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THE MINERALOGY AND PETROLOGY OF A RODINGITE DIKE, HINDUBAGH, PAKISTAN

S. A. BILGRAMI* AND R. A. HOWIE, *Geology Department, The University, Manchester, England.*

ABSTRACT

A rodingite dike is described from Pastoki, 15 miles south of Hindubagh, Pakistan, and chemical analyses are given of the serpentinite country rock as represented by a xenolith in the dike, of four specimens of rodingite, and of a typical unaltered dolerite dike and a peridotite of the area. The mineralogy of the rodingite includes the extensive development of calcium-rich minerals such as prehnite and hydrogrossular and the dike is traversed by numerous veins of xonotlite. Analyses and optical properties are given for hornblende, prehnite, sphene, chlorite (pycnochlorite), diopside, and xonotlite from the rodingite and for lizardite from the serpentinite xenolith. The chemistry and mineralogy of the rodingite indicate the introduction of calcium, carbon dioxide and water and the removal of sodium and potassium. The calcium-rich hydrothermal solutions involved may be related to the serpentinization of the peridotite country rocks.

INTRODUCTION

An area of about 90 square miles around Hindubagh, a small town 74 miles north-east of Quetta, in the former Baluchistan, Pakistan, has been mapped on a scale of 4 inches to a mile. The igneous complex of which the Hindubagh area forms a part occupies over 2000 square miles and consists of dunites, chromitites, serpentinites, harzburgites, and peridotites all cut by later dolerite dikes. It is proposed to discuss here the mineralogy and petrology of a rodingite or garnetized doleritic dike near Pastoki, about 300 yards north-east of hill 8083 which lies approximately 15 miles south of Hindubagh.

The term rodingite was first used by Marshall (1911) to describe certain dike rocks from Roding River, Dun Mountain area, Nelson, New Zealand, consisting of grossular, and diallage, and sometimes also prehnite. Since then the name rodingite has been applied to garnetized gabbros and dolerites by various authors. Grange (1927), Miles (1950), and Bloxam (1954) have described garnetized gabbros from different parts of the world applying the name rodingite to these rocks. It is in this extended sense that the term is here applied to a Hindubagh dike rock.

FIELD OCCURRENCE (S.A.B.)

Only one dike of rodingite composition has been proved in the area but recent field work has yielded specimens from other dikes which suggests that in a few cases partial or incipient garnetization has occurred. The Pastoki rodingite dike is Y-shaped and varies in thickness from 14

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* Present address, 196 P.I.B. Colony, Karachi 5, Pakistan.

to 19 feet. It has been intruded into serpentinite which here forms the country rock. Several varieties of the dike can be distinguished in the field. On the outermost margin the rock is fine-grained, buff-colored, and very tough: no minerals can be separately distinguished in hand specimen. Nearer the center of the dike the rock is white, speckled with green patches, though again no individual minerals can be recognized and the rock is remarkably compact. In places the marginal rock is pale green in color and is traversed by numerous veins of a white mineral, and inwards from this is a part of the dike consisting mainly of brown hornblende in a white or light green matrix. In some places this zone is represented by a dark chocolate-brown rock composed entirely of brown hornblende. In the core of the dike numerous xenoliths of serpentinite occur. All these rock types are traversed at varying intervals by veins of a very fine-grained white material which follow no definite direction. At several places patches of a dark colored medium-grained doleritic rock traversed by white veins occur: this, as far as can be judged, appears to represent the original dike rock which has escaped complete alteration.

PETROGRAPHY (S.A.B.)

Under the microscope the marginal rock is seen to be composed of a dense brown isotropic material showing good flow structure. It is traversed by veins of fibrous material which has been identified from its *x*-ray powder pattern as the hydrated calc-silicate xonotlite. Other marginal specimens show weak anisotropism and varying amounts of xonotlite veining. The latter veins pinch, swell and branch, and do not follow any definite pattern: their general appearance suggests a replacement origin. The xonotlite is colorless, and its cleavage is poor or absent. Under crossed polarizers it appears as sheaves and tufts with first-order gray polarization colors in radiating fibers. Detailed optical properties of the mineral together with a chemical analysis are given in Table 4.

