Geological structure and evolution of Shaw Massif, central part of the Prince Charles Mountains (East Antarctica)

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Summary Shaw massif is situated in the central part of the Prince Charles Mountains and represents a complex with complicated fold structure and compositions that include biotite leucogneisses, garnet-biotite gneisses and plagiogneises (Lambert gneisses); amphibole-biotite melanogneisses, garnet-biotite plagiogneisses (Shaw melanogneisses). Also, there are poorly developed garnet-sillimanite-biotite gneisses (Isabelle paragneisses) which are met in the form of xenolith bodies among the Lambert gneisses and could be the fragments of the ancient sedimentary layer. The obtained U-Pb data reflect the two main geological events with ages 900-1100 Ma and 450-550 Ma corresponding to Rayner and Pan-African tectonothermal events. The Shaw Massif terrane has been affected by at least 5 deformation events and three stages of metamorphic reworking. The structural geological position of the Shaw Massif region could be interpreted as a younger, high grade metamorphic region framing the Fisher Province.

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Introduction

In the course of the 50-th Russian Antarctic expedition (2004-2005) geological studies were undertaken in the central part of the Prince Charles Mountains (PCM) on the Shaw Massif, Mounts Johns and Isabelle, and Ely Nunatak (East Antarctica), within the sector with coordinates - $71^0 59'-72^0 31'$ s.w., $66^0 35'-67^0 10'$ e.l. The Shaw Massif and associated areas had seen very little previous work. The only one reconnaissance investigation of the Shaw Massif was organized by Soviet geologists in 1988-1989. Also, fragmentary information about geological constitution of the Shaw region is presented in literature (Mikhalsky et al., 2001).

Shaw Massif is located 360 km southward of Prydz Bay. The Massif area is about 72 km^2, maximum length (from the west to the east) by 15 km wide. Shaw massif is a united peneplanated mountain complex. The region is located within the Precambrian East Antarctic platform, in the south of the marginal part of Proterozoic Wegener-Mawson polycycle mobile belt. Rocks of the Shaw Massif – Mount Johns area were included in a separate Lambert Complex by Kamenev et al. (1990) on the basis of metamorphic grade, and range across the typical varieties of gneisses and migmatites. It was suggested that the Lambert Complex had a polymetamorphic genesis, and was derived from both prograde metamorphosed Ruker Terrane rocks and retrogressed granulite facies of the northern PCM (Beaver Complex) rocks, with possible additions of some new matter (Kamenev et al., 1990). Being a transition zone between Beaver belt and Archaean Ruker granite-greenstone terrain, the Lambert Complex consists mainly of high grade metamorphic (from upper amphibolite to granulite metamorphic facies) rocks, formed from Mesoproterozoic to early Neoproterozoic time (1200-950 Ma). The Lambert Complex is a part of the well known Beaver-Lambert Terrane, suggested by Mikhalsky et al. (2001).

Geologic structure of Shaw massif

Geologic position, tectonic structure and metamorphic grade are similar for the whole region – from Shaw Massif to Jones Mountain. The Shaw Massif comprises a block made up by the rocks of a single metamorphic unit which include two main rock types (from young to old): leucocratic biotite (±amphibole), garnet-biotite gneisses and plagiogneisses, migmatites – Lambert gneisses; melanocratic amphibole-biotite, garnet-biotite plagiogneisses – Shaw melanogneisses. In some units xenogenic bodies of garnet-sillimanite-biotite gneisses and schists, calciphyres – Isabelle paragneisses. These rocks are the oldest geologic material in this region. Isabelle paragneisses are marked only in the northern part of Shaw Massif. They form xenoliths from meters in size to xenogenic layered bodies up to 4-5 m thick among the Lambert gneisses.

The Shaw Massif metamorphic complex is cut by a series of metaintrusive and veins rocks which can be divided into 8 groups. This complex includes the following rocks (from old to young): metabasites, peridotites, pyroxenites, biotite and two-mica (±garnet) pegmatites, garnet-quartz veins, quartz veins, aplites and veins of hydrothermal metasomatites.

Cenozoic glacial formations at Shaw Massif are represented by late Pleistocene-Holocene and Holocene sediments (Mikhalsky et al., 2001).

