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Potential for ruby mineralization in upper Kaghan, NW Himalaya

M. QASIM JAN & M. ASIF KHAN

National Centre of Excellence in Geology, University of Peshawar, Peshawar

ABSTRACT: *The Precambrian to Early Paleozoic basement of the upper Kaghan has a cover of metamorphosed sedimentary and volcanic rocks of Late Paleozoic-? Early Triassic age. About 3 km NE of Naran, the cover rocks contain a few tens of meters thick marbles containing thin (mostly <1 cm) micaceous bands one of which hosts tiny (up to a millimeter) grains of pinkish-red corundum. The occurrence of the ruby corundum is similar to the Hunza and Azad Kashmir ruby deposits, thereby necessitating further search in the area.*

The marbles consist of calcite ± muscovite ± biotite ± quartz ± pyrite. The micaceous bands consist of the two micas + pyrite + opaque oxide ± calcite ± rutile ± quartz ± plagioclase ± chlorite ± garnet. Microprobe analyses are presented for the common phases. Petrography and preliminary geothermobarometry suggest that the marbles were metamorphosed at 450-500°C, 6 kbar, followed by a lower temperature (~ 280°C) overprinting of chlorite-epidote grade during retrogression. Considerable inter- and intra-granular variations in the Cr content of green mica and ruby suggest a lack of mobility of Cr during metamorphism. The abundance of micaceous minerals and pyrite, and local occurrence of garnet and corundum suggest that the thin bands associated with the marbles were highly aluminous and iron-rich (?lateritic), and that reducing environments prevailed during their diagenesis.

INTRODUCTION

Corundum-bearing rocks have been reported from several places in the Himalaya-Karakoram region of Pakistan. Some of this corundum has been marketed as semiprecious to precious gem material. The two principal ruby-grade corundum occurrences in Hunza and upper Neelum valley are in marbles. In the course of mapping in upper Kaghan valley, we found traces of ruby corundum in marbles containing green and dark micas. The general aspects of these rocks are similar to the Hunza and Neelum ruby deposits. In view of the potential economic feasibility, the occurrence merits a brief description and further search.

Geological setting

The Kaghan valley presents a more or less complete cross- section through the Himalayas of N. Pakistan, from sub-Himalayas in the core of the Hazara-Kashmir syntaxis, through lesser Himalayas in the middle and Higher Himalayas in the upper reaches of the valley. The area around Naran forms a part of the Higher Himalayas. Chaudhry and Ghazanfar (1987) include rocks of this area in their Sharda Group and consider them to form part of a higher-Himalayan thrust sheet emplaced onto the Kaghan Group of Lesser Himalayan affinity along the Batal Thrust, considered by some to be equivalent of the Main Central Thrust (Greco & Spencer, 1993; Chaudhry & Ghazanfar, 1987).

The local geology of the Naran area is described by Greco et al. (1989) and Smith et al. (1994). Two principal rock units have been mapped; granitic gneisses and carbonate-garnet schists. The granitic gneisses in this area are predominantly two-mica, K-feldspar augen gneisses probably derived from plutonic intrusions (Greco et al., 1989). These granitic gneisses are widely exposed at a distance of about 2 km from Naran on northern and eastern sides, and are included in the Higher Himalayan basement (Greco et al., 1989; Smith et al., 1994). A large area in the immediate vicinity of Naran comprises garnet-carbonate schists. These are considered to represent part of the cover sequence, forming the lower limb of a large recumbent fold of which the upper limb consists of the Burwai Formation, exposed about 10 km upstream from Naran (Greco et al., 1989). Alternatively, Smith et al. (1994) include them in the basement and consider them to underlie the granitic gneisses with a thrust contact. Nonetheless, the garnet carbonate schists around Naran comprise predominantly a metasedimentary assemblage, with a greater abundance of calcareous lithologies including marbles.