In some sections of the marginal rock colorless grossular and xonotlite can be identified, but the bulk of the rock consists of dirty brown amorphous material. In some instances the xonotlite veins are as much as 1 cm. in thickness. Calcite is present in veins and patches and is considered to be a secondary mineral.

In the next zone brown hornblende in large crystals is the dominant mineral: crystals measuring up to $2\frac{1}{2}''$ by $2''$ are common. In hand specimens the hornblendes are black to chocolate-brown in color with an almost pearly lustre on cleavage faces. Under the microscope this hornblende is dark brown, strongly pleochroic, with 2V 81°, $\gamma = 1.671$ and $\gamma : c = 2°$. Faint zoning and single twins are observed in some crystals and the mineral is traversed by veins of prehnite. An analysis of this hornblende is given in Table 3. The prehnite veins are very variable in thickness and the mineral also occurs as discrete patches in the rock (167). It is optically positive with 2V 68°, and γ 1.638: its chemical analysis also is given in Table 3. A small amount of almost colorless epidote is also present in aggregates of small crystals. Pale green chlorite is present in all the specimens, and varies in abundance from rare grains to being second in importance only to the brown hornblende.

The specimens from the Y junction of the dike show well-developed schistosity in thin section and are seen to be composed of pale green chlorite, euhedral sphene and colorless diopside (e.g. 177). The chlorite is in large anhedral crystals with prominent cleavage, distinct pleochroism from pale green to colorless, and brush polarization colors. It is mostly in clean grains, but where surrounded by sphene it has inclusions of minute needles of a brownish material throughout the crystal. The chlorite has $2V_\alpha$ 14°, γ 1.625. A chemical analysis is given in Table 2, as also is an analysis of the sphene from the same rock. The sphene is euhedral in form, brownish-pink in color and fairly strongly pleochroic from brownish-pink to very pale pink; $2V_\alpha$ is 39°. The crystals are often elongated and sub-parallel to each other giving a definite schistosity to the rock. The associated diopside is in clear or clouded crystals which are often bent or broken. An intricate intergrowth between diopside and chlorite is also observed, and inclusions of sphene in diopside are common. The diopside has $2V_\alpha$ 62°, γ 1.707, and $\gamma{:}c=39°$.

The white vein rock is microcrystalline and microporphyritic in thin section, showing anhedral and rounded crystals of colorless diopside set in a matrix of dirty pale brown or colorless grossular. The diopside has a moderate 2V and $\gamma{:}c=43°$: it shows a marked tendency to twinning, and simple twins are common. The garnet forms shapeless patches, and well developed crystals are not observed: in some sections the mineral is entirely clear, whereas in others it has a dirty brown appearance. It has not proved possible to separate an entirely pure sample for chemical analysis, but its cell edge of 11.920 Å indicates that it is hydrogrossular. In some thin sections of this rock a few grains of brown spinel occur which are associated with a dense brown alteration product appearing golden-brown in reflected light. A small amount of a brown serpentinous material is also present, and veins of pectolite and prehnite also occur.

The rock thought to be the nearest representative of the original doleritic dike rock is composed of almost colorless pyroxene in a matrix of green and brown serpentine, sericite, and leucoxene, penetrated by numerous veins of xonotlite.

The serpentinite xenoliths are olive-green and are very fine-grained, and sparse crystals of chromite can be recognized in a hand specimen. In thin section the rock is seen to be composed of pale green serpentine traversed by numerous magnetite veins, probably developed as an alteration product of olivine: a small amount of chromite is also present, in anhedral grains. The pale green serpentine mineral appears to be optically positive in aggregate and an *x*-ray examination has shown it to be lizardite; chemical analyses of a serpentinite xenolith and of the lizardite are given in Tables 1 and 4.

