepheline is almost completely replaced by micaceous aggregates (liebenerite). Chessboard albite appears occasionally. Again, the dark constituents are entirely replaced by chlorite, epidote and titanite. Accessories: apatite, titanite, magnetite. Sodalite, cancrinite, and primary calcite are commonly lacking.

Although the fresh white and reddish altered nepheline syenites are gradational, it may be stated that the fresh white rocks are mainly distributed in the central part (Ujhavas and Pricske and sourroundings) and some minor occurrences, while the reddish altered ones appear, above all, in the north-east (valleys of Sáros Putna and Tatár patak) and in the uppermost Bekeny patak (surroundings of P. 1143).

The commonly mesocratic rocks of the *dioritic* complexes are extremely varied according to mineralogy and texture. More rarely massive, they are commonly foliated, at places even schistose. Plagioclase and amphibole are the main constituents, but biotite, pyroxene (diopsidic augite, titanaugite, aegirine-augite), and sometimes even K-feldspar (microcline-perthite and -antiperthite) and nepheline appear in variable amounts. The rocks are different from normal diorites by their essexitic and theralitic chemistry, so that terms such as "alkali diorites" and "alkali gabbros" could be considered. According to their mineral content, the rocks should be described as diorites, monzodiorites, monzonites, nepheline diorites, nepheline monzodiorites, monzosyenites, and even malignites and shonkinites. In analogy to the "Oslo-essexites" of BARTH (1944), which, again, are not true essexites, we suggested for the extremely large variety of rock types the comprehensive term "Ditro-essexites" (STRECKEISEN 1952, p. 273; 1954, p. 394–401; 1960, p. 231), which we still consider useful[4]).

The rocks of the Lower Orotva Valley complex have been described very well by CODARCEA et al. (1958). The complex consists of dioritic rocks that are mainly composed of plagioclase and amphibole, frequently with pyroxene (titanaugite, diopsidic augite) and biotite, occasionally with olivine. The rocks, some leucocratic, others mesocratic and even melanocratic, are in part massive but commonly foliated and particularly heterogeneous; varieties with dark schlieren are observed. Gabbros are subordinate. Hornblendites that frequently contain titanaugite and sometimes also olivine, form a larger mass in the north-western part of the complex. Of particular interest are some poikilitic hornblendites with enclosed titanaugite and olivine, which appear in Tászok patak (= păr. Teascului) and Gudu patak; they are similar to cortlandtite and schriesheimite.

The rocks of the Czengelér-Güdücz complex are somewhat different and have not been treated by CODARCEA et al. (1958). They are commonly foliated, at places even schistose. Bands of foliated syenite are interbedded in the dioritic rocks which, moreover, are intricately penetrated by veins of massive, even pegmatoid, syenite and nepheline syenite. Large tabular grains of slightly zoned oligoclase (core An 25–35, margin An 18–25), arranged parallel to the foliation direction, are common. Sometimes more basic plagioclases (An 45–60) are present, occasionally with relics of bytownite (An 80–85). Also, smaller grains of albite and acid oligoclase are encountered. Often, large tablets of microcline-perthite and -antiperthite and large grains of nepheline, accompanied by frequent cancrinite and subordinate primary calcite, are observed. A strongly zoned basaltic amphibole (core reddish-brown, margin brownish-green), rich in Fe and Ti (see chemical analyses in STRECKEISEN 1954, p. 363), is the main dark constituent. It commonly contains relics of diopsidic augite or titanaugite and is occasionally replaced by green biotite and titanite. Locally, aegirine-augite is common. A dark-brown biotite (lepidomelan) is frequently encountered. Honey-yellow, envelope-shaped titanite can be a main constituent. Epidote is common. Accessories are apatite, titanomagnetite, and more rarely pyrite or pyrrhotite. Veinlets of sodalite penetrate occasionally along fractures, diaclases, and intergranular boundaries. Occasionally, unusual nepheline-plagioclase, scapolite-plagioclase, and amphibole-plagioclase intergrowths are observed (Nr. 144, 145, 414); TILLEY (1958, p.351 and pl. 29, fig. 3) interpreted the rock as a hybrid invaded

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[4]) STRECKEISEN (1934, 1938) introduced the name "orotvite" for these rocks, which term, however, may be considered superfluous, as there are already too many terms in descriptive petrology.

by nepheline-bearing solutions. – At places, medium-grained ultramafic rocks are encountered that consist of basaltic amphibole, aegirine-augite, brown biotite, titanite, and some apatite and magnetite. They could possibly be explained as a cumulate if a magmatic origin should be considered.

