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SERPENTINITE-LIMESTONE CONTACT AT TALERI MOHAMMAD JAN, ZHOB VALLEY, WEST PAKISTAN*

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ABSTRACT

Mineralogical and petrographic description is given of a serpentinite-limestone contact at Taleri Mohammad Jan, West Pakistan. Chemical analyses and optical properties of a diopside, an idocrase and a clinochlore are given and their possible mode of origin discussed.

INTRODUCTION

Taleri Mohammad Jan is a small village about seven miles northwest of Hindubagh, West Pakistan (Fig. 1). Here serpentinite is in contact with limestone and an interesting suite of contact minerals (wollastonite, grossularite, idocrase, clinochlore, diopside, etc.) is developed. Unfortunately the area was visited early by amateur mineral collectors, who indiscriminately used explosives to obtain idocrase crystals; consequently at most places the contacts between the igneous and the sedimentary rocks can only be inferred. No work has been done on these rocks before. The present paper is the first attempt at describing the mineralogy and petrology of the rocks of this area and forms a part of the study of the Zhob Valley igneous complex.

PETROGRAPHY

The rocks described here were collected from the contacts between a stoped limestone block and the enclosing serpentinite. The limestone block is about 2,000 square meters in area and projects above the serpentinite surface from 0 to 30 meters; the downward extent is not known. At the contact the serpentinite is very fine grained and chocolate brown in color. Away from the contact the limestone is buff colored and very fine grained. At the contact, however, recrystallization has taken place and the limestone is also traversed by veins of green idocrase and colorless clinochlore. The veins are from a fraction of a centimeter to 7 or 8 centimeters thick, are several meters long, and do not follow any definite direction or pattern. Intersection of veins is common. In addition, idocrase, clinochlore and grossularite are also developed on joint and fracture planes and it is only here that euhedral crystals of idocrase and grossularite are developed.

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FIG. 1. Map of West Pakistan showing the location of Hindubagh.

Under the microscope the contact serpentinite (Specimen B-7*) is composed of colorless antigorite, euhedral sphene, veins of grossularite, idocrase, clinochlore and a few anhedral crystals of picotite. Rarely diopside crystals also occur. Antigorite is colorless and cryptocrystalline. Sphene is euhedral in form and is markedly pleochroic from pale pink to brown. It occurs as individual grains and in small veinlets. Most of the veins and grains have altered to leucoxene. Grossularite is in clear, colorless, euhedral crystals which when magnified ×300 are of the size of a pinhead. They occur in irregular veins as well as in crystal aggregates. Idocrase in clear colorless crystals is in veins and patches and shows typical abnormal interference colors. The chlorite occurs in very minor amounts, is extremely fine grained and shows abnormal interference colors. Picotite in dark green crystals is also very minor in amount. Colorless diopside and needles of apatite occur in some specimens.

The contact limestone shows greater variation than the serpentinite

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and it is necessary to describe some of the specimens in detail. Specimen B-1. Very fine grained, buff colored rock in which no minerals can be recognised in the handspecimen. In this section the rock is composed of almost equal proportions of wollastonite, idocrase and grossularite. Wollastonite occurs as prismatic crystals, some of which are poorly developed, are dirty brown in color (probably due to minute inclusions), show one set of perfect cleavages and an extinction angle ($X{:}c$) of 44°. The mineral is optically negative with a $2V=38°$. Idocrase is in clear, colorless, irregular plates with no cleavages and abnormal interference colors. Grossularite occurs in irregular, pale brown patches and is intergrown with idocrase. All the three minerals appear to have developed simultaneously, although there appear to be second generations of wollastonite and idocrase which form veins and exhibit euhedral form.