CHEMISTRY OF THE RODINGITE (R.A.H.)

Four chemical analyses of the Hindubagh rodingite and an analysis of a serpentinite xenolith from the dike are given in Table 1, together with those of rodingites from other localities. The analysis of the type rodingite from Roding River (anal. B) shows higher alumina and lime and lower silica than any of the Hindubagh specimens though analyses 2, 3 and 5 show the same general trend, with relatively high CaO, low MgO and low SiO_2 unlike those of normal dike rocks of the area. An analysis of a typical normal dolerite of the area is also given (anal. 5), and analyses of five other Hindubagh dolerites show that in all of them CaO is around 10%. Thus the overall change in composition from a rock of doleritic composition to a rodingite can be seen to involve a considerable increase in calcium with a correspondingly proportional decrease in most of the other constituents except alumina, which remains approximately the same. The rock of analysis 4 has markedly different chemistry from the other rodingites and this is reflected in its very unusual mineral composition: it is composed almost entirely of chlorite, diopside, and sphene which account for its high water, magnesia and titania content. In general the analysis (D) of a prehnite-zoisite aggregate from a New Zealand gabbro shows close similarities with that of the marginal rock (anal. 5) whereas that of the rodingite from Ayrshire (anal. A) is comparable with the analysis for the altered doleritic rock from Hindubagh (anal. 2).

CHEMICAL MINERALOGY OF THE RODINGITE (R.A.H.)

Seven minerals have been separated from the rocks of the Pastoki dike and purified by means of an isodynamic magnetic separator, followed by treatment with heavy liquids. The results of the chemical analyses of these minerals together with their optical and other properties are given in Tables 2, 3 and 4.

Analyses of diopside, sphene, and chlorite from the same rock (177) are given together with that of the rock itself in Table 2. The diopside is relatively low in the $FeSiO_3$ molecule, it is also low in Al_2O_3 and in the structural balance all the Al has been included with Si in the *Z* group. The sphene is seen to belong to the grothite variety, being relatively rich

TABLE 1. CHEMICAL ANALYSES OF THE HINDUBAGH RODINGITES AND ASSOCIATED ROCKS

	1	2	3	4	5	6	7	A	B	C	D
SiO_2	37.04	38.58	44.23	34.43	49.54	41.22	39.33	38.04	33.95	45.31	43.04
TiO_2	0.58	1.21	0.73	2.91	0.92	0.41	tr.	0.82	0.42	0.46	0.43
Al_2O_3	15.15	17.81	14.02	12.37	15.61	4.47	1.31	15.07	19.91	7.49	15.61
Fe_2O_3	1.81	1.41	1.14	2.76	4.93	4.58	5.65	1.78	1.28	1.02	0.67
FeO	6.98	5.64	6.48	9.67	8.12	5.62	1.31	3.02	6.98	5.12	4.99
MnO	0.13	0.11	0.14	0.10	0.09	0.05	0.08	0.21	0.28	0.31	0.32
MgO	6.70	8.28	7.47	18.96	5.79	34.69	38.46	9.62	5.23	14.66	9.14
CaO	27.35	19.75	16.67	10.91	9.65	2.84	0.04	25.84	26.95	22.70	19.99
Na_2O	0.18	1.17	2.43	0.06	2.32	0.32	0.01	0.18	0.15	0.04	0.17
K_2O	0.02	0.06	0.04	0.00	0.54	tr.	tr.	0.04		0.04	0.00
H_2O^+	4.04	5.39	3.75	7.57	2.56	5.47	12.39	4.19	4.85	2.65	4.70
H_2O^-	0.21	0.19	0.21	0.13	0.04	0.32	0.93	1.15		0.24	0.45
Cr_2O_3	—	—	—	—	—	0.10	0.41	—	0.00	0.26	0.00
P_2O_5	0.09	0.02	0.11	0.05	0.17	0.11	0.02	0.24	0.00	0.08	0.00
CO_2	—	0.28	2.69	0.28	—	—	—	nil	—	0.06	0.20
Total	100.28	99.90	100.11	100.20	100.28	100.20	99.94	100.20	100.00	100.47	99.76

Analyst: 1, 2, 3, 4 & 7 R. A. Howie; 5 & 6 S. A. Bilgrami.