This study is focussed on one of the marble bands in the garnet-carbonate schist unit, exposed along the western bank of the Kaghan river, about 500 m downstream of Bharjali Nar-Kaghan confluence. This marble band contains local biotite and green fuchsite-looking mica. This paragenesis is of interest for two reasons. 1) Fuchsites in northern Pakistan essentially occur in areas containing altered ultramafic rocks, but there is no ultramafic rock in the vicinity that may have contributed chromium in the present case. 2) The phlogopite-fuchsite marbles in Hunza and neighboring Neelum valley contain ruby corundum some of which is of high gem quality. Our preliminary and quick search also revealed tiny grains of pinkish-red ruby corundum in one micaceous band in the marbles.

THE CORUNDUM-BEARING ROCKS

Petrography

The marbles to the west of the mouth of the Bharjali Nar are mostly thin- to medium-bedded (less than 1 to 50 cm thick), brownish to white in colour, and range from nearly pure to impure calcitic rocks. They contain thin bands and films of metamorphosed micaceous rocks. These bands are 1 mm to 2 cm thick, deformed, and they may disappear laterally within a couple of meters. Some of them are peraluminous and full of mica (white and/or brown, commonly with abundant brown-red oxidized pyrite). Such bands are normally thin (1-3 mm). Most of the micaceous bands also contain carbonate and represent calc-"pelites" or pelitic limestones. At least one of these bands contains ruby corundum. The overall quantity of the "pelitic" material is no more than a few percent in the corundum-bearing outcrop about 500 m west of the Bharjali-Kunhar confluence. The samples from this outcrop comprise the following assemblages (mineral symbols after Kretz, 1983):

1) Cal
2) Cal-Py
3) Cal-Ms
4) Cal-Ms-Py
5) Cal-Ms-Qtz
6) Cal-Ms-Qtz-Opaque
7) Cal-Ms-Qtz-Pl-Py-Opaque-?Crn
8) Cal-Ms-Bt-Py
9) Cal-Ms-Bt-Py-Crn
10) Cal-Qtz-Bt-Ms-Grt-Rt-Opaque-Pl-Chl
11) Cal-Ms-Qtz-Pl-?Ilm-?Ep-Rt
12) Cal-Qtz-Bt-Grt-Ms-Opaque-Rt-?Crn-Tur
13) Qtz-Ms-Pl-Grt-Cal-Py-Opaque
14) Ms-Bt-Py-Ilm
15) Ms-Py

Most of the rocks are calcite marbles, medium- to fine-grained and granoblastic, with mica showing some alignment. The micaceous bands are distinctly schistose. Garnet is rare and some of it forms idioblasts up to 1.5 cm across.

Deformation features are displayed by minerals, especially micas. Most of the rocks consist of various proportions of calcite, muscovite, reddish mica, and pyrite, but a number of other minerals occur in minor quantities. Some of the rocks contain a rather large number of mineral phases, and on an ACF diagram they would show crossing tie-lines. These are thinly banded or non-homogeneous rocks and the phases probably represent more than one lithology.

Carbonate is principally calcite. It is colorless to brown-stained but, in a few rocks, the colourless calcite forms thin bands/veins or clots in a brown carbonate matrix. The dark mica is reddish pleochroic and locally chloritized. Muscovite is colourless in most cases, but in some it is pale green to emerald green. In thin sections, the green mica is intimately associated with colourless muscovite and occurs in local pools and patches, or forms parts of the colourless grains. Such inter- and intra-granular colour variations in chromian muscovite have been observed in other places also, e.g., Northwest Nelson, New Zealand (Challis et al., 1995), Betic Cordilleras, Spain (Sanches-Vizcaino et al., 1995), and Outokumpu, Finland (Treloar, 1987).

