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A SKARN ROCK FROM DIR, NORTHWEST PAKISTAN

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ABSTRACT

The geology and petrology of a skarn from northwest Pakistan are presented. The chemistry of the rocks and their constituent minerals is discussed briefly and compared with other similar occurrences. The rock chemistry and the abundance of ferrosalite, andradite-rich garnet, and epidote ($Fe^{3+}/(Fe^{3+} + Al) \simeq 0.30$) *are considered to be due to metasomatism (mainly the introduction of iron, and possibly silica) of the country metasediments or, less likely, volcanic rocks by a biotite-two pyroxene tonalite intrusion.*

INTRODUCTION

Rocks occurring just north of Dir town and extending some 5 km further north to Panakot bridge were reported in a preliminary note by Kempe and Jan (1980) as melanite- and aegirine-augite-bearing metasyenite. Chemical analysis of the rock and constituent minerals, however, show them to represent a garnet-clinopyroxene-epidote skarn.

The skarn rocks are banded and occur within the Dir Group of Utror Volcanics and related rocks, a formation comprising mainly calc-alkaline volcanic rocks and slates, which extend eastwards into Swat Kohistan and westwards into Afghanistan. They have been assigned an Eocene age on the basis of fossils found in the sediments (Khan, 1979). To the south the Dir Group is bounded by the quartzites and siliceous schists of the (?) Cretaceous Kalam Group, and to the north by the Deshai diorites (Tahirkheli and Jan, 1979). The Kalam and Dir Groups have undergone low grade regional metamorphism, generally not extending beyond the biotite zone.

These formations all form part of the Kohistan island arc sequence (Tahirkheli and Jan, 1979; Tahirkheli *et al.*, 1979; Bard, 1983). It is probable that the skarn was produced by metasomatism resulting from the intrusion of a tonalitic facies of the Deshai diorites into Dir Group metasediments or dacitic volcanic rocks.

FIELD RELATIONS

The tonalites occurring north of Dir form a part of the several hundred kilometers long Kohistan-Ladakh granitic belt (cf. Jan and Asif, 1983). They are medium-grained, homogeneous, and moderately foliated; they contain biotite (locally > 1 cm) and two pyroxenes, and petrographically resemble some of the quartz diorites described from the Kalam area of Swat (Jan and Mian, 1971; Jan and Kempe, 1973; Khalil and Afridi, 1979; Majid, 1979). Pegmatites and aplites are rare but fractures filled with feldspathic material do occur. The tonalite is locally stained blue-green by malachite.

Xenoliths are rare but in a road-cut 4 km north of the contact a 5 x 1 m group of xenoliths occurs, ranging from mafic plutonic to grey porphyritic volcanic rocks, to others rich in biotite and/or amphibole or clinopyroxene. The xenoliths reach 15 cm in size, are angular to rounded, and in some cases resemble orbs (cf. Symes *et al.*, in prepn). Some are slightly feldspathised or have felsic reaction rims. About 2 km north of the contact there is a 30 cm xenolith composed of calcic plagioclase,clinopyroxene, biotite, quartz, magnetite, and (?)K-feldspar. Close to this is a 5 x 2 m block of fine-grained rock in the tonalite containing biotite and two pyroxenes. Since orthopyroxene has not been found in any other xenolith, this block, with its fine-grained texture, may be an autolith. Perhaps surprisingly, no garnet has been found in the xenoliths.

The contact aureole between the tonalite and Dir Group rocks is represented by a zone, approximately 300 m wide, of banded rocks, with tonalite and biotite microtonalite sheets generally in the northern part and a few small bodies of aplitic granite and pink (?)orthoclase pegmatite in the middle part. The higher grade metamorphism (i.e. calcic plagioclase, clinopyroxene, garnet) displayed by this zone than elsewhere in the rocks of the Kalam and Dir Groups must be due to the contact or metasomatic effects of the tonalite. Absence of orthopyroxene and the presence of epidote suggest that metamorphism was probably in the hornblende hornfels facies in the inner aureole.

