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In search of whiteschists and kornierupine in the southwestern Pamirs, USSR

Whiteschists contain the critical assemblage of talc and kyanite, which is characteristic of moderate to high pressures in highly magnesian rocks. Kornierupine is a complex magnesium-iron-aluminum borosilicate whose paragenesis remains poorly understood in many cases. Whiteschists and kornierupine both occur in bodies containing magnesium-skarns, magnesite marbles, and other magnesian rocks in the southwestern Pamir mountains, an exposure of Archean metamorphic rocks in the Himalayan belt.

This article reports the preliminary findings of two expeditions to this remote area, one of which included an American geologist, the first Western geologist to visit the area since the early part of the 20th century. Material collected on these expeditions will be used to address questions about the origin of the highly magnesian rocks, the physico-chemical conditions of their formation, and the source of boron for kornierupine and tourmaline.

Figure 1.—Localities investigated in study in southwestern Pamirs, USSR, as well as Sar-e Sang, Afghanistan, the classic whiteschist locality and lapis lazuli deposit. Arrow shows location of map in the USSR (inset).

Introduction

W. Schreyer (1977) first applied the term "whiteschist" to talc+kyanite schists from the lapis lazuli mine at Sar-e Sang, Afghanistan, about 95 km southwest of the Soviet border at Ishkashim, USSR (fig. 1). Since that time, Schreyer has emphasized the importance of whiteschists and related rocks in the study of high-pressure metamorphism because the mineral parageneses in these rocks are sensitive indicators of the physical conditions of metamorphism (see, for example, Schreyer, 1988).

The southwestern Pamirs are underlain by amphibolite-facies (locally granulite-facies) metasedimentary and metaigneous rocks of Archean age (Shanin and others, 1979; Budanova and Budanov, 1983). These rocks are part of a block of crystalline rocks that is exposed in northeastern Afghanistan as well and includes Sar-e Sang (Vlasov and D'yakov, 1989).

L.L. Perchuk (personal communication) first suggested that whiteschists should occur among the highly magnesian rocks of the upper amphibolite-facies Goran Series in the southwestern Pamirs. His prediction has been confirmed by finds of talc+kyanite+gedrite or enstatite (Budanova, 1987) and talc+kyanite+hornblende (Grew and others, 1988).

To explore further the extent of whiteschists in the southwestern Pamirs, N.N. Pertsev organized expeditions there in 1989 and 1990. E.S. Grew participated in the second expedition, thereby becoming the first American geologist to work in the southwestern Pamirs. Grew's research project, supported by the exchange program between the U.S. National Academy of Sciences and the USSR Academy of Sciences, was carried out within the framework of the International Geological Correlation Programme's Project 235 ("Metamorphism and Geodynamics").

In this article, we report preliminary findings of these two expeditions and outline directions for further research on the materials obtained on the two expeditions.

Purpose of the field work

Whiteschists are chemically simple, in many cases consisting mostly of MgO , Al_2O_3 , SiO_2 , and H_2O . Thus, whiteschists are readily modeled both experimentally and theoretically for use in determining the physico-chemical conditions of formation. The most recent experimental and theoretical work in this system indicates that the minimum water pressures necessary for talc+kyanite+quartz stability are 0.6–0.8 GPa at temperatures between 600 and 700 °C ($p(\text{H}_2\text{O}) = p(\text{total})$, Massonne, 1989; Berman, 1988). The purpose of our field work was to collect a variety of talc schists and associated rocks in order to assess the conditions of formation of the talc+kyanite assemblage.

Kornerupine is a silicate of magnesium (Mg), aluminum (Al), and iron (Fe) that, aside from rare exceptions, contains boron (B) (as much as 4 wt percent B_2O_3 , Grew and others, 1990). Kornerupine is compositionally complex, and its paragenesis remains poorly understood in many cases. It has been reported from about 50 localities worldwide, but the occurrence in the southwestern Pamirs, first reported by Levitskiy and others (1988), is only the fifth occurrence known from the USSR. This particular occurrence is of special interest because it is one of the few occurrences of kornerupine in amphibolite-facies rocks.