At one time the Czengelér-Güdücz complex was well exposed at the Ditro-Tulgheş road (see STRECKEISEN 1952, p. 291–296). Good exposures are now found in the upper Güdücz Valley.

Near Ujhavas and Tatárhavas and on their northern slopes appear, among others, mesocratic and even melanocratic rocks that are mainly composed of perthite and antiperthite, albite and chess-board albite, nepheline accompanied by cancrinite, basaltic amphibole, aegirine-augite, some biotite, and titanite. According to their mineralogy, they should be described as malignites and shonkinites.

CODARCEA et al. (1958) have called attention to widespread hybridization phenomena and metasomatic changes that have occurred in the dioritic rocks of the Orotva complex. Similar effects are observed in the Czengelér-Güdücz complex. Among others, there appear schistose rocks that represent apparently crystalline schists which have been metasomatically changed into schistose rocks of dioritic appearance (Nr. 139, 364, 387, 1922, etc.); they contain smaller grains, flakes and prisms of biotite, basaltic amphibole, diopsidic augite, epidote, and titanite. It may be questioned whether all rocks of the complex, some foliated others even schistose, represent crystalline schists affected by metasomatic changes, or whether igneous rocks of alkali dioritic and gabbroic composition have undergone metasomatic alteration in response of later intrusions of nepheline-bearing magmatic solutions. This problem will be discussed later.

The massif contains a large variety of *dike rocks*.

1. *Tinguaites* appear as fine-grained, dark-green rocks which form small dikes (0.1 up to rarely 1 m thick) in the areas occupied by fresh white nepheline syenites; they have not been found outside the massif. The rocks may contain phenocrysts of nepheline, microcline and microcline-perthite, or, more rarely, aegirine-augite or aegirine, brown biotite, and bluish-green amphibole. The especially fine-grained matrix consists of small grains of albite, microcline and nepheline, abundant fine needles of aegirine (which convey the dark color to the rocks), flakes of brown biotite, and small prisms of brownish-green amphibole. Cancrinite and primary calcite are common, likewise, titanite and magnetite. Epidote is subordinate. Veinlets of cancrinite and sodalite traverse the rock.

2. *Lamprophyres* form dikes 0.2 up to 5 m thick, which cut sharply across the rocks in which they appear. They are particularly widespread in the dioritic complexes, but appear also in the other parts of the massif, and are found up to 15 km or more outside the massif. A camptonite (Nr. 1700) has been found, at the base of Magas tetö, 5 km WNW Tomeşti, 16 km south of the massif. At similar distances from the massif lamprophyres have been recorded in the Tulgheş area (see ATANASIU 1928, p. 426–451). The chemistry of the lamprophyres and the lamprophyre at km 7.575 on the Ditro-Tulgheş road (see STRECKEISEN 1952, p. 296, fig. 8) indicate that these rocks are related to the massif. The most widespread lamprophyres are camptonites. Spessartites, as well as microdiorites and microsyenites and some diabases, are more subordinate.

a) *Camptonites* may contain phenocrysts of reddish-brown kaersutite (bordered by aegirine-augite or bluish-green amphibole, and occasionally replaced by pennine)[5]), titanaugite or diopsidic augite (sometimes replaced by actinolite), more subordinate

[5]) CURRIE (1971), supported by WILKINSON (1973), calls attention to the fact that amphibole in camptonites is commonly kaersutite, not barkevikite, which agrees with the high titanium content of the rocks.

brown biotite, and olivine (commonly replaced by talc, serpentine and carbonates). The matrix consists of feldspar (fresh lath-shaped labradorite, but also albite and acid oligoclase, slightly sericitized, and andesine have been observed), kaersutite, pyroxene (titanaugite, diopsidic augite), brown or greenish-brown biotite (sometimes distinctly biaxial), and magnetite. Accessories: titanite, epidote, apatite, opaques.

