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# Geochronology of the Neogene calc-alkaline intrusive magmatism in the "Subvolcanic Zone" of the Eastern Carpathians (Romania)

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**Abstract:** The Poiana Botizei–Ţibleş–Toroiaga–Rodna–Bârgău intrusive area (PBTTRB), northwest Romania, known as the "Subvolcanic Zone", is located between the Gutâi (NW) and Călimani (SE) volcanic massifs. It consists of rocks displaying a wide range of compositions and textures: equigranular or porphyritic with holocrystalline groundmass (gabbro-diorites, diorites, monzodiorites and granodiorites), and/or porphyritic with fine holocrystalline or glassy-cryptocrystalline groundmass, similar with effusive rocks: basalts, basaltic andesites, andesites, dacites and rhyolites. The time-span of intrusive rocks emplacement is similar with the nearest calc-alkaline volcanic rocks from Gutâi (NW) and Călimani (SE) massifs. They are represented by stocks, laccoliths, dykes and sills typical for an upper crustal intrusive environment. In the absence of biostratigraphic evidence, a comprehensive K-Ar study of intrusive rocks using whole rock samples, groundmass and monomineral fractions (biotite, hornblende) has been carried out in order to understand the magmatic evolution of the area. The oldest K-Ar ages recorded in the analysed rocks are close to 11.5 Ma and magmatism continued to develop until about 8.0 Ma. The inception of intrusion emplacement in the PBTTRB is coeval with intrusive activity spatially related to volcanism within the neighbouring Gutâi and Călimani massifs. However, its culmination at ca. 8 Ma ago is younger than the interruption of this activity at ca. 9.2 Ma in Gutâi and Călimani Mts where intrusive activity resumed for ca. 1 Myr. These circumstances strongly suggest that the geodynamic evolution of the area controlled the development of both volcanic and intrusive activity and their reciprocal relationships. The overall geological data suggest that in the PBTTRB intra-lithospheric transpressional-transtensional tectonic processes controlled the generation and emplacement of intrusive bodies between ca. 12–8 Ma.

**Key words:** Eastern Carpathians, geodynamic aspects, intrusive magmatism, K-Ar dating, Neogene calc-alkaline rocks.

## Introduction

The Poiana Botizei–Ţibleş–Toroiaga–Rodna–Bârgău intrusive area (PBTTRB) represents a particular segment of the Carpathian Neogene magmatic arc characterized by intrusive magmatism with no trace of volcanic products in contrast to the neighbouring segments — the Gutâi and Călimani Mts (Fig. 1) — where intrusions are closely related to volcanic activity. This area is traditionally referred to in the Romanian geological literature as the "Subvolcanic Zone" of the Eastern Carpathians (e.g. Peltz et al. 1972).

The timing of polyphase Miocene tectonics in the Maramureş area (Northern Romania), combined with field observations, stratigraphic arguments and fission-track analysis suggests that during the Miocene the area was subjected to geodynamic evolution stages developed in sinistral transpressional (16–12 Ma) followed by sinistral transtensional (12–10 Ma) stress regimes along the major transcrustal Bogdan Vodă–Dragoş Vodă fault system (Tischler et al. 2006). Although Miocene magmatic rocks are widely distributed in the PBTTRB, the emplacement history of these intrusive rocks remained obscure up to now because of the scarcity of radiometric age data (e.g. Pécskay et al. 1995b) and uncertainty of stratigraphical relationships with the host Miocene sedimentary rocks.

Comparative radiometric data of the intrusive rocks and related mineralizations from Poiana Botizei, Ţibleş and Oaş-Gutâi Mts were published by Kovacs et al. (1997). During the last decade K-Ar age data have been accumulated making it possible for the first time to discuss the evolution of magmatism in the PBTTRB. For chronostratigraphic assignment we refer to the time-scale of the Central Paratethys according to Vass & Balogh (1989).

## Geological setting

The study area is located in the internal Eastern Carpathians (Northern Romania) (inset in Fig. 1). It consists of the northeastern part of the Tisia (Biharia Unit) and Dacia blocks (Bucovinian nappes) that have been deformed in mid-Cretaceous times ("Austrian" phase) until Late Cretaceous