An important question related to both the whiteschists and kornerupine concerns the origin of these highly magnesian, commonly boron-bearing rocks. Clearly, both highly magnesian sedimentary precursors and metasomatic exchange during metamorphism played significant roles in the development of these rocks. I.A. Zotov (oral communication, 1990) suggests that premetamorphic acidic volcanism, together with silicification, resulted in the formation of the peraluminous quartzose rocks and thus played a role in the formation of certain unusual bulk compositions. Our aim was to sort out the influence of pre- and synmetamorphic factors and to clarify to what extent and how each factor determined the final outcome.

Field program

The field program involved studying the more accessible and better exposed localities of the highly magnesian rocks that were associated with marbles. Zotov and Sidorenko (1968), Kiselyov and Budanov (1986), and Rossovskiy and others (1988) reported approximately 10 major localities throughout the southwestern Pamirs. During the two field seasons, we visited six of these: Kuhi-lal, Darai Stazh, Mulvoj, Changan, Ishkashim, and Lyajvardara (fig. 1). Our emphasis was on the first three. Kuhi-lal, Ishkashim, and Lyajvardara are accessible by road, and we worked from a camp set up by our vehicle. The other three localities required climbs of 800 to 1,400 m and thus were sampled on day trips from the Pyanj valley, except for Darai Stazh, where we camped out one night in 1990 at 3,500 m.

Kuhi-lal

Kuhi-lal, which means "mountain of lal," that is, ruby-red spinel, has been known since ancient times as a source of gem spinel. It also has the most extensive occurrence of magnesite marbles and associated magnesian rocks, which crop out over an area of 1×1.5 km. Unusual minerals and rocks that are found here in addition to talc+kyanite include kyanite+gedrite rocks (Zotov and Sidorenko, 1968), sapphirine (Zotov, 1966), and magnocolumbite (Mathias and others, 1963).

Talc+kyanite assemblages are rare among the kyanite-bearing rocks at Kuhi-lal. Far more common are kyanite+amphibole schists. These rocks range from gray to black depending on the amount of graphite and sulfide present. Kyanite and amphibole form porphyro-

Figure 2.—Looking south at fold in pegmatite (P) at Kuhi-lal, USSR.

blasts, which in places have overgrown trains of finely disseminated graphite. The colorless mica in these schists appears to be largely phlogopite. Talc+kyanite schists are lustrous gray rocks in which amphibole is subordinate or absent. We found talc+kyanite± hornblende schist in situ at only one locality, where it occurs sporadically in a band of talc and phlogopite schists 1 to 1.5 m thick between a dravite-bearing pegmatite and a gray rock that consists of dominant enstatite and subordinate spinel and forsterite. The schist band could be interpreted as either a metasomatic zone adjacent to pegmatite or as a schist developed from metamorphism of magnesian argillaceous sediments into which the pegmatite subsequently was emplaced. The pegmatite itself is deformed into tight folds (fig. 2).

Another assemblage at Kuhi-lal that deserves further study is talc+enstatite. Though the reaction talc+4 enstatite=anthophyllite, this assemblage implies pressures above 0.2–0.6 GPa at 600–700 °C (Evans and Guggenheim, 1988), irrespective of $p(\text{H}_2\text{O})$. As anthophyllite is also commonly found with talc at Kuhi-lal, relationships among talc, enstatite, and amphibole, in terms of FeO and Al_2O_3 contents, deserve further study in order to assess the validity of talc+enstatite as an indicator of metamorphic conditions.

Thin sections of graphitic skarns collected in 1989 contain an assemblage not reported previously from Kuhi-lal: enstatite±spinel±orthoamphibole+chondrodite+sapphirine. The latter pair has been reported from only one other locality worldwide: Assam, India (Lal and others, 1978). We plan to investigate the role of fluorine and boron in stabilizing this assemblage. Fluorine is an essential constituent of most chondrodites, and boron has been reported in a few chondrodites (as much as 1.2 wt percent B_2O_3 according to Hinthorne and Ribbe, 1974). In addition, sapphirine has been found to incorporate as much as 0.85 wt percent B_2O_3 (Grew and others, 1990).

