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STRUCTURAL EVOLUTION OF MYLONITIZED GNEISS ZONE FROM THE NORTHERN FLANK OF THE SZEGHALOM DOME (PANNONIAN BASIN, SE HUNGARY)

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ABSTRACT

Metamorphic basement of the Pannonian Basin consists of blocks of incompatible metamorphic and structural evolution in the area of the Szeghalom high. Here evolution of a large-scale shear zone from the northern flank of the uplifted dome is studied. Textural relics suggest that the original rock type was orthogneiss widespread in the surroundings. Deformation produced a wide (over 200 m) shear zone with well-developed mylonite in the centre. We show, that the deformation followed the last progressive metamorphic event of the basement.

Key words: Pannonian Basin, orthogneiss, shear zone, mylonite

INTRODUCTION

Although metamorphic basement of the Pannonian Basin was regarded substantially impermeable for a long time, more recent works demonstrated that the fractured basement plays a significant role in the present hydraulic system of the Pannonian Basin (Tóth et al., 2001). This highly deformed rock mass not only conducts and stores a huge amount of water, it also contains a significant amount of hydrocarbon, which could migrate to the basement rocks along tectonic zones from the adjacent, deeper sedimentary basins.

One of the most important basement reservoirs in the Pannonian Basin is the Szeghalom Dome (SzD), which is part of the elevated basement highs embracing the deep Békés Basin on the north (Fig. 1). Previous studies suggested a rather complicated structure of the region. Analysing seismic data D. Lőrincz (1996) inferred activity of seven subsequent tectonic events from the Upper Cretaceous up to present for the wide surroundings. SzD itself was subdivided into four blocks of incompatible metamorphic and structural evolution, which got juxtaposed due to Neogene movements (M Tóth et al., 2000). They mention mylonitized gneiss samples from the northern flank of the crystalline high in question, which produce evidence for a considerable ductile shear zone. Unpublished reports of the Hungarian Oil- And Gas Co. regularly mention mylonite in core description based on the disturbed fabric of the rock too.

The aim of this study is to characterise the shear zone of the northern SzD based upon the changing microstructural features along the wide shear zone. Samples were collected from core material of two neighbouring wells, which penetrated the basement from a moderately deformed gneiss zone down to mylonite. Characterisation of this event is of basic importance in case of the fractured oil reservoir, because tectonic zones of different evolution may result in rather distinct migrational properties.

GEOLOGICAL SETTING

Based on geochemical, petrological and age constraints Szeghalom Dome (SzD) can be subdivided into four independent regimes (M Tóth et al, 2000). Three of them form the southern and central parts of the high, while the northern flank consists of a single block dominated by medium grade orthogneiss and post-kinematic granite.

Igneous relics in the gneiss are widespread throughout the area. M Tóth et al. (2002) inferred altered myrmekitic inclusions in fresh K-feldspar grains of magmatic origin that is also confirmed by the frequent appearance of euhedral zircon, apatite and tourmaline crystals. Resorbed garnet

Fig. 1. Map of the Békés Basin and the surrounding metamorphic highs. Present-day depth of the pre-Neogene basement is shown. Inset: Location of the Pannonian Basin in the Alpine-Carpathian-Pannonian system.

indicates the earliest metamorphic event of the area, which was followed by cooling down allowing pseudomorphic replacement of garnet by chlorite. Secondary biotite generally surrounds these chlorite-bearing pseudomorphs suggesting a second progressive event (M Tóth et al., 2000). The peak of this metamorphism did not reach 600 °C.

There is not much presented about the deformation history of the northern SzD orthogneiss terrane. Mylonite samples of the neighbouring Sz-É-2 and -11 wells, nevertheless, clearly suggest the presence of a ductile shear zone.

METHODS

18 rock specimens were studied, which represent the two wells with significant hiatuses. The cores are not oriented. Thin sections were made along the plane perpendicular to the foliation and parallel to the lineation.

RESULTS

In order to be able to reconstruct the petrological, microstructural and geochemical constraints of the deformation event observed in several borecores from the northern flank of the SzD, we studied samples from two neighbouring wells, Sz-É-2 and Sz-É-11, respectively. Both wells penetrated the metamorphic basement over a hundred metres and served a sufficient material for a detailed petrological and geochemical study.