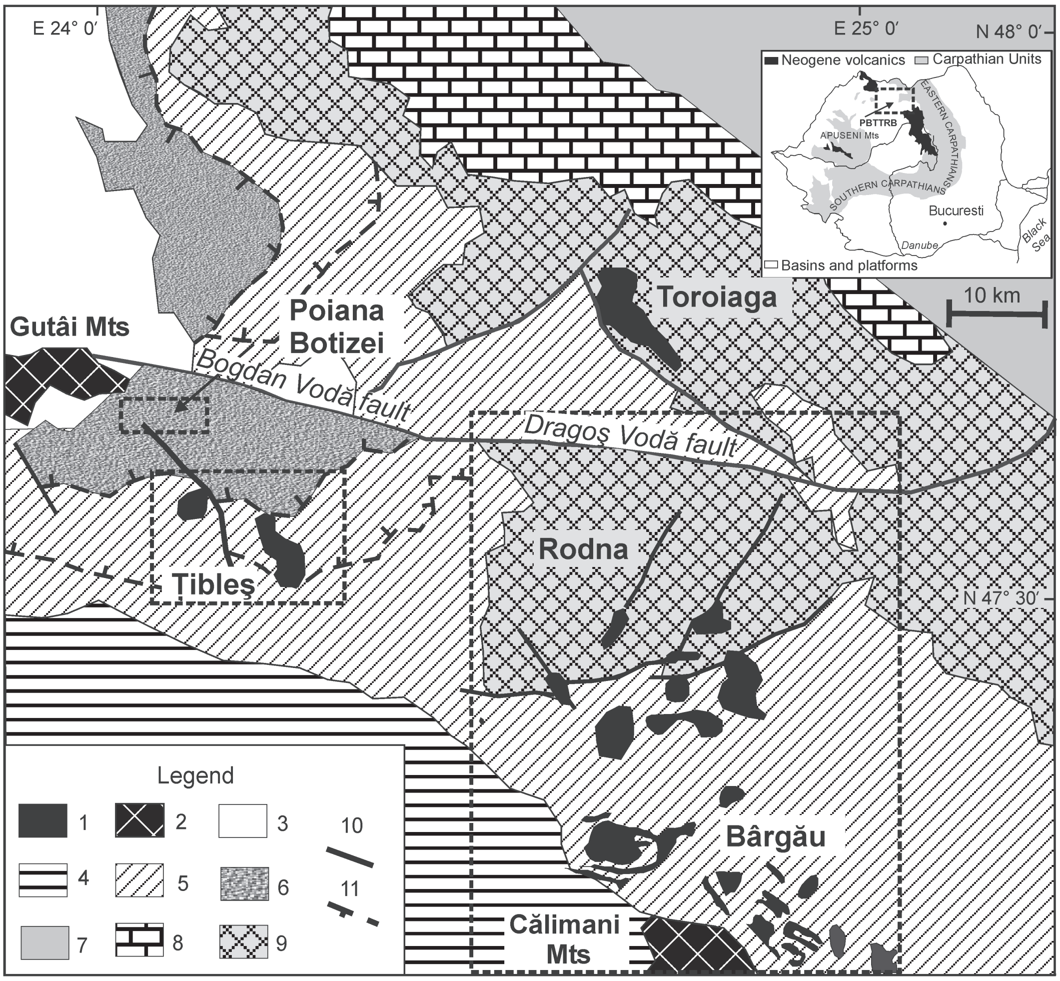


**Fig. 1.** Simplified geological map of the Poiana Botizei–Ţibleş–Toroiaga–Rodna–Bârgău area (northern Eastern Carpathians) showing the occurrences of intrusive bodies. The inset shows the location of the area in Romania. **1** — Outcrop areas of the main intrusive bodies; **2** — Outcrop areas of volcanic rocks belonging to the Gutâi and Călimani massifs; **3** — Post-Miocene sediments; **4** — Middle to Upper Miocene sediments; **5** — Eocene to Lower Miocene sediments; **6** — Pienides units; **7** — Moldavides units; **8** — Transylvanides units; **9** — Bucovinian units; **10** — Faults; **11** — Thrust/reverse faults. The large frames correspond to figures 2 and 3, respectively. The smallest frame shows the occurrence area of small intrusions in the Poiana Botizei area.

times ("Laramide" phase) (Săndulescu 1984, 1994). Upper Cretaceous-Paleocene sediments unconformably cover all tectonic contacts between the Tisia and Dacia blocks and are unconformably covered by Eocene-Lower Miocene strata. The Tisia and Dacia blocks, together with their cover, were overthrust by the Pienides during Early Miocene times (Săndulescu et al. 1981). The post-Lower Miocene deposits of the Pannonian and Transylvanian Basins begin with the deposition of the Middle Miocene (Badenian) Dej tuff during a period of mainly explosive rhyolitic volcanism (Szakács 2000). Intermediate calc-alkaline magmatism started during Middle Miocene times in the Eastern Carpathians (13.5 Ma, Pécskay et al. 1995a,b). The most obvious tectonic feature in the study area is the >75 km long E-striking left-lateral Bogdan Vodă–Dragoş Vodă fault system (e.g. Săndulescu et al. 1981). Most of the intrusive bodies in the PBTTRB, except for those in the south Bărgâu Mts, which are related to a NW-SE strike slip tectonic system beneath the Călimani volcanic area (e.g. Fielitz & Seghedi 2005; Seghedi et al. 2005), have been emplaced in relation to this E-W strike-slip tectonic system (Fig. 1).

## General features of the intrusive magmatism

Poiana Botizei, Ţibleş, Toroiaga and Rodna–Bârgău areas are each characterized by a cluster of isolated intrusive bodies of varied size and composition. The Poiana Botizei intrusions are situated in the eastern extension of the Gutâi massif where both intrusive and volcanic products occur (Kovacs et al. 1995) (Fig. 1). Similarly, in the south-east the intrusions in the Bârgău area appear as the northward extension of the Călimani Massive. It has been pointed out that intrusive activity predated volcanism in the Călimani volcanic area (Török 1961; Seghedi et al. 2005) and postdated the early volcanic activity in the Gutâi-Oaş area (Kovacs et al. 1995).

The areas of intrusive magmatism are briefly described in the following sections while their petrographic summary and modal composition are given in the Appendix. The most important bodies are of stock or laccolith type surrounded by a complex system of sills and dykes. Also individual dykes or sills of different size, from several km to several meters, can be found. At the contact with sedimentary strata haloes of hornfelses or breccias occur. At the margin of the large bodies, as well as in the dykes or sills, the porphyritic texture with fine holocrystalline or glassy-cryptocrystalline groundmass is dominant suggesting rapid cooling; therefore, the effusive nomenclature was used. A large petrographic spectrum was identified: rhyolites, dacites, andesites, basaltic andesites and basalts. In central parts the large intrusions show medium to large equigranular or porphyritic texture with holocrystalline groundmass (gabbro-diorites, diorites, quartz diorites, monzodiorites and granodiorites), which are altered by hydrothermal solutions (i.e. propylitic and argillic facies).

***Poiana Botizei area***

Small-size (up to 800 m) intrusive bodies of various shapes pierce Paleogene sedimentary deposits (Săndulescu 1984). The intrusions cluster within a ca. 5 km wide and ca. 10 km long east-west-oriented area (Fig. 1). Typical calc-alkaline rocks are represented by diorites, quartz diorites, quartz monzodiorites, porphyritic microgranodiorites, andesites and dacites. According to geological evidence, the microgranodiorites and dacites are apparently younger than other rocks.

***Ţibleş area***

This area, situated between the Gutâi and Rodna Mountains, is represented by a complex succession of intrusive bodies, which pierce Paleogene and Lower Miocene sedimentary deposits, south of the Dragoş Vodă fault (Figs. 2, 3B). The Ţibleş Mts represent a polyphase intrusive complex consisting of a few large km-sized and numerous small-sized bodies (up to several hundred meters across) emplaced during several magmatic pulses (e.g. Pop et al. 1984). The large intrusions in the north-western and central part of the area (e.g. Hudin and Tomnatec, Fig. 3) are composed of microgranodiorites and dacites; the south-eastern part is dominated by the monzodioritic intrusion Ţibleş-Bran-Măgura Neagră (5 km in length) surrounded by a ring composed of Arcer quartz diorites, microdiorites and andesites (Fig. 3B) (Udubaşa et al. 1983; Pop et al. 1984). A large number of small intrusions composed of diorites, quartz diorites, microdiorites and andesites are clustered around the main intrusions throughout the whole area (Fig. 2). The main monzodioritic intrusion pierces the amphibole dacites near Tomnatec Peak, as also proved in the underground mining gallery. Crustal contamination is suggested by Pop et al. (1984) based on the presence of cordierite in the Hudin microgranodiorites.

Contact phenomena form hornfelses and skarn accumulations (magnesian skarns with phlogopite described by Udubaşa et al. 1982). Ore deposits associated with the main intrusion are represented by (1) a vein system mostly oriented NE–SW, showing a lower temperature outer belt (Sb, As, Ag) and a higher temperature internal belt (Zn, Pb, As, Cu), and (2) a core with disseminated copper-enriched ore (Cu, Zn, Pb) related to a deep, hidden porphyry system with magnetite and chalcopyrite (Udubaşa et al. 1983).

