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The magmatic and metamorphic evolution of the north-eastern part of the Mórágy Block

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Abstract

Rocks from the Mórágy Granite Formation were formed by a mixing of felsic and mafic magmas. The magma mixing is supported by both the features and analyses of contacts of the main rock types, the similarities in mineralogical compositions and mineral chemistry, as well as by the similar geochemical features of both rock types. The mafic enclaves with amphibole aggregates represent relics of a non-perfect magma mixing, while the "diluted" enclaves may indicate the homogenised or partly homogenised portions of the complex. Leucocratic, late-magmatic dykes with sharp contacts crosscut the nearly solidified complex.

The magmatic crystallisation of the Mórágy Granite Formation was followed by metamorphism. The metamorphism appears mostly in structural aspects, emphasised first of all by the formation of a NE–SW striking, regional foliation. Classical metamorphic mineral transformations and chemical changes have also taken place, but these are less characteristic. Based on microstructural features and the mineralogical composition of the rocks, the metamorphic temperature can be broadly placed into the higher greenschist facies (>350 °C) during the ductile deformation, and it could have reached a maximum – at least in certain zones – of approximately 500–550 °C.

The metamorphic event, which was of variable intensity, can be traced within the whole granitoid body. The ductile structures are parallel to the strike of those within the neighbouring Mecsekalja Zone and also parallel to the Zone itself. Therefore, it seems very likely that the metamorphism is of a regional character.

Introduction

The genesis of the rocks from the Mórágy Granite Formation has been discussed by several authors, albeit from different aspects. ROTH (1875) recognised some metamorphic features in the granitoid body and classified certain rock types as gneiss. JANTSKY (1953) described the dynamometamorphic transformation of the granitoid body in certain zones. However, until recently this idea had been ignored by geological research.

SZÁDECZKY-KARDOSS (1959) and CSALOGOVITS (1964) argued for the migmatitic-metasomatic origin of the Mórágy Granite Formation and this supposition was further developed by JANTSKY (1979) and BUDA (1974, 1985); consequently, the mafic enclaves were considered as restites.

The theory of magma mixing, where the mafic enclaves are relics of a non-perfect magma mixing, was first described by BUDA (1999) and BUDA et al. (2000). This description was part of work related to the project on the final disposal of low- and intermediate-level radioactive waste. However, the origin of the granitoid body is still a matter of debates. Based on the age data in the literature (BALOGH et al. 1983; BUDA 1985; KLÖTZLI et al. 2004) the magmatic crystallisation of the granitoid body is Variscan.

BUDA (1996, 1998, 1999) and DITRÓI-PUSKÁS (1996, 1998, 1999) also recognised metamorphic features, qualifying them as the result of a "dislocation metamorphism". BALLA (2000) reported on the general metamorphism of the Mórágy Granite Formation. KIRÁLY (2001) described the metamorphism of all rock types occurring in the Mórágy Granite Formation, based on detailed petrographic investigations.

During the detailed surface exploration of 2002–2003 great attention was paid to the possible proofs of magma mixing, as well as to the metamorphic features. In the following sections (1) the macroscopic and petrographic observations, the electron microprobe, and the geochemical analyses that support magma mixing and (2) the microstructural and mineralogical-petrological changes that occurred in solid state during the cooling of the granitoid body are briefly summarised.

Due to their geological significance the following are also described: the most important structural-petrological features of the metasandstone bodies (Bátaapáti Sandstone Member, Ófalu Formation) occurring near the northern boundary of the Mórágy Granite Formation and the volcanic dykes (Rozsdásserpenyő Formation) which crosscut the Mórágy Granite Formation.

Characterisation of the Mórágy Granite

In the following the general features of the main rock types including their field relationships, and petrographic and geochemical character are first described.

Major rock types

Three main rock groups of the Mórágy Granite Formation are the granitoids, mafic enclaves and leucocratic dykes. The most widespread rock type is the *granitoid* with a monzogranitic composition; it consists of plagioclase and microcline (which occur in various quantities), quartz, biotite and more rarely, in less deformed rocks, amphibole. As accessory minerals zircon, allanite, titanite, apatite, epidote and in rare instances muscovite can be found. The mostly medium-grained (2-7 mm) granitoid rocks regularly contain microcline megacrystals although (up to 5 cm)they can also occur without these. The grain size of the megacrystal-free types is generally smaller. More or less deformed varieties and more mafic granitoid can also be recognised (KIRÁLY 2003).

The granitoid rocks contain rounded or oval, mezo-melanocratic *mafic enclaves,* or bodies of variable sizes (from a few cm to 200-300 ms) which are called mafic enclaves. Their composition is usually monzonitic, but in some cases they are syenitic or dioritic with or without quartz. Large mafic bodies mostly belong to the dioritic range, while very dark, fine-grained enclaves often exhibit a syenitic composition. The distribution of the enclaves is changeable and mostly depends on the distance from large mafic bodies. Three groups of mafic enclaves are distinguished: (1) enclaves with amphibole aggregates, (2) "diluted" enclaves and (3) the fine-grained enclaves.

The largest mafic bodies (in Boreholes Üh–27, Üh–37) belong to the enclaves with amphibole aggregates (1). They are generally medium-grained rocks with more mafic granitoid rocks around them. Some smaller enclaves also fit into the first group.

The "diluted" enclaves (2) also appear in larger bodies with medium- to small-grain sizes and they are often strongly altered, and characterised by red and green colours (Üh–4, Üh–5, Üh–28). They are considered as partly or completely homogenised parts of the complex. Their typical composition is quartz monzonitic between the monzogranitic (felsic type) and monzonitic (mafic type) compositions. The boundary of these partly homogenised bodies is not always clear since faults, vein systems or strong alterations complicate their contacts. In some cases darker mafic enclaves can also be discovered in them.

The typically small (some cm), shred-like fine-grained enclaves (3) are very dark and fine-grained and contain internally undeformed minerals with preferred orientation and no mineral aggregates.

Both the granitoid rocks and their enclaves are crosscut by at least two or three generations of *leucocratic dykes* with varying widths and in different positions. Their rock-forming minerals are microcline, quartz, plagioclase, subordinated biotite, and also some accessories (*e.g.* titanite, opaque minerals). In a few cases muscovite and garnet have also developed. The leucocratic dykes are differentiated from the felsic liquid and considered as the product of a late-magmatic event. The minimum temperature for the formation of leucocratic dykes is about 700 °C on 2 kbar (KIRÁLY, TÖRÖK 2003).

Contacts

The most typical contacts between the granitoid rocks and mafic enclaves are characterised by uneven surfaces. This is due to half-mingled plagioclase phenocrystals or other relatively large minerals which have developed in the felsic magma. Small melanocratic injections also occur in the granitoid body. In some cases rims have formed along the contact. On side of the granitoid leucocratic enrichments and on the inner side of mafic enclaves biotite-rich bands can be present. The biotite-rich bands often contain many accessories (apatite, allanite, titanite) at the edge of the biotite tables. The quantity of the biotite always grows towards the rim in the mafic enclaves as a consequence of the effect of the felsic liquid. Some leucocratic enrichments are very similar to the leucocratic segregations characterised by large feldspar crystals and large, individual, twinned amphibole laths. The latter were considered as infiltrations of the felsic melt to the mafic bodies.

In the boreholes, transitions between the granitoid and mafic bodies can be investigated, while the individual magmatic contacts are mostly well-defined. If mafic bodies dominate in the core, the filtering granitoid melt is also more mafic. If the granitoid rocks contain only few and small mafic enclaves, they are more felsic.

Contacts between the granitoid rocks and leucocratic dykes are mostly sharp but lobated injection towards the host rock, formed mostly from microcline, can be evident as well. In a few cases, vertical to the wall, coarse-grained mineral growth is apparent. In these cases the aplite itself is often strongly deformed. The small, drop-like quartz inclusions or myrmekite more frequently appear at the edge, towards the granitoid rocks and they represent migration inside a tight zone.