Petrography

Petrographically, each sample studied reminds of an analogous starting material, the studied wells penetrated the two-feldspar biotite gneiss terrane typical in the surrounding area. A continuous change in both mineralogical and microstructural properties of the gneiss can be followed along the wells, while maximal strain is reached at the deepest structural level. The most obvious parameters, which appoint to the vertical variation, are the following:

a) matrix biotite is increasingly replaced by chlorite,
b) chlorite is replaced by muscovite,
c) average grain size decreases,
d) number of the garnet pseudomorphs diminishes,
e) quantity of opaque grains parallel to the mean foliation increases,
f) the strongly folded, gneissosity (S1) diminishes and is succeeded by a mylonitic foliation (S2).

Based on these features the rock column was divided into three rough intervals. The uppermost zone is only hardly deformed allowing the original textural features clearly observe. The deepest zone exhibits a pure mylonitic texture, and we also defined a transition zone between the two extremes. Hereafter petrographical characterization of the three zones follows.

Uppermost zone

The rather disturbed and non-contiguity foliation of the gneiss is defined by reddish brown to dark green coloured biotite flakes. At places the foliation is strongly folded, and biotite forms kink-band microstructure. Biotite is partially replaced by chlorite and contains interlayered carbonate grains. Some feldspar clasts exhibit a continuous excitation from the rim to the core and usually are strongly altered to sericite inside. The most frequent accessory phases are apatite, zircon and tourmaline, which show euhedral and subhedral habit. Apatite crystals range in size up to 400 µm. Large, isometric relics were found in all structural levels consisting mainly of chlorite, quartz and an undetermined carbonate phase. In the core of a few of these pseudomorphs also small (300 µm) garnet remnant could survive. Quartz grains usually are aligned in curved (S-shape) (Fig. 2A) rows.

Some feldspar grains contain V-shaped deformation twins, which are tapered to towards the crystal centre and are restricted to certain parts of a crystal (Fig. 2B) (Passchier et al., 1996). Both the growth twins and the deformation twins are often curved.

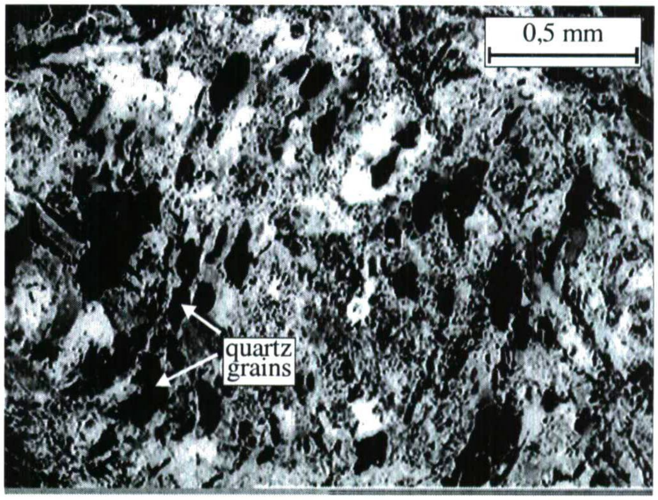

Fig. 2A. Microphoto of garnet pseudomorph with subvertical, curved inclusion trails (invert photo).

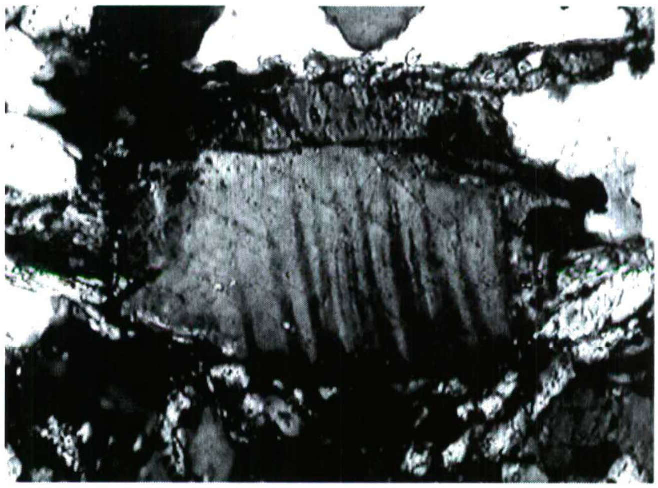

Fig. 2B. Microphoto of V-shaped, slightly curved deformation twins in feldspar.

Transition zone

Rock samples of the transition zone consist essentially of medium-grained feldspar and quartz. Biotite is almost entirely replaced by chlorite. The rock is determined by S2 mylonitic foliation, S1 gneissosity occurs only in relic fragments.