Variation from the above specimen is exhibited by another contact specimen (B-3) which is extremely fine grained and earthy yellow in color. At the contact with serpentinite the limestone has acquired a greenish tint and a gradation from limestone to serpentinite can be seen. Idocrase and clinochlore are developed on the surface of the specimen. The age relationships of the two minerals are rather confusing but it appears that the two minerals developed simultaneously. In thin section the rock is composed of pale brown, poorly developed garnet, ill-formed crystals and needles of wollastonite, sporadic crystals of idocrase and clinochlore. The last two minerals also form veins. The garnet forms the bulk of the slide and encloses wollastonite and idocrase. The clinochlore veins do not follow any definite direction but show a banded structure under crossed nicols. Branching and closing of idocrase and clinochlore veins is common, although veins composed of one mineral do not intersect those composed of the other. Rarely the two minerals occur in the same vein.

In one contact specimen (B-8) yellow chondrodite is developed in addition to garnet, colorless clinochlore and antigorite, wollastonite and spinel, all cut by later composite veins. Chondrodite is yellow in color, does not show any form, is faintly pleochroic from pale yellow to yellowish brown and in places is altered to a serpentinous mineral. The composite veins consist of idocrase, clinochlore and antigorite. The limestone is traversed by serpentinite veins and at the contact these veins are very fine grained. Under crossed nicols the serpentine (antigorite) shows banded structure (Fig. 2). About one centimeter from the contact antigorite of the vein is replaced by a colorless clinochlore and the line of contact between the two minerals is quite sharp. One centimeter from this contact idocrase makes its appearance in composite veins. It is colorless, anhedral in form and is intergrown with clinochlore (Fig. 3). The mineral

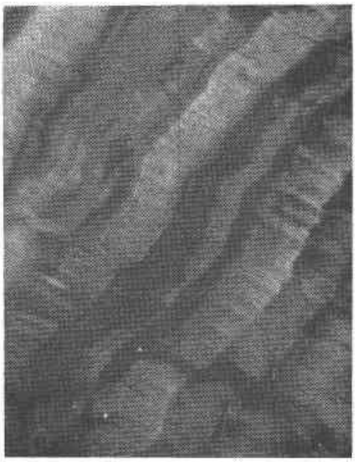

FIG. 2. Photomicrograph showing banded structure in antigorite. Crossed nicols. ×40.

FIG. 3. Photomicrograph of composite vein showing intergrowth between idocrase and clinochlore. ×40.

does not appear to be different from the variety described before. In some composite veins idocrase occurs as inclusions in clinochlore (Fig. 4). Other specimens taken a few centimeters from the contact show development of clear grossularite crystals. Under the microscope these specimens (B-14 and B-14A) are composed of wollastonite, prehnite, grossularite ($a_0 = 11.851$ Å), a little chlorite and biotite. Skeletal crystals of ilmenite are evenly distributed throughout the slide. Prehnite is colorless and anhedral in form with one set of well developed cleavages. The mineral is optically positive with a moderate 2V. Chlorite is pale green in color and markedly pleochroic from pale green to green. Biotite is in very small amounts and is pale brown to colorless. Skeletal crystals of ilmenite are mostly altered to leucoxene. In specimen B-14A, a little clear albite is also present, and prehnite shows bow tie structure. Another contact specimen (B-12), is very fine grained and unusually rich in sphene. The mineral is dark brown in color, is strongly pleochroic and is replaced by idocrase, which occurs in colorless crystals in veins cutting across all other minerals.

In another contact specimen (B-13) pale brown garnet, colorless diopside, apatite and a little sphene are present and are cut by antigorite veins. Garnet shows rounded crystals (Fig. 5) and alteration to a dense brown isotropic material. Other minerals do not show any variation from those described above.

A marked variation from the above described specimens is shown by B-4, which is a medium grained, dark colored rock with euhedral crystals of chromite set in a very fine grained dark matrix. The rock is composed of pale green chlorite, pink garnet, euhedral chromite, spinel and a little kaolinite. Chlorite is pale green, shows one set of well developed cleavages and has a bleached appearance in parts. It shows abnormal interference colors, uniformly in the bleached and unbleached parts; the refractive index γ is 1.585, the 2V is 25° and it is optically negative. Most of the chlorite appears to have formed by the alteration of garnet. Inclusions of minute chromite crystals in chlorite are common. Garnet is pale pinkish brown in color, shows anhedral form and is partly altered to chlorite. Spinel is almost colorless, shows anhedral form and occurs as individual crystals as well as crystal aggregates. Euhedral crystals of chromite are evenly distributed throughout the slide. Kaolinite occurs in small colorless patches, is extremely fine grained and shows wavy extinction, possibly due to its very fine grained nature.