b) *Spessartites* may contain phenocrysts of diopsidic augite (occasionally with some relics of kaersutite), frequently bordered by pale green hornblende or replaced by actinolite. The matrix consists of pale green hornblende and plagioclase (mainly oligoclase and andesine, frequently slightly sericitized; but also fresh lath-shaped labradorite occurs). Accessories: titanite, magnetite, ilmenite.

c) *Microdiorites* and *microsyenites* are composed of the same constituents as the more coarser "dioritic" rocks.

3. *Nepheline syenite aplites* are fine-grained white rocks with massive or trachytoid texture. They may contain phenocrysts of nepheline and microcline-perthite. The matrix consists of albite, microcline, and nepheline. Brown biotite is the sole dark constituent. Furthermore, muscovite, some epidote, abundant zircon, titanite, calcite, and occasionally muscovite-cancrinite intergrowths appear. Small veinlets of sodalite frequently penetrate the rocks.

4. Small veinlets of *carbonatites*, sometimes with natrolite (Nr. 1904), are occasionally found in various rocks.

Contact Aureole

The massif has developed with the mainly pelitic country rock a typical thermal contact aureole (STRECKEISEN 1952, p. 275–278; 1960, p. 230; 1968, p. 752 and 774). At the immediate contact appear beautiful hornfelses with biotite, cordierite (commonly replaced by pinite), andalusite, corundum (frequently surrounded by micaceous aggregates), and more rarely spinel and alkali amphibole, occasionally chloritoid[6]). Calc-silicate hornfelses are not present. Black quartzites that occasionally are interbedded in the rocks of the contact aureole, have been recrystallized developing a coarse-grained granoblastic mosaic of quartz with streaks of graphitic matter which cross the quartz grains (Nr. 857).

Farther from the contact spotted and knotted schists with porphyroblasts of cordierite (commonly replaced by pinite), andalusite, and corundum occur. Biotite is present in the matrix. Phenomena of incipient contact metamorphism can be followed at much larger distances (2–3 km) from the contact of the massif and may be detected in microscopic sections by the growth of minute grains and flakes of a weakly pleochroic, light reddish-brown, Mg-rich biotite that is usually oriented randomly with respect to the schistosity; some grains have grown also along s-planes, probably because of easier growth in this direction. In contrast to this, the larger mica flakes that have developed by

[6]) Particularly interesting are some unusual hornfelses with biotite, cordierite (commonly replaced by pinite), andalusite, corundum, and spinel (Nr. 489, 490, 491) that occur at the northern margin west of Rivó tetö.

regional metamorphism in the micaschists of the mesozonal series (except transverse biotite porphyroblasts) and are at places accompanied by garnet, staurolite, and sillimanite, are well oriented parallel to the s-planes of the schistosity. The small grains and flakes formed by contact metamorphism are easily distinguished from the older regional metamorphic ones. At places, syenites bordering the immediate contact zone may contain cordierite, andalusite, and corundum as a result of endomorphic contact metamorphism.

The contact is commonly sharp. At the immediate contact, veins and veinlets from the massif penetrate into the country rock and dissect it (see, e. g., Streckeisen 1952, p. 297, fig. 9). Xenoliths are frequent in the border zone of the massif, but also in the granitic rocks of the upper Orotva Valley. At the northern margin lenses of quartz from the country rock are introduced into the rocks of the massif and assimilated (Nr. 1914), by which process some of the granitic rocks may have developed (Ianovici 1932a). Also, bands and lenses of crystalline schists, hybridized and metasomatized to various degrees, are frequently encountered in the massif. But no diffuse contacts with progressive dissolution of the country rock and its replacement by igneous-looking rocks have ever been observed, nor have fenizitations been recorded.