Garnet shows alteration to chlorite and epidote along margins and fractures. Pyrite is common (in some micaceous rocks abundant) and mostly altered red. Much or all of the opaque mineral is ilmenite showing local alteration to leucoxene, but there may also be a little graphite in some cases. Plagioclase composition could not be determined but it is more calcic than albite. Several corundum grains occur in one sample. The grains are pinkish red and rounded to subelongate, the largest measuring about 1.0 mm. The ruby corundum is closely associated with green mica and white calcite in a 4 mm thick band within a brownish marble containing green mica, pyrite, and clusters and thin veins of white calcite.

Mineral chemistry

Electron microprobe study of the mineral phases in three thin sections was carried out. Representative analyses are listed in Table 1, with a brief description in the following.

The carbonate in all the three samples is essentially calcite (95.3 to 98.7 mole %), with small amounts of magnesite (1.1 to 4.4 %) and siderite (0.2 to 2.2 %) components (analysis 1). The low amount of siderite suggests that the brownish colour of some carbonate is due to iron staining. Garnet analyses (no. 2) in an aluminous band show that the mineral is almandine-rich (60.8 mole %). It contains appreciable amounts of grossular (30.6 to 31.6 %), and pyrope (7.1 to 8.2 %), and small amounts of spessartine (0.4 to 0.5 %). Like garnet, three analyses of chlorite (no. 3) are also uniform and classify as ripidolite on Hey (1954) diagram. The analysis of a grain adjacent to garnet recalculates to $Si_{5.39}$ $Al_{5.50}$ $Fe^{2+}_{4.52}$ $Mg_{4.44}$ on the basis of 28 oxygens. It thus appears that it has not necessarily grown retrogressively after the garnet.

Many analyses were performed on micas. The white and green mica is muscovite with some phengitic substitution (anal. 4, 5, 6). The variation from white to light- and dark-green colours is directly related to the Cr_2O_3 content which ranges from <0.1 to 0.9 wt %. (One analysis with poor total contains 2.3% Cr_2O_3). The analyses in one sample contain 0.1 to 0.7 % TiO_2, 0.1 to 1.3 % Fe_2O_3, 0.0 to 0.1 % MnO and CaO, and high (0.84 to 0.91) $K_2O/(K_2O + Na_2O)$. It is interesting to note that in one of the samples containing both white and green mica, the MgO content (0.5 to 1.1, average 0.7%) of the green mica is higher than that (0.5 to 0.6 %) of the white mica. In another sample, the muscovite shows slightly higher phengite content (Fe_2O_3 = 0.8 to 1.3%, MgO = 0.8 to 1.1 %, TiO_2 = 0.4 to 0.6 %) and lower paragonite content (K/(K + Na) = 0.87 to 0.91). The reddish mica shows

TABLE 1. SELECTED MICROPROBE ANALYSES OF PHASES IN THE MARBLES

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	0.00	38.75	25.43	47.52	48.79	44.89	37.46	36.07	1.95	0.00	0.03	0.03
TiO_2	0.00	0.19	0.08	0.39	0.08	0.39	1.16	0.43	0.00	—	—	—
Al_2O_3	0.00	20.9	22.03	31.96	36.23	34.42	17.12	32.59	0.04	92.25	95.17	95.57
Cr_2O_3	0.00	—	—	—	0.02	0.87	—	0.42	0.00	2.80	1.47	0.67
FeO*	0.16	27.16	25.51	1.21	0.07	0.23	15.57	0.73	80.68	0.26	0.16	0.25
MnO	—	0.17	0.01	0.00	0.00	—	0.00	—	—	—	—	—
MgO	0.43	2.05	14.06	1.09	0.51	0.61	13.64	10.12	0.45	—	—	—
CaO	55.42	10.68	0.06	0.03	0.00	0.05	0.01	1.30	0.20	—	—	—
Na_2O	0.00	0.00	0.02	0.58	0.89	1.11	0.26	2.34	0.03	—	—	—
K_2O	0.02	0.00	0.00	9.37	9.22	9.50	8.17	0.05	0.00	—	—	—
Total	56.01	99.91	87.20	92.15	95.79	92.07	93.37	94.75	83.35	95.31	96.83	96.52

Fe = FeO in 1 to 9 and Fe_2O_3 in 10 to 12.