The effects of leucocratic dykes and veins on mafic enclaves are stronger than on the granitoid rocks. The edges of veins or dykes are not always sharp, often being smudgy and bent. Lobate, sinus budgets and zigzag or folded contours also occur. Microcline can have penetrated into the mafic enclaves, and mafic minerals can be also found in the leucocratic veins.

Mineralogical composition and mineral chemistry

The mineralogical compositions and the mineral chemistries are very similar in the granitoid rocks and in all three groups of the mafic enclaves. Differences can be detected mainly in the proportion of minerals.

Among *mafic minerals,* clinopyroxene is a unique mineral, which is only found in the first group of enclaves. It appears in two textural positions (in aggregates or as individual, large subhedral tables). Its typical composition in both textural appearances is ferroan diopside, in some cases with low chromium content (maximum 0.63%; KIRÁLY 2002). Neither zoning nor variability in composition are apparent.

Among other mafic minerals, amphibole tends to occur in enclaves and biotite in the granitoid rocks. A trend in the quality and the proportion of mafic minerals can be recognised from the mafic enclaves, with aggregates through the "diluted" enclaves to the shred-like small enclaves. The largest amphibole content was detected in the first group of mafic enclaves; the second group contains more biotite formed at the expense of amphibole; and the third group mostly includes biotite as mafic mineral.

Amphibole (like pyroxene) predominantly occurs in aggregates or as individual, large amphibole laths. There is no characteristic chemical difference between these two textural types. However, amphibole in aggregates often displays patchy, at times concentric zoning. Large, individual amphibole laths frequently contain rounded opaque minerals.

Biotite has several distinct textural occurrences as: (1) a large, magmatic, often kinked table, (2) an inclusion in feldspar, (3) an alteration of amphibole, and (4) very fine grains at the edges of large magmatic biotite. There is no significant difference in the chemical composition of the biotite which occurrs in the granitoid rocks and mafic enclaves. Locally, a very weak compositional zoning (*i.e.* Mg is exchanged for Fe towards the rim) can be detected in magmatic biotite tables in both the granitoid rocks and the enclaves. This zoning is probably due to the magmatic differentiation.

The *leucocratic minerals* present are plagioclase, microcline and quartz. Their ratios are diverse in the enclaves, especially the ratio of plagioclase and microcline.

Plagioclase appears as phenocrystals and as matrix crystals. Its composition in the granitoid rocks refers to oligoclase or andesine and, in rare instances, albite. In mafic enclaves andesine is the most typical composition, and more rarely, labradorite or basic oligoclase. The compositional trend of plagioclase is more acidic in the granitoid rocks than in the mafic enclaves.

Microcline also has two generations: megacrystals and matrix microcline. Each mineral which occurs in the matrix is also represented as an inclusion in the megacrystals. However, their alteration is stronger in the megacrystals. One or two inclusion rings of plagioclase and/or biotite could have developed in some microcline megacrystal in the granitoid rocks.

The triclinity of microcline megacrystal suggests formation at low temperatures (500–685 °C — BUDA 1985; HÁDEN 1997) in agreement with the regularly low Na content in the microcline. The BaO content at the margin of the microcline can increase up to 4.88% in patches close to the plagioclase grains.

Quartz has formed mainly in the granitoid (10–30%) and leucocratic dykes (15–35%) and is subordinate in mafic enclaves (0–15%). Its appearance depends on the rate of deformation (see below).

Accessory minerals are normally euhedral or subhedral titanite, allanite, zircon and apatite. Titanite and apatite have developed mainly in the mafic enclaves. Zircon and allanite have formed mainly in the granitoid rocks. Titanite and allanite in leucocratic segregations show two or more zones in the distribution of REE. In some cases small magmatic garnet grains — spessartine–almandine in composition — or white mica were found in leucocratic dykes.

Geochemical characters

Comparing the geochemical characters of the enclaves to those of the granitoid rocks very similar characters and some regularities can be identified as well. The *main elements* (except Si and Al) are enriched in the mafic enclaves (Figure 1, A), but their quantities are more diverse than in the granitoid rocks. In Harker diagrams granite samples normally fit to a linear trend, but the mafic enclaves fit only to a smaller extent (KIRÁLY 2002). In the case of potassium no characteristic trend occurs, however the potassium content of the mafic enclaves is higher and more diverse.

According to the *trace elements* in the granitoid–enclave pairs, we can also recognise the similarity. The enclaves have a slightly higher REE concentration than the granitoid rocks have. A negative Eu anomaly often characterises the enclaves (Figure 2); however, its opposite also occurs. Among trace elements, U, Th, Pb and Be are regularly enriched in the granitoid rocks (Figure 1, B). If four samples are taken — two from the inner part of the enclaves and the granitoid rocks, and two very close to the contact — it can be recognised that the contacts have been slightly leached by fluids (Figure 2).

The *geochemical characters* of the mafic enclaves were also compared to those of amphibolite from the Mecsekalja Zone (KIRÁLY 2002). Amphibolites contain less LIL- and LRE-elements, whereas the enclaves are enriched in them. Differences can also be recognised in HSF elements: en-

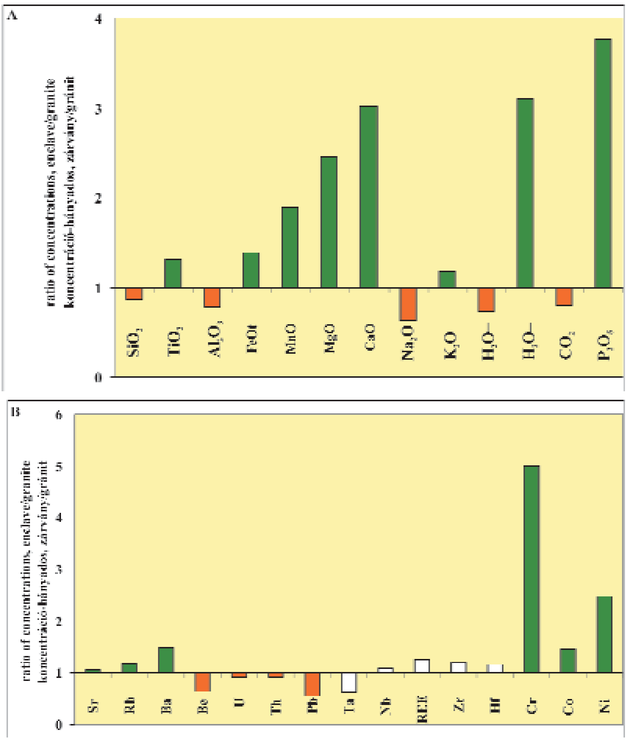

Figure 1. Characteristic geochemical differences between the granitoid rocks and their enclaves

A – in main element distributions; B – in trace element distributions. Red marks the elements enriched in the granitoid, white displays the non-characteristic elements, and dark green shows the elements enriched in enclaves

1. ábra. Jellegzetes geokémiai különbségek a granitoid és zárványai között

A – a főelemeloszlásokban; B – a nyomelem-eloszlásokban. Pirossal a granitoidban dúsuló elemeket, fehérrel a nem karakterisztikus elemeket, sötétzölddel pedig a jellegzetesen zárványokban dúsuló elemeket jelöltük

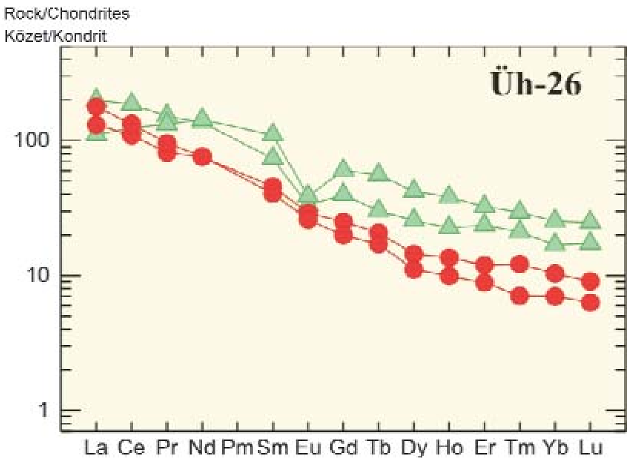

Figure 2. REE distribution in granitoid-enclave pairs (Üh-26)

Red is the REE pattern of the granitoid rocks from the inner part and from the contact. Green is the REE pattern of the enclave from the inner part and from the contact. In both rock types lower REE content characterises the contact, while a higher REE content can be detected in their cores

2. ábra. RFF-eloszlás granitoidzárvány-párokban (Üh-26)

Piros a granitoid RFF-eloszlása, zöld a zárvány RFF-eloszlása. Az alacsonyabb RFF-tartalmú minták a kontaktusról származnak, a magasabb RFF-tartalmú minták pedig a kontaktustól távolabbról, a granitoid, illetve a zárvány belsejét jellemzik

claves have higher Ni and Cr contents and a lower Ti content than the amphibolites of the Mecsekalja Zone.