The hornfels zone of the immediate contact is about 50 m large. The aureole affected by contact metamorphism is much larger. Porphyroblasts of andafusite occur, e. g., in the Fülpe patak valley (Nr. 1350) in the north, at 1.5 km lrom the contact, and at the confluence of Vár patak and Bekeny patak (Nr. 1487) E Gheorgheni, at 2 km distance from the contact. The area of incipient contact metamorphism is still larger: newly-formed biotite has been recorded on both sides of the Mureș River south of Sărmaș (Nr. 266, 609, 611) at 2 km distance from the contact; in the upper part of Fülpe patak (Nr. 1338) E Sărmaș at even 3 km from the contact; and on the southern side of Bekeny patak (Nr. 182), above the confluence of Magasbükk patak, east of Gheorgheni, again at 3 km from the contact. It seems that the contact surface of the dome-shaped massif is more gently sloping to the north and the south and that the adjacent area has been particularly affected by contact metamorphism.

The occurrences of andalusite, corundum, spinel, alkali amphibole, and chloritoid are indicated, and the limit of contact metamorphism is shown in Fig. 2. Note that it crosses the isograds of regional metamorphism almost perpendicularly (Fig. 1; see also Streckeisen 1968).

ORIGIN OF THE MASSIF

The earlier investigators of the massif (A. Koch, F. M. Berwerth, B. Mauritz and co-workers, V. Ianovici (up to 1938), and also A. Streckeisen) did not doubt its magmatic origin. In a stimulating study relating especially to the exposures of the lower Orotva Valley, A. CODARCEA et al. (1958) have called attention to the widespread phenomena of hybridization and metasomatism which the rocks of the Orotva dioritic complex have undergone. They advance the idea that the dioritic complex has been formed by metasomatic transformation of the older crystalline rocks. According to this hypothesis, the massif represents the migmatic cover of an anatectic diapir and "was produced by Na-alkaline metasomatism and redistribution of the mineral substances taking place against a background of crystalline schists. The transformation of different crystalline rocks, some strongly basic, others very acid, gave rise to a hornblenditic, a dioritic, and a granitic complex and finally culminated in the formation of alkaline syenites" (IANOVICI 1968, p. 10). A very important aspect of the study was the evidence for widespread hybridization and metasomatism which they found in the massif. These phenomena seem to be related to the later stages of formation.

On the other hand, the Ditro association has been interpreted by STRECKEISEN (1954, p. 403–408; 1960, p. 233–238) as formed by magmatic differentiation, the line of descent of which ends with nepheline syenites and tinguaites that lie close to the eutectic point feldspar-feldspathoid in the system SiO_2-$NaAlSiO_4$-$KAlSiO_4$. Magmatic differentiation may be questioned, and the line of descent could likewise show the path on which the rocks of the dioritic complexes have been hybridized and metasomatized by the later intruding nepheline-bearing magmatic solutions. But, in any case, the nepheline syenites and tinguaites show a distinct anchi-eutectic character that could hardly be interpreted otherwise than by magmatic phenomena.

The crucial point is the interpretation of the dioritic complexes. It may be noted that the crystalline rocks of the surroundings are mainly pelitic, psammitic, and rhyolitic, and that basic rocks are particularly subordinate. As the Czengelér-Güdücz complex (and likewise the Orotva complex) is confined to the interior of the massif and does not link up with the country rock of the thermal aureole, a direct metasomatic transformation of the surrounding crystalline schists may be excluded. There exists, however, the possibility that crystalline schists of the basement, metasomatized at the depth, have been brought up from the depths by the later rise of the nepheline syenite intrusion. Another possibility would be that gabbroic and dioritic intrusions have been emplaced lit-par-lit into the crystalline schists, which, in turn, have been metasomatized by the later syenite and nepheline syenite intrusions. The common foliation of the rocks of the area may be explained in this manner.

Regarding the complicated structure of the complex, it is easily understood that, in the course of time, we have advanced various ideas of its formation, some of which we would not now maintain. At various stages of the investigation, we explained the formation of the massif by Daly's theory of limestone syntexis (STRECKEISEN 1931, p. 627; 1934, p. 4; 1938, p. 159f.; DALY 1933,

p. 501 and 525) but have finally abandoned this idea for reasons explained in Streckeisen (1960, p. 236f.)