The contact rocks are strongly banded and locally have a migmatitic aspect; there is some shearing, suggesting forceful intrusion, which might have aided the development of garnet. The bands are generally white to grey but some are brown or green due to a high proportion of garnet and epidote, pyroxene, or rarely malachite, respectively. They range from mere streaks to a few centimetres in thickness, with a N 40°–60° E strike and a 35°–40° NW dip. The mineral composition of the bands is given in Table 1; not included in the table are mm-scale thin bands exceptionally rich in biotite. Garnet is not ubiquitous and is not developed in the immediate vicinity of the contact, but principally in a 3 m thick zone, also containing the pink feldspar pegmatite, about 150 m north of Panakot bridge and 5 km north of Dir town. Clinopyroxene is extensively developed in this zone. To the south of Panakot bridge, the banded "gneisses" pass into often banded siliceous schists containing oligoclase ($\approx An_{30}$), biotite, and minor local amphibole, but no clinopyroxene or garnet. Further south occur rocks

TABLE 1. MINERAL COMPOSITION OF SOME BANDED GNEISSES AND ASSOCIATED ROCKS NEAR PANAKOT BRIDGE, 5 KM NORTH OF DIR

	Plagio-clase	Garnet	Clino-pyroxene	Epi-dote	Sphene	Quartz	K-feld-spar	Amphi-bole	Ore	Mala-chite	Carbon-ate	Bio-tite
Xenolith in tonalite	+	—	+	—	—	—	+	—	+	—	—	—
Greenish grey band	+	—	+	+	+	+	+	?	+	—	—	—
Greyish black band	+	+	+	?	+	—	?	—	—	—	—	—
Grey band	+	+	+	+	+	+	—	—	+	+	—	+
Greenish grey band	+	+	+	+	+	+	—	—	+	—	—	+
Grey band	+	—	+	—	+	+	—	—	+	—	—	+
Grey band	+	—	+	+	+	+	—	—	+	—	—	—
Brownish band	+	+	—	+	—	+	—	—	+	—	—	—
Brownish band	+	+	+	+	+	+	—	—	+	—	—	—
Brownish band	+	+	+	+	—	—	—	—	—	—	—	—
Brownish green band	+	—	+	—	+	+	—	—	+	+	—	+
Greenish white band	+	—	+	—	+	+	+	—	—	—	—	—
Light grey gneiss	+	—	+	—	+	?	+	—	+	—	—	—
Whitish green band	+	—	+	+	+	+	—	—	+	—	—	—
Whitish band	+	+	+	+	+	+	+	—	—	—	—	—
*Greenish-grey banded schist	+	—	—	+	—	+	?	+	+	—	+	—
*Brownish-grey schist	+	—	—	—	—	+	+	—	+	—	+	+

* The last two rock types are the farthest away from the intrusion and are only mildly affected by contact metamorphism. The last rock also contains chlorite; calc-silicate lenses are found in the upper part of these rocks. Plagioclase in the rocks is generally labradoritic but in the last two types it is oligoclase (An_{30}).

with even lower grade metamorphism, unaffected by the contact metamorphism associated with the tonalite. The siliceous schists resemble the quartzites and siliceous schists of the Kalam Group found to the south of Dir.

PETROLOGY

The banded contact rocks or skarns contain bands of brown andradite garnet up to 2 cm thick in a 'layered' matrix of green epidote- and pyroxene-rich material, alternating with pale layers of plagioclase and altered potassium feldspar. Sphene, quartz, and magnetite, and rare calcite and scapolite are the most important accessory minerals. The garnet and epidote may be disseminated or porphyroblastic; a few bands contain lenses of garnet and epidote up to 2 and 4 cm thick, respectively.

An analysis of the rock (Table 2) shows no unusual features: it is very poor in MgO and rich in CaO and K_2O. Normatively (CIPW), the rock is just oversaturated with 1.1% Q. Similar analyses of skarns are rare in the literature, one of the nearest being of a rock from a zoned scapolite-bearing skarn body in California, in which forsterite, diopside, actinolite, epidote, and garnet occur (Shay, 1975; see Table 2).

