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APPLICATION OF SYMMETRY PRINCIPLES TO SOME MIGMATITES FORMED IN SITU

(4 Figs.)

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A b s t r a c t: According to the Curie's symmetry principle a symmetry of effect may include the same elements as a complex symmetry of causes producing this effect or be higher. Therefore, minimum symmetry of the migmatites formed in situ must be determined by elements general for all of systems (causes) of migmatite formation environment. Maximum symmetry will be identical with a symmetry of the most symmetric system.

Banded rocks have axial symmetry and are considered as infinite structures. A main feature of symmetry of these rocks is the ∞ axis perpendicular to a plane of bedding or banding, and to a translation axes lying in this plane. Symmetry of homogeneous rocks (without consideration of the form of bodies) is spherical; translation axes exist. Generally, deformation of rocks proceeds at $\sigma_1 > \sigma_2 > \sigma_3$, therefore, the stress field has orthorhombic symmetry.

Under conditions of prograde metamorphism and homogeneous strain, the most favourable conditions are created for formation of migmatites with maximum symmetry when complete coincidence of the planes of maximum stress and banding are reached. These migmatites inherit a symmetry of the original rocks and are stromatic (axial symmetry, translation axes are present). Occasionally, a formation of migmatites with orthorhombic symmetry is possible. In all cases a coincidence of orientation and location of symmetry elements of leucosome, melanosome and paleosome is necessary.

Under repeated migmatite formation and superimposed deformation leucosome and melanosome have orthorhombic symmetry. An orientation of symmetry elements must coincide with the orientation of symmetry elements of superimposed structures. These migmatites are formed in layers with properties favourable for migmatite formation, but they have failed to inherit their symmetry elements. If a leucosome is formed under shear deformatios its symmetry may be monoclinic.

As compared with extensive sedimentary and volcanic layers, small geological bodies (pebbles of conglomerates, xenoliths, small intrusive bodies and so on) are finite structures. As a result of high strain they may be transformed into very flattened ellipsoids or spheroids with a corresponding symmetry, but unlike truly stromatic fabrics the translation axes can not appear in them.

K e y w o r d s: symmetry principles, symmetry of: migmatites, stress field and migmatites in situ.

Introduction

The problem of migmatite origin remains a major petrological controversy. Efforts of investigators of this field are concentrated, mainly, on studying of modal mineral and chemical compositions of migmatite components, their primary fabrics, interelations and mineral

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compositions, melt and fluid inclusions and so on (Atherton–Gribble, 1983; Glebovitsky et al., 1985; Ashworth et al., 1988). Against this background the number of studies concerned with the link between migmatites and strain, and especially with structure and morphology of migmatites, is limited. It is obvious, however, that conclusions about origin of migmatites without considerations of structural features are uncomplete.

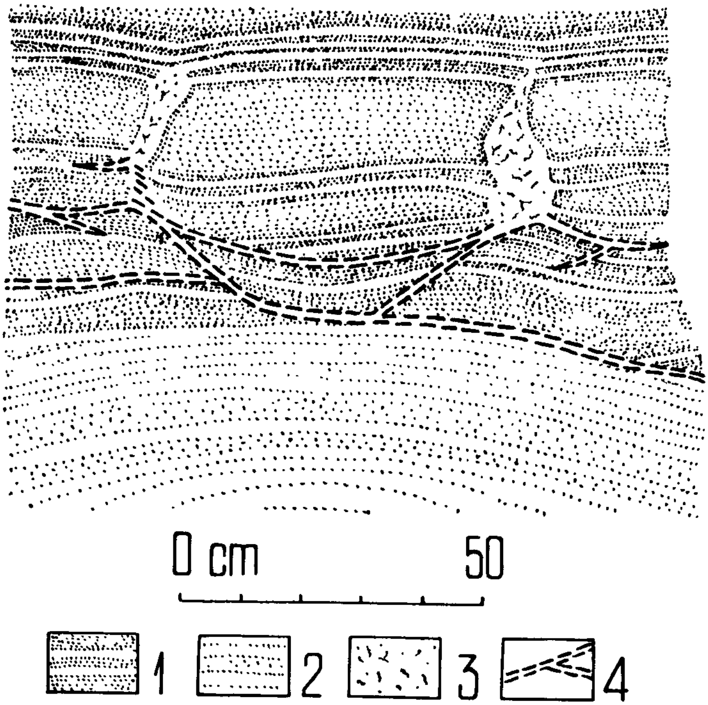

Fig. 1. Symmetric pattern of leucosome. North Karelia.
1 – plagioamphibolite; 2 – gneiss; 3 – leucosome of tension cracks between boudins; 4 – thin veins of leucosome.