Accepting the widespread hybridization and metasomatic changes which have obviously occurred in the massif in the later stages of its formation, we nevertheless consider a magmatic origin as probable for the following reasons:

1. The sharp contact which does not show any progressive dissolution of the country rock and its replacement by igneous-looking rocks.
2. The distinctive thermal contact aureole with the production of minerals such as cordierite, andalusite, and corundum.
3. The presence of magmatic intrusions which is testified by dike rocks, tinguaites and camptonites, which show the same chemistry as the nepheline syenites and Ditro-essexites, respectively.
4. The general structure of the area: In the southern part of the Eastern Carpathians the crystalline schists show a general trend of N-S to NNW-SSE. Approaching the massif, the trend turns to WNW-ESE and W-E (Fig. 1). This conveys the idea that a body has risen from the depths, contorting and putting aside the crystalline schists that surround the massif (Streckeisen 1968).

The structure of the massif is complicated to such a degree that much work will have to be done by future investigators. In a provisional, tentative manner we would like to suggest a model which assumes the succession of events as follows:

1. Gabbroic and dioritic magmas intruded, lit-par-lit, into the crystalline schists that formerly existed at the place that is now occupied by the dioritic complexes. Alternatively, it may be assumed that crystalline schists existing at the depth have been brought up by the later rising syenite and nepheline syenite intrusions.
2. Intrusion of syenitic magmas followed, which penetrated the massive or foliated rocks of the dioritic complexes, some conformable with the foliation, others cutting it in an intricate manner. On the margins of the massif they developed granitic rocks, partly by assimilation of country rock.
3. The most prominent event was incontestably the rise of nepheline-bearing magmatic solutions (melts, fluid and hydrothermal solutions), which produced widespread hybridization and metasomatic changes in all parts of the massif, especially in the dioritic complexes. In any case, a gas phase was envolved, which was composed mainly of CO_2 (cancrinite and primary calcite) and later of Cl (sodalite).
4. Aside from some rare later nepheline syenite aplites and pegmatites, lamprophyres (mainly camptonites) represent the final stage of the intrusion. They cut with sharp contacts the rocks of the massif, but also occur outside the massif, both nearby and several km away.

We consider that this scheme could explain the facts that have been recorded by the many geologists who have investigated the massif.

We would like to call attention to the Messum Complex of South-West Africa, which is similar in many respects, different in others (Korn et Martin 1954, Mathias 1956, 1957, Martin et al. 1960). This complex is interpreted to have a magmatic origin with later intense metasomatic hybridization.

AGE OF THE MASSIF

According to geological data the massif is younger than the surrounding crystalline schists and considerably older than the Pliocene deposits and Quaternary volcanics that cover it.

For a long time the exact age of its emplacement could not be determined and only conjectures have been presented.

Considering the fresh character of the rocks of the massif Reinhard (1911) assumed a relatively young, post-Neocomian age. He also suggested a genetic relation between the massif and the volcanics of the Călimani-Hargita chain. Mauritz (1923, p. 313) excluded a pre-Mesozoic age for the same reasons. Streckeisen (1932, p. 410) suggests an age of intrusion in Upper Cretaceous time.

Ianovici (1938) opposed Reinhard's view by calling attention to the peneplain that overlies the massif, and to the chemical differences between the alkaline character of the massif and the much younger calc-alkaline volcanics. Considering the Liassic alkaline igneous rocks of the Brașov area (Savul et Kräutner 1936b), he assumed a Jurassic age for the massif.

The first ages were determined by the Pb-α method by Ionescu et al. (1966; see also Note expl. 1968, p. 25). They resulted in 297 m. y. for zircon and 326 m. y. for monazite. Consequently, a Hercynian age was assumed for the intrusion of the massif.

To obtain further information on the age of the massif 5 samples have been analyzed by the K-Ar method: 3 biotites two of which from nepheline syenites and one of a contact hornfels, and 2 total rocks determinations from tinguaite dikes. Table 1 presents the analytical data and age results.