From tectonic point of view, Shaw Massif is a complicated fold complex. Its structure is controlled by alternation of layered bodies of Lambert gneisses and layers of melanogneisses with different composition. The major feature of the geological cross section is the presence of rock sets different in composition, gradual transformation from one type to another which took place in layering over the scale of a few meters.

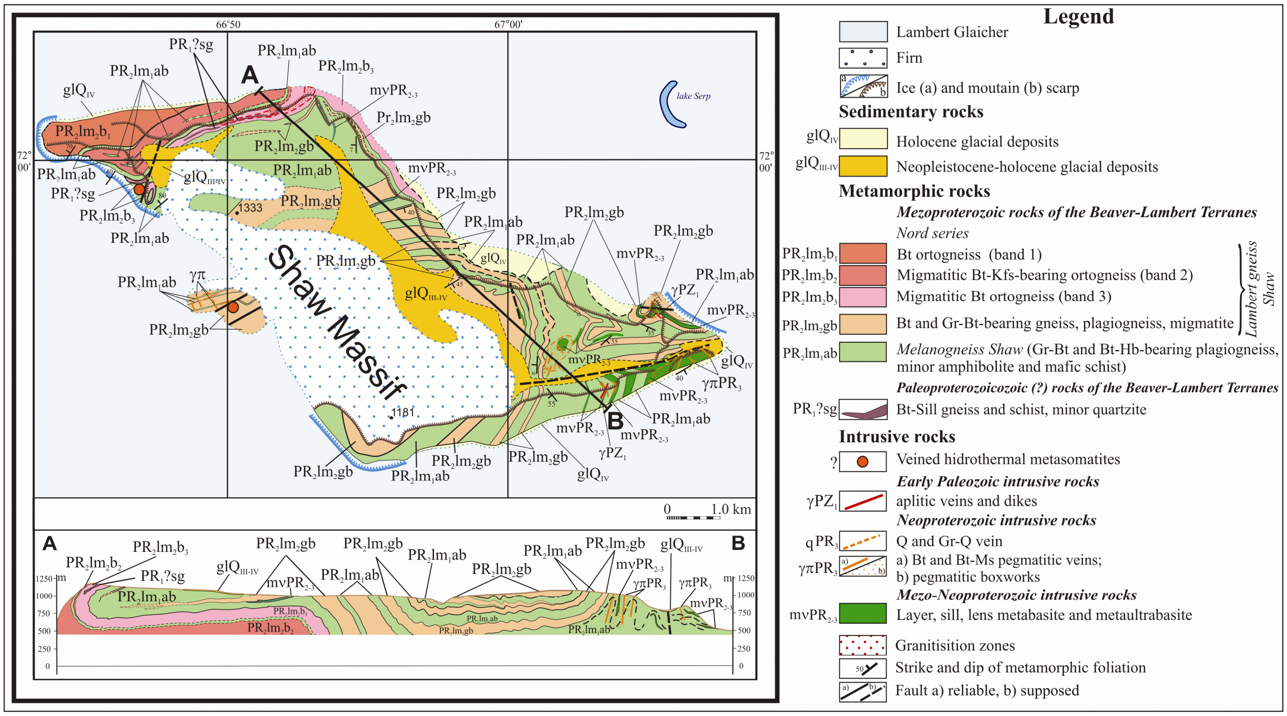

Figure 1. Geologic Map of Shaw Massif.

In most cases the rocks are migmatizated with layered branchy and ptygmatic migmatites. Lambert leucocratic biotite (±amphibole), garnet-biotite gneisses are developed over the whole territory of the massif. In the NE part of Shaw Massif there is a thickness of Lambert gneisses which consists of three rock types (Fig. 1). Shaw melanogneisses occur within the whole Shaw Massif and by the extent of their development are very close to Lambert gneisses. Their largest outcrops are in the northern and SE parts of the massif. They form single bodies with thick layers. To this group belong garnet-biotite, amphibole-biotite (± orthopyroxene) gneisses and plagiogneisses, and transitional types of amphibole-biotite schists and amphibolites which are found rather rarely. Within Shaw massif the most contacts are NE striking, with the metamorphic layering dipping either NW or SE.