While studying the structural-metamorphic evolution of repeatedly migmatized polymetamorphic rocks of the Northern–Western Belomorian region, a twice migmatized amphibolite with a surprisingly symmetric pattern of later leucosome development was discovered (Fig. 1). The leucosome forms a reasonably complex pattern of veins producing an integral system with pegmatoid material which fills spaces between boudins of amphibolite. A co-ordination of symmetric patterns of leucosomes and amphibolite structures on the whole is apparent. A formation of leucosome in situ is evident in this case. This conclusion is influenced directly by the observed characteristics of leucosome and melanosome morphology also evident here, and the well-known link between the formation of migmatites and deformation of rocks (Robin, 1979). Thus, good grounds exist for use of symmetry of migmatites to recognise their origin.

The definition of migmatite given by J. R. Ashworth and his co-authors (Ashworth et al., 1988) is used in this paper. According to this definition a migmatite is a rock which occurs in the medium and high grades of regional metamorphism and is always nonuniform macroscopically, one component of the rock being light-coloured and having a quartz--feldspathic or feldspathic composition. This paper deals with the erection of criteria to recognise the migmatites formed in situ on the basis of symmetry principles.

The Curie's symmetry principles

The Pierre Curie's symmetry principle determines the correlations between "causes" and "effects". He formulated it as follows:

"...If several phenomena of a different origin are superimposed in one and the same system, their asymmetry is sumed. The system symmetry elements are those which are general for each phenomenon taken separately.

When some causes produce some effects, the symmetry elements of the causes should be detected in the effects produced.

If some effects show some asymmetry then this asymmetry should be found also in the causes which produced these effects" (Curie, 1966, p. 102).

As is generally known P. Curie has added and broadened an idea of a symmetry in the end, "regarding it as a state of space which is characteristic of the environment in that the given phenomenom takes place" and pointed out that in order to determine the influence of the environment on the body formed in it, it is necessary to take into consideration the state and composition of the environment, the motion of the body studied relative to the environment which forms this body or the environment motion relative to the given body and, at last, the influence of other physical factors on the body (Shafranovsky, 1985, p. 50).

I. I. Shafranovsky, a great popularizer of this principle, formulated: "As if a symmetry of the producing environment is superimposed on the symmetry of the body formed in this environment. The form of the body resulted preserves only the elements of its own symmetry which coincide with the environment's elements superimposed on this body "(Shafranovsky, 1985, p. 50). As it has been shown later on the basis of new physical data (Shubnikov–Koptsik, 1972), this principle (the asymmetrization principle) is true only of heterogeneous systems, while for addition of homogeneous systems the effect of symmetrization may occur, i. e. the effect of the symmetry increasing of the totality of these systems. In the long run the symmetry group of the effect may have the same elements as the symmetry group of the cause or be higher but not lower.

P. Curie convincingly has shown the necessity of the use of symmetry in studies of *all* physical phenomena. Subsequent development of the doctrine of symmetry has shown the utility of such an approach (Shubnikov–Koptsik, 1972) in the study of geological objects (Verhoogen et al., 1974; Shafranovsky, 1985). Although our world is complicated, the Curie's symmetry principle, according to the modern data, looses its uniqueness only at a level of quantum mechanics (Koptsik, 1988). For this reason, the use of the symmetry principle to recognise the origin of migmatites is valuable.

The symmetry of a migmatite formation environment

The symmetry of original rocks

Apart from crystals, symmetrically ideal geological objects are difficult to find in nature. As a result, it is possible to distinguish the symmetry elements of rocks only under certain assumptions. The main assumption is that layered and banded sedimentary and volcanic rocks are infinite structures (i. e. Steno's principle). Such an assumption apparently will be correct also of stratiformed plutonic rocks.