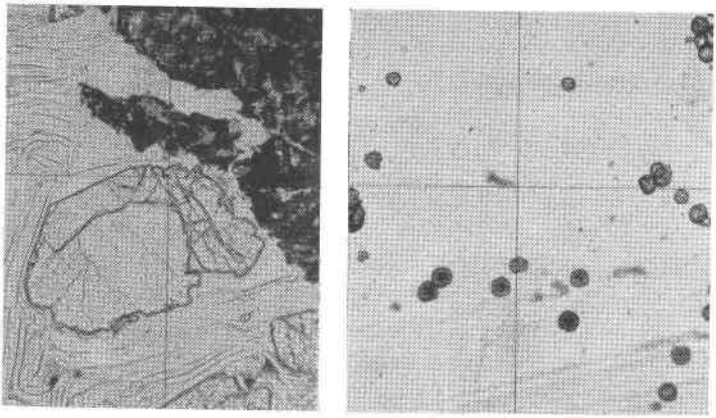

FIG. 4. Photomicrograph of composite vein showing inclusions of idocrase crystals in clinochlore. ×40.
FIG. 5. Photomicrograph showing rounded grossularite crystals in a matrix of colorless antigorite. ×40.

In addition to the above, the limestone is traversed by veins of idocrase. These veins range from a fraction of a centimeter to 7 or 8 centimeters in thickness and do not follow any definite direction. In the handspecimen the veins seem to be composed almost entirely of massive or crystalline idocrase. In the crystalline veins idocrase crystals are from a millimeter to 2 centimeters long and up to about one centimeter thick. They vary from pale to dark brownish green in color and show a pearly luster. All crystals show perfect prism faces and rarely bipyramidal crystals are also found. In this sections some specimens (B-17, B-17A), exhibit a core of colorless diopside, and brown garnet is often present.

Idocrase is anhedral in form and colorless although some crystals show a pale brown color. The mineral occurs in veins as well as in the groundmass of the thin sections and the former shows a better crystal form. Faint zoning, twinning and undulose extinction are exhibited by some crystals. Garnet does not show any crystal form and appears to be intergrown with diopside and the groundmass idocrase. Diopside is colorless and in very minute crystals which are intergrown with or included in the idocrase. A little wollastonite is present in some slides. The best development of the diopside is exhibited in B-17A, where the mineral forms the core of an idocrase vein about 2½ centimeters thick. The vein consists of pale green idocrase crystals which are 2 to 3 millimeters long and show pearly luster. In thin section the rock is composed of colorless, granular diopside, veins of colorless chlorite and a colorless mineral, possibly chondrodite. Idocrase does not show any variation from the above described varieties. Diopside is granular in form, has two sets of well developed cleavages and often shows simple and multiple twins. Optical properties of the mineral and a chemical analysis with comparisons are given in Tables 1 and 2. Chlorite is colorless, extremely fine grained and shows abnormal interference colors. A few crystals of dolomite enclosing diopside are present in some specimens. A pale yellowish brown idocrase traversed by veins of colorless diopside is present in another veins specimen (B-18). Primary (?) calcite is also present in this slide.

CHEMICAL MINERALOGY

Diopside. A chemical analysis of a diopside from an idocrase vein is given in Table 1 (analysis 1) with a comparison. It is higher in MgO and CaO and lower in total iron and alkalies than the diopside from the skarn rock (Table 1, anal. 3). The presence of 0.75% of CO_2 in the analysis may be due to minute calcite or dolomite inclusions in the diopside. The carbonate may be an alteration product of the diopside. The determined refractive indices of this diopside agree well with the values obtained by plotting the analysis on Hess's graphs for refractive indices and chemical composition of clinopyroxenes (Hess, 1949, 641). The structural formula of the diopside calculated on the basis of 6 oxygen atoms is given in Table 3 and is in general agreement with the theoretical formula for the mineral. The summation of the Z positions is slightly lower than the theoretical value of the group and this would seem to confirm the earlier suggestion of the carbonate alteration of the mineral which would decrease its silica content.