***Toroiaga area***

The Toroiaga intrusive area, situated north of the Rodna Mountains and north of the Dragoş Vodă fault, consists of a complex of subvolcanic intrusions that pierce metamorphic rocks and in its southern part, Paleogene and Miocene sedimentary deposits, suggesting a multiphase intrusive activity (Berza et al. 1982, 1984). In the Toroiaga Massif, five dis-

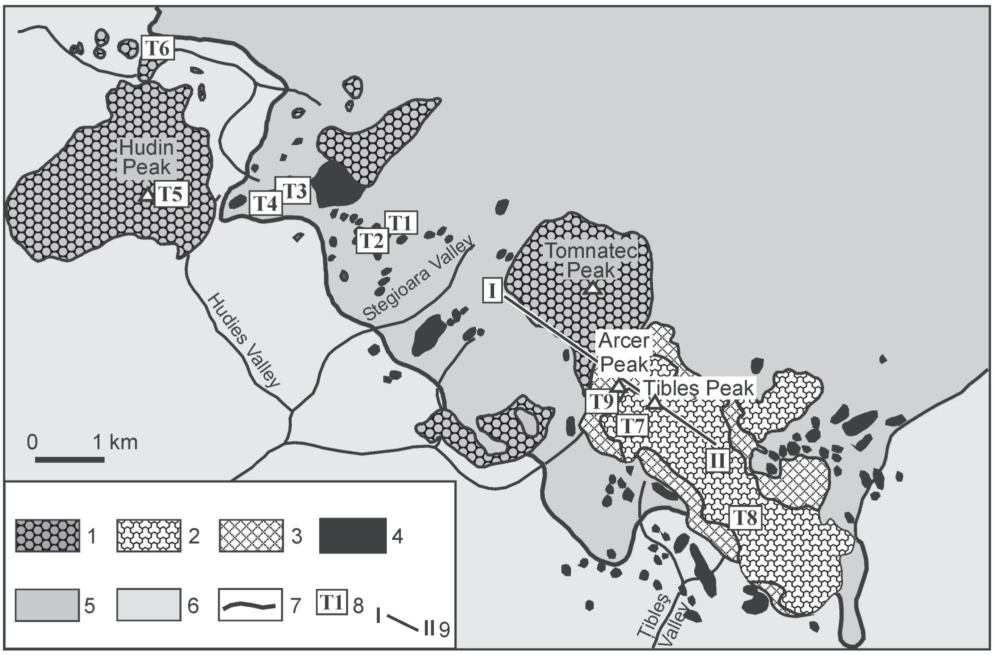


**Fig. 2.** Geological map of the Ţibleş Mts. **1** — Biotite microgranodiorites (Hudin type) and amphibole-bearing dacites (Tomnatec type); **2** — Quartz monzodiorites (Ţibleş type); **3** — Pyroxene andesites (Arcer type); **4** — Diorites, quartz diorites, microdiorites and andesites; **5** — Paleogene flysch; **6** — Oligocene-Miocene sedimentary deposits; **7** — Thrust faults; **8** — K-Ar sample locations; **9** — Geological cross-section (Fig. 3B).

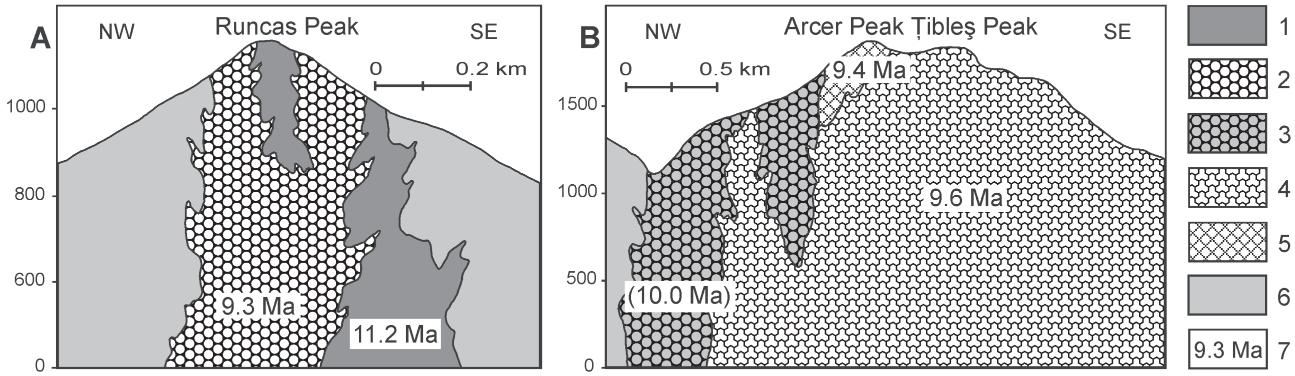


**Fig. 3.** Geological cross-sections showing age relationships between intrusive bodies. **A** — Runcaş intrusive body in the Poiana Botizei area. **B** — The main intrusive body of the Ţibleş Mts. **1** — Pyroxene microdiorites; **2** — Biotite dacite/microgranodiorites; **3** — Amphibole-bearing dacites (Tomnatec type); **4** — Quartz monzodiorites (Ţibleş type); **5** — Pyroxene andesites (Arcer type); **6** — Paleogene flysch; **7** — K-Ar ages.

tinct phases of calc-alkaline rocks (diorites, quartz diorites, microgranodiorites, microdiorites and andesites) (Berza et al. 1982) intrude metamorphic rocks of the Median Dacides belonging to Bucovinian units (Săndulescu 1994). Hydrothermal activity and mineralization processes are related to the second and third intrusion phases.

### *Rodna–Bârgău area*

This area is situated south of the Dragoş Vodă fault (Fig. 1) and extends from the southern part of the Rodna Mountains and continues over 75 km NE–SW below the Călimani Mountains volcanic edifice. The main contributions to the knowledge of magmatic rocks in this area come from Kräutner (1930), Athanasiu et al. (1956), Mânzăraru (1965), Teodoru et al. (1973), Istrate in Kräutner et al. (1978), Seghedi in Kräutner et al. (1990), Ureche (2000), Niţoi et al. (2002), Papp et al. (2005).

A cluster of many subvolcanic intrusions with highly variable geometries intrudes metamorphic rocks and Paleogene and Miocene sedimentary deposits (Fig. 4), either as results of a single moment of intrusion or multiphase intrusive activity. Laccoliths are the most common type, as at Bucnitori, Cornii, Heniu, Oala, Căsarul, Colibiţa (e.g. Mânzăraru 1965; Seghedi in Kräutner et al. 1990). They are always surrounded by swarms of smaller bodies which form an intricate system of sills and dykes. Individual dykes and sills can be followed along strike from several meters to several kilometers. Hornfelses and, less frequently, breccias are present at the contact with sedimentary rocks. Porphyritic texture with fine-grained groundmass, allowing the usage of the effusive nomenclature, is the most common rock fabric, suggesting rapid cooling of magma in a shallow environment. The largest dioritic-andesitic bodies (up to 10 km across) such as Cornii, Heniul and Colibiţa are mostly equigranular, fine-grained or less frequently coarse-grained in their central part. They commonly affected by propylitic and argillic hydrothermal alterations, sometimes associated with Cu, Pb, (Au) mineralization. The rock-types of small individual bodies range across a large petrographic spectrum: basalts, basaltic andesites, andesites, dacites and rhyolites. The intrusions of acidic composition (rhyolites and dacites, sometimes garnet-bearing) mostly occur in the south-eastern part of the Rodna Mts. A few of them with small dimensions (several tens or hundred of meters in length) are located close to the Călimani volcanic area. Frequent xenoliths are present mainly in the intermediate to basic types (microdiorites, diorites, basaltic andesites and andesites) (Niţoi et al. 2002).