U-Pb isotopic dating of Shaw Massif

U-Pb zircon isotope dating was performed at the Centre of Isotope Research (VSEGEI, St.Petersburg) by SHRIMP-II. Measuring of U-Pb ratios of the studied zircons was carried out according the method described by Williams (1998). For isotope dating 5 samples were chosen of the main rock types of the massif: garnet-biotite plagiogneiss (50214-01, melanogneisses Shaw, Fig.2), garnet-biotite migmatite and biotite gneiss (50307-01, 50331-03, Lambert gneisses), metagabbro (50317-01), aplite (50322-02).

Isotope compositions of the studied zircons reflect two main geologic events with ages 900-1100 Ma and 450-550 Ma. The latest event is connected with intrusion of aplite veins and dykes and corresponds to 457±8 Ma (50322-02). Pan-African activity at 500-550 Ma is traced by formation of new zircons with this age (50307-01, 509.6 ±7.0 Ma), and recrystallization of the older zircons (50317-01), and appearance of young rims over older zircon grains (50214-01, 557 ±10 Ma).

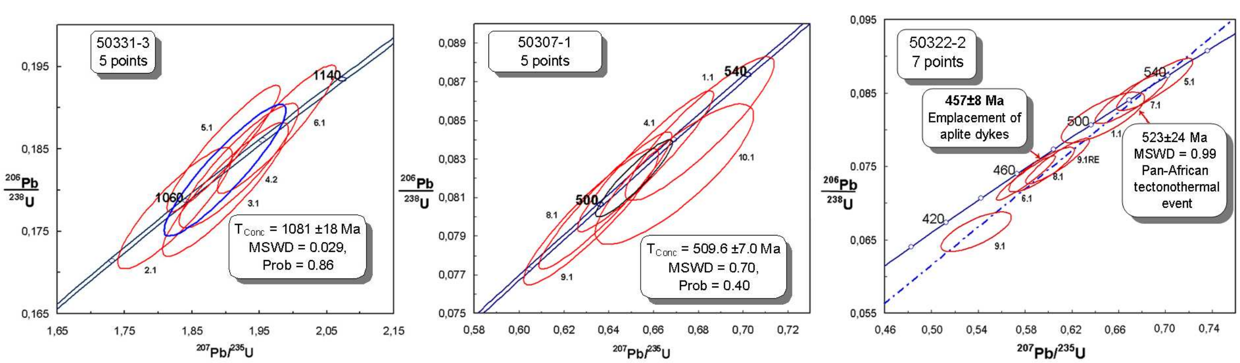

Figure 2. U-Pb concordia diagrams for zircons form Shaw Massif rocks. Size of error ellipses corresponds to 2σ level.

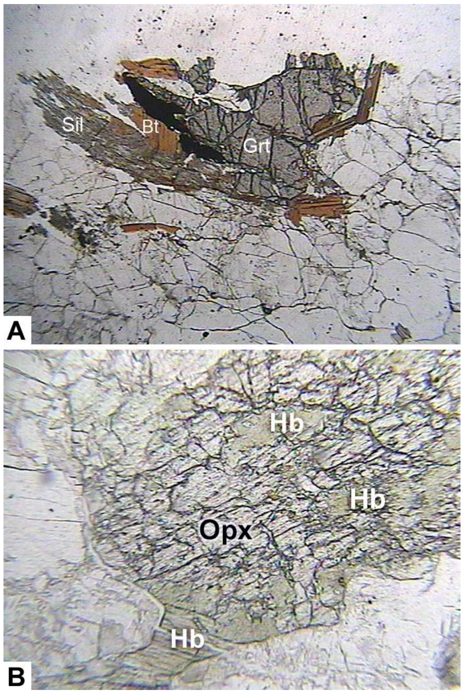

Figure 3. Microphotos of thin-section of Shaw Massif gneisses. A) paragneisses with relics of garnet substituted by ore mineral (black)+Bi+Sill, B)Shaw melanogneisses with substitution of orthopyroxene by hornblende.

The earliest metamorphism determined in the studied samples corresponds to a Rayner event of 900-1100 Ma (50214-01, 50307-01, 50331-03). Protoliths of the orthogneisses intruded at the time corresponding to 1081±18 Ma (50214-01, 50331-03). The obtained data allow correlation of the events at Shaw Massif with geochronologically characterized events at Clemens Massif (Corvino et al., 2005).