Clinochlore. The clinochlore analysis is compared with an analysis of a leuchtenbergite, a variety of clinochlore (Hey, 1954, 280), in Table 1 (anal. 4 and 6). The two analyses show general similarity but the mineral

TABLE 1. CHEMICAL ANALYSES OF DIOPSIDE, CLINOCHLORE AND IDOCRASE WITH COMPARISONS

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	53.46	54.22	53.79	32.39	32.66	31.44	36.91	36.79	36.52	37.75	41.42
Al_2O_3	0.34	0.34	1.41	16.52	16.66	17.62	20.37	16.16	15.12	2.17	0.74
TiO_2	0.00	0.00	0.04	0.05	0.05	—	0.11	0.31	0.31	0.04	tr
Fe_2O_3	0.08	0.09	0.33	0.38	0.38	—	0.07	2.21	4.71	2.94	3.62
FeO	1.39	1.40	2.60	2.78	2.80	tr	0.46	1.51	0.67	2.37	1.12
MnO	0.24	0.24	0.22	0.29	0.29	tr	0.09	0.30	0.30	0.16	0.08
MgO	17.50	17.76	16.64	33.27	33.56	37.64	3.01	3.22	3.18	43.42	40.12
CaO	25.94	25.56	24.66	0.99	0.77	tr	36.36	35.60	36.01	tr	tr
Na_2O	0.00	0.00	0.14	0.03	0.03	—	0.02	0.09	0.25	0.31	nil
K_2O	0.01	0.01	0.04	0.02	0.02	—	0.01	0.02	0.20	0.12	nil
H_2O^+	0.32	0.32	0.10	12.44	12.55	13.19	2.38	2.04	2.70	9.76	12.74
H_2O^-	0.06	0.06	0.04	0.23	0.23	—	0.00	—	—	0.46	0.32
F	—	—	—	—	—	—	0.03	0.76	—	—	—
CO_2	0.75	—	—	0.23	—	—	—	—	—	—	—
	100.09	100.00	100.01	99.62	100.00	99.89	99.82	99.92	99.97	100.15†	100.16
O=F							0.01	0.31			
							99.81	99.61*			

1. Diopside, Taleri. Analyst C. O. Ingamells.
2. Same as above recalculated to 100% after deducting 1.5% calcite.
3. Diopside, Skarn rock from Clifton Mine, St. Lawrence Co., N. Y. (Hess, 1949, 662, anal. 36). Analyst Lee C. Peck.
4. Clinochlore, Taleri. Analyst C. O. Ingamells.
5. Same as above recalculated to 100% after deducting 0.46% calcite.
6. Leuchtenbergite, colorless to pale green, in metamorphosed limestone, Philipsburg, Mont. (Shannon, 1923). Analyst E. V. Shannon.
7. Idocrase, Taleri. Analyst C. O. Ingamells.
8. Green idocrase, limestone quarry near Sala, Sweden (Wickman, 1950). Analyst K. Johnson.
9. Green idocrase at contact of marble with serpentine and amphibolite. (Sedlacek, 1949). Analyst Sedlacek.
10. Typical dunite of the Hindubagh area. Analyst S. A. Bilgrami.
11. Green lizardite from a serpentine xenolith in rodingite. Analyst R. A. Howie (Bilgrami and Howie, 1960).

* Total includes 0.91% B_2O_3.
† Total includes $Cr_2O_3=0.53\%$ and $P_2O_5=0.12\%$.