## Radiometric age determination

### *Experimental techniques and sample preparation*

About 200 g of each rock sample was crushed and sieved to 300 μm. Adhering fine particles were removed by rinsing in distilled water. Approximately 0.8 g of sieved rough sample was weighed for whole rock and amphibole and about 0.2 g for biotite. The amount of radiogenic $^{40}$Ar was determined by the isotope dilution method using $^{38}$Ar as a spike. Mass discrimination of Ar isotopes was corrected by measuring atmospheric Ar.

For the determination of K content, about 1 g of the identical sample that was used for Ar measurement was grounded in an agate mortar to the grain size finer than 50 μm. About 100 mg of this powdered sample was dissolved in hydrofluoric acid and nitric acid using a Teflon bomb. Potassium contents were determined using flame photometry with Li internal standard. The decay constants of Steiger & Jäger (1977) were used in the age calculation. The inter-laboratory standards Asia 1/65, HD-B1, LP-6 and GL-O as well as atmospheric Ar were used for control and calibration of analyses. All analytical errors represent one standard deviation (i.e. 68% analytical confidence level). Details of the instruments, the applied methods and results of calibration have been described elsewhere (Balogh 1985).

We dated whole rock samples, mono-minerals (amphibole and biotite) or groundmass following thin section investigations. A standard technique (i.e. heavy liquids, magnetic separator) for mineral separation was used. The purity of the mineral fraction was improved by handpicking. Biotite was cleaned in ethyl-alcohol with ultrasonic cleaner with addi-

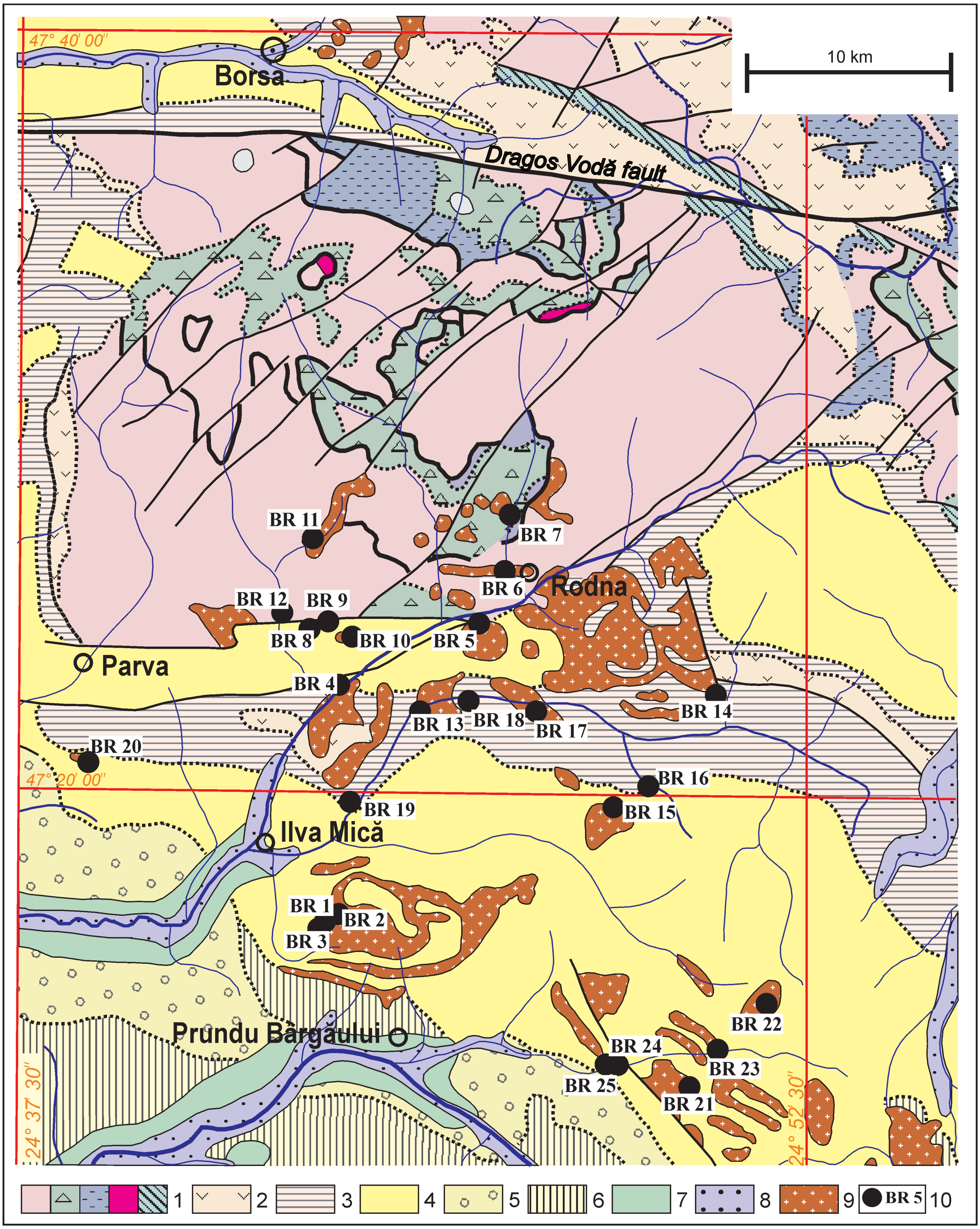


**Fig. 4.** Geological map of the Rodna–Bârgău area (according to the Geological map of Romania, scale 1 : 200,000; Geological Institute of Romania). **1** — Metamorphic formations; **2** — Eocene sediments; **3** — Oligocene sediments; **4** — Oligocene–Lower Miocene sediments; **5** — Lower Miocene sediments; **6** — Middle-Upper Miocene sediments; **7** — Pleistocene sediments; **8** — Quaternary alluvial deposits; **9** — Intrusive bodies; **10** — K-Ar sample locations.

tional shaking. For the whole rock dating we selected the samples that have not been affected by secondary alteration.

### *Results*

Analytical results of 54 K-Ar age determinations of intrusive rocks from the PBTTRB are presented in Table 1 (new results) and Table 2 (data previously published by Pécskay et al. 1995b). Holocrystalline rocks are normally excellent for dating as the high temperature mineral phases retain radiogenic argon quantitatively. However, coarse-grained intrusive rocks can sometimes give inconsistent ages. The most suitable radiometric datings have been acquired by analysing biotite and amphibole. Feldspars have not been used since they easily lose radiogenic argon due to thermal effects. Intrusive rocks are prone to slow cooling after emplacement and may undergo thermal metamorphism that can rejuvenate the rock and give younger apparent ages. Low $^{40}$Ar-rad (%) increase dramatically the analytical errors (e.g. sample BR-21; Table 1). Therefore, our most important conclusions were based on the samples with the highest $^{40}$Ar-rad (%).