TABLE 2. ANALYSIS OF THE DIR SKARN ROCK

	1			A
SiO_2	51.8			53.02
TiO_2	0.80	p.p.m.		—
Al_2O_3	16.0	Cr	15	14.58
Fe_2O_3	6.34	Li	9	—
FeO	1.74	Ni	10	6.48*
MnO	0.38	Co	5	—
MgO	0.71	Cu	45	3.51
CaO	12.5	Zn	60	12.40
Na_2O	1.75	V	100	nil
K_2O	6.16	Sr	85	—
H_2O+	0.56	Ba	360	—
H_2O-	0.13	Rb	210	—
P_2O_5	0.13			—
CO_2	0.80			—
Others	0.10			—
Total	99.90			89.99

1. Skarn rock from near Panakot, ca 5 km N of Dir town. Analyst: V.K. Din, using XRF, AAS, redox titration, and CHN analyser.

A. Skarn rock (73-132) from epidote zone, zoned scapolite-bearing skarn body on San Gorgonio Mountain, California (Shay, 1975). Analyst: P.G. Stummer, using XRF; partial analysis only; total Fe as FeO*.

The garnet, pyroxene, and epidote have been analysed by microprobe and average compositions for five analyses each of the garnet and epidote, and four of the pyroxene, are given in Table 3. The garnet analyses all fall within ½% of the average atomic proportions of Fe, Mg and Ca; the epidotes within 2%; and the four pyroxenes within 1%, a fifth analysis lies within 3%.

The garnet closely resembles an andradite from Jersey, produced by the contact metasomatism of andesite by a granitic intrusion (Oliver, 1958), as also occurs around the Shap granite, Westmorland (Firman, 1957). The calculated end-member compositions of the two garnets are even closer (cf. Deer *et al.*, 1962, p. 90, anal. 4), as shown in Table 3. The pyroxene is a ferrosalite – $Ca_{50}Mg_{20}Fe_{30}$ – closely resembling a pyroxene from a skarn rock associated with the magnetite deposit of St. Lawrence County, New York (Hess, 1949; Deer *et al.*, 1978, p. 216, anal. 7; and Table 3). The epidote ($Fe^{3+}/(Fe^{3+} + Al) \approx 0.30$) is typical of its kind, resembling in composition several analyses reported by Tempel (1938; see also Deer *et al.*, 1962, p. 198).

Magnetite skarns are associated with the Precambrian Lahor granite intruding Salkhala metasediments in Allai Kohistan, northern Pakistan (Ashraf *et al.*, 1980), but these are of a totally different nature from the Dir occurrence. A closer analogy lies with the wollastonite, diopside, grossular and dark red garnet, and idocrase skarns produced by the reactions of a calcareous xenolith within the Swat granite-gneiss, at Manglaur (Shams, 1963). Also with the scapolite-garnet-hedenbergite-epidote-hornblende rocks of Karera, district Bhilwara, Rajasthan, northwest peninsular India (Sharma, 1981). These rocks contain minor plagioclase, sphene, apatite, quartz, ilmenite, magnetite, and hematite; analyses of the pyroxene and garnet are included in Table 3. The rocks occur as thin bands and lenses within the Banded Gneissic Complex underlying the marbles, calc-silicate rocks, and subordinate pelitic schists of the Early Precambrian Aravalli Group. They are not thought to result from metasomatism, however, but on phase relations, textural, and geological criteria are considered to have formed by equilibrium recrystallisation of an impure calcareous sediment, the chlorine in the scapolite deriving from an evaporite component of the Aravalli metasediments. Lastly, ferrohastingsite-hedenbergite-garnet-epidote-wollastonite-axinite skarns occur in the Obira, Kinbu, and Moji mines of Japan, associated with iron and copper ore minerals (Matsumoto, 1974).

The assemblage andradite-hedenbergite-epidote-feldspar is typical of skarns produced when FeO, Fe_2O_3, and SiO_2 are introduced into a calcareous environment; the two characteristic minerals may be produced according to the reaction :

$$2Fe_2O_3 + 2FeO + 5SiO_2 + 4CaCO_3 \rightarrow Ca_3Fe^{+3}{}_2Si_3O_{12} + CaFeSi_2O_6 + Fe_3O_4 + 4CO_2.$$

The classic example of such rocks was described by Eskola (1914) from Finland; andradite-hedenbergite skarns in general are discussed briefly by Deer *et al.* (1962, p. 93; and 1978, pp. 274–6), Turner and Verhoogen (1960, pp. 572–4), and by Einaudi and Burt (1982 and *et seq.*).