1. Fine-grained rodingite (20),* Pastoki.
2. Brown hornblende-prehnite rock (167), Pastoki.
3. Fine-grained rodingite (173), Pastoki.
4. Chlorite-diopside-sphene rock (177), Pastoki.
5. Normal dolerite of the Hindubagh area.
6. Typical peridotite of the Hindubagh area.
7. Serpentinite xenolith in rodingite dyke (170), Pastoki.

* Numbers in parentheses refer to collection in Department of Geology, University of Manchester.

A. Rodingite, Byne Hill, Ayrshire, Scotland (Bloxam, 1954). Anal.: W. H. Herdsman.
B. Rodingite, Roding River, Nelson, New Zealand (Marshall, 1911).
C. Garnetized gabbro, Eulaminna, Western Australia (Miles, 1950). Anal.: J. D. Hayton (also includes NiO 0.03).
D. Prehnite-zoisite aggregate in altered gabbro, Macquarie Island, New Zealand (Grange, 1927). Anal.: F. T. Seelye (also includes NiO 0.04, S 0.01%).

TABLE 2. CHEMICAL ANALYSES, STRUCTURAL FORMULA AND OPTICAL PROPERTIES OF DIOPSIDE, SPHENE, AND CHLORITE FROM ROCK 177, PASTOKI, HINDUBAGH

	1	2	3	4		1A		2A		3A	
SiO_2	53.20	28.45	28.32	34.43	Si	1.955	1.99	1.850	2.00	1.415	2.00
TiO_2	0.12	36.30	0.09	2.91	Al	.032		.150		.585	
Al_2O_3	0.75	3.14	19.03	12.37	Al	—		.091		.530	
Fe_2O_3	0.76	2.70	1.19	2.76	Fe^{+3}	.021		.132		.048	
FeO	2.92	0.70	14.85	9.67	Mg	.948		.072	2.11	1.769	
MnO	0.21	0.03	0.09	0.10	Ti	.003		1.775		.003	
MgO	17.32	0.75	23.72	18.96	Fe^{+2}	.088	2.03	.038		.621	3.01
CaO	24.41	27.20	0.62	10.91	Mn	.007		.002		.003	
Na_2O	0.07	0.02	0.01	0.06	Na	.003		.002	1.91	—	
K_2O	tr.	0.07	0.00	tr.	Ca	.959		1.895		.033	
P_2O_5	—	—	—	0.05	K	—		.006		—	
CO_2	—	—	—	0.28	OH	—		.360		3.985	
H_2O^+	0.05	0.83	11.95	7.57							
H_2O^-	0.06	0.03	0.06	0.13							
Total	99.87	100.22	99.93	100.20							
α	1.680	—	1.620								
β	1.693	—	1.621								
γ	1.707	—	1.625								
2V	62°	39°	14°								
$\gamma:c$	39°	—	—								
Sp. Gr.	3.266	3.488	2.82								

Analyst: R. A. Howie.

1. Pale greenish white diopside (atomic % Ca 47.4, Mg 47.0, Fe 5.6).
   1A. Number of ions on the basis of 6 (O).
2. Brown sphene (grothite). Analysis also includes F nil.
   2A. Numbers of ions on the basis of 10 (O, OH).
3. Green chlorite (pycnochlorite), Fe total/Fe+Mg=0.273.
   3A. Numbers of ions on the basis of 9 (O, OH).
4. Rock (quoted from Table 1).