Darai Stazh

Our prime interest at Darai Stazh centered on talc-bearing lenses exposed in two prospects between 3,500 and 3,700 m altitude on either side of the stream by that name. Corundum-phlogopite and corundum-plagioclase rocks that are associated with lenses of magnesite at 4,000 m altitude were sampled in 1989 and are now being studied by A.K. Litvinenko. Each of the talc-bearing lenses appears not to extend more than a few tens of meters and not to exceed 10 m in thickness. Several samples contain the assemblage talc+kyanite. Fibrolite, a variety of sillimanite, is present in quartzose layers or veinlets and locally ap-

pears in association with kyanite. Thin-section study is needed to clarify the relationship between fibrolite and kyanite; at Kuhi-lal, fibrolite is the later phase (Grew and others, 1988).

Levitskiy and others (1988, 1990) reported cordierite and kornerupine from both prospects we sampled, the latter mineral being present in zones, nests, and veinlets. We found several large blocks (as large as $0.5 \times 0.25 \times 0.25$ m) consisting exclusively of kornerupine (fig. 3) or tourmaline derived from the alteration of kornerupine. The kornerupine forms coarsely crystalline, columnar aggregates and sunbursts. Analyses of material collected in 1989, together with X-ray powder diffraction data, give a low content of iron (1 wt percent as FeO) and a modest boron content (roughly 1.5–2 wt percent B_2O_3). In one block, the kornerupine appears to be virtually unaltered, whereas in other blocks, secondary pale-brown and pale-green tourmaline, white chlorite, and corundum (in part blue) are abundant. Two of the kornerupine blocks have phlogopitic rinds. One rind contains kyanite and amphibole, and the other, sapphirine and corundum. We did not find any kornerupine in situ. Possibly the kornerupine blocks originated in talc and amphibole schists, in which case the phlogopitic rinds developed between kornerupine and talc. The assemblage kornerupine+talc is apparently restricted to high H_2O activities (Grew, 1988).

Our observations do not confirm the sequence of replacement that Levitskiy and others (1988, 1990) deduced for kornerupine, which was (1) cordierite, (2) kornerupine±corundum, (3) tourmaline+phlogopite, and (4) chlorite. We have no evidence for relict cordierite in kornerupine. Instead, sapphirine, a mineral not reported by Levitskiy and others (1988, 1990), is included in kornerupine and must have formed earlier, and kornerupine appears to have been partly replaced by cordierite. Although coarser grained corundum appears to have formed earlier and (or) coevally with kornerupine, as Levitskiy and others (1988, 1990) suggested, finer grained corundum accompanies tourmaline and chlorite, so all three seem to have formed from the breakdown of kornerupine. Chemographic relationships indicate that these three minerals and cordierite could have formed from kornerupine as calcium- (Ca) and sodium- (Na) bearing aqueous fluids were introduced: $\text{kornerupine} + \text{CaO} + \text{Na}_2\text{O} + \text{H}_2\text{O} = \text{corundum} + \text{tourmaline} + \text{chlorite} + \text{cordierite}$.

Levitskiy and others (1988) also reported that cordierite-rich rocks formed from metasomatic replacement of magnesite, which they described as a new genetic type of cordierite-bearing rock. In 1990, we collected what appear to be the monomineralic nodules of cordierite described by Levitskiy and others. Through a study of these rocks, we can assess the validity of the hypothesis that they proposed.

Mulvoj

The body of magnesian rocks at Mulvoj is exposed for more than 1 km at altitudes of 3,500 to 3,750 m and attains 300 m in width (Kiselyov and Budanov, 1986). We examined a section along the crest of the ridge near the southeast limit of the lens (fig. 4). Host rocks for the lens include biotitic and amphibolitic quartzofeldspathic gneisses, in part migmatitic. The lens itself includes marbles, amphibolites, calc-silicate skarns, amphibole skarns, and amphibole and talc schists. The amphibole schists exposed in a trench on the ridge crest contain kyanite, phlogopite, and talc, whereas the talc schists contain veinlets of quartz and nodules of enstatite, in part altered to talc. Tourmaline forms not only dark-brown crystals up to several centimeters across but also blue, fibrous aggregates in veins that cut the amphibole schists. Kyanite also was found in talcose amphibole schists in a second trench further west in the body. One of these schists contains kornerupine, which has not been reported previously from Mulvoj. This schist consists largely of talc plus kyanite porphyroblasts and rare quartz. Kornerupine, found as prisms 0.2–1.7 mm across, is restricted to a

Figure 3.—Block of kornerupine that has phlogopitic rinds (at arrows), Darai Stazh, USSR.