In conclusion, then, the Dir skarn (iron calcic exoskarn) probably formed as a result of metasomatism (mainly the introduction of iron, and possibly silica)

TABLE 3. ANALYSES OF MINERALS FROM THE DIR SKARN ROCK

	Garnet			Pyroxene			Epidote
	1	A	B	2	A	B	
SiO_2	35.60	36.40	40.77	47.80	45.80	49.2	37.00
TiO_2	0.65	0.05	0.02	0.13	0.31	—	0.07
Al_2O_3	4.80	4.25	9.02	2.46	5.11	1.7	22.00
Fe_2O_3	26.56	25.29	22.44	—	5.87	—	14.80
FeO	—	2.41	—	17.30	12.44	19.7	—
MnO	1.43	1.55	0.43	0.89	0.41	0.3	0.39
MgO	0.14	0.02	5.72	6.70	6.86	5.1	nil
CaO	29.97	30.51	23.33	22.43	22.54	23.9	23.09
Na_2O	0.02	0.14	—	0.60	0.35	0.2	nil
K_2O	0.02	0.08	—	nil	0.02	0.15	nil
H_2O	—	—	—	—	0.26	—	n.d.
Total	99.19	100.70	101.73	98.31	99.97	100.25	97.35

NUMBERS OF IONS ON THE BASIS OF :

	24 (O)						6 (O)						13 (O, OH)	
Si	5.925	6.00	6.017	6.02	6.50	6.50	1.912	2.00	1.794	2.00	1.95	2.00	3.108	3.11
Al	0.075		—		—		0.088		0.206		0.05		—	
Al	0.867		0.818		1.7		0.028		0.030		0.03		2.178	
Fe^{+3}	[3.009]	3.96	3.146	3.97	2.2	3.90	—		0.173		—		0.936	3.12
Ti	0.081		0.006		—		0.004		0.009		—		0.004	
Mg	0.035		0.005		1.38		0.400		0.400		0.30		—	
Fe^{2+}	[0.318]		0.333		0.51		0.579	2.05	0.407	2.01	0.65	2.01	—	2.11
Mn	0.202	5.91	0.217	6.02	0.06	6.00	0.030		0.013		0.01		0.028	
Ca	5.343		5.405		4.05		0.961		0.946		1.01		2.078	
Na	0.006		0.044		—		0.047		0.026		0.01			
K	0.004		0.017		—		—		0.001		—			
Almandine	5.5		5.5		8.5	Ca	49.6		48.8		51.5			
Andradite	76.2		78.5		54.5	Mg	20.0		20.6		15.3			
Grossular	14.3		12.3		13.0	Fe	30.4		30.6		33.2			
Pyrope	0.6		0.1		23.0									
Spessartine	3.4		3.6		1.0									

1. Brown andradite garnet from Dir skarn rock. Average of five microprobe analyses by G.C. Jones. Total Fe as Fe_2O_3; numbers of ions and end-members calculated using similar Fe^{3+}/Fe^{+2} ratio as in analysis A.

A. Chestnut-brown massive andradite garnet in metamorphosed andesite near granite contact, Cotil Point, Jersey (Oliver, 1958). Analyst: R.L. Oliver.

B. Andraditic garnet from calc-silicate rock from Rajasthan, NW peninsular India (Sharma, 1981). Analyst: N.D. MacRae. Total Fe as Fe_2O_3; Fe^{3+} calculated as excess over required total of Fe^{2+}.

2. Green ferrosalite from Dir skarn rock. Average of four microprobe analyses by G.C. Jones. Total Fe as FeO; Fe_2O_3 omitted from calculation.

A. Ferrosalite from skarn, St Lawrence County, New York (Hess, 1949). Analyst: L.C. Peck.

B. Hedenbergite (ferrosalite) from calc-silicate rock from Rajasthan, NW peninsular India (Sharma, 1981). Analyst: R.C. Newton. Total Fe as FeO.

3. Pale green epidote from Dir skarn rock. Average of five microprobe analyses by G.C. Jones. Aotal Fe as Fe_2O_3; H_2O not determined.

related to the nearby tonalite intrusion. The country rocks may originally have been banded metasediments or, less likely, volcanic flows or tuffs.

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