Magmatic evolution

The magmatic evolutionary history of the Mórágy Granite Formation is discussed through the features of the main rock types, their contacts, the mineral chemistry and geochemical features. The mafic enclaves have a key position in the understanding of the magmatic evolution of the Mórágy granitoid rocks.

Origin of the enclaves

Enclaves can occur in the felsic melt as solid (xenolith, restite) or liquid phase (autolith, mafic microgranular enclaves — MME, Table 1). X e n o l i t h s are angular with sharp margins and they have a different geochemical character from the host. R e s t i t e s are generally surmicaceous enclaves with an elongated shape and with biotite zone at their contacts. Their geochemical characters depend on the origin of the restite and on the regularity of the partial melting. According to their oval shapes and their sharp or transitional contacts, a u t o l i t h s are similar to the mafic microgranular enclaves (MME). However, their geochemical characters seem to be more primitive, *i.e.* less differentiated.

T h e m a f i c m i c r o g r a n u l a r e n c l a v e s are preserved as relicts of a non-perfect magma mixing. The similarity in mineralogical composition and mineral chemistry to those of the host granitoid rocks and the similar geochemical characters of both the host and the mafic enclaves indicate magma mixing. Their contacts are also evidence of this. The pillow- or bubble-like appearance of the mafic enclaves at outcrop scale represents dispersed liquid drops in a more viscous liquid. Around large mafic bodies smaller and smaller oval relics of mafic melt can be recognised.

Comparing the *geochemical characteristics* of the granitoid rocks and mafic enclaves, some regularities can be noticed: the similarity of the mafic enclaves to the granitoid rocks suggests a long period in which both rock types existed together in a liquid form. If they had existed in a solid phase, the chemical transfers could not have been so effective and so complete. Enrichment in U, Th, Pb, and Be and varying Hf and Zr contents in the granitoid rocks signify a more differentiated rock character and the presence of accessory minerals in varying quantities, while the light REEs and LILEs are enriched in the mafic enclaves as a possible result of the overcompensation. Along the rock boundaries migration is suspected.

The similarity in the mineralogical composition and in the mineral chemistry in felsic and mafic rocks suggests comparable p–T conditions and *processes of formation* for both rock types. No relics of metamorphic minerals or textures have been detected in the mafic enclaves. This observation goes against any suggestion of a restite origin. The differences between the distribution of Ni, Cr and Ti in the

Table 1. Nomenclature and features of enclaves after DIDER and BARBARIN (1991)

Term	Origin	Contact	Shape	Petrographical features	Geochemical features
xenolith	piece of country rocks	sharp	angular	contact metamorphic textures and minerals	different from granite more diverse
surmicaceous enclaves	residue of melting (restite)	sharp with biotite crust	lenticular	metamorphic texture, micas and Al-silicates	depend on the origin and the rules of melting out
mafic microgranular enclave	blob of coeval magma	mostly sharp	ovoid	fine-grained igneous texture	similar to granite, LILE- and REE-rich
autolith (cumulate) enclave	disrupted cummulate	mostly gradual	ovoid	large-grained cumulate texture	similar to granite, more primitive

mafic enclaves and in the amphibolites from the Mecsekalja Zone are also evidence against the formation of restites from these amphibolites (KIRÁLY 2002). On the other hand, the development of clinopyroxene fits well to the early phase of magmatic evolution. The clinopyroxene (diopside or augite) is a common mineral in monzonite.

Magmatic crystallisation

The formation of large euhedral–subhedral pyroxene, amphibole, plagioclase and titanite may represent the *early crystallisation phase* in the mafic magma. These large minerals might have developed before the mixing occurred. Their composition could have been re-equilibrated later, during the later magmatic and/or metamorphic processes. Therefore there is no detectable compositional difference between the large and smaller pyroxene and amphibole grains.

The mafic magma must have intruded into the felsic magma relatively early — *i.e.* at the beginning of crystallisation — so as to have been able to mix (Figure 3). Homogenisation can only occur in the early phase of magma life, before the degree of crystallisation reaches 30% (PITCHER 1997; DIDIER, BARBARIN 1991). The "diluted" enclaves can be considered as the completely homogenised or partly homogenised portions of the complex, while the enclaves with amphibole aggregates probably represent a relic of the mafic magma.

Minerals have also formed in the felsic melt parallel to the evolution of the mafic enclaves. The early crystallisation stage can be represented by large, magmatic biotite tables, perhaps amphibole, accessories (zircon, allanite) and basic plagioclase cores in the granitoid rocks. Drop-like biotite inclusions in the plagioclase phenocrystals suggest earlier crystallisation of the biotite. The amphibole might have developed at the early stage of felsic melt or could have entered the felsic melt as xenocrystal from the mafic magma.

The rate of the crystallisation in the felsic melt would have been slower at the beginning, so the grain size is coarser than in the mafic enclaves. The appearance of two hydrous phases (biotite, amphibole) and the lack of any orthoclase and of any metamorphic structure of the protolith indicate a water saturated felsic melt (PITCHER 1997).

The inclusion rings of plagioclase and/or biotite in some microcline megacrystals and the REE zoning in titanite and allanite support the changes in the magmatic processes, most probably in the magma mixing (PITCHER 1997; Vernon oral com.).

The *major phase of crystallisation* of the mafic melt took place in the felsic melt. The textural evidence of this event can be found in the development of mafic minerals (mainly amphibole and more rarely pyroxene) in aggregates (Figure 4). They behave as they would during contact metamorphism. In the latter process,the cooler and more viscous felsic melt suddenly chills the hotter and less viscous mafic melt; therefore the aggregates in the mafic enclaves are similar to the knots of the contact metamorphic "Knotenschiefer" (VERNON 1991).

After the first threshold of felsic magma (crystallinity between 30–70%), the relics mafic blobs disperse in the felsic, visco-plastic liquid and develop further separated from each other. Consequently, their geochemical characteristics are more diverse than those of the granitoid.