1. Carbonate (calcite = 98.7, magnesite = 1.1, and siderite = 0.2 mole%).
2. Garnet consisting of 60.8 mole % almandine, 8.2 % pyrope, 0.4 % spessartine and 30.6 % grossular.
3. Chlorite (ripidolite containing Si=5.39, Al=5.5, Fe=4.52, Mg=4.44 atoms per 28 oxygens). Occurs close to 2.
4. Muscovite. From the same sample as 2.
5. Muscovite.
6. Chromian muscovite associated with 5.
7. Biotite $(Si_{5.65} Al_{2.35}) (Al_{0.70} Ti_{0.13} Fe^{2+}_{1.97} Mg_{3.07}) (Na_{0.08} K_{1.57}) O_{22}$. From the same sample as 2.
8. Dravite, total includes an assumed content of 10.70% B_2O_3.

   It thus recalculates to: $(Na_{0.74} Ca_{0.23}) (Mg_{2.46} Fe^{2+}_{0.10} Al_{0.44}) (Al_{6.21} Cr_{0.05} Ti_{0.05}) (Si_{5.88} O_{18}) (BO_3)$.
9. Goethite (orange red).

10, 11, 12. Ruby corundum analyses in apparently a single grain about 0.9 mm across.

substantial variation and may be ranging from phlogopite to biotite. It has an Mg/(Mg + Fe) ratio of 0.53 to 0.64 and contains 0.6 to 1.4 wt % TiO_2, 0.1 to 0.3 % Na_2O, and is devoid of MnO and CaO. A representative analysis is given in Table 1 (anal. 7).

Tourmaline, analysed in one rock, is pale yellow chromian dravite (anal. 8). It contains little or no K_2O and MnO, and only small amounts of TiO_2 (0.1 to 0.4 %), FeO (0.1 to 1.0 %), CaO (0.3 to 1.3%) and Cr_2O_3 (0.3 to 0.5 %). An analysis of magnetite contains 0.5 % TiO_2 and that of goethite (anal. 9) contains 0.45 % MgO and unusually high (1.9%) SiO_2. Rutile is pure except for about 0.3 % Cr_2O_3; it contains only traces (0.1 to 0.03 %) of SiO_2 and Fe_2O_3. Ruby corundum (anal. 10-12) contains only small amounts of SiO_2 (< 0.05 %), Fe_2O_3 (0.15 to 0.28 %), and MgO (<0.15). Like green mica, it shows much variation in the Cr_2O_3 content (0.7 to 2.9 %) within short distances in the same grain. The variation in Cr content within mineral phases over short distances reflects: 1) original sedimentary variations in Cr content, and 2) insufficient mobility of Cr during metamorphism to achieve even local homogeneity (Treloar, 1987).

The assemblages suggest that the rocks have been metamorphosed under garnet grade conditions with a retrograde overprint of chlorite-epidote grade. Garnet-phengite thermometry yields 444°C (Krogh & Raheim, 1978) and 504°C (Green & Hellman, 1982), and garnet-biotite thermometry yields 450-475°C (Goldman and Albee, 1977; Perchuck, 1977; Hodges and Spear, 1982; Indares and Martignole, 1985). For a temperature of 475°C, the Si contents of the white micas (analyses 4 & 5, Table 1) give pressure estimates of 6 kbar, following Massone (1980). These estimates should, however, be cautiously taken because (1) of the calcic nature of the rocks, and (2) possible lack of equilibrium between the three phases since the analysed grains are not in contact. Chlorite thermometry of De Caritat et al. (1993) provides a retrograde overprint estimate of 280°C.