Sedimentary and volcanic rocks are characterized by an axial group of symmetry (Verhoogen et al., 1974). In uniform rocks there should be observed a higher subgroup of axial symmetry – a cylinder symmetry ($\infty/m \cdot 2/m \cdot 2/m$); in nonuniform rocks, especially of rhythmically graded bedding – a cone symmetry corresponding to the symmetry of the gravitational field (∞ mm). The main elements of the symmetry of bedded rocks are the ∞ axis perpendicular to the bedding plane and the translation axes which are situated in this plane. Asymmetry of volcanic rocks as to the plane of banding may be represented, for instance, by cavities (traces of gas holes) situated in the upper part of flows. From the point of view of chemical element distribution and the Curie's symmetry principle sedimentary and volcanic rocks are always asymmetric as to the top and bottom of stratigraphic column.

Stratiform plutonic rocks formed under the influence of the gravitational field should be characterized by the same symmetry as sedimentary and volcanic rocks. Uniform plutonic rocks have a sphere symmetry unless the morphology of the bodies they compose is taken into account. Among the symmetry elements of these rocks the translation axes should be prominent.

The symmetry of a stress field

In geology a stressed state of rocks is enough to be characterized by direction and values of principal stresses (σ_1, σ_2 and σ_3) to solve many problems. A stressed state in a point is well shown by a stress ellipsoid. At $\sigma_1 > \sigma_2 > \sigma_3$ the ellipsoid is a three-axial one and has an orthorhombic symmetry, at $\sigma_1 > \sigma_2 = \sigma_3$ or $\sigma_1 = \sigma_2 > \sigma_3$ it is a extended or flattened spheroid (an axial symmetry) and at $\sigma_1 = \sigma_2 = \sigma_3$ it is a sphere with the corresponding symmetry (Verhoogen et al., 1974). Many studies have shown that rock deformation generally takes place in a stress field described by a three-axial ellipsoid (orthorhombic symmetry).

The symmetry of the migmatites formed in situ

Formation of migmatites in situ depends mainly on the T-P condition of metamorphism and the composition of original rocks (Mehnert, 1971). The relation between migmatite formation and rock deformation occurring with metamorphism is widely known (Robin, 1979; Sawyer–Robin, 1986). As temperature is a scalar and the notion of a symmetry can not be applied to it, the symmetry of the migmatites formed in situ according to the Curie's principle will be determined by combinations of the symmetry elements only of the original rocks and the imposed stress field.

From the point of view of migmatite formation the most important element of the symmetry of a stress field is a plane of maximum compression along which leucosome forms (Robin, 1979). In rocks the same important element of the symmetry (or asymmetry) is a plane of bedding or banding and the ∞ axis perpendicular to it. The influence of variations in chemical composition of the original rocks on migmatite formation in situ is well known (Mehnert, 1971). The development of some stromatic migmatites is possible on account of the nonuniform (banded) rocks (Gupta–Johannes, 1982). Thus, the most favourable conditions for migmatite formation in situ will take place at the coincidence of the orientations of the two important planes of a stress field and original rocks with each other. Such conditions seem to be often achieved at prograde metamorphism. In this case the intersection of the planes in question is possible only in hinges of the earliest folds which, as a rule, are small asymmetric isoclinal ones and arise in rocks occurring nearly horizontally (Miller, 1982).

A complex structure of metamorphic terrains is formed later at superimposed deformations.

The migmatites with maximum symmetry should originate when coincidence of the plane of maximum compression with the banding plane occurs under the condition of prograde metamorphism. The highest symmetry is characteristic of the original rocks (axial symmetry, the translation axes are present). As was mentioned above the effect symmetry may be higher than the complex symmetry of all causes. Hence, the migmatites formed in situ should inherit the symmetry of the original rocks completely. Morphologically it should be the ideal stromatic migmatites with the ∞ axis perpendicular to the plane banding and the translation axes lying in this plane. The development of migmatites with orthorhombic symmetry is also possible. In all these cases the symmetry elements of leucosome, melanosome and paleosome must coincide with each other.

As it is well-known the occurrence of stromatic leucosomes parallel to pre-existing banding is very common, and is unlikely to be always due to the banding being exactly perpendicular to a maximum compression axis. More likely, the development of these leucosomes occurs when this axis is oblique to the banding, but the axis and banding should be almost perpendicular to each other. As will be shown below, leucosomes marking the maximum compression plane do not coincide with the pre-existing banding when an orientation of the stress axes are very oblique to the banding.