Figure 5 displays a synoptic view of all the available K-Ar age data grouped according to the occurrence areas and rock types. Although the intrusions in the Rodna and Bârgău areas suggest a quite homogeneous area, we presented them in two groups according to a geographical divide separating the Rodna Mts with metamorphic host rocks from the Bârgău Mts with sedimentary host rocks. It is obvious that the emplacement of intrusions spans a time interval of ca. 3.5 Myr between ca. 11.5 and 8 Ma, entirely belonging to the Pannonian time (according to Vass & Balogh 1987). Except for Toroiaga, where very few data are available, there is no significant difference between the age distributions of intrusive rocks in the different areas. However, the intrusions in the western part of the study area (Poiana Botizei and Ţibleş) appear to have been generated during a shorter time interval (2.5 Myr) since the youngest dated rocks are about 9 Ma old.

Figure 6 shows a statistical representation of the K-Ar data available for the PBTTRB according to rock types and in comparison with age ranges of volcanic activity and intrusive magmatism in the neighbouring Oaş-Gutâi and Călimani volcanic areas. More than 50 % of the K-Ar ages cluster in the 10.5–9 Ma age interval. The two peaks apparently reflect the most important pulses of intrusive activity in the area. A third peak at the youngest ages around 8 Ma suggests a sudden end of the intrusion emplacement after a short final pulse. Although no systematic correlation between rock types and age can be observed, it is worth mentioning that the only dated rhyolite occurring at the boundary between the Rodna and Bârgău Mts belongs to the youngest age group.

According to the available data, the inception of the intrusion emplacement in the PBTTRB is coeval with intrusive activity spatially related to volcanism within the neighbouring Gutâi and Călimani massifs (Fig. 6). On the other hand,

**Table 1:** Analytical results of K-Ar age determinations.

| Sample# | Lab# | Location | Rock type | Dated fraction | K (%) | $^{40}$Ar rad (ccSTP/g) ×10$^{-7}$ | $^{40}$Ar rad (%) | K-Ar age (Ma) |
|---|---|---|---|---|---|---|---|---|
| **BR-1** | 5956 | Valea Strâmbă-B | mDi | wr | 1.07 | 4.317 | 20.6 | 10.4±0.7 |
| **BR-2** | 5957 | Valea Strâmbă-B | mDi Am | wr | 0.71 | 2.371 | 31.9 | 8.6±0.4 |
| **BR-3** | 5958 | Valea Strâmbă, forest road-B | mDi Am | wr | 1.12 | 4.167 | 21.5 | 9.5±0.6 |
| **BR-4** | 5959 | Sângeorz-Băi, Quarry-R | D Bi | wr | 1.49 | 6.271 | 52.9 | 10.8±0.4 |
| **BR-5** | 5960 | Măgura Rodnei, Someş v. quarry-R | D AmBi | wr | 2.45 | 7.630 | 54.1 | 8.0±0.4 |
| **BR-6** | 5961 | Vinului v., lower -R | A Am | wr | 1.71 | 6.416 | 42.4 | 9.6±0.4 |
| **BR-7** | 5962 | Vinului v., Upper-R | D BiAm | wr | 2.74 | 8.504 | 25.7 | 8.0±0.4 |
| | | | | Bi | 7.21 | 22.51 | 68.5 | 8.0±0.3 |
| **BR-8** | 5963 | Pleşilor v.-R | BA | wr | 0.46 | 2.053 | 17.9 | 11.4±0.9 |
| **BR-9** | 5964 | Pleşilor v., upstream-R | A GrAm | wr | 0.94 | 3.755 | 52.2 | 10.3±0.4 |
| **BR-10** | 5965 | Pleşilor v., Măgura Porcului-R | A Am (Bi) | wr | 2.23 | 7.838 | 43.2 | 9.0±0.4 |
| **BR-11** | 5966 | Vinului v., (Cormaia tributary) -R | D BiAm | Bi | 7.17 | 22.39 | 45.4 | 8.0±0.3 |
| **BR-12** | 5967 | Cormaia v., downstream Vinului v.-R | D Bi | Bi | 7.04 | 27.23 | 30.2 | 9.9±0.5 |
| **BR-13** | 5968 | Poiana Ilvei, quarry before tunnel-R | D AmGr | wr | 1.10 | 4.085 | 52.1 | 9.5±0.4 |
| **BR-14** | 5969 | Lunca Ilvei, Şant road-old quarry-B | A Am | wr | 1.51 | 5.188 | 50.2 | 8.9±0.4 |
| | | | | Am | 0.67 | 3.344 | 11.9 | 12.7±1.5 |
| **BR-15** | 5970 | Măgura Neagră Ivăneşti -B | A Am (Bi) | gm | 1.52 | 6.563 | 31.1 | 11.1±0.5 |
| **BR-16** | 5981 | Ivăneşti- Ivăneşti valley-B | BA Px | gm | 1.92 | 6.956 | 14.7 | 9.3±1.0 |
| **BR-17** | 5972 | Arsişa quarry, Măgura Arsiţei-B | A AmBi | wr | 1.49 | 5.729 | 36.2 | 9.8±0.5 |
| **BR-19** | 5974 | Zagra quarry-B | A Am | wr | 1.03 | 3.492 | 45.6 | 8.7±0.4 |
| **BR-20** | 5975 | Rebra, Pietriş Hill-B | R | wr | 3.08 | 9.674 | 70.1 | 8.0±0.3 |
| **BR-21** | 5976 | Colibiţa, Căsărel Hill-B | BA PxAm | gm | 0.45 | 1.909 | 10.2 | 10.8±1.4 |
| | | | | Am | 0.27 | 1.115 | 16.3 | 10.4±0.9 |
| **BR-22** | 5977 | Tihuţa, Zîmbroiu Hill-B | A Am | wr | 1.70 | 5.979 | 43.0 | 9.0±0.4 |
| | | | | Am | 0.63 | 2.163 | 20.8 | 8.8±0.6 |
| **BR-23** | 5978 | W Tihuţa, road side outcrop-B | BA PxAm | wr | 0.62 | 2.253 | 22.9 | 9.3±0.6 |
| **BR-24** | 5979 | W Tihuţa, road side outcrop-B | A Am | wr | 0.82 | 3.464 | 35.7 | 10.8±0.5 |
| **BR-25** | 5980 | Mureşenii Bârgăului, road side quarry-B | A Am | wr | 0.93 | 3.782 | 20.0 | 10.4±0.9 |

**Areas:** R — Rodna, B — Bârgău; **Rock-types:** BA — basaltic andesite, mDi — microdiorite, A — andesite, D — dacite, R — rhyolite; **Minerals:** Am - amphibole, Px — pyroxene, Bi — biotite, Gr — garnet; **Dated fraction:** wr — whole rock, Am — amphibole, Bi — biotite, gm — ground mass.

