

Xonotlite and rodingites from Wairere, New Zealand

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SUMMARY. Xenoliths of eucritic gabbros in an alpine-serpentinite body at Wairere have been altered to rodingites and xonotlite about their margins by hydrothermal metasomatism at temperatures between 430–470 °C. A chemical analysis and the optical properties of the xonotlite are reported, the textures of the rocks are described, and the metasomatic process is discussed.

A LENSOID mass of serpentinite is continuously exposed over some 650 m along the trace of the NNE.-trending Waipa Fault at Wairere (38° 33' S., 175° 2' E.) south of Te Kuiti (Fleming, 1948; O'Brien, 1970). Extensive quarrying of the deposit has revealed the presence of numerous highly-altered xenoliths of gabbro ranging in size from hand specimens to about 120 m³ and exhibiting strongly grooved and slicken-sided surfaces. The original composition of the majority of specimens examined was close to that of a eucrite but hydrothermal alteration has not only destroyed the original texture of the rock but also resulted in saussuritization and albitization of the feldspars. About the margins of several xenoliths, rodingites have formed and veins and layers of xonotlite occur both within and around many of the gabbros (fig. 1).

Dr. P. Marshall, in Bell, Clarke, and Marshall (1911), proposed the name 'rodingite' for certain 'grossularite-diallage' phases associated with the Dun Mountain massif. His definition was based upon the rock occurring at the type locality in the upper reaches of the Roding River, Nelson. Lauder (1965, p. 485) redefined rodingite to include '... all leucocratic vein and dike rocks in ultrabasic terrains that contain considerable amounts of grossular, diopside and serpentinite and may contain a greater or less amount of prehnite, vesuvianite and perhaps other minerals'.

Considerable mineralogical variation exists in rodingites and Lauder's definition is felt to be too restrictive. If a strictly mineralogical and textural definition is required the criteria given by Marshall are probably sufficient but for the purposes of this discussion the term has been extended to include any metasomatic rock, of basic or ultrabasic parentage, consisting of clinopyroxene, which may be derived from the parent, garnet derived wholly by metasomatic process, and possibly other metasomatic products such as prehnite, serpentine, chlorite, and xonotlite.

Specimen numbers quoted in the text are those of the University of Auckland Geology Department rock and thin section collection.

Petrography

Gabbro. In hand specimen the rock is medium-grained, grey, dense, and exceptionally hard. Numerous well-developed veins of prehnite and xonotlite radiate from the contact. Coarse veins of recrystallized ortho- and clino-chrysotile are less common.

Because of the high degree of hydrothermal alteration the original texture is not determinable in most thin sections but both intergranular and subophitic relationships have been recognized. The plagioclase in specimens near the contact has been albitized (An_{5-18}) giving the rock a dioritic character. Plagioclase laths are often fractured and bent and both prehnitization and saussuritization have occurred. Near the centres of the xenoliths plagioclase (up to 1.3 mm in length) is calcic (An_{76-83}). The

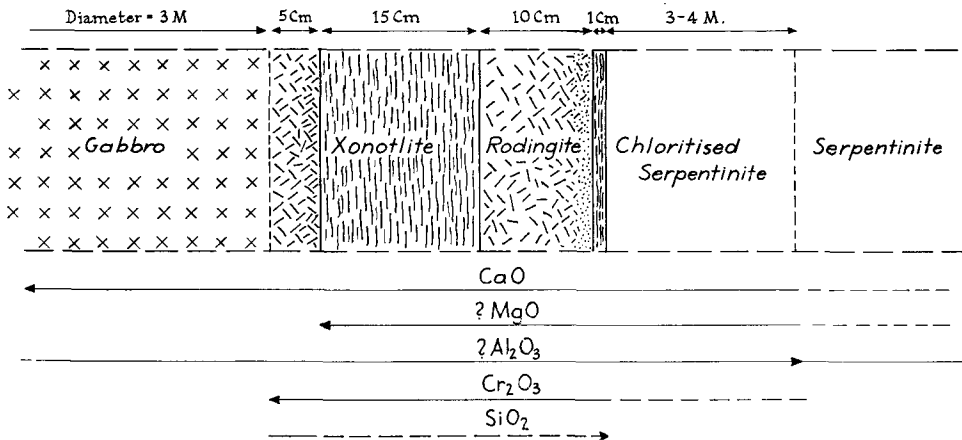


FIG. 1. Summary of probable metamorphic effects at gabbro-serpentinite contacts.

chief mafic mineral is augite with a mean composition $Wo_{39}En_{36}Fs_{25}$. Some of the augite crystals have been fractured and the subhedral outlines corroded and sometimes rimmed by pleochroic uralite. Augites are often twinned on (100) with occasionally polysynthetic twinning on (001). Pools of pleochroic green chlorite are associated with the augite and are possibly derived from that mineral. The texture of the rock is most frequently destroyed by the patchy development of sheaves or interlocking anhedral of prehnite, which is also concentrated in veins. The accessory minerals include intergranular euhedral magnetite and needles of apatite. Analyses of altered and relatively unaltered gabbro are given in table I.