Superimposition of deformations under other T-P conditions (next stage of the same metamorphism or repeated metamorphism) usually results in situations where the planes of maximum compression and banding do not coincide with each other. In these cases the extent of the definite leucosome should be limited by the thickness of layers with properties favourable for migmatite development. Hence, the symmetry of migmatites will depend only on the stress field symmetry. The orientation of the symmetry elements of leucosome and melanosome should be co-ordinate with the orientation of the symmetry elements of superimposed structures. If the leucosome isolation occurs under the condition of shear deformation which has a monoclinic symmetry (Verhoogen et al., 1974), then a decrease of the symmetry of leucosome to a monoclinic one is possible.

In uniform rocks, when deformation takes place under a similar condition the migmatites with analogous symmetry should occur. At $\sigma_1 = \sigma_2 = \sigma_3$ the symmetry of migmatites will completely depend on the symmetry of original rocks, and leucosomes close to isometric spots and surrounded by melanosome and vice versa should occur in uniform rocks.

Discussion

From the statements given above we will analyze the situation shown in Fig. 1. Formation of the later leucosome (symbol 3 and 4, Fig. 1) is related to formation of boudinage of an earlier migmatized amphibolite. Two planes of symmetry occur here. The first coincides with the plane of figure, and the second is located perpendicular to it between necks of boudins. The intersection line of these planes is the 2-fold axis of symmetry. A 2·mm subgroup belongs to the group of orthorhombic symmetry.

The environment where leucosome has been formed is of a distinct asymmetry relative to the contact between two rocks of different composition (amphibolite and gneiss). It is this situation that is the cause of the absence of the third plane of symmetry perpendicular to the 2-fold axis; otherwise the leucosome might have the highest symmetry of orthorhombic group (2/m·2/m·2/m) that coincides with symmetry of a stress field.

The leucosome under consideration appeared after the peak of metamorphism. This circumstance seems to have been the reason of very small misalignment of orientation of the