TABLE 2. OPTICAL PROPERTIES* OF DIOPSIDE, CLINOCHLORE AND IDOCRASE WITH COMPARISONS

	1	3	4	6	7	8	9
α or e	1.6681	1.6740	1.5911	1.572	1.7122	1.7133	1.722
β	1.6753	1.6805	—	1.572	—	—	—
γ or o	1.6972	1.7029	1.5961	1.575	1.7272	1.7146	1.725
$\gamma-\alpha$	0.0291	0.0289	0.005	0.003	0.0139	0.0023	0.003
2V	$55\frac{1}{2}°$	$56\frac{3}{4}°$	15°–21°	6–14°	—	—	—
Z:c	39°	$39\frac{1}{2}°$		—	—	—	—
s g.	3.255	—	2.722	—	3.368	3.37	3.376

Numbers same as in Table 1.
* All determinations in sodium light. Values ±0.002.

Table 3. Structural Formulae of Diopside, Clinichlore and Vesuvianite

	2		5			7		
Si	1.967	1.98	3.075		4.00	8.630		9.00
Al	0.015		1.845	.925 .923	5.97	5.627	0.370 4.000 1.257	4 00 2.00
Ti	0.000	2.04	0.003			0.011		
Fe'''	0.002		0.026			0.018		
Fe''	0.053		0.220			0.090		
Mn	0.007		0.022			0.017		
Mg	0.968		4.707			1.124	0.624 0.500	9.65
Ca	1.012		0.067			9.137		
Na	0.000		0.004			0.008		
K	0.004		0.002			0.002		
OH	—		7.850		7.85	3.72		3.74
F	—		—			0.021		

2. Diopside from Taleri. Cations on the basis of 6(O).
Formula $= (Ca, Mg, Fe)_{2.04}(Si, Al)_{1.98}(O)_6$.
5. Clinochlore, Taleri. Cations on the basis of 18(O, OH, F).
Formula $= (Si, Al)_4(Al, Mg, Fe)_{5.97}(O)_{10}(OH)_{7.85}$.
7. Idocrase, Taleri. Cations on the basis of 38(O, OH, F).
Formula $= (Ca, Mg)_{9.65}(Mg, Fe)_{2.00}Al_{4.00}Si_{9.00}(O)_{34}(OH, F)_{3.74}$.
Numbers 2, 5, and 7, same as in Table 1.

described by Shannon (anal. 6) appears to be quite unique in the simplicity of its chemical composition. The Taleri clinochlore when plotted on Hey's diagrams for chlorites (Hey, 1954, Figs. 1*a* and 4) falls within the clinochlore field and the determined refractive indices are in close agreement with those obtained from his diagrams. The structural formula of the mineral calculated on the basis of 18(O, OH) is given in Table 3 and agrees well with the theoretical formula $(Si, Al)_4(Al, Mg, Fe)_6(OH)_8(O)_{10}$. It will be seen that slightly over half the total Al present in the mineral is placed in the Z positions replacing Si. This would cause a charge imbalance and is compensated by the replacement of Mg by Fe''' and Ti.

Idocrase. A chemical analysis of Taleri idocrase is compared with analyses of two specimens from different localities (Table 1, anal. 7–9). The three analyses show close similarity although the Taleri specimen is higher in alumina and lower in total iron and alkalies. The high alumina content of the Taleri specimen is a unique feature and search of the literature has shown that idocrase with comparable alumina content is rare. The structural formula of the mineral calculated on the basis of 38(O, OH, F) is given in Table 3 and is in close agreement with the general formula of the mineral given by Warren and Modell (1931). In calculating the structural formula Si—Al, Al, and Fe—Mg positions were filled to their theoretical values and the excess of Mg was allotted to Ca position to make up part of the deficiency in this group. This deficiency appears to be due to the replacement of calcium by magnesium. Water is slightly lower than the theoretical value and may be due to the fact that silicate minerals do not release all their structural water on being heated in a glass tube. No attempt has been made to correlate the optical properties of idocrase with its chemical composition but it appears from the available data that no simple relationships exist.

DISTRIBUTION OF TRACE ELEMENTS

The distribution of trace elements in some of the minerals and rocks of the Taleri area is given in Table 4. The trace elements have been determined on an optical spectrograph using D.C. arc and standard samples for comparison. The accuracy of the determinations is considered to be ±30%.