TABLE 3. CHEMICAL ANALYSES, STRUCTURAL FORMULAS AND PROPERTIES OF HORNBLENDE AND PREHNITE FROM ROCK 167, PASTOKI, HINDUBAGH

	1	2	3		1A		2A	
SiO_2	42.28	42.86	38.58	Si	6.162	8.00	5.930	6.00
TiO_2	2.36	0.01	1.21	Al	1.838		.070	
Al_2O_3	12.46	24.41	17.81	Al	.304	5.09	3.900	3.99
Fe_2O_3	2.42	0.52	1.41	Fe^{+3}	.262		.050	
FeO	9.48	0.28	5.64	Mg	3.113		.006	
MnO	0.15	0.06	0.11	Ti	.258		.001	
MgO	14.38	0.03	8.28	Fe^{+2}	1.154		.033	
CaO	12.01	26.89	19.75	Mn	.017		.008	
Na_2O	2.14	0.32	1.17	Na	.594	2.52	.081	4.06
K_2O	0.20	0.01	0.06	Ca	1.871		3.973	
H_2O^+	2.21	4.45	5.39	K	.034		.002	
H_2O^-	0.04	0.08	0.19	OH	2.150		4.096	
P_2O_5	—	—	0.02					
CO_2	—	—	0.28					
Total	100.13	99.92	99.90					
α	1.650	1.613						
β	1.664	1.624						
γ	1.671	1.638						
2V	81°	68°						
$\gamma:c$	2°	—						
Sp. gr.	3.153	2.936						

Analyst: R. A. Howie.

1. Chocolate-brown hornblende.
   1A. Numbers of ions on the basis of 24 (O, OH).
2. White prehnite.
   2A. Numbers of ions on the basis of 24 (O, OH).
3. Rock (quoted from Table 1).

in both Al_2O_3 and Fe_2O_3. It has been recalculated on the basis of 10(O, OH, F) and again considerable Al has to be included in the *Z* group: the Fe^{+3} probably replaces some Ti. Although the rock contains 18.96% MgO, the sphene has only 0.75%, probably indicating that the Mg ion does not readily substitute for tetravalent Ti of similar ionic radius, and is equally out of place in any possible replacement of the considerably larger Ca ion in this structure. In view of the substitution reported in many sphenes of appreciable F for OH, F was looked for spectrographically, but this element, if present, was below the level of sensitivity (100 p.p.m.). The co-existing chlorite occurs in fairly large pale green crystals and shows the typical anomalous interference colors. Its analysis shows it to be fairly rich in Mg and Al, and following the classification of Hey (1954) it may be termed a pycnochlorite, with Fe (total):(Fe+Mg) =0.273 and Si 2.83, on the basis of 14 oxygens (anhydrous): the basal spacing $d_{100}=14.22$ Å. No comparable analyses have been found in the literature, those given by Wiseman (1934) and Macgregor (1941) being considerably richer in Al and Fe^{+2}.

The rather coarse-grained dike rock (167), with chocolate-brown hornblende crystals 1 inch or more in length in the hand specimen, has also been studied mineralogically. The analysis of this hornblende is given in Table 3 together with that of its associated prehnite and of the rock itself. The hornblende is relatively rich in magnesium and its calcium content is slightly higher than that of many hornblendes, in line with the overall high calcium content of the rodingites. The prehnite although essentially colorless contains small amounts of both ferrous and ferric iron, and a minor amount of sodium substitutes for calcium. The structural formula approximates closely to the theoretical $Ca_4Al_4Si_6O_{20}(OH)_4$ and