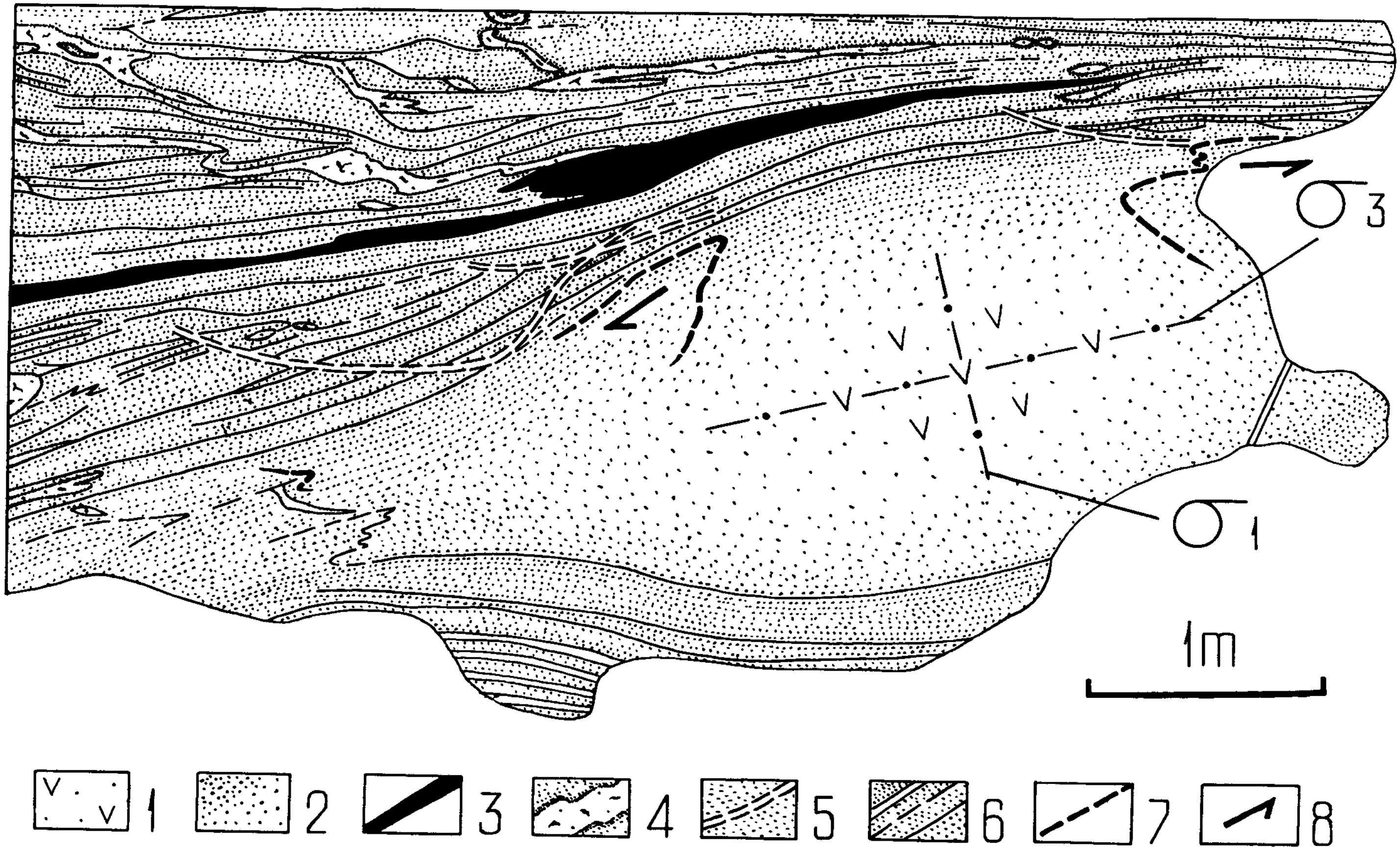

Fig. 2. The features of deformation and migmatization of uniform rocks. North Karelia.
1 – massive metagabbro; 2 – the same metagabbro showing amphibolization and schistosity (dence points indicate higher amphibolization and schistosity); 3 – melanocratic garnet amphibolite; 4 – the latest coarse granitic material; 5 – quartz-feldspar veins of later boudinage; 6 – leucosome of the peak of deformation and metamorphism; 7 – thin quartz-feldspar veins of the earliest stage of deformation and metamorphism, 8 – movement of matter transfer during lens convertion.

planes of maximum compression and banding. Thus, this case provides good support for the application of the Curie's symmetry principle to migmatites. It should be stressed that despite the observation of only a small amount of melanosome, a leucosome symmetry unambiguously points to the formation of the leucosome in situ (i. e. in such cases a slight transfer of leucosome material took place, but the transfer is limited to distances of only few centimetres). Veins of the leucosome cut earlier foliation and banding. Hence, the presence of cross-cutting contacts is not always a reliable criterion that the leucosome results from an injection of granite melt.

Earlier migmatites (Fig. 1) are stromatic ones (lit-par-lit type) with well-developed leucosome, melanosome and paleosome. All of these have an axial symmetry, and their elements exactly coincide with each other. On the exposure scale these migmatites may have translation axes. From the symmetry point of view they were also formed in situ.

Initially uniform rocks (gabbro, more seldom diorite) which have undergone repeated migmatization are shown in Fig. 2. Two deformed quartzo-feldspar veins feature this situation: the veins occur symmetrically both relative to each other and to a lens, the lens being of tectonic origin (Fig. 2, the veins are shown by symbol 7). The vein formation predated the intensive process of schistosity development in basites; the veins prior to their strain occurred at an angle of 45° relative to the principal stresses. Such an orientation is characteristic of shearing stresses along which shear joints develop. Hence, vein formation is related to the initial stages of lens conversion and metamorphism of the basites when the brittle deformation still could occur. The system of conjugated veins has an orthorhombic symmetry (2 · mm) and its elements coincide with the elements of symmetry of the sum total of rocks and structures. Thus, the veins in question are the leucosomes of the earliest migmatites formed in situ. The conclusion that the leucosome formed in situ may be located along shearing stresses is of great importance. Shear joints are usually considered as channels for an injection of melt.

The main migmatization (Fig. 2, leucosome is shown by symbol 6) took place at the peak of metamorphism and high strain of the basites. The leucosome is located along the planes of maximum compression as predicted by theory (Robin, 1979). Some leucosomes are characterized by limited extension and probably have an orthorhombic symmetry. The other leucosomes on the scale of the exposure have an axial symmetry and also contain the translation axes. On morphology these migmatites are close to stromatic ones. The symmetry of total rocks is orthorhombic.