**Table 2:** Published K-Ar age data (according to Pécskay et al. 1995).

| Sample # | Location | Rock type | K-Ar age (Ma) |
|---|---|---|---|
| **Poiana Botizei** | | | |
| **PB-1** | Runcaş Peak | mDiPx | 11.2±0.9 |
| **PB-2** | Roţii Valley | APx | 11.1±0.7 |
| **PB-3** | Ulmului Valley | mDiPx | 10.4±0.6 |
| **PB-4** | Poienii Valley | APx | 10.3±0.5 |
| **PB-5** | Rugului Valley | MDiPx | 10.3±0.5 |
| **PB-6** | Prisacele Peak | DBiAmPx | 9.7±0.4 |
| **PB-7** | Runcaş Peak | DBiAmPx | 9.3±0.4 |
| **PB-8** | Pietroasa Peak | QDiPx | 9.3±0.5 |
| **PB-9** | Izvorul Rugului V. | DPxAmBi | 9.0±0.4 |
| **Ţibleş** | | | |
| **T1** | Stegioara Peak | QDiPx | 11.5±0.5 |
| **T2** | Stegioara Summit | QDiPx | 10.9±0.5 |
| **T3** | Hudieş Peak | DiPx | 10.6±0.7 |
| **T4** | Hudieş Summit | DiPx | 10.2±0.4 |
| **T5** | Hudin Peak | mGDiBiAmPx | 10.0±0.4 |
| **T6** | Arieşului Valley | mGDiBiAmPx | 10.0±0.4 |
| **T7** | Arcer gallery | MDiPx | 9.8±0.5 |
| **T8** | Cascadelor Valley | MDiPx | 9.6±0.4 |
| **T9** | Arcer Peak | APx | 9.4±0.9 |
| **Toroiaga** | | | |
| **TR1** | Secului Valley | GDiBi | 9.7±0.5 |
| **TR2** | Secului Valley | GDiBi | 9.6±0.4 |
| **TR3** | Toroiaga Summit | ABi | 9.0±0.6 |
| **Rodna** | | | |
| **R535** | Măgura Rodnei | DAmBi | 8.6±0.4 |
| **RD7** | Cormaia Valley | ABiAm | 9.0±0.5 |
| **Bârgău** | | | |
| **RD5** | Măgura Sturzii quarry | DBiAm | 10.6±0.7 |
| **RD3** | Runcu quarry | DiPx | 10.4±0.8 |
| **RD9** | Cornii drill 3/470 | DiAm | 9.9±0.7 |
| **RD8** | Cornii drill 11/670 | DiAm | 9.8±0.8 |
| **RD1** | Turnuri quarry | DiAm | 9.3±0.4 |
| **RD6** | Zagra quarry | AAm | 9.1±0.6 |
| **RD2** | Chicera-Arşiţa | GbDiPx | 8.8±0.5 |

**Rock-types:** Di — diorite, mDi — microdiorite, Mdi — monzodiorite, GDi — granodiorite, mGDi — microgranodiorite, QDi — quartz-diorite, GbDi — gabbrodiorite, A — andesite, D — dacite;
**Minerals:** Am — amphibole, Px — pyroxene, Bi — biotite.

intrusions continued to be emplaced in the PBTTRB until ca. 8 Ma, after the roughly simultaneous interruption of intrusive activity in Gutâi and Călimani ca. 9.2 Ma. Intrusive magmatism resumed for ca. 1 Myr in Gutâi and Călimani roughly at the time when the youngest intrusions were emplaced in the PBTTRB ca. 8 Ma (Fig. 6).

K-Ar ages of the main magmatic rock types in the Poiana Botizei area range between 11.2–10.3 Ma for the intermediate-basic rocks and 9.7–9.0 Ma for the more acidic rocks. These data are in agreement with the field evidence: microgranodiorites/dacites dated to 9.3 Ma pierce the 11.2 Ma microdiorites in Runcaş Peak (Fig. 3A).

Besides the nine age determinations from magmatic rocks belonging to the two main phases in the Ţibleş Mts (Table 1, Fig. 5) three K-Ar ages were obtained from postmagmatic minerals (phlogopite from magnesian skarns and illite from hydrothermal veins; Kovacs et al. 1997). The dacitic rocks of the larger intrusions are ca. 10 Ma (two determinations). 9.8–9.4 Ma is the age interval of the main monzodioritic intrusion and its ring. Small intrusions from the north-western part of the complex cluster between 11.5–10.2 Ma. These ages confirm the observed field relationships between the rocks of the two main phases (the quartz monzodiorites of the Ţibleş-Bran-Măgura Neagră pierce the Tomnatec dacites, Fig. 3B). The small andesitic-dioritic intrusions emplaced outside the ring in the north-western part of the mountains are slightly older than the rocks of the larger intrusions. The radiometric age of phlogopite from the magnesian skarns (10.0 ± 0.5 Ma; Kovacs et al. 1997) in the contact area of the monzodioritic main intrusion, found in a mining gallery, confirms the age of the generating intrusion. The 7.8 and 8.0 Ma ages obtained from two illite samples from hydrothermal veins (Kovacs et al. 1997) near the main monzodioritic intrusion are consistent with the ages obtained from the fresh igneous rocks.