Discussion

On the basis of petrologic and isotope data it is possible to construct the following evolution of metamorphic processes within the Shaw Massif: middle-temperature granulite facies (M_1)→ amphibolite facies (M_2)→ low-temperature greenschist facies (M_3). Stage M_1 is determined by the presence of different paragenesises with hypersthene in different rocks of the region – Opx+Cpx+Hb, and paragenesis– Gr+Ksp+Sill+Bi. In the latter paragenesis the relics of garnet are substituted by association ore mineral+Bi+Sill suggests the presence of earlier metamorphic event (M_1?) when the garnet was formed (Fig. 3a).

Amphibolite metamorphism of migmatite stage M_2 is developed over the whole studied region and shadowed considerably the previous events. It is determined on the base: a) mineral paragenesis in leucocratic rocks of the massif – Pl+Ksp+Bi+Qu+Gr±Hb±Sill; b) substitution of orthopyroxenes and clinopyroxenes by hornblende in melanocratic gneisses and mafic metaintrusive rocks (Fig.3b); c) substitution of relic garnet (formed at stage M_1) by association ore mineral+Bi+Sill (Fig. 3a).

Stage M_3 determines the presence of low-temperature mineral association in the rock of Shaw massif – light- green amphibole, chlorite, muscovite, and carbonate minerals in the rocks enriched by CaO, sericitization and saussuritization of plagioclases, pelitization of microcline and orthoclase.

Tectonic processes played vital role in the formation of Shaw massif geologic structure. Based on detail structural study there could be identified 5 deformation stages within the massif but only during D_1 and D_2 stages the main structures were formed.

The main structure F_1 is represented by an isoclinal recumbent fold, about 5 km in length and more than 1 km wide, (Fig. 1). Different kinds of rocks make up two thirds of the massif and form the low limb of this structure. Its central part is placed in the north of the massif while the upper limb is cut by erosion. Wave-like axial plane NE extension (130-135°) is complicated by the next deformation stages and gradually dipping with angle (7-10°) to NW. Direction of schistosity S_1 in the whole is parallel to axial plane of isoclinal structure. All types of rocks including bodies of metabasics took part in folding F_1. Deformations D_1 were probably connected with the peak of regional metamorphism M_1 (up to granulite facies). Such folding forms could be the result of longitudinal disturbance of piles or during formation of tectonic covers. At this time emplacement of sub-concordant layer-bodies of ultramafic and mafic rocks occurred as well (precursors of Shaw melanogneisses). Intrusion of these rocks could take place during the stage D_1 and continued in the next stage D_2 representing the dyke complex of metabasic protoliths. The main isocline in metamorphic rocks of Shaw Massif is complicated by isoclinal folding of lower degree (up to 20 m length) and weak, irregular, often isoclinal disharmonic folding with amplitude of the first centimeters.

It is supposed that deformations D_2 could associate with the beginning of M_2 metamorphism. At this period tectonic movements changed their direction and there were formed new rather large folds F_2 which complicate the main structure of Shaw Massif. On the east there is a large fold F_2 which determines the structure of the whole E-SE part of Shaw Massif. This fold is an asymmetric complicated structure more than 1 km long and more than 500 m wide. It is a very flat fold sometimes with isoclinal wings with very inclined axial plane. The strike of the axial plane of this structure differs from isoclines of the main folding F_2 in 25-35^0. There are isoclinal structures of the second and third order with position similar to F_2. Perhaps, stage D_2 was a direct continuation of D_1 without any interruption in time. General regional strike of the axial planes of the main structures F_1 and F_2 is also relatively close, morphological features of the folds are also similar.

Stage D_3 is connected with formation of folds F_3 which complicate the older structures first of all the isoclinal folds F_1. D_3 is associated with metamorphism M_3. This is secondary folding represented by brachy-folds with low amplitude 2.5-2.7 km long and more than 2 km wide. Perhaps, after gently sloping folding F_3 had been formed intrusion of pegmatoid bodies which are observed among metamorphic rocks.