In the main crystallisation phase of the felsic melt, microcline begins to develop during the crystallisation range of

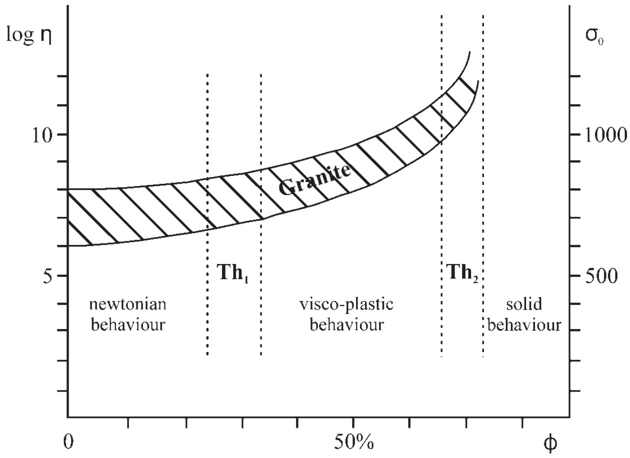

Figure 3. Rheology of granitic magma according to FERNANDEZ, BARBARIN (1991)

During the evolution of granitic magma there were two rheological thresholds. Before the first threshold (Th_1) the magma behaved as a Newtonian liquid. Between the first and second threshold the magma showed visco-plastic behaviour. After the second threshold (Th_2) the granitic magma behaved as the solid phase. Notice that during the latest period the liquid still existed (Φ = the degree of crystallinity; η = the viscosity; σ = stress)

3. ábra. A gránitmagma reológiai viselkedése FERNANDEZ, BARBARIN (1991) nyomán

A gránitos olvadék fejlődésében két reológiai küszöb figyelhető meg (Th_1 és Th_2). Az első küszöbértéket megelőzően az olvadék newtoni folyadékként viselkedik. Az első és második küszöbérték között az olvadék viszko-plasztikus viselkedésű, míg a második küszöbértéket követően már szilárd fázisú, bár ekkor még mindig van jelen olvadék (Φ = kristályossági fok, η = viszkozitás, σ = feszültség)

Figure 4. Amphibole aggregate in mafic enclave. (Üh-37, 175.9 m)
Small grains of amphibole form aggregate. ×N

4. ábra. Amfibol-aggregátum mafikus zárványban (Üh-37 fúrás, 175,9 m)
Aggregátumba rendeződött aprószemcsés amfibol. ×N

mafic minerals and plagioclase, while more basic plagioclase (48 An%) without an albitic rim can be analysed in the inner part of the microcline megacrystal (rather than the outer part). According to the experiments of Winkler and Schultes (1982) the K-feldspar begins to crystallise in the presence of a 65–70% melt. If the microcline is the first leucocratic mineral, then it could not form megacrystal.

The temperature of the mafic magma becomes similar to that of the felsic magma and the crystallisation develops in a similar way to the felsic magma: the grain size increases and the same minerals develop. The effect of the felsic melt on the mafic magma is enhanced by the fact that the temperatures of the two magmas approach each other. A poikilitic texture develops as a result of almost complete crystallisation of the mafic magma and hence there is not enough space for the crystallisation of large grains. In agreement with the observation of Vernon (1991), microcline has the most typical poikilitic texture and often occurs with a large portion (up to 50%) of inclusions. Quartz and biotite can also display a poikilitic texture if they have not been formed from the enclave magma.

During the main phase of the K-feldspar crystallisation the temperature can be estimated at between 650–663 °C. This indicates, approximately, some hundreds years in the life of a normal sized pluton (Winkler, Schultes 1982). This temperature range is in agreement with the measurement of the triclinity of microcline by Buda (1985), whereas the crystallisation temperature of microcline 675 °C was given. If the liquid is less than 30% in the magma, K-feldspar is not able to form large crystals since there is not enough room for large crystals.

In the *late phase of the magmatic evolution* 30% of liquid can still be present (Figure 3). In this stage the migratory and chemical transfers play the most important role and early dyke systems can break through the mainly solid magmatic complex as well.

The K content of mafic enclaves is generally higher than in the host granitoid rocks. The K builds very quickly in the microcline of the mafic enclaves and thus the residuum of the mafic melt can take up more K from the felsic melt again. This process leads to an overcompensation of K in the mafic magma (Debon 1991), although the major portion of K originates from the felsic magma.

The mafic minerals in the enclaves with amphibole aggregates are protected from alterations (uralitisation, biotitisation) by microcline. Therefore the main phase of microcline formation occurred either earlier or at the same time as the main phase of alteration. It supposes a water-saturated system which appears parallel to or after the formation of microcline. The alteration (*i.e.* sericitisation, biotitisation) and the formation of microcline in "diluted" enclaves seem to be connected to the presence of felsic melt. The relationship between the alteration and the effect of felsic melt differs in the mafic enclaves with aggregates from the "diluted" enclaves.

General features of the metamorphism

The metamorphism of the Mórágy Granite Formation is best displayed in the ductile structural transformation of the original magmatic intrusion. Deformation-related mineralogical and chemical changes also occur, but their significance is subordinate in comparison to the structural changes.

Focusing on the ductile structures in the outcrop and hand-specimen scale, the most striking metamorphic feature of the rocks is the presence of two foliation generations (steep, sub-vertical S_1 and less steep S_2 foliation), formed during solid-state deformation of the granitoid rocks. During the formation of these foliations, the mafic enclaves were rotated into the foliation planes and their shape also changed. Occasionally, narrow mylonitic zones were also formed, mostly parallel to the S_2 foliation.

These features are described in detail by Maros et al. (2004), where it is mentioned that all previously listed structural features trend roughly to NE–SW, parallel to the strike of the ductile structures within the neighbouring Mecsekalja Zone, as well as that of the Zone itself.

In the following sections those microstructural and mineralogical-petrological transformations will be briefly introduced which are related to the metamorphic evolutionary stage of the Mórágy Granite Formation.

Microstructural transformations

The metamorphic effect is very well reflected in the *microfabric* of the different rock types of the Mórágy Granite Formation. The original magmatic minerals are partly transformed into a fine-grained matrix, the quantity of which depends on the intensity of the deformation. The more rigid minerals form angular or rounded, internally relatively weakly deformed porphyroclasts of variable grain size. During microstructural transformations, oriented microfabric is formed; this microfabric is defined by the alternation of elongate quartz, feldspar, biotite, and amphibole grains and/or aggregates aligned parallel to their long axes.

The microstructural changes are accompanied by the intensive dynamic recrystallisation of quartz, which is one of the most prominent metamorphic features at the thin section scale (Figure 5). Occasionally dynamic recrystallisation also occurs in feldspars and biotite, but to a much lesser extent. The proportion of recrystallised new grains (in this sense metamorphic minerals; BUCHER, FREY 1994, p. 3) reaches about 20–40% in the well-foliated, gneissic rock types; but in some ultramylonites the quantity of re-crystallised material is quite high (up to 90%, KOROKNAI 2003).

The dynamic recrystallisation of q u a r t z is practically complete in the well-foliated and mylonitic rocks: the elongate-flattened quartz lenses are made up of small, recrystallised grains with strongly serrate-sutured boundaries (Figure 5). Weakly deformed rocks generally exhibit a considerably smaller proportion of dynamically recrystallised grains. Crystalplastic deformation in these rocks is indicated by the strong undulatory extinction of larger, magmatic quartz grains; sometimes deformation lamellae can be also observed. The formation of subgrains and incipient dynamic recrystallisation — especially along grain boundaries — are also characteristic. Based on the extensive dynamic recrystallisation of the quartz, the temperature surely exceeded 270-300 °C (VAN DAALEN et al. 1999) during deformation.

Dynamic recrystallisation of b i o t i t e is generally subordinate (Figure 5). The small (<0.05 mm) new grains often form thin, heavily elongated tails around the original grains parallel to the foliation. The internal deformation of large magmatic biotite is indicated by widespread undulatory extinction and kink-bands.

Dynamic recrystallisation of f e l d s p a r s is also rather subordinate. However, crystalplastic deformation is reflected in the presence of frequent undulatory extinction, kinked magmatic twins, occasionally deformation twins, and the formation of subgrains along micro-cracks.

Beside crystalplasticity, *bulk deformation* is largely accommodated by rigid-body rotation and fracturing of the different minerals (mainly biotite, feldspars, and amphibole). Rigid-body rotation of biotite, amphibole, and feldspars has basically contributed to the formation of foliation. During rotation, the edges and corners of minerals often became rounded. In the pressure shadows of larger feldspar grains, synkinematic tails were often formed (σ and δ clasts). In the rigid minerals (mostly feldspars) micro-cracks are widespread in every rock type, thus indicating predominantly brittle behaviour during deformation (Figure 6). Very small displacements of mineral fragments along the micro-cracks sometimes resulted in virtually continuous deformation on a hand-specimen scale.