Mineral aggregates of sigmoidal shape are common, in which the core is composed of feldspar and recrystallized quartz forms the wings. Quartz generally develops recrystallized and strongly elongated lenses or ribbons, which generally are bordered by phyllosilicate packets. Huge quartz grains (ca 10 mm) are boudinaged and oriented sub-parallel to the S2. The neck and fractured parts within the boudins consist of carbonate (Fig. 2C). Also carbonate grains form ribbons along the S2 foliation, which are characterized by sub-microscopic grain size and a dark brown colour.

There are only a few garnet pseudomorphs of the type mentioned above, which are rimmed by an asymmetric (stair stepping) aggregate of fine-grained minerals (Fig. 2D). The rim of the pseudomorph is formed by biotite, while the wings consist of carbonate, and chlorite in the internal core. The accessory minerals mentioned earlier also occur in the transition zone, although apatite crystals are smaller in size and show rounded, fractured habit.

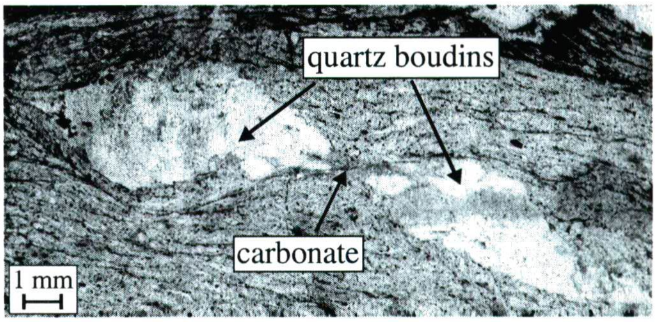

Fig. 2C. Microphoto of quartz boudinage with a neck composed of carbonate.

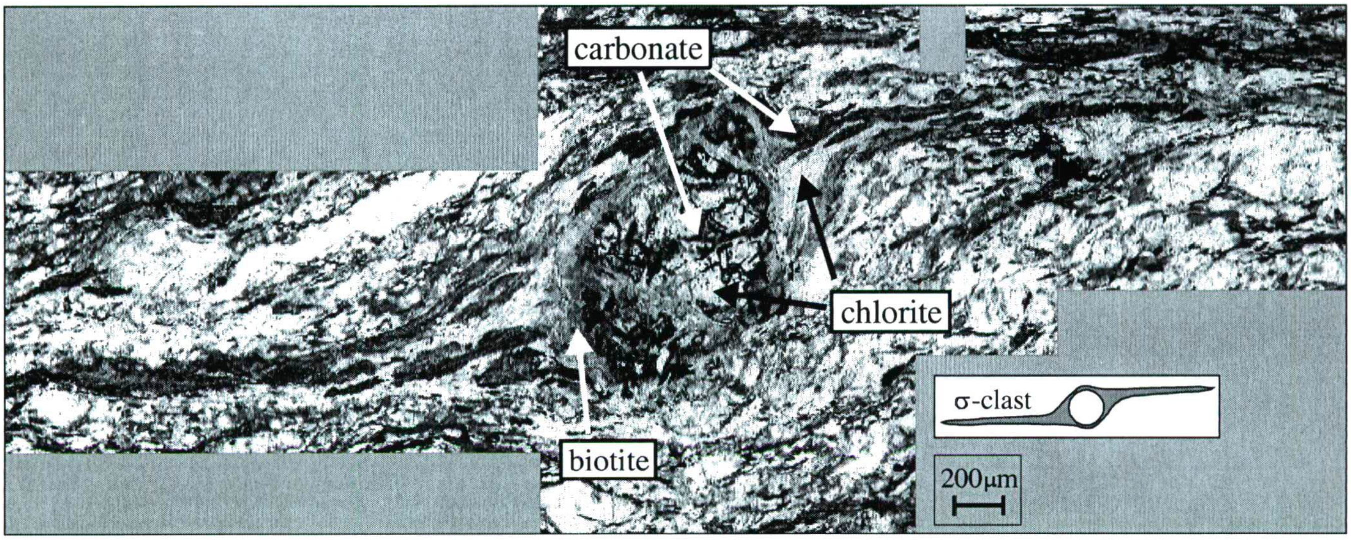

Fig. 2D. Combined microphoto of mantled porphyroclast surrounded by recrystallized chlorite-carbonate wings.