Here one can observe even later leucosome (Fig. 2, symbol 5). Evidently these were formed after the peak of metamorphism, migmatization and strain. The location of all of these veins is described by a definite symmetry that can be orthorhombic under some assumptions.

In Fig. 3 is a typical situation where leucosomes are located parallel to an axial planes of folds and within a definite layer only. Symmetry of these leucosomes is orthorhombic or monoclinic. In Fig. 4 leucosomes marking an axial planes of shear folds are shown. The leucosomes are surrounded by very narrow melanosome zones. No evidence of deformation which whould have broken up the leucosomes after migmatization has been observed in this exposure. These folds are very open and rapidly disappear along their axial planes (intrafolial type). Monoclinic symmetry of these leucosomes and folds is evident from s-like (and z-like in other exposures) curves of the axial planes. The stromatic migmatites with corresponding symmetry can be observed in the exposures given in Figs. 3 and 4. From the symmetry point of view all migmatites in question can be considered to have formed in situ.

K. Mehnert (Mehnert, 1987, Fig. 7) gave the example of gneiss with close to isometric spots formed by melanosome (the central part of spots) and leucosome (the marginal one). From the symmetry point of view this is an example of migmatization of uniform rock in a stress field at $\sigma_1 = \sigma_2 = \sigma_3$.

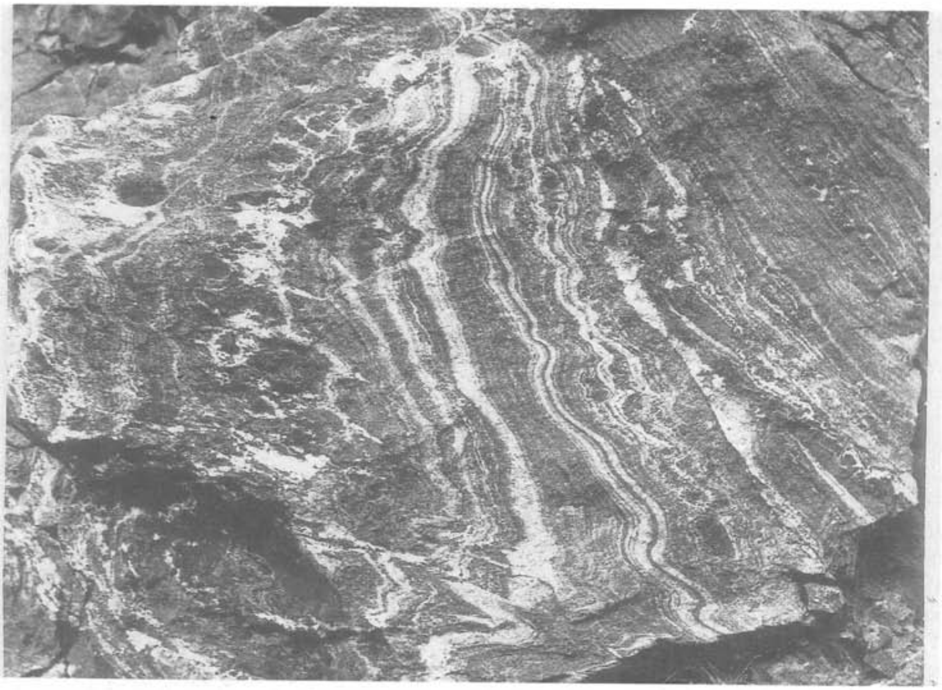

Fig. 3. Migmatized amphibolite with later leucosome parallel to an axial planes of folds. Shirokaya Salma, Kola Peninsula.

A. F. Park (Park, 1983) described the lit-par-lit migmatite fabrics in a metagabbro-anorthosite complex and deduced that these resulted from the high strain of different geological bodies of closed form (for example, xenoliths). He suggested that stromatic migmatites in acidic rocks may well be indicative of high strain and resultant rotation of originally discordant elements into parallelism. This conclusion may be considered from the symmetry point of view.