Deformations D_4 and D_5 mark the transition from plicative to disjunctive deformations. Formation of shear-zones with cataclastic schistosity S_4 associates with D_4. The main result of stage D_5 was formation of disjunctive structures with small amplitude which cut all types of the Shaw Massif rocks. The time of brittle deformation D_5 is still unclear. The main fracture zone by length and amplitude is a dislocation in the eastern part of the massif.

Table 1. Geological evolution of Shaw Massif, central part of the Prince Charles Mountains

NN	Events	Age
8	Deformations $D_{4\text{-}5}$: shear-zone formations, NW and sublatitudinal faults, hydrothermal metasomatism	(?)
7	Emplacement of aplite dykes	457 ± 8 Ma
6	Pan-African tectonothermal event: injection of bt- and two-micas pegmatite and garnet-quartz veins; metamorphism M_3 – low-T green-schist facies (?); deformations D_3: schistosity S_3, folding F_3.	550 – 500 Ma
5	Rayner tectonothermal event (?): metamorphism M_2 – amphibolite facies; deformations D_2: schistosity S_2, folding F_2. (metamorphism M_3?)	916 ± 40, 911 ± 67, 950-850 Ma (?)
4	Emplacement of dykes and layers of ultrabasic and basic rocks (metabasic protoliths)	after 950 Ma
3	Rayner tectonothermal event (?): metamorphism M_1 – middle-T granulite facies; deformations D_1: schistosity S_1, folding F_1	1100-950 Ma (?)
2	Emplacement (or deposition?) of melanogneiss protoliths, emplacement of protoliths of studied orthogneisses (Lambert gneisses)	1100-950 Ma (?), 1081 ± 18 Ma
1	Formation of sedimentary layers (protolith of paragneisses)	before 1100 Ma

In the eastern part of Shaw massif together with Shaw melanogneisses there are bodies of metabasic rocks. This fact can be considered quite predictable if we suppose that the rocks of melanogneisses, metagabbroids and ultrabasics primarily belonged to one series of hypabyssal intrusions with long-lived polyphase period of formation. Perhaps, emplacement of syntectonic mafic-ultramafic rocks continued on the background of strong metamorphic processes. Mafic bodies of the starting phases of magmatic cycle could absolutely loose the features of intrusive genesis in the result of two consequent metamorphic stages (M_1 and M_2) developed in the region. Amphibolization of pyroxenes, different stages of which are observed in metamorphic and metaintrusive rocks, is just one of such metamorphic alterations. It is quite possible, that this geologic association could represent volcano-plutonic complex the main components of which are abyssal and hypabyssal rocks of different origin (stocks, dykes, sills, covers) but by composition corresponding to magmatic rocks from ultramafic peridotites through gabbroids and dolerites to andesites and diorites. The latter formed layers of plagiogneisses.

Metamorphic evolution of Shaw Massif is similar to the other regions of Lambert complex but but the mineralogical composition of the Shaw Massif rocks is shifted towards mafic and transitional rocks in comparison with Mawson region and Clemens Massif. More then 40% of the rocks of Shaw Massif belong to metamorphosed (or metamorphic) ultramafic, mafic and transition rocks (half of the studied samples show SiO_2 content less than 53%).

Conclusions

Due to its geological position the Shaw region is a key location for developing a general understanding the geotectonic structure of the central PCM. Shaw region is situated at the intersection of protocraton block – Ruker granite-greenstone area and Fisher zone. Based on structural and tectonic features and peculiarities of metamorphism we deduce that the Shaw Massif is close to Clemens Massif. But at the same time, the mineral and chemical composition of the rocks of Shaw massif are similar to the rocks which make up Fisher complex. The obtained isotope dating points to the two main geologic events with ages 1100-900 and 550-450 Ma corresponding to Rayner and Pan-African tectonothermal events. The study of the deformation stages and their structures in the Shaw Massif are connected with the two main stages of deformation – D_1 and D_2. These deformations coincide with the corresponding metamorphic events (M_1 and M_2). Fold formation at these stages was the leading not only for the Shaw massif but for the whole investigated region as well. Structural-geologic position of Shaw region could be interpreted as a younger and high metamorphosed region which frames the Fisher province.

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