Lowermost zone

The rock samples, which represent the deepest explored part of the shear zone consist mainly of quartz and chlorite. There is no trace of S1 gneissosity in the rock matrix, S2 foliation is defined by high contiguity chlorite bunches. The main foliation is often crosscut by high strain shear bands (S3), which contain fine-grained quartz ± chlorite ± carbonate infill (Fig. 2E). In addition white mica of pale green colour occurs. Its up to 3 mm small flakes generally form mica fishes parallel to the S2 foliation. Along the cleavage plains of the mica flakes, tails of opaque mineral grains appear.

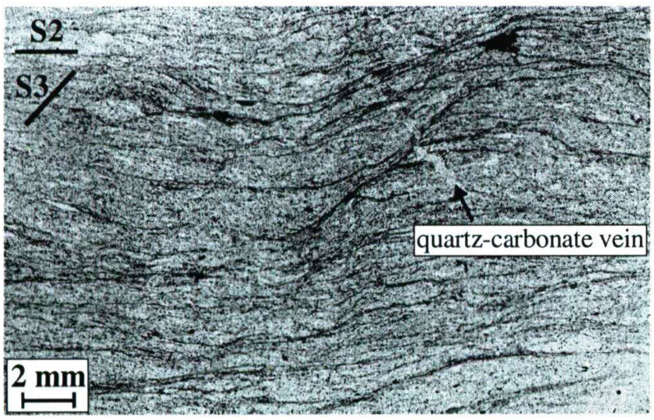

Fig. 2E. Microphoto of S/C mylonite from the lowermost zone.

In all structural levels of the shear zone studied microstructural features of a post-mylonitic deformation occur. In some hand specimens fresh mylonite and cohesive breccia are in contact along a sharp boundary. The fine-grained carbonate-cemented breccia encloses fractured pieces of the adjacent mylonite. In several parts fractured quartz grains with a strong undulose extinction form chocolate tablet microstructure. The reconstructed shape of the fragments, which are sitting in a very fine-grained carbonate matrix, resembles a boudinage structure (Fig. 2F). Some of these quartz grains also contain an extremely high number of secondary fluid inclusion planes. All along the wells steeply dipping veins with an aperture of about 0.5–1 mm crosscut sub-horizontal S2 foliation. The host rock is uneven along the vein walls and optically does not indicate alteration. Vein filling minerals are similar along the wells, with a various proportion of the phases; pyrite, quartz and various carbonate phases.

Discussion

Remnants of the metamorphic evolution

Because of the strong deformation, the rock studied could not preserve much evidence for the details of its metamorphic evolution. Zoned feldspar grains with sericitic inclusions as well as euhedral accessory phases (apatite, zircon) of the uppermost zone are important textural features of the orthogneiss common in the whole northern part of the SzD (M Tóth et al., 2002). Mineralogy and texture of the garnet replacing chlorite and calcite bearing pseudomorphs are identical to those described by M Tóth et al. (2002) characteristic of the region. Preserved snowball structure outlined by quartz inclusion trails in these structures suggests garnet of metamorphic origin instead of an igneous relic phase.

Samples studied show a homogeneous lithology along the two wells, which is identical to the common orthogneiss of the northern flank of the SzD.

Development of the shear zone

The significant grain size reduction towards the lowermost zone is caused by different deformation mechanisms, which depend on the rheology of the minerals involved at the given temperature and strain rate. The size of the hard mineral grains (such as feldspar and muscovite in part) can be reduced by brittle deformation, while different dynamic recrystallization processes transform quartz grains.

In the lower part of the shear zone mica fishes, asymmetric porphyroclasts and S3 shear band cleavage (SBC) show characteristic monoclinic appearance indicating a deformation with a dominant non-coaxial component. Mica fish may form by a combination of brittle and crystal-plastic processes (Lister et al., 1984). On microscopic scale the spacing between S3 cleavage domains is relative large (2-4 bands per thin sections). Based on the arrangement and shape of the S2 and S3 cleavages, they form an S/C fabric (Lister et al., 1984). The age relationship of the S-C-surfaces has been discussed by several authors (e.g. Berthé et al., 1979; Platt et al., 1980; Vernon et al., 1983). Berthé et al. (1979) suggest that the S/C-surfaces develop simultaneously, while others (e.g. Vernon et al. (1983)) concluded that the accumulation of finite strain first led to the development of foliation (the S-surfaces) and later (ongoing) deformation led to the formation of cross-cutting shear bands (the C-surfaces). Since in the studied samples the S3 (C) planes clearly crosscut the much more developed S2 (S) planes, we prefer the successive evolution model and use the S2-S3 terminology. Trails of mica flakes often surround recrystallized quartz ribbons on both sides, making recrystallization of quartz possible, but also restrict its change in external shape or form.