The good agreement between the 3 biotite ages shows that we have dated a true age; otherwise the nepheline syenites and the contact hornfels would not give the same figure. As the crystalline schists of the Eastern Carpathians are covered in the neighboring Tulgheș area by unmetamorphosed Mesozoic sediments (Fig. 1), which lie on a pre-Permian erosion surface, it is unlikely that a thick crystalline cover existed on top of the massif. This fact and the contact aureole that overprints the regional metamorphism of the country rock lead to the conclusion that the determinations are dating an event related

Table 1

sample	rock	mineral	cm³ Ar^{40} rad/ g STP 10^{-6}	% rad	% K	age in m.y.
Str 429	nepheline syenite	biotite	50.50	69.0	8.04	151 ± 9
Str 1764	nepheline syenite	biotite	50.67	94.8	7.98	153 ± 3
Str 1195	contact hornfels	biotite	48.54	95.5	7.84	150 ± 6
Str 835	tinguaite	total rock	31.64	96.1	4.73	161 ± 7
Str 204	tinguaite	total rock	26.01	96.7	4.01	156 ± 6

For the analytical procedure see PURDY (1973) and HUNZIKER (1974). For the age calculation the following constants have been used: $\lambda_\epsilon = 0.585 \times 10^{-10}$ y^{-1} and $\lambda_\beta = 4.72 \times 10^{-10}$ y^{-1} and for the atomic abundance of K^{40} the value of 1.19×10^{-4} moles K^{40}/mole K.

Samples:

Str 429 Coarse-grained white nepheline syenite, Komarnik t. P. 1248. Large grains of microcline-perthite and nepheline (occasionally bordered by cancrinite). Large flakes of dark-brown biotite (lepidomelan). Smaller grains of albite and microcline. Cancrinite and primary calcite. Some zircon, apatite, titanite, and magnetite.

Str 1764 Coarse-grained white nepheline syenite. Ditrói patak (= Valea Ditrăului), gallery no. 1. Large grains of microcline-perthite and -antiperthite and of nepheline (partially replaced by flakes of white mica and grains of calcite). Large flakes of dark-brown biotite (lepidomelan) and large grains of calcite (primary?). Accessories: zircon, apatite, magnetite bordered by chlorite. Some veinlets of sodalite.

Str 1195 Contact hornfels. Tászok (= Teascu), 750 m SE P. 1152. Hornfels texture. Albite and acid oligoclase (with incipient sericization). Brown to greenish-brown biotite. Cordierite (replaced by micaceous pinite aggregates). Some muscovite and magnetite.

Str 204 Tinguaite. Csánód feje, 500 m E P. 1502. Phenocrysts: microcline, nepheline, aegirine, biotite, titanite, opaques; diopsidic augite (corroded). Matrix: alkali feldspar, nepheline, aegirine, biotite. Some small diaclases of sodalite.

Str 835 Tinguaite. Pricske, 500 m NE P. 1545. Phenocrysts: nepheline, alkali feldspar. Matrix: alkali feldspar, nepheline, aegirine, titanite. Some small diaclases of sodalite.

to the emplacement of the massif. The biotite ages of about 150 m. y. represent the time of cooling to about 300° C – the cooling after the Ditro event. To date the time of the emplacement we analyzed the total rocks of two tinguaite dikes. The slightly older total rock age of the dikes is probably nearer to the real time of the emplacement, i. e., an intrusion older than Jurassic is most unlikely. On the other hand, it is known that dikes may contain larger amounts of inherited argon, so that the exact age of the emplacement is not fully dated. In any case, an emplacement around 160 m. y. seems reasonable. This would be in good agreement with the Upper Liassic alkaline rocks of the Brașov area (JEKELIUS 1924, p. 17; 1936, p. 5; 1938, p. 383, SAVUL et KRÄUTNER 1936b; MANILICI 1960).

Our results are in disagreement with the Pb-α determinations of IONESCU et al. (1966). As the rocks of the Ditro massif contain many inclusions of country rock and have been affected by considerable metasomatic changes and exchanges, a component of inherited lead cannot be ruled out. A proper common lead correction would probably lower the Pb-α ages considerably.

According to our results the emplacement of the massif of Ditro occurred at about 160 m. y., and the figure of about 150 m. y. represents the moment at which the neo-formed biotites cooled to the temperature of 300° C.

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The Ditro collection (samples, slices, maps) will be deposited at the Naturhistorisches Museum der Stadt Bern.

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