TABLE 4. CHEMICAL ANALYSES, STRUCTURAL FORMULAE AND PROPERTIES OF XONOTLITE AND LIZARDITE

	1	2		1A		2A	
SiO_2	49.53	41.42	Si	4.964	5.00	3.895	3.98
TiO_2	0.01	tr.	Al	.036		.083	
Al_2O_3	0.75	0.74	Al	.052	5.09	—	5.97
Fe_2O_3	0.47	3.62	Fe^{+3}	.034		.259	
FeO	0.12	1.12	Mg	.003		5.614	
MnO	0.03	0.08	Fe^{+2}	.010		.088	
MgO	0.02	40.12	Mn	.004		.006	
CaO	46.48	tr.	Na	.005		—	
Na_2O	0.04	nil	Ca	4.980		—	
K_2O	nil	nil	OH	1.787		7.988	
H_2O^+	2.68	12.74					
H_2O^-	0.04	0.32					
Total	100.17	100.16					
α	1.582	1.568					
β	—	1.569					
γ	1.592	1.581					
Sp. gr.	2.710	2.581					

Analyst: R. A. Howie.

1. White to flesh-pink, fibrous xonotlite, veins in rodingite, Pastoki, Hindubagh.
   1A. Numbers of ions on the basis of 16 (O, OH).
2. Green, fine-grained lizardite, serpentinite xenolith in rodingite, Pastoki, Hindubagh.

2A. Numbers of ions on the basis of 18 (O, OH).

optical properties are not far removed from those for pure prehnite. This rock also contains fine-grained turbid material in the groundmass which is isotropic or weakly anistropic. It has not proved possible to separate a completely pure fraction for analysis, but the mineral grains are yellowish-white and give the *x*-ray powder pattern of garnet, with $a = 11.920 \pm 0.005$ Å. It is thus tentatively identified as hydrogrossular, a mineral first recognized in rodingite from the type area in New Zealand (Hutton, 1943).

Xonotlite occurs as veins and stringers of varying thickness throughout the rodingite itself. In hand specimen the mineral is chalky-white to light flesh-pink in color and forms a close, compact, extremely tough fibrous mass. Under the microscope it is seen as a mesh of fibers giving straight extinction and fairly low polarization colors. Its analysis is given in Table 4, where it has been recalculated on the basis of 16 (O, OH) to the formula $5CaSiO_3 \cdot H_2O$. If the infra-red absorption spectra (Kalousek and Roy, 1957) are interpreted as indicating unbonded hydroxyl groups this should perhaps be written as $Ca_5Si_5O_{14}(OH)_2$. Various formulas have been assigned to this mineral particularly with respect to the ratio of calcium silicate to water: Berman (1937) considered it to be close to $3CaSiO_3 \cdot H_2O$, Taylor (1954) gave the formula as $5CaSiO_3 \cdot H_2O$, while Mamedov and Belov (1955) on structural grounds preferred the formula $Ca_6Si_6O_{17}(OH)_2$. The analysis of the Hindubagh xonotlite confirms the 1:1 ratio of Si:Ca and shows relatively small amounts of other cations replacing these. The (OH) group at 1.787 is slightly less than the theoretical 2.0 but shows evidence that the older formula of $3CaSiO_3 \cdot H_2O$ had considerably too much water. A detailed investigation of xonotlites from other localities is now being carried out particularly with regard to their water content: most of the new analyses report H_2O+ around 2.65 to 2.85% which would indicate a formula approaching $11CaSiO_3 \cdot 2H_2O$. Although it might be expected that, like wollastonite, xonotlite may contain appreciable iron replacing calcium, for the Hindubagh xonotlite the iron content is low.

The serpentine mineral in the xenotlith of serpentinite occurring in the center of the dike has been separated and its analysis is given in Table 4. The *x*-ray powder diffraction pattern of this serpentine showed it to have the single-layer orthohexagonal structure of the lizardite serpentine subgroup (Whittaker and Zussman, 1956), and some details of this Hindubagh specimen were given in the original description of the mineral lizardite (Whittaker and Zussman, 1956, p. 118, and p. 125, No. 18). The analysis shows that the mineral is fairly close to the ideal formula $Mg_6Si_4O_{10}(OH)_8$, but with an appreciable amount of both ferric and ferrous iron. That this iron is present in the structure of the mineral, probably replacing magnesium, is indicated both by the lack of any visible grains of magnetite or other ore in the analyzed specimen and also by the slight increase in the refractive indices of this material above those for pure $Mg_6Si_4O_{20}(OH)_8$.