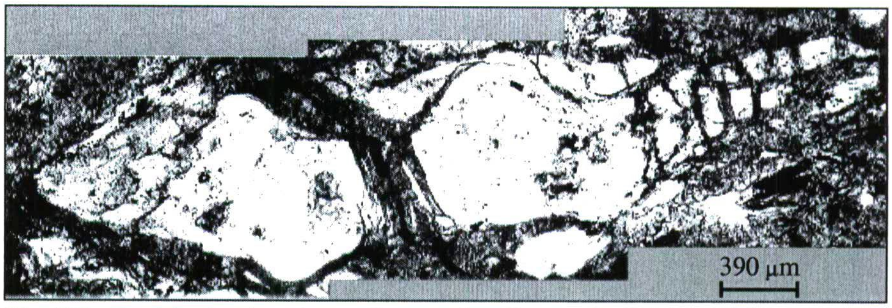

Fig. 2F. Combined microphoto of quartz boudinage effected by subsequent brittle deformation forming chocolate tablet structure.

After Passchier (1991b) S/C fabric is a common feature of strongly foliated extensional mylonites. The well-developed S-surfaces (S2) relative to the C-planes (S3) suggest that the rock is a Type I mylonite in the terminology of Lister et al. (1984). Since the shear zone boundary was not observed on the core material, a more exact specification of the SBC (Berthé et al., 1979a,b) is not possible. The shear bands in the study area are filled by chlorite±quartz±carbonate, which is consistent with McCaig's (1987) observations, namely that the shear band cleavage is usually indicative of retrograde metamorphic conditions.

The strongly elongated and flattened quartz grains usually show strong undulose extinction, which is probably caused by the interaction of diverse mechanisms. In addition to crystalplastic processes (dislocation creep, solid state diffusion) also pressure solution may form elongated quartz ribbons, especially because it is the favourable deformation mechanism of quartz at relatively low homologous temperature in the presence of water (Passchier et al., 1996). LT conditions can be deduced from the complicated quartz-to-quartz sutures (Kruhl et al., 1996) observed. Bulging might indicate grain boundary migration during the deformation (Passchier et al., 1996).

Softening, which is generally ascribed to nucleation and development of ductile shear zones is often related to fluid migration and infiltration (Ingles et al., 1999). Kerrich et al., (1988) suggest that meteoric water might penetrate down to 10-15 km along fault zones. Hydration alteration of strong mineral phases, such as feldspar, was probably a considerable softening process in the study area as well. The progressive grain size reduction is obvious downwards in the shear zone, which through the surface increase of the mineral grains might further promote the effect of hydration weakening. In the upper level of the shear zone the feldspar→mica alteration is the main hydration reaction, while biotite→chlorite becomes more intense towards the deeper levels. Further downwards chlorite→muscovite replacement is dominant. All of these hydration reactions lead to volume reduction (Wintsch et al., 1995), which enables further fluid migration into the shear zone (Rumble et al., 1983). The growth of phyllosilicates via feldspar replacement reactions is a widespread phenomenon in meteoric water-dominated failure systems (Wintsch et al., 1995). The feldspar consuming and clay mineral producing alteration is one of the most effective reactions, which can lower the strength of granitoid rocks. Thus, nucleation and recrystallization of the oriented phyllosilicate grains might further reduce the strength of the rock.

A thin biotite rim surrounds the garnet replacing pseudomorphs of the transition zone. Biotite, however is entirely missing from the fine-grained chlorite and carbonate bearing wings, which frame the pseudomorph on both ends. Such a structure suggests syn-kinematic recrystallization of the garnet replacing chlorite, and in this way the structure might be considered a stair-stepping, σ-type mantled porphyroclast. The presence of biotite in the rim of the pseudomorph and its absence in the wings shows that the deformation proceeded below the biotite isograde. The presence of the clast forming minerals in the wings, on the other hand, suggests that garnet altered to biotite or chlorite prior to or simultaneously with the deformation. Undeformed structures of identical composition are widespread in the northern flank of the SzD and represent a garnet→chlorite→biotite reaction sequence (M Tóth et al., 2000).