Symmetry of original rocks may be variable – from spherical to triclinic. If the main factor of migmatite formation and body morphology is strain only, symmetry of these bodies can not be higher than orthorhombic at $\sigma_1>\sigma_2>\sigma_3$ and axial at $\sigma_1>\sigma_2 = \sigma_3$. Under high shear strain and rotation bodies with morphology of extended ellipsoids should be formed, and axes of these bodies should lie in a plane of foliation and banding. The bodies of closed form are finite structures (in contrast to layers of sedimentary and volcanic rocks that are infinite structures according to the Steno's principle); hence, an appearance of translation axes in the bodies (elements typical for truly stromatic fabrics) is impossible as a result of strain only.

High strain of conglomerate pebbles is taken as an example related to problems of migmatite origin by K. Mehnert (Mehnert, 1987, Fig. 1). The difference between these deformed pebbles and stromatic migmatites is obvious from the symmetry point of view. Similar deformed conglomerates with pebbles of granitoids are known in the Precambrian terrains of the Kola Peninsula. Transfer of deformed pebbles into ideal stromatic leucosomes has not been observed. On the other hand, it is obvious that high superimposed deformations make it difficult to establish the origin of these or that fabrics including the migmatite ones and use of the symmetry principles may be usefull.

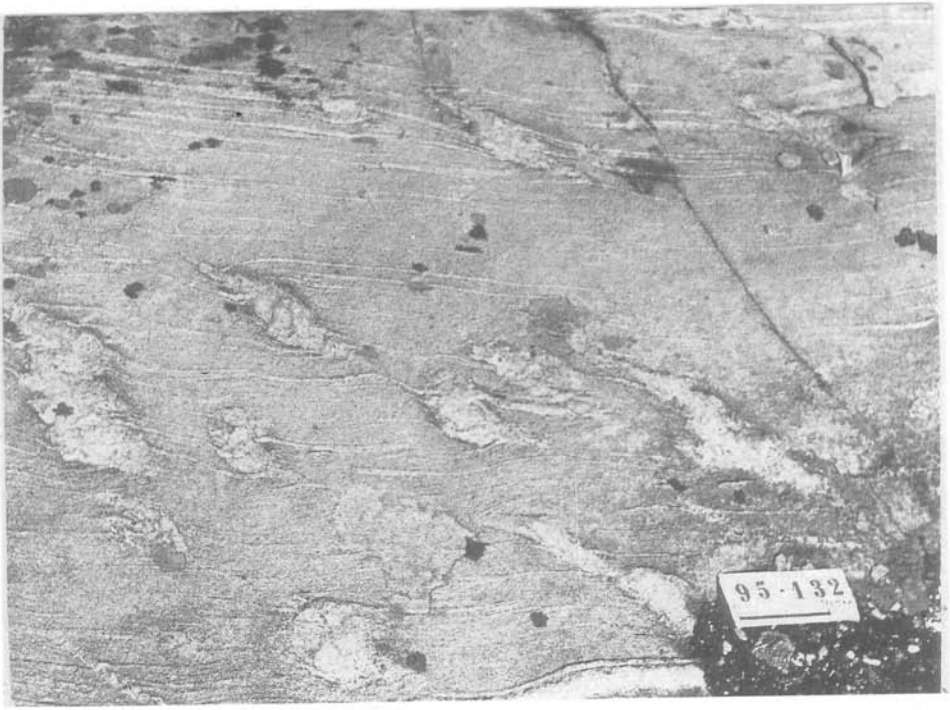

Fig. 4. Open shear folds marked by leucosome. Voche-Lambina, Kola Peninsula.

It should be pointed out that from the symmetry point of view a rather unexpected conclusion may be made – the overwhelming majority if not all the stromatic migmatites have been formed in situ. The most favourable conditions of their development seem to be ones of prograde metamorphism up to the beginning of high fold and fault deformations. This is confirmed by the observations that in many metamorphic terrains the earliest stromatic migmatites are deformed by folds of the first recognisable deformation stage in a rather long structural-metamorphic evolution.

Conclusion

1. According to the Curie's symmetry principle which determines the cause-effect relation, the symmetry (morphology) of the migmatites formed in situ is defined by the symmetry of migmatite formation environment that in its turn depends upon the character of coincidence of the symmetry elements of the original rocks and imposed stress field.