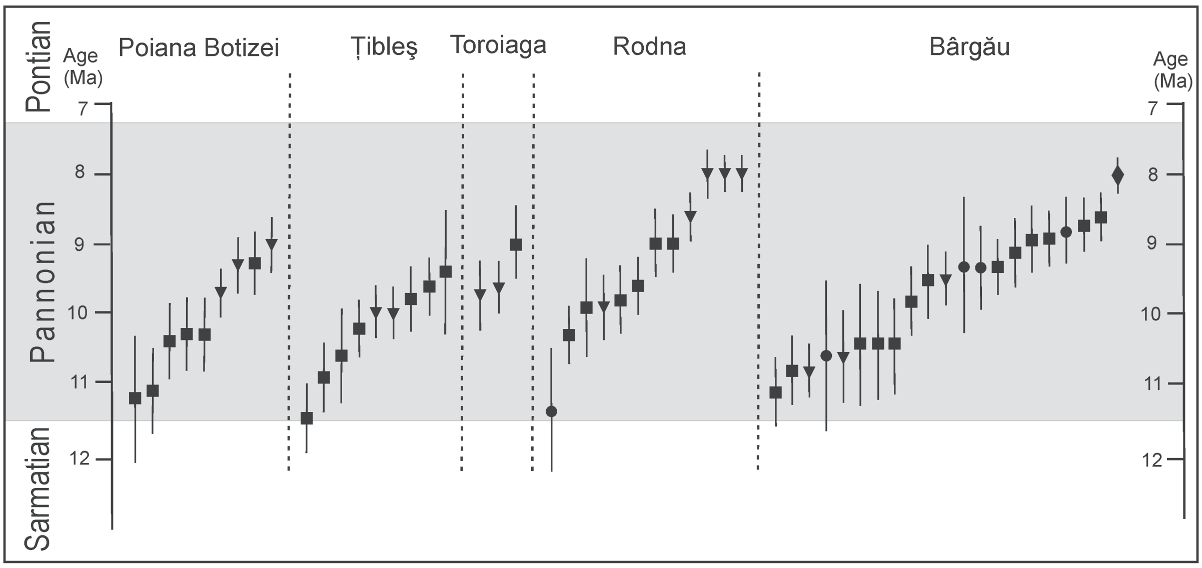


**Fig. 5.** Summary of K-Ar age determinations clustered according to the occurrence areas shown within the chronostratigraphic scale of Vass & Balogh (1989). Individual K-Ar ages are displayed with error bars. Rock types are shown by symbols: **circles** — gabbro-diorites and basalts/basaltic andesites; **squares** — diorites and andesites; **triangles** — granodiorites and dacites; **diamonds** — rhyolites.

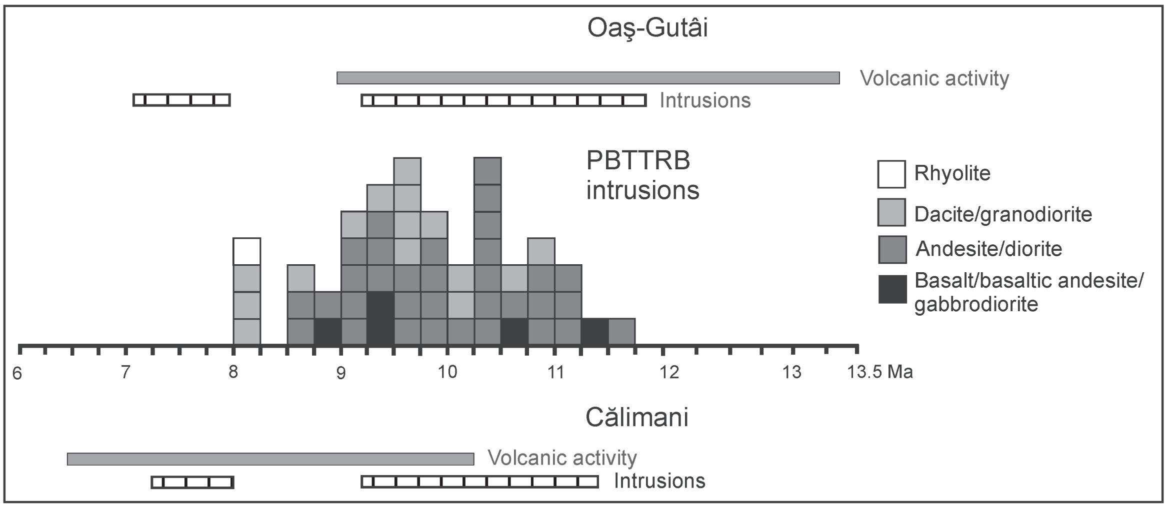


**Fig. 6.** Histogram with K-Ar age distribution of intrusive rocks in the PBTTRB in comparison with the time intervals of volcanic activity and intrusive magmatism in the neighbouring Oaş-Gutâi and Călimani massifs.

In the Toroiaga Massif only Vertic granodiorites (9.7 and 9.6 Ma) and Toroiaga andesites (9.0 Ma) have been dated. The ages of the rocks are comparable with the ages of the intermediate rocks from Ţibleş Mts and Rodna–Bârgău area. However, the much shorter time interval may reflect rather the scarcity of radiometric age data than the real age range of intrusion emplacement.

No obvious relationships could be pointed out between rock types and intrusion ages in the Rodna and Bârgău areas (Fig. 5). The K-Ar ages are in agreement with geological observations on a local scale suggesting the emplacement of different rock compositions in individual bodies at various time intervals. The obtained ages are relevant for emplacement times of the small-sized intrusions, while in the case of the large bodies (Cornii, Heniul and Colibiţa) the emplacement history cannot be resolved yet. However, the data suggest long-range development of intrusive activity for those bodies for which multiple datings are available (e.g. 10.6–8.4 Ma for Heniu, 9.9–8.9 Ma for Cornii).

## Discussion

The PBTTRB represents the eastern segment of the arc-type Carpathian magmatic front which attained its maximum length (ca. 700 km) in the ca. 12–10 Myr time interval (Szakács et al. 2007). The western segment of the same magmatic front includes a number of small-sized intrusions in eastern Moravia and in the Pieniny area in Poland (Pécskay et al. 1995a and Pécskay et al. 2006) with no trace of volcanic activity, while its central segment is volcanic. The PBTTRB intrusive activity is delayed (11.5–8 Ma) compared to that of the Eastern Moravia-Pieniny intrusions (13.5–10.8 Ma; Pécskay et al. 1995a, 2006). This evolutionary pattern records a progressive extension of the magmatic front in the 15–10 Myr time interval which is, in fact, the only period during which a clearly defined magmatic front was present along the Carpathian arc (Szakács et al. 2007).

### *Links between intrusive magmatism and regional geodynamics*

Tischler et al. (2006) invoke sinistral transpression 16 to 12 Ma along the Bogdan Vodă fault that shifts to sinistral transtension 12–10 Ma along the coupled Bogdan-Dragoş-Vodă fault system. The coeval inception of intermediate intrusive activity ca. 11.5 Ma might be explained speculatively as a response to the change in the regional tectonic regime from transpressional to transtensional 12 Ma (Tischler et al. 2006) allowing magma ascent and shallow intrusion emplacement. The spatial distribution of intrusive bodies in the PBTTRB does not show a direct relationship with the main trace of the Dragoş Vodă fault. They are rather controlled by secondary conjugate extensional faults (NW–SE and NE–SW) located both to the North (Toroiaga) and South (Poiana Botizei, Ţibleş, Rodna–Bârgău) of the main fault trace.

Conclusive petrological studies are missing in this area. Seghedi et al. (1995) concluded that most of the acidic rocks in the PBTTRB were derived from crustal melts rather than from differentiation of a basic parent magma, resulting from melting in the lithospheric mantle. The recent geochemical and isotopic studies in the Rodna–Bârgău area (Niţoi et al. 2002; Papp et al. 2005) account for different magma sources to explain the large diversity of rock types; it is suggested that each intrusion evolved independently with specific fractionation, crustal assimilation and/or magma mixing processes.

Sinistral transpressional (16–12 Ma) followed by sinistral transtensional (12–10 Ma) stress regimes along the Bogdan-Dragoş-Vodă fault system (Tischler et al. 2006) controlled the generation and emplacement of intrusive bodies ca. 12–8 Ma as related to the melting of the local heterogeneous mantle lithosphere, that was previously fertilized via subduction processes (e.g. Seghedi et al. 2004). The resulting rocks show one of the most composite petrographic varieties in the entire Carpathian-Pannonian region.