PETROGENESIS

Various hypotheses have been advanced for the origin of rodingites. Marshall (1911) considered that the grossular-bearing rocks originally described from Roding River resulted from magmatic differentiation. Benson (1926), Grange (1927) and Turner (1934) suggested that the rodingites have been formed by the garnetization of gabbroic rocks by concentrated magmatic waters acting at high pressures, whereas Arshinov and Merenkov (1930) demonstrated that garnet-pyroxene, garnet-chlorite and garnet-vesuvianite dikes had been formed by the garnetization of micro-diorite and the alteration of pyroxenite schlieren by calcium metasilicate solutions, liberated in the process of serpentinization. Miles (1951) has described dike-like outcrops of garnetized gabbro from the Eulamina district, Western Australia, and concluded that they were garnetized by hot solutions also responsible for the serpentinization of the surrounding peridotite. The breakdown of monoclinic pyroxene and calcic plagioclase feldspars is assumed to have supplied the calcium required for the formation of grossular and other lime-bearing silicates. Bloxam (1954) has suggested that the rodingites of the Girvan-Ballantrae complex, Ayrshire, were formed by lime-rich hydrothermal solutions and CO_2 which immediately post-dated serpentinization, and which were responsible for the alteration of the gabbro to rodingite and also produced local carbonatization of the serpentinite.

In all the occurrences of rodingites and garnetized gabbros whose descriptions are known to the present authors two facts are pre-eminent. Firstly the occurrence of these rocks typically as dike-like bodies apparently of original gabbroic or doleritic composition; and secondly the association in the area, either immediately adjacent to the rodingite or within a short distance of its outcrop of an ultrabasic peridotite or serpentinite mass (e.g. Graham, 1917; Grange, 1927; Turner, 1930; Arshinov and Merenkov, 1930; Watson, 1942, 1953; Miles, 1951; Bloxam, 1954). It must thus be considered probable that the ultrabasic rocks are in some way related to these altered basic rocks, and, as has been noted above, Grange (1927) and Arshinov and Merenkov (1930) suggested that the breakdown of pyroxene in the serpentinization process could have yielded the necessary calcium involved in the metasomatism of the dolerite or gabbro. Although Bloxam (1954) considered this hypothesis, in the Girvan-Ballantrae district the ultrabasics are dominantly harzburgites (olivine and bronzite) and are unlikely to have yielded much calcium. In the Hindubagh area at present under consideration, however, the ultrabasic rocks include both peridotites and hornblende-peridotites. An analysis of a typical peridotite of the area is given in Table 1 (anal. 6) showing it to contain 2.84% CaO while the hornblende-peridotite although less abundant in the area has up to 7.7% CaO. In contrast the serpentinite xenolith in the rodingite has only 0.04% CaO. The probability of serpentinization having occurred after the intrusion of the dike is demonstrated by the fact that elsewhere in the area dikes cut through fresh peridotite and there is no development of rodingites at such contacts. It therefore seems not unreasonable to suggest that the serpentinization of the peridotites of the Pastoki, Hindubagh, area could have brought about the breakdown of the pyroxene (and the small amounts of calcic plagioclase sometimes present) releasing calcium in a reaction of the general form:

$$3CaMgSi_2O_6 + 2H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + 3CaO + 4SiO_2$$

This CaO then being added to the dolerite body by percolating hydrothermal solutions rich in CO_2, giving rise to new calcium aluminum silicates and minor calcite, the aluminum coming from the original plagioclase of the dolerite.