With the notable exception of Ba and Sr most elements in the minerals show values closer to the contact serpentinite than the limestone and this suggests that the serpentinite was the source of these elements. Limestone, however, appears to be the source of Ba and Sr, which are characterstically high in this rock. In idocrase and diopside Ni, Co and Cr follow Mg but clinochlore shows a low content of all the trace elements determined. Copper appears to vary sympathetically with Si and V seems to follow total iron. These trends are in general agreement with the behavior of these elements in the rocks and minerals from other areas (Wager and Mitchell, 1951, Nockolds and Allen, 1953, 1954 and 1956).

TABLE 4. DISTRIBUTION OF TRACE ELEMENTS IN THE ROCKS AND MINERALS OF TALERI MOHAMMAD JAN AREA

Specimen	All values in parts per million. ±30%						
	Cu	Ni	Co	V	Cr	Ba	Sr
Limestone	<5	<4	<3	<2	8	75	900
Contact serpentinite	220	250	60	12	350	10	25
Idocrase	100	5	3	15	2	10	500
Clinochlore	20	4	5	10	5	<5	10
Diopside	115	70	35	100	150	<5	80

Analyst S. A. Bilgrami.

PETROGENESIS

The rocks and minerals described here appear to be the result of two different but probably related processes.

Contact Metamorphism. The contact metamorphism of the limestone by the dunite will result in the formation of wollastonite and grossularite. At moderately high temperatures no excessive pressure is needed for the formation of these minerals (Fyfe, Turner and Verhoogen, 1958, 156). Fyfe and Turner (1958, 156) are of the opinion that if excess silica is present anorthite and wollastonite would form and since anorthite has not been identified in the rocks of Taleri area there appears to have been a slight deficiency of silica which is also reflected in the chemical composition of the minerals from this area.

Hydrothermal Activity. The extensive serpentinization and the development of hydrous minerals like chlorites and idocrase all point to a large scale hydrothermal activity. The development of clinochlore and idocrase, however, also requires large amounts of alumina, part of which would be available during the serpentinization of the dunite (by breakdown of orthopyroxene and spinels) and the remainder was probably supplied by the limestone. That alumina is released during the serpentinization of dunites is suggested by the fact that natural serpentines do not accommodate much Al in their structure. Analyses of a dunite and a serpentine mineral (lizardite) from the adjoining Hindubagh area (Table 1, anal. 10 and 11) also illustrate this fact. The above postulated hydrothermal activity, however, raises the problem of the stability of grossularite in hydrothermal environment (Flint, McMurdie and Wells, 1941, and Yoder, 1950). Fyfe and Kennedy found that "the synthesis of hydrogarnets is due to loss of silica from the system during the hydrothermal experiment" (Fyfe, Turner, and Verhoogen, 1958, 156). They further noted that hydrogarnets were not formed in the presence of excess silica. The absence of quartz and hydrogarnets from the rocks of Taleri area suggests that in natural environment there might be factors other than the mere deficiency of silica contributing to the formation of hydrogarnets.

Goldschmidt (1911) has suggested that idocrase might form through the reaction of grossularite and wollastonite with the addition of water and MgO. While it is possible that some of the idocrase of the Taleri area might have formed thus, the petrographic evidence is wholly lacking.

Roy and Roy (1955, 156–157) have demonstrated that clinochlore shows a very wide range of temperture and pressure conditions of formation and a fairly wide range of association. From their experimental work on the system $MgO—Al_2O_3—SiO_2—H_2O$ they concluded that high pressures greatly stabilize clinochlore (p. 156). According to them clinochlore is a stable mineral at least as low as 450° C., when it forms at the expense of an aluminous serpentine. This, however, does not mean that clinochlore is not stable below this temperature. These observations, coupled with our knowledge of the paragenesis of idocrase and grossularite, would suggest that the temperature of the hydrothermal solutions responsible for the development of clinochlore in the Taleri area was at least 450° C., and the extensive occurrence of this mineral would also suggest the prevalence of high pressures.

The variation in the mineralogy exhibited by rocks under consideration may be due, in part at least, to the compositional variations in the limestone.

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