Figure 5. Microfabric detail from a well-foliated monzogranite (Üh-29, 111.9 m)

Detail of a dynamically recrystallised quartz lense showing small, new grains with sutured grain boundaries. In the middle, a smaller biotite mica-fish with very fine-grained, recrystallised biotite along the grain boundaries can be seen. ×N

5. ábra. Szöveti részlet jól palásodott monzogránitból (Üh-29 fúrás, 111,9 m)

Dinamikusan átkristályosodott kvarclencse részlete apró, erősen varratos szemcsehatárú kvarckristályokkal. A kép középső részén kisebb, szigmoid alakú biotitszemcse („csillámhal") látható, amelynek peremein rendkívül finomszemű, átkristályosodott biotit képződött. ×N

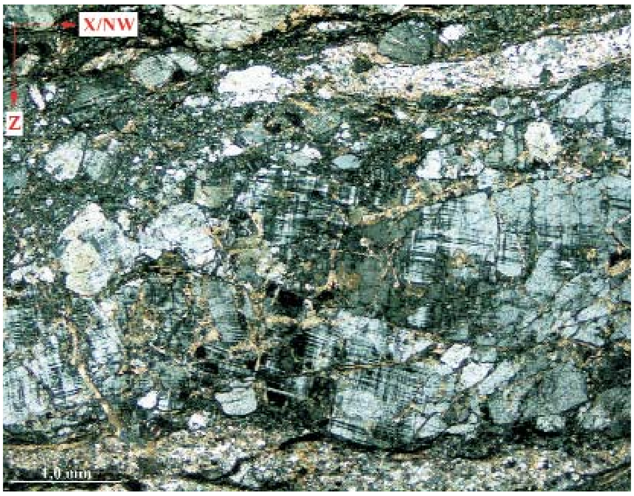

Figure 6. Microfabric detail from a protomylonitic monzogranite (Üh-29, 137.25 m)

Strongly fractured, cross-hatched microcline grain. Along the microfractures network small-scale displacements of the individual fragments and fine-grained carbonate infillings can be observed. ×N

6. ábra. Szöveti részlet protomilonitos monzogránitból (Üh-29 fúrás, 137,25 m)

Erősen töredezett, keresztrácsos mikroklinszemcse. A mikrorepedés-hálózat mentén apró elmozdulások és finomszemű karbonátos kitöltés figyelhető meg. ×N

Metamorphic mineral reactions and changes in mineral chemistry

The metamorphic mineralogical changes of all rock types occurring in the Mórágy Granite Formation (granitoid rocks, mafic enclaves and leucocratic dykes) were studied by both optical microscopy (KIRÁLY 2001, 2003; KOROKNAI 2003) and electron-microprobe analysis (HORVÁTH et al. 2003).

As mentioned above, the changes in mineralogy and/or mineral chemistry are generally subordinate in comparison to the structural changes. The intensity of these mineralogical changes is rather variable in the area of investigation, but it mostly shows a good correlation with the intensity of the macroscopically detected rock deformation.

The chemical aspects of the metamorphism can be best demonstrated in the case of *biotite*. Biotite in different microstructural positions, displays slightly different chemical compositions: the large (several mm), often kinked, magmatic biotite flakes generally have a higher titanium content (TiO_2 up to 4-5 wt%, clearly indicating magmatic origin) than the small, re-crystallised (and/or mechanically broken) biotite grains in the fine-grained matrix have a lower titanium content (TiO_2<2%). Along the grain boundaries or splitting planes of the large grains, mostly anhedral, fine-grained, secondary titanite has formed; this represents an accumulation of the titanium released from the original magmatic biotites during metamorphic processes.

Another example of the metamorphic transformation of biotite is the formation of extremely fine-grained (<0.05 mm), syntectonic white mica rims around larger, strongly deformed "biotite-fish". Coarser-grained (0.1–1 mm), syntectonic white mica along heavily deformed biotite- and feldspar-rich zones were also observed in some mylonitic zones (Figure 7). According to microprobe measurements, the muscovite has relatively high Fe, Mg, and Ti content, which indicates the formation of muscovite at the expense of biotite.

Plagioclase is transformed into fine-grained epidote–clinozoisite and albite, these are often related to the fine-grained, recrystallised feldspar-rich layers of the rocks. The metamorphic origin of *epidote–clinozoisite* is clearly indicated by the fact that it forms fine-grained aggregates parallel to the foliation, or to the stretching lineation in the sections parallel to the foliation. Thus its formation is obviously related to ductile deformation. The inhomogeneous distribution of *albite* along cleavages, micro-cracks and margins of plagioclase grains generally indicates a metamorphic process. In the mafic enclaves and in the leucocratic segregations among them *prehnite* has formed locally in small quantities at the expense of plagioclase (Figure 8).

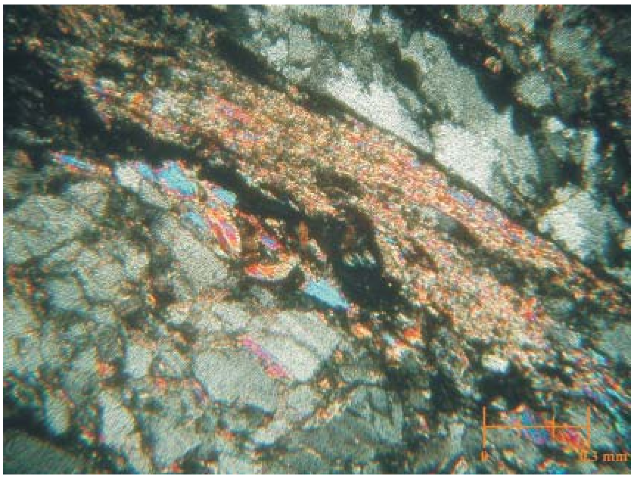

Figure 7. Microfabric detail from a mylonitic monzogranite (Üh-29, 139.2 m)

Fine-grained, white-mica (muscovite) band with somewhat bigger grains on its edge. Muscovite can be also observed in the microfractures of the larger feldspar grain. ×N

7. ábra. Szöveti részlet milonitos monzogránitból (Üh-29 fúrás, 139,2 m)

Finomszemű muszkovitsáv, amelynek peremén kissé durvább kristályos szemcsék figyelhetők meg. A muszkovit a földpátszemcse mikrorepedés-hálózatában is megjelenik. ×N

Myrmekite and flame perthite are frequently found at the margin of larger *microcline* crystals. In the well-foliated rock types myrmekite often occurs in the slightly asymmetric shortening quarters in the rim of large microcline grains. This microstructural arrangement, together with flame-perthites at the grain boundaries, indicates intensive ductile shearing (SIMPSON, WINTSCH 1989; PRYER 1993; PRYER, ROBIN 1995).

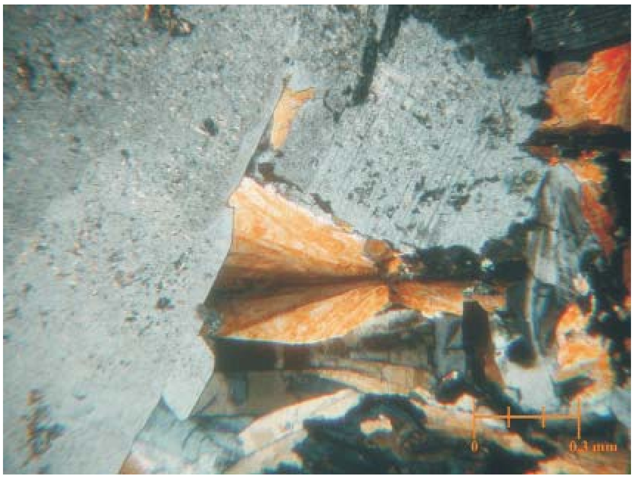

Figure 8. Microfabric detail from a weakly-deformed monzonite (Üh-27, 137.45 m)

Fibrous prehnite crystals among large, euhedral plagioclase grains. ×N

8. ábra. Szöveti részlet alig deformált monzonitból (Üh-27 fúrás, 137,45 m)

Szálas prehnitkristályok plagioklásztáblák között. ×N

According to the microprobe measurements, the original composition of *amphiboles* also changed: *actinolite* with high Mg content (occasionally almost tremolite) was formed at the expense of the magmatic magnesio-hornblende.