The estimation of intrusion depths of the subvolcanic bodies looks very important for the understanding of possible relationships with volcanism especially related to larger bodies (~10 km across), but a detailed assessment is missing. Such bodies may represent magma chambers to feed volcanism on the surface. Volcanic deposits possibly emplaced on the surface could be eroded away completely due to the strong uplift of the study area (e.g. at least 1 km in the Rodna Mts) as pointed out by exhumation histories according to fission track studies (e.g. Tischler et al. 2006), but no volcanic products have been identified so far in the PBTTRB area.

## Conclusions

The intrusive magmatism located in the internal Eastern Carpathians of Northern Romania (PBTTRB) developed over ca. 3.5 Myr during Pannonian times. The inception of intrusive activity was roughly coeval in the Poiana Botizei, Ţibleş and Rodna–Bârgău areas ca. 11.5 Ma. Most intrusions were emplaced in the 9–10.5 Myr time interval. The latest intrusions are obviously older (ca. 9 Ma) in the western part of the area (Poiana Botizei and Ţibleş) than in the east (ca. 8 Ma in Rodna–Bârgău). There is no obvious relationship between rock-types and age, but the only rhyolitic rocks belong to the youngest age group. The tighter age spectrum of Toroiaga intrusions probably reflects the very few radiometric age determinations available as compared to the other occurrence areas. In the 8–9 Ma age interval the PBTTRB is the only area in the Eastern Carpathians where intrusive magmatism took place, whereas around 11.5–9 Ma intrusions were also emplaced in the neighbouring Oaş-Gutâi and Călimani volcanic massifs. It is interesting to note that the end of intrusive magmatism in the PBTTRB (8 Ma) coincides with the reactivation of intrusion emplacement in both adjacent areas; the geodynamic significance of these developments are to be unraveled by future studies. The PBTTRB area was characterized during Pannonian time by a complex transpressional-transtensional tectonic regime (Tischler et al. 2006) that gave way to magma emplacement processes during continental lithosphere transtension at ~12 Ma that controlled all major phases of shallow intrusions.

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## Appendix

Main petrographic types together with the modal data

**Poiana Botizei:**

- Diorites/quartz diorites: Pl—62–78 %, Px—18–30 %, Q—2–7 %;
- Porphyritic texture: phenocrysts (Pl—35–55 %, Px—15–25 %); groundmass—holocrystalline (25–50 %);
- Porphyry quartz monzodiorites: phenocrysts (Pl—26–45 %, Px—10–25 %); groundmass—holocrystalline (35–60 %) with graphic intergrowths;
- Porphyry microgranodiorites/dacites: phenocrysts (Pl—23–30 %, Px—2–8 %, Am—1–5.5 %, Bi—0.5–3 %, Q—0.5–2.2 %); groundmass (56–63 %), holocrystalline, equigranular or microlithic;
- Andesites: phenocrysts (Pl—13–30 %, Px—6–17 %, Am—0–3 %, Bi—0–2 %); groundmass (53–82 %), microlithic to microgranular.

**Ţibles:**

- Diorites/quartz diorites: phenocrysts (Pl—40–60 %, Px—3–15 %, Am—0.5–6 %, Bi—1–7 %, Q—2–10 %); groundmass (20–43 %) equigranular to porphyric microgranular (Hudieş and Stegioara);
- Quartz monzodiorites: phenocrysts (Pl—18–48 %, Px—2.5–10 %, Am—2–9 %); groundmass (20–50 %), holocrystalline with graphic intergrowths, or Pl—40–68 %, K-feldspar—5–20 %, Q—6–15 %, Px+Am—15–25 % (Arcer gallery);
- Microgranodiorites: phenocrysts (Pl—20–30 %, Bi—2–10 %, Px—2–7 %); groundmass (58–70 %), microgranular with quartz and K-feldspar (Hudin);
- Andesites: phenocrysts (Pl—36–50 %, Px—2–12 %); groundmass (46–65 %), microgranular to cryptocrystalline (Arcer);
- Dacites: phenocrysts (Pl—20–35 %, Px—4–12 %, Am—1–3 %, Bi—0–4 %); groundmass (62–70 %), microgranular to pilotaxitic (Tomnatec).

**Toroiaga:**

The petrography and the modal data of the main rock types are according to Berza et al. (1982 and 1984), as follows:

- Diorites and andesites show similar composition but contrasting grain-size: phenocrysts (Pl—55 %, Px—1.5–5 %, Am—7.5 %, Bi—7.5 %, Q—1.5 %); microgranular, cryptocrystalline or granophyric groundmass ~25–30 %; (Secu-Novaţ and Toroiaga);
- Andesites: phenocrysts (Pl—25 %, Am—2.5 %, Bi—3 %, Q—2.5 %); microlithic to cryptocrystalline groundmass ~67 % (Piciorul Caprei);
- Andesites-dacites: phenocrysts (Pl—35 %, Am—3.5 %, Bi—7 %, Q—3 %); microgranular to cryptocrystalline groundmass ~45 % (Vertic);
- Quartz adesites-dacites: phenocrysts (Pl—35 %, Am—3 %, Bi—7 %, Q—2.5 %); microgranular to cryptocrystalline groundmass ~52.5 % (Novicior).

**Rodna–Bârgău:**

- Microdiorites, diorites or gabbrodiorites: phenocrysts (Pl—55–59 %, Px—1.5–9 %, Am—5–7.5 %, Bi—0–3 %, Q—0–2 %); groundmass ~20–35 % — medium-microgranular or granophyric;
- Amphibole-garnet-bearing microdiorites/microgranodiorites or andesites and dacites: phenocrysts (Pl—20–28 %, Am—4–7 %, Q—1–3 %, Gn—1–3 %), groundmass—microgranular (75–65 %);
- Basaltic andesites and basalts: phenocrysts (Pl—2–3 %, Am—0–5 %, Cpx—2–3 %), groundmass—microgranular (90–75 %);
- Amphibole pyroxene andesites: phenocrysts (Pl—16–24 %, Am—7–10 %, Cpx—5–8 %, Opx—1–2 %), groundmass—microgranular (70–60 %);
- Amphibole andesites: phenocrysts (Pl—18–26 %, Am—10–14 %), groundmass—microgranular (70–60 %);
- Amphibole-biotite andesites: phenocrysts (Pl—20–28 %, Am—3–6 %, Bi—1–4 %, Q—1–3 %), groundmass—microgranular (75–60 %);
- Dacites: phenocrysts (Pl—10–24 %, Q—2–4 %, Am—5–8 %, Bi—1–3 %), groundmass—microgranular to cryptocrystalline (80–65 %);
- Rhyolites: phenocrysts (Pl—5–12 %, Q—2–4 %, Bi—1–4 %), groundmass—cryptocrystalline (90–80 %).