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Two papers have been published recently dealing with an occurrence of grossular-chlorite-vesuvianite rodingite in the ultrabasic complex of Anderson's Creek, Beaconsfield district, northern Tasmania. Baker (1958) concludes that the rodingite was derived from hornblende gabbro by a process of lime metasomatism which antedated the intrusion of serpentine, whereas Green (1959) considers that the dike-like gabbros were intruded into the ultrabasic rocks before the latter were serpentinized.

REFERENCES

ARSHINOV, V. V. AND MERENKOV, B. J. (1930), Petrology of the chrysotile asbestos deposits of the Krasnouralky Mine in the Ural Mountains: *Trans. Inst. Econ. Miner.*, No. **45**, Moscow.

Baker, G. (1958), Rodingite in nickeliferous serpentinite, near Beaconsfield, northern Tasmania. *Journ. Geol. Soc. Australia*, **6,** 21–35.

Benson, W. N. (1926), The tectonic conditions accompanying the intrusion of basic and ultrabasic igneous rocks: *Mem. Nat. Acad. Sci., Washington*, **19,** No. 1.

Berman, H. (1937), Constitution and classification of the natural silicates: *Am. Mineral.*, **22,** 342–408.

Bloxam, T. W. (1954), Rodingite from the Girvan-Ballantrae Complex, Ayrshire: *Mineralog. Mag.*, **30,** 525–528.

Graham, R. P. D. (1917), Origin of massive serpentine and chrysotile-asbestos, Black Lake-Thetford area, Quebec: *Econ. Geol.*, **12,** 154–202.

Grange, L. I. (1927), On the "rodingite" of Nelson: *Trans. New Zealand Inst.*, **58,** 160–166.

Green, D. H. (1959), Geology of the Beaconsfield district, including the Anderson's Creek ultrabasic complex. *Rec. Queen Victoria Mus., Launceston (Tasmania)*, New Ser., No. 10.

Hey, M. H. (1954), A new review of the chlorites: *Mineralog. Mag.*, **30,** 277–292.

Hutton, C. O. (1943), Hydrogrossular, a new mineral of the garnet-hydrogarnet series: *Trans. Roy. Soc. New Zealand*, **73,** 174–180.

Kalousek, G. L. and Roy, Rustum (1957), Crystal chemistry of hydrous calcium silicates: II, characterization of interlayer water: *Journ. Amer. Ceram. Soc.*, **40,** 236–239.

Macgregor, A. M. (1941), Native gold and silver with other minerals from the Old West mine, Penhalonga, Southern Rhodesia: *Mineralog. Mag.*, **26,** 97–104.

Mamedov, Kh. S. and Belov, N. V. (1955), The crystalline structure of xonotlite: *Doklady Acad. Sci. USSR*, **104,** 615–618.

Marshall, P. (1911), The geology of the Dun Mountain subdivision, Nelson: *New Zealand Geol. Surv.*, Bull. **12,** 31–35.

Miles, K. R. (1951), Garnetised gabbros from the Eulamina district, Mt. Margaret Goldfield: *Geol. Surv. Western Australia*, Bull. **103,** part 2.

Taylor, H. F. W. (1954), The identity of jurapaite and xonotlite: *Mineralog. Mag.*, **30,** 338–341.

Turner, F. J. (1934), The metamorphic and intrusive rocks of southern Westland; *Trans. New Zealand Inst.*, **63,** 178–284.

Watson, K. P. (1942), Zoisite-prehnite alteration of gabbro: *Am. Mineral.*, **27,** 638–645.

——— (1953), Prehnitization of albite: *Am. Mineral.*, **38,** 197–206.

Whittaker, E. J. W. and Zussman, J. (1956), The characterization of serpentine minerals by *x*-ray diffraction: *Mineralog. Mag.*, **31,** 107–126.

Wiseman, J. D. H. (1934), The central and south-west Highland epidiorites: a study in progressive metamorphism: *Quart. Journ. Geol. Soc. London*, **90,** 354–417.

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