Determination of the metamorphic facies

The observed microstructural changes and metamorphic mineral reactions, as well as the mineral paragenesis (*i.e.* stable biotite and amphibole) during ductile deformation suggest a basically higher-temperature *greenschist facies* conditions (>350 °C) for the metamorphism. It is in agreement with the formation of secondary, metamorphic biotite, epidote, zoisite, and elongated–flattened quartz lenses with a dynamically recrystallised internal structure. These have been described by JANTSKY (1953), who regarded all these features as proofs of "epizonal" metamorphism.

Absolutely fresh amphibole in large quantities (according to microprobe measurements uniformly magnesio-hornblende), associated with biotite and dynamically recrystallised plagioclase (uniformly oligoclase), and microcline were found in a strongly mylonitic monzonite sample from Borehole Üh–27 (200.5 m). This paragenesis indicates that the metamorphic temperature could reach the transitional zone between the greenschist and amphibolite facies (approximately 500-550 °C) during ductile deformation.

The role of *chlorite* is still problematic. It is absolutely missing in many strongly deformed rocks. In other cases, it seems to replace deformed biotite. At first sight, this phenomena could indicate that chlorite was predominantly formed after the metamorphism. On the other hand, chloritisation shows a good correlation with the "intensity" of foliation (namely, the proportion of chlorite is higher in the well-foliated rocks) in the southern part of the research area (DITRÓI-PUSKÁS 1998). We can suppose that chloritisation is also a metamorphic process, but it is connected to the later, lower-temperature phase of metamorphism.

Metamorphic rocks in the Mórágy Granite

Metasandstones and *metasiltstones* (Bátaapáti Member, Ófalu Formation, BALLA et al. 2003) occur near the northern margin of the granitoid body. They are restricted to a 100-150 m wide strip, 0.8-1 km south-east of the Mecsekalja Zone, as JANTSKY (1979) recognised earlier. The metamorphites form 5–20 m wide, slab-like bodies — most probably lenses — within this strip. The strip itself can be followed for a distance of approximately 2.5 km along the strike from the estern side of the Hutai Valley to the north-eastern side of the Körtvélyesi Valley (BALLA et al. 2003).

The lenses have a rather steep *position* and they dip mostly to the NW, occasionally to the SE with an angle exceeding 80°. This orientation is practically the same as that of the steep foliation (S_1) in the Mórágy Granite Formation (MAROS et al. 2004) and it is also very similar to the main structural features of the Mecsekalja Zone.

According to the microscopic investigations the *striped structure* observed in these rocks (of an outcrop scale) originates from the primary sedimentary bedding. A weak gradation and compositional changes can, albeit rarely, also be identified (LELKESNÉ FELVÁRI 2002). The metamorphic foliation which has developed in these rocks cuts the bedding at low angles (maximum 20-25°) and can be distinguished by small biotite flakes. The flakes occur in large quantities and are aligned parallel to their long axis. Locally, small, tight to isoclinal folds can be observed in the bedding planes. Both the bedding and the foliation have a very similar orientation to the position of the metasandstone lenses themselves. The orientation of the foliation in the metasandstone is roughly parallel to that of the weakly-foliated host granitoid rocks in the outcrop at the abandoned Bátaapáti wine-cellars.

The *contact* of the metasandstone bodies and the granitoid rocks is generally sharp in the outcrops; however, there is no trace of a large-scale brittle or ductile shear along the boundaries of these rocks.

The *mineralogical composition* of the metasandstones (metasiltstones and slates) is characterised by fine-grained, subhedral–anhedral quartz, plagioclase, biotite, and (locally) K-feldspar. In the quartz–feldspar-rich layers and lenses polygonal microfabric is widespread suggesting static recrystallisation. The biotite appear as small (0.1–0.5 mm), internally undeformed, oriented flakes, or locally, stacks aligned parallel to their long axis. Besides these, muscovite is also occasionally present in relatively large quantities. Tourmaline is a very characteristic accessory mineral forming euhedral and the relatively large grains contain small quartz inclusions. Opaque minerals also occur in relatively large quantities and sometimes epidote and clinoziosite appear as well. Further accessories are zircon and apatite.

In certain samples very fine-grained, light yellow (1N), round to oval-shaped, often oriented, elongate aggregates (pseudomorphs?) are characteristic. These aggregates consist of very fine-grained biotite, muscovite (sericite) and quartz. According to the microprobe measurements these could represent the alteration products of K-feldspar. LELKESNÉ FELVÁRI (2002) interprets these aggregates as probably being pseudomorphs after andalusite and/or cordierite. The prevailing metamorphic paragenesis observed in most metasandstones suggests a metamorphic effect of an approximately biotite isograde.

Volcanic dykes in the Mórágy Granite Formation

The Mórágy Granite Formation, the metamorphic rocks of the Mecsekalja Zone (Ófalu Formation), and the Vasas Formation NW of the Zone (BALLA et al. 2003) are crosscut by steeply dipping (~70°), mostly (and approximately) NE-SW striking subvolcanic dykes with a maximum width of 6 m. At the northern part of the Mórágy Block (Trench A2, Huta and Nagymórágy Valley, quarry of Kismórágy) the dyke swarms can be followed for some kilometres. The age of these dykes is reckoned to be Cretaceous on the basis of petrographical analogies.

A detailed petrographic description of the volcanic dykes *from the outcrops* on the north-eastern part of the Mórágy region was given by HARANGI (2003). He recognised (1) orange-coloured trachyte with sanidine phenocrystals ("bostonite") and (2) greenish grey tephrite with pseudomorphs after nepheline, olivine and amphibole and/or with small biotite. One sample is very similar to that of the intrusive breccia from a borehole (see below).

Two Lower Cretaceous volcanic suites of the Eastern Mecsek area were distinguished by HARANGI, ÁRVA-SÓS (1993) based on mineralogical and geochemical characteristics. The ancaramite–alcalic basalt suite is strongly porphyric with olivine and clynopyroxene phenocrystals. Apart from these minerals the matrix contains plagioclase and Fe–Ti oxides as well. The basanite–phonolite suite is undersaturated in Si. Apart from plagioclase, amphibole, biotite, and needle-like apatite also occur in this suite.

According to HARANGI (2003), the tephrites from the outcrops of the Mórágy Block display some similarities to the basanite–phonolite suite from the eastern Mecsek Mountains. However, the rocks of the latter are more enriched in mafic components. Trachyte also exhibits some similarities in geochemical character to the basanite–phonolite suite; however, there is no similarity in their petrographic features.

The *boreholes* (Üh–27 in 396.95–405 m and Üh–29 in 238.56–264.05 m) penetrated greenish grey, strongly altered (montmorillonitised) volcanic dykes which have a maximum width of 4.22 m. At their margins chilled zones or intrusive breccias can be detected and occasionally feldspar grains such as xenocrystals from the granitoid rocks are also present. The rocks show magmatic flow-structures, and their texture is porphyric–intersertal. Two types of pseudomorphs after feldspar and amygdales (filled with calcite) can be observed. The K-feldspar/plagioclase ratio measured by X-ray diffraction is about 0.5-1.

The dykes cut by the boreholes are neither unambiguously analogous to dykes studied in quarries of the Mórágy region, nor to igneous rocks of the Eastern Mecsek. However according to HARANGI (2003) some similarities can be recognised. These rocks are similar to tephritic dykes from the outcrops of the Mórágy Block in their textural orientation and the presence of amygdales filled with calcite. They are, however, more leucocratic than the basanite–phonolite suite of the Eastern Mecsek Mountains. Therefore, their relationship is unclear.