The occurrence of carbonate patches parallel to the mylonitic foliation and in the external zone of the wings in the σ-clasts suggests that the fine-grained carbonate precipitated in the entire shear zone during the deformation process. This should correspond with the carbonate precipitated at the maximal elongation zone of the boudinaged quartz grains indicating the presence of carbonate during the ductile deformation.

This estimate agrees well with the presence of re- and neocrystallized quartz grains in absence of any trace of feldspar recrystallization as quartz begins to recrystallize above 270 °C, while feldspar behaves brittle below 450-500 °C (Voll, 1980). Feldspar grains generally exhibit limited ductility in low temperature (greenschist facies) mylonites and they fracture (or recrystallize) before exhibiting any marked elongation (White et al., 1980).

Based on the above microstructural observations we conclude that the lowermost part of the wells represent the most intensively deformed part of a mylonitic shear zone.

The non-continuous, en-echelon arrangement of the veins in the maximal strain zone suggests formation probably by tension, rather than shearing. The angles between the veins and the S2 show a consistent change in the chlorite-rich and chlorite-poor parts of the rock. The dip of the veins decreases abruptly where they crosscut the foliation. Leaving the phyllosilicate-rich plane they return to the original, steep dip. Several authors (Meschede, 1994; Colletta et al., 2002) describe the change in the dip of veins in strongly foliated rocks composing mineral zones of extremely different rheological properties.

On this basis vein formation is thought to be independent from the mylonitic deformation and its PTd properties and relative age constraints are out of scope of the present study.

Traces of brittle deformation observed on quartz boudins ("chocolate tablet structure") as well as the breccation of the mylonite suggest a late tectonic event connected probably to the exhumation of the shear zone. Stable isotopic composition of the carbonate cement of the breccia and investigation of the secondary fluid inclusions in quartz could help to estimate PT conditions of the subsequent brittle event.

CONCLUSIONS

The aim of this study was to interpret microstructural data of a wide ductile shear zone in the northern flank of the SzD. We showed that in the studied wells orthogneiss forms the basement of mineralogical and textural features identical to those described from the whole area previously. In addition to the early igneous history this rock type also encloses the remnants of multiphase metamorphic evolution. Retrogression of the orthogneiss led to the chloritization of garnet, while the often myrmekitic magmatic feldspar altered to sericite (M Tóth et al., 2002). Isometric garnet pseudomorphs are good evidence for low strain during the retrogression. The following progressive event well below 600 °C (M Tóth et al., 2000) resulted in formation of a secondary biotite in place of the chlorite and recrystalization of sericitized feldspar grains as fresh microcline (M Tóth et al., 2002). The fact that undeformed biotite does not appear in the recrystallized wings of the σ-clasts suggests that ductile deformation followed the thermal peak (Fig. 3). Probably due to the late uplift of the gneiss terrane, complicated brittle structures overprinted the mylonitic rocks.

The rock column studied exceeds 200 m in width from the moderately deformed gneiss down to the mylonitic centre of the shear zone suggesting a high strain rate during the deformation. This reason also infers that the ductile event studied is of fundamental importance in the metamorphic and deformation history of the northern SzD orthogneiss terrane. Keeping also the widespread brittle deformation structures in mind, one can state that the mylonite zone presented in this paper seems an excellent candidate as a fluid migration pathway that is worth being investigated further.

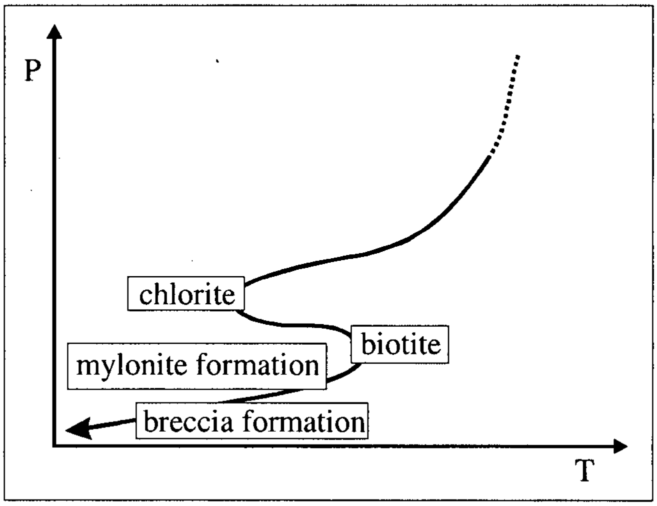

Fig. 3. Estimated PTd evolution of the othogneiss terrane of the northern SzD. Not to scale.

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