COMPARISON WITH HUNZA AND AZAD KASHMIR

The geology of the corundum-bearing rocks of Kaghan is not much different than the known ruby occurrences of Pakistan, i.e., Hunza and upper Neelum valley. Both these areas have been commercially exploited. The Hunza rubies occur in a metasedimentary sequence at the southern edge of the Karakoram plate. The sequence consists largely of metamorphosed pelites (from chloritoid grade near the Shyok suture to sillimanite grade near the Karakorum batholith to its north) with marble layers, amphibolites and granites. The marbles near Karimabad attain a thickness of 2 to 3 km and extend for 24 km (Faruqi, 1978). They contain ruby corundum and/or spinel + phlogopite ± pargasite ± diopside ± anorthite ± sulfide ± chlorite ± margarite. Faruqi (1978) reports that the ruby mineralization is restricted to favourable bedding-, cleavage- and joint planes, fractures and pockets, and is granite-related hydrothermal in origin. Okrusch et al. (1976) and Broughton et al. (1985) favour a regional Barrovian-type metamorphic origin of rocks of appropriate composition at 600-650° C, 5.5 - 6.5 kbar. According to Okrusch et al. (1976), the marble was derived from a limestone complex in which Al was enriched relative to silica, possibly by lateritic weathering in a karst environment. A certain enrichment of Ti and Cr is consistent with this interpretation.

The geology of the upper Neelum valley is an apparent continuation of that of the upper Kaghan valley. There is a migmatitic basement of metasedimentary, granitic and amphibolitic rocks. This package is overlain by a cover consisting of a sequence of calc schists, quartzites and corundum-bearing marbles, and a sequence of pelitic schists, paragneisses and quartzite. The ruby corundum occurs in several places in bluish grey calcite (± phlogopite ± muscovite ± pyrite ± rutile) bands 1 to 30 cm thick. These bands are spaced at 0.2 to 1.0 m distance in a 30 to 45 m thick marble zone. Some of the rubies are of high quality and have been described by Malik (1995). This area has also passed through high-grade amphibolite facies metamorphism with locally occurring eclogites.

We have been told by natives that ruby corundum also occurs in the Nanga Parbat massif. There is no information on the host rocks of these rubies, but it would not be surprising at all if these are also hosted by marbles.

DISCUSSION

The presence of ruby in marbles is not unusual. Many occurrences of this type have been documented in different parts of the world as summarized in Hunstiger (1990). The formation of the mineral requires excess Al over Si. In marbles, it has been attributed to 1) hydrothermal/pneumatolytic activity related to igneous intrusions, 2) derivation of marbles from calcareous rocks that had undergone lateritic weathering in a karst environment, 3) metamorphism of mixture of calcareous rocks and alumina-rich sediments such as bauxites and clays either developed in situ, transported from elsewhere, or both. The Naran marbles, as already described, contain thin bands of mica-rich material one of which hosts the corundum. This suggests an input from a highly aluminous source. The marbles may well be a mixture of Al-rich sediments with limestones. During burial and diagenesis, the environments must have been depleted in oxygen and enriched in H_2S. This resulted in the formation of pyrite in the marbles and, more abundantly, in the micaceous bands which were probably more enriched in iron to begin with.

The red colour of the ruby has been related to the presence of small quantities of chromium. This also is the case with the Kaghan ruby corundum, which contains up to 3% Cr_2O_3 and is associated with chromian muscovite. Calcareous rocks are generally depleted in chromium but, in the absence of any evidence suggesting introduction of Cr from outside, it is likely that small quantities of Cr were present in the host rocks. Chromium in sediments can occur as detrital grains, as adsorbed material on mineral grains or absorbed by clays, and as solutes of Cr compounds in sea water such as in contact with stagnant bottom waters. Some enrichment in Cr may be related to weathering if the Al-rich sediments were derived from laterites. In any case, the local presence of green mica and ruby would suggest that only small quantities of Cr were available.

The presence of a few tiny grains of rubies in a thin horizon in the Kaghan marbles is of no direct economic relevance. But the occurrence is important because of its similarity with the other two ruby occurrences of Pakistan. A thorough search of the marble horizons of the area is required, particularly those containing green fuchsitic muscovite.

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