Summary

Rocks from the Mórágy Granite Formation were formed by the mixing of felsic and mafic magmas. The evidence for the magma mixing is supported by: the features and analyses of the contacts of the main rock types, the similarities in mineralogical compositions and mineral chemistry, and by the similar geochemical features of both rock types. The mafic enclaves with amphibole aggregates represent relics of a non-perfect magma mixing, while the "diluted" enclaves may indicate the homogenised or partly homogenised portions of the complex.

Leucocratic, late-magmatic dykes crosscut the nearly solidified complex which is characterised by sharp contacts, while lobated injection towards the host rock which has been formed mostly from microcline can also be detected along the contacts.

The magmatic crystallisation of the Mórágy Granite Formation was followed by metamorphism. The metamorphism appears mostly in structural aspects, emphasised first of all by the formation of a NE–SW striking, regional foliation. Classical metamorphic mineral transformations and chemical changes have also occurred, but these are less characteristic. Based on microstructural features and the respective mineralogical composition of the rocks, the metamorphic temperature can be broadly placed into the higher greenschist facies (>350 °C) during the ductile deformation, and it could have reached a maximum — at least in certain zones — approximately 500-550 °C.

The metamorphic event with its variable intensity can be traced within the whole granitoid body. The ductile structures are parallel to the strike of those within the neighbouring Mecsekalja Zone and to the Zone itself. Therefore, it seems very likely that the character of the metamorphism is regional.

References — Irodalom

BALLA Z. 2000: Kis és közepes radioaktivitású erőművi hulladékok végleges elhelyezése. Az üveghutai telephely. Földtani összesítés biztonsági értékeléshez (in Hungarian: Final disposal of low- and intermediate-level radioactive waste from the nuclear power plant. Geological summary for the safety assessment). – *Manuscript,* Geological Institute of Hungary, Budapest.

BALLA Z., ALBERT G., CHIKÁN G., DUDKO A., FODOR L., FORIÁN-SZABÓ M., FÖLDVÁRI M., GYALOG L., HAVAS G., HORVÁTH I., JÁMBOR Á., KAISER M., KOLOSZÁR L., KOROKNAI B., KOVÁCS-PÁLFFY P., MAROS GY., MARSI I., PALOTÁS K., PEREGI ZS., RÁLISCH L.-NÉ, ROTÁRNÉ SZALKAI Á., SZŐCS T., TÓTH GY., TURCZI G., PRÓNAY ZS., VÉRTESY L., ZILAHI-SEBESS L., GALSA A., SZONGOTH G., MEZŐ GY., MOLNÁR P., SZÉKELY F., HÁMOS G., SZŰCS I., TURGER Z., BALOGH J., JAKAB G., SZALAI Z. 2003: Az atomerőművi kis és közepes aktivitású radioaktív hulladékok végleges elhelyezésére irányuló program. A felszíni földtani kutatás zárójelentése, Bátaapáti (Üveghuta), 2002–2003 [in Hungarian: Programme for final disposal of low- and intermediate-level radioactive waste from the nuclear power plant. Final report of the geological exploration from the ground surface, Bátaapáti (Üveghuta), 2002–2003]. – *Manuscript,* Geological Institute of Hungary, Budapest.

BALOGH, K., ÁRVA-SÓS, E., BUDA, G. 1983: Chronology of granitoid and metamorphic rocks of Transdanubia (Hungary). – *Anuarul Institutului de Geologie şi Geofizică* 61, pp. 359–364.

BUCHER, K., FREY, M. 1994: *Petrogenesis of metamorphic rocks.* – Springer Verlag, Berlin, Heidelberg, 318 p.

BUDA, GY. 1974: Investigation of the alkali feldspar polymorphs of the Hungarian granitoid rocks. – *Acta Geologica Academicae Scientiarum Hungaricae* 18 (3–4), pp. 465–480.

BUDA GY. 1985: Variszkuszi korú kollíziós granitoidok képződése Magyarország, Ny-Kárpátok és a Központi Cseh (Bohémiai)-masszívum granitoidjainak példáin. Kandidátusi értekezés (in Hungarian: Origin of Variscan collision granites on examples of the granites from Hungary, West Carpathians and Central

Bohemian Massif. Doctoral dissertation). – *Manuscript,* Library of the Hungarian Academy of Sciences Budapest.

BUDA GY. 1996: Összefoglaló jelentés az Üveghuta-1 mélyfúrás granitoid kőzeteinek vizsgálatáról (in Hungarian: Summary report on the studying the granitoid rocks from Borehole Üveghuta-1). – *Manuscript,* Geological Institute of Hungary, Budapest.

BUDA GY. 1998: Összefoglaló jelentés az Üveghuta-2, -3, -4, -5, -6, -8 mélyfúrások granitoid kőzeteinek vizsgálatáról (in Hungarian: Summary report on the studying the granitoid rocks from Boreholes Üveghuta-2, -3, -4, -5, -6, -8). – *Manuscript,* Geological Institute of Hungary, Budapest.

BUDA GY. 1999: Összefoglaló jelentés az Üveghuta-22, -23, -24 mélyfúrások granitoid kőzeteinek vizsgálatáról (in Hungarian: Summary report on the studying the granitoid rocks from Boreholes Üveghuta-22, -23, -24). – *Manuscript,* Geological Institute of Hungary, Budapest.

BUDA GY., PUSKÁS Z., GÁL-SÓLYMOS K., KLÖTZLI, U., COUSENS, B. L. 2000: Mineralogical, petrological and geochemical characteristics of crystalline rocks of the Üveghuta boreholes (Mórágy Hills, South Hungary) [Üveghutai mélyfúrások kristályos kőzeteinek ásvány-kőzettani és geokémiai jellemzése (Mórágyi-rög)]. – *Annual Report of the Geological Institute of Hungary, 1999,* pp. 231–252.

CSALOGOVITS I. 1964: De la palingénese calédonienne et des rapports de grande tectonique du massiv de socle cristallin du sud du bassin Pannonien (Cisdanubie). – *Annales Historico-Naturalis Musei Naturalis Hungarici* 56, pp. 31–57.

VAN DAALEN, M., HEILBRONNER, R., KUNZE, K. 1999: Orientation analysis of localized shear deformation in quartz fibres at the brittle-ductile transition. – *Tectonophysics* 303 (1–4), pp. 83–107.

DEBON, F. 1991: Comparative major element chemistry in various "microgranular enclave-plutonic host" pairs. – In: DIDIER, J., BARBARIN, B.: *Enclaves and granite petrology,* Elsevier, Amsterdam-Oxford – New York – Tokyo, pp. 293–313.

DIDIER, J., BARBARIN, B. 1991: *Enclaves and Granite Petrology.* – Elsevier, Amsterdam – Oxford – New York – Tokyo, 625 p.

DITRÓI-PUSKÁS Z. 1996: A Mórágyi-rög gránitterületén mélyült Üveghuta-1 (Üh-1) fúrás anyagának kőzettani vizsgálata [in Hungarian: Petrographical study of the rocks from Borehole Üveghuta-1 (Üh-1) drilled in the Mórágy Block]. – *Manuscript,* Geological Institute of Hungary, Budapest.

DITRÓI-PUSKÁS Z. 1998: A Mórágyi-rög gránitterületén mélyült Üveghuta (Üh) környéki Üh-2, Üh-3, Üh-4, Üh-5, Üh-6 és Üh-8 fúrások anyagának kőzettani vizsgálata [in Hungarian: Petrographical study of the rocks from Boreholes Üveghuta (Üh) Üh-2, Üh-3, Üh-4, Üh-5, Üh-6 and Üh-8 drilled in the Mórágy Block]. – *Manuscript,* Geological Institute of Hungary, Budapest.