Figure 4.—View east at Mulvoj, USSR, at about 3,600 m altitude. Prospects for magnesian rocks extend along the slope just below the first ridge crest in center of picture. A.K. Litvinenko is seated on the ridge crest in foreground (lower righthand corner of the photograph).

phlogopite layer that is about 1 cm thick, whereas tourmaline and orthoamphibole occur in both the talc schist and phlogopite layer. This distribution suggests that kornerupine was not stable with the talc+kyanite±quartz assemblage; additionally, it could explain the phlogopite rinds on the kornerupine blocks from Darai Stazh.

Other localities

Enstatite-rich skarns are present at Changin and Ishkashim, but kyanite+talc rocks were not found. Corundum-bearing rocks rich in plagioclase, phlogopite, or amphibole are abundant at Ishkashim. Phlogopite schist at Ishkashim contains light-purplish-gray sapphirine porphyroblasts that are as long as 2 cm; Rossovskiy and others (1988) reported these to be highly depleted in iron (0.56 wt percent FeO).

Lyajvardara is mined for lapis lazuli. The mine is located behind a vertical wall of marble at 4,500–4,600 m altitude that is within full view of Mayakovsky Peak, 6,095 m. The lapis lazuli occurs as scattered lenses up to several meters across in marble that was originally

dolomitic. The lapis lazuli formed by metasomatic replacement of pegmatoidal rocks in the marble, and an outer zone of phlogopite commonly surrounds the lenses of lapis lazuli. Country rock below the lapis-bearing marble is biotite- and hornblende-bearing gneiss that is cut locally by metamorphosed and folded mafic dikes.

Problems to be addressed

Talc+kyanite schists, or whiteschists, are an integral, if rather rare, component of the magnesian rocks in the southwestern Pamirs. This assemblage, together with kyanite+amphibole in the magnesian rocks and kyanite+potassium feldspar in the migmatitic host rocks, can be used to infer the prograde metamorphic conditions. Talc+enstatite, which could be a prograde as well as a retrograde assemblage, is also potentially useful in this regard. On the other hand, corona assemblages around kyanite porphyroblasts can give indications of the retrograde path. These coronas, which are universally present in rocks containing talc and (or) amphibole, consist of cordierite, plagioclase (Grew and others, 1988, reported An_{90-97}), corundum, and sapphirine in narrow margins around kyanite (fig. 5) (see also Zotov, 1966; Zotov and Sidorenko, 1968). The coronas indicate decompression following peak conditions of metamorphism, possibly accompanied by a small increase in temperature. In contrast, alteration of kornepine to cordierite, tourmaline, chlorite, and corundum involved hydration and a decrease in temperature; this may represent a different metamorphic event. Schreyer and Abraham (1976) reported relics of the prograde path in whiteschists found at Sar-e Sang, Afghanistan: chlorite+quartz and paragonite, for example. Thus, one of our main tasks is to determine the metamorphic evolution on the basis of mineral assemblages in the magnesian rocks.

Folding of pegmatite veins at Kuhi-lal and of mafic dikes at Lyajvardara are clear indications that multiple deformation took place in the southwestern Pamirs. Therefore, interpretation of metamorphic textures will have to take into account a polydeformational history.

Borosilicates are minor constituents in several of the magnesian bodies. At Kuhi-lal, finely disseminated tourmaline is a typical accessory mineral in the kyanite-bearing talc and amphibole schists, whereas larger crystals occur locally in marble. As dravite is an widespread accessory mineral in the Kuhi-lal pegmatites, one might infer that the tourmaline in the schists formed from the infiltration of fluids associated with the pegmatites. Alternatively, tourmaline in the schists may have developed from boron in the sedimentary precursors. Even more problematic is the origin for the boron in the kornepine aggregates at Darai Stazh. These kornepine aggregates clearly are metasomatic in origin, but their relationship to pegmatitic tourmaline is far from obvious. Thus, an important question to be investigated is the origin of boron and its mobility during metamorphism and metasomatism.

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Figure 5.—Photomicrograph of talc+kyanite+hornblende schist illustrating reaction rim of corundum (Co), anorthite (An), and cordierite (Cd) between kyanite (Ky) and hornblende (Hb). Talc (Tc) is also visible in this sample 7KKhL-18/83, which was described by Grew and others (1988).

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