2. Migmatites with the maximum symmetry are formed when planes of maximum compression and banding coincide with each other or very close to each other. The conditions of prograde metamorphism seem to be most favourable for their development. These migmatites inherit the symmetry of the original rocks (an axial group; the ∞ axis is perpendicular to the plane of banding; the translation axes lying in this plane) and are ideal stromatic migmatites. The coincidence of orientation and occurrence of the symmetry elements of leucosome, melanosome and paleosome is nesessary.

3. When the planes of maximum compression and banding do not coincide with each other considerably as it takes place under the condition of superimposed deformations and retrograde or repeated metamorphism, the symmetry of the migmatites formed in situ is defined by the symmetry of an imposed stress field and an orthorhombic one. Leucosome is formed within the layers with the most favourable properties and their extent is limited by the thickness of these layers. Under shear deformation the symmetry decreases to a monoclinic one. These are typical isolated leucosomes parallel to the axial planes of folds and granitoid material in tension cracks between boudins.

4. In the stress field at $\sigma_1 = \sigma_2 = \sigma_3$ the migmatites formed in situ in nonuniform rocks inherit the symmetry of the original rocks. In uniform rocks a symmetry should trend to a spherical one; an example of such migmatites representing the flecky gneisses was given by K. Mehnert (Mehnert, 1987, Fig. 7).

5. Geological bodies of closed form (xenoliths, pebbles and so on) have finite structures. From the symmetry point of view, the development of symmetry elements characteristic of infinite structures (translation axes) in such bodies as a result of high strain only is not possible.

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REFERENCE

ATHERTON, M. P. – GRIBBLE, C. D. (eds.), 1983. Migmatites, melting and metamorphism. *Shiva Publishing Ltd.* 326 pp.

ASHWORTH, J. R. – JOHANNES, W. – GRANT, J. A. – OLSEN, S. N. – McLELLAN, E. L. – TRACY, R. J. – BARR, D. – TOURET, J., 1988. Migmatites. *Mir,* 344 pp. (in Russian).

CURIE, P., 1966. Collected transactions. *Nauka,* 400 pp. (in Russian).

GLEBOVITSKY, V. A. – SINGER, T. Ph. – KOZAKOV, I. K. – KOTOV, A. B. – KRILOV, D. P. – MANUILOVA, M. M. – MITROFANOV, F. P. – ORLOVSKAYA, K. V. – SAMORUKOVA, L. M. – SEDOVA, I. S., 1985. Migmatization and formation of granites at different thermodynamic regimes. *Nauka,* 310 pp. (in Russian).

GUPTA, L. N. – JOHANNES, W., 1982. Petrogenesis of a stromatic migmatite (Nelaug, southern Norway). *J. Petrology* (Oxford), 23, pp. 548–567.

KOPTSIK, V. A., 1988. Principle of causality, system approach and symmetry. *System. Symmetry. Harmony. Mysl,* pp. 200–227 (in Russian).

MEHNERT, K., 1971. Migmatites and origin of granites. *Mir,* 328 pp. (in Russian).

MEHNERT, K., 1987. The granitization problem – revisited. *Fortschr. d. Mineral.* (Stuttgart), 65, 2, pp. 285–306.

MILLER, Yu. V., 1982. Tectonic-metamorphic cycles. *Nauka,* 160 pp. (in Russian).

PARK, A. F., 1983. Lit-par-lit migmatite fabrics in a metagabbro-anorthosite complex, Sygnefjell, Jotunheim, South Norway. Migmatites, melting and metamorphism. *Shiva Publishing Ltd.,* p. 296.

ROBIN, P. – Y. F., 1979. Theory of metamorphic segregation and related processes. *Geochim. Cosmochim. Acta* (London), 43, pp. 1587–1600.

SAWYER, E. V. – ROBIN, P. – Y. F., 1986. The subsolidus segregation of layer-parallel quartz-feldspar veins in greenschist to upper amphibolite facies metamorphism. *J. Metamorph. Geol.,* 4, pp. 237–260.

SHAFRANOVSKY, I. I., 1985. Symmetry in nature. *Nedra,* 168 pp. (in Russian).

SHUBNIKOV, A. V. – KOPTSIK, V. A., 1972. Symmetry in science and art. *Nauka,* 340 pp. (in Russian).

VERHOOGEN, J. – TURNER, F. – WEISS, L. – WAHRHAFTIG, C. – FYFE, W., 1974. The Earth. An introduction to physical geology. – 1. *Mir,* 392 pp. (in Russian).

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