DITRÓI-PUSKÁS Z. 1999: Kis és közepes radioaktivitású erőművi hulladékok végleges elhelyezése. Telephelykutatás Üveghuta körzetében. A Mórágyi-rög gránitterületén mélyült Üveghuta (Üh) környéki Üh-22, Üh-23 és Üh-24 fúrások anyagának kőzettani vizsgálata [in Hungarian: Petrographical study of the rocks from Boreholes Üveghuta (Üh) Üh-22, Üh-23 and Üh-24 drilled in the Mórágy Block]. – *Manuscript,* Geological Institute of Hungary, Budapest.

FERNANDEZ, A. N., BARBARIN, B. 1991: Relative rheology of coeval mafic and felsic magmas: Nature of resulting interaction processes. Shape andmineral fabrics of mafic microgranular enclaves. – In: DIDIER, J. BARBARIN, B (eds): *Enclaves and granite petrology.* Elsevier, Amsterdam-Oxford – New York – Tokyo, pp. 263–277.

HARANGI SZ. 2003: Mecseki kőzetminták petrográfiai leírása és kőzettani összehasonlítása a Keleti Mecsekben előforduló alsó-kréta vulkáni kőzetekkel (in Hungarian: Petrographical description of rock samples from the Mecsek Mountains and their petrographical comparison with the Lower Cretaceous volcanic rocks which occur in the Eastern Mecsek Mountains). – *Manuscript,* Geological Institute of Hungary, Budapest.

HARANGI SZ., ÁRVÁNÉ SÓS E. 1993: A Mecsek hegység alsó-kréta vulkáni kőzetei I. Ásvány- és kőzettan [Early Cretaceous volcanic rocks of the Mecsek Mountains (South Hungary) I. Mineralogy and Petrology]. – *Földtani Közlöny* 123 (2), pp. 129–165.

HÁDEN S. 1997: A fazekasboda–mórágyi-röghegységi granitoidok kálifoldpátjainak ásványtani vizsgálata. Szakdolgozat (in Hungarian: Mineralogical study of the potassium feldspars from the granitoids of the Fazekasboda–Mórágy Block). – *Manuscript,* Eötvös Loránd University, Faculty of Natural Sciences, Mineralogical Department, Budapest.

HORVÁTH P., NAGY G., DEMÉNY A. 2003: Üveghutai granitoid képződményekből készült vékonycsiszolatok ásványfajtáinak elektron-mikroszondás vizsgálatairól (in Hungarian: On the electron microprobe analysis of the thin sections made of granitoid rocks from Üveghuta). – *Manuscript,* Geological Institute of Hungary, Budapest.

JANTSKY B. 1953: A mecseki kristályos alaphegység földtani viszonyai (in Hungarian, with French abstract: Les conditiens géologiques du socle cristallin du Mecsek). – *Annual Report of the Geological Institute of Hungary, 1950,* pp. 65–77.

JANTSKY, B. 1979: (mecseki gránitosodott kristályos alaphegység földtana (in Hungarian: Géologie du socle cristallin granitisé de la montagne Mecsek). – *Annals of the Geological Institute of Hungary* 60, 385 p.

KIRÁLY E. 2001: Vékonycsiszolatok petrográfiai leírása, Üveghuta. Üh-2, Üh-3, Üh-4, Üh-5, Üh-22, Üh-23 (in Hungarian: Petrographic description of thin sections, Üveghuta Üh-2, Üh-3, Üh-4, Üh-5, Üh-22, Üh-23). – *Manuscript,* Geological Institute of Hungary, Budapest.

KIRÁLY E. 2002: A Nyugat-Mecsek, a Görcsönyi-hátság, a Mecsekalja-zóna és a mórágyi régió amfiboltartalmú kőzeteinek fejlődéstörténete vékonycsiszolatos, elektron-mikroszondás és geokémiai vizsgálatok alapján. Doktori értekezés (in Hungarian: Evolution of the amphibole-bearing rocks of the Görcsöny Ridge, Mecsekalja Zone and Mórágy Region based on petrographic, electron microprobe and geochemical investigations. Ph.D. Thesis). – *Manuscript,* Eötvös Loránd University, Budapest.

KIRÁLY E. 2003: A gránit kőzettani értékelése (in Hungarian: Petrological evaluation of the granite). – *Manuscript,* Geological Institute of Hungary, Budapest.

KIRÁLY, E., TÖRÖK, K. 2003: Magmatic garnet in deformed aplite dykes from the Mórágy granitoid, SE Transdanubia, Hungary. – *Acta Geologica Hungarica* 46 (3), pp. 239–254.

KLÖTZLI, U. S., BUDA, GY., SKIOLD, T. 2004: Zircon typology, geochronology and whole rock Sr–Nd isotope systematics of the Mecsek Mountain granitoids in the Tisia Terraine (Hungary). – *Mineralogy and Petrology* 81 (1–2), pp. 113–134.

KOROKNAI B. 2003: Az irányított minták mikrotektonikai vizsgálata és összefoglaló értékelése (in Hungarian: Microtectonic study and summarising evaluation of the oriented samples). – *Manuscript,* Geological Institute of Hungary, Budapest.

LELKESNÉ FELVÁRI GY. 2002: Bátaapáti környéki metamorf kőzetek vékonycsiszolati leírásai (in Hungarian: Description of thin sections made of metamorphic rocks from the surroundings of the village of Bátaapáti). – *Manuscript,* Geological Institute of Hungary, Budapest.

MAROS GY., KOROKNAI B., PALOTÁS K., FODOR L., DUDKO A., FORIÁN-SZABÓ M., ZILAHI-SEBESS L., BÁNNÉ GYŐRY E. 2004: Tectonics and structural history of the north-eastern Mórágy Block (A Mórágyi-rög ÉK-i részének tektonikája és szerkezetalakulása). – *Annual Report of the Geological Institute of Hungary, 2003* (this volume).

PITCHER, W. S. 1997: *The nature and origin of granite.* – Chapman & Hall, London, 387 p.

PRYER, L. L. 1993: Microstructures in feldspars from a major crustal thrust zone: the Grenville Front, Ontario, Canada. – *Journal of Structural Geology* 15 (1), pp. 21–36.

PRYER, L. L., ROBIN, P. Y. F. 1995: Retrograde metamorphic reactions in deforming granites and the origin of flame perthite. – *Journal of Metamorphic Geology* 14 (1), pp. 645–658.

ROTH S. 1875: A Fazekasboda–mórágyi hegylánc eruptív kőzetei (in Hungarian: Eruptive rocks of the Fazekasboda–Mórágy Hills). – *Földtani Közlöny* 5 (1–12), pp. 135–145.

SIMPSON, C., WINTSCH, R. P. 1989: Evidence for deformation-induced K-feldspar replacement by myrmekite. – *Journal of Metamorphic Geology* 7 (2), pp. 261–275.

SZÁDECZKY-KARDOSS E. 1959: A kárpáti közbenső tömeg magmás mechanizmusáról (in Hungarian: On the mechanism of the magmatism of the Carpathian Median Massif). – A Magyar Tudományos Akadémia Műszaki Tudományok Osztályának Geokémiai Konferenciája, 1959. október 5–10. 2. kötet (Conference on Geochemistry of the Department of Technical Sciences of the Hungarian Academy of Sciences, 5–10. October, 1959, Volume 2). – *Manuscript,* Hungarian Academy of Sciences, Budapest.

VERNON, R. H. 1991: Interpretation of microstructures of microgranitoid enclaves. – In: DIDIER, J., BARBARIN, B.: *Enclaves and granite petrology,* Elsevier, Amsterdam – Oxford – New York – Tokyo, pp. 277–293.

WINKLER, H. G. F., SCHULTES, H. 1982: On the problem of alkali feldspar phenocrysts in granitic rocks. – *Neues Jahrbuch für Mineralogie, Monatshefte,* 1982 (12), pp. 558–564.