Rodingite. At some contacts chloritized serpentinite is separated from the grooved and slickensided surface of the xenolith by a 'skin' of white, or less commonly pink or green, compact xenotlite (17903). Otherwise the contact is sharp. At one locality, where blasting permitted detailed examination, the outer 10 cm of the xenolith is a metasomatic zone consisting principally of fine grained rodingite (17895 and 17896) in which an euhedral clinopyroxene, optically determined as an endiopside ($En_{56}Fs_{15}Wo_{39}$), is enclosed in a pink-brown garnet. This rodingite contains small amounts of apatite and secondary chlorite and is transected by veins of prehnite and pennine. The prehnite veins contain small amounts of pink chromian chlorite. Endiopside crystals are bent or have a wavy extinction. Both the garnet and the clinopyroxene have been fractured and fractures in the endiopside have been filled by garnet. Pen-

nine with deep blue anomalous interference colours forms small aggregates continuous with pennine veins. There is a gradation of texture through this outer zone. Immediately adjacent to the contact, phenocrysts of the clinopyroxene are enclosed in an indeterminate fine-grained matrix, seemingly clinopyroxene and garnet (17895). Away from the contact garnet becomes increasingly rich in included material and almost opaque while the rodingite becomes transected by wide veins of xonotlite

TABLE I. *Analyses of altered eucritic gabbros, Wairere Serpentinite*

	1	2	
SiO ₂	47.0	42.6	
TiO ₂	0.95	6.95	
Al ₂ O ₃	14.9	15.1	
Fe ₂ O ₃	2.1	2.0	
FeO	8.6	7.2	
MnO	0.1	0.1	
MgO	4.2	8.6	1. 17253, highly altered gabbro close to xenolith contact, Wairere. Anal: T. H. Wilson.
CaO	15.5	16.5	2. 17250, slightly altered gabbro, xenolith core, Wairere. Anal: T. H. Wilson.
Na ₂ O	2.1	1.5	
K ₂ O	0.25	0.2	
P ₂ O ₅	0.53	0.47	
H ₂ O ⁺	3.4	4.2	
H ₂ O ⁻	0.3	0.6	
Total	99.8	99.7	

oriented approximately parallel to the contact, and separating it from an inner rodingite phase. This inner rodingite consists principally of clinopyroxene with minor garnet (17902). Garnet is lath-like, strongly oriented parallel to the contact and appears to have pseudomorphed plagioclase. Approximately 30 cm from the contact rodingite passes into a zone of heavily prehnitized and saussuritized gabbro (17885).

In one loose block from a quarry stockpile (17892), a dike or lens of rodingite 4 cm wide is contained in massive dark serpentinite. The contact is sharp and appears to be magmatic rather than tectonic. Fractures and veins visible in hand specimen are late features and can be traced from the serpentinite across the rodingite and back into the serpentinite. In thin section mesh and hourglass structures, elsewhere characteristic of the serpentinite, have been destroyed, but bastite pseudomorphs are still recognizable. A half-millimetre zone of euhedral impure and very nearly opaque garnet lies adjacent to the contact. Orange to pink chromian chlorite is prominent in the rodingite forming a matrix in which the clinopyroxene and garnet are held.

In thin section 17893, prepared from a hand specimen similar to 17892, there is little evidence of strain at the serpentinite-rodingite contact. Rodingite is separated from massive serpentinite by a half-millimetre zone of recrystallized serpentine, and serpentine structures are preserved to within a millimetre of the contact. Clouded laths of garnet, with weak parallelism, form a two-millimetre zone adjacent to the contact, which passes into a diopside-chlorite zone containing very little garnet.

Mineralogy

Garnet. Two garnet species form the rodingite matrix. The one, a colourless slightly birefringent mineral with a low refractive index ($n = 1.704$) is an intermediate (hydro-grossular) member of the hibschite-grossular series and is the less common. The other, comprising more than 50 % of most rodingite specimens, contains an opaque impurity, probably an alteration product, which gives the mineral its colour and probably contributes to its higher refractive index ($n = 1.845$). Comparison of this refractive index with the determinative chart of Winchell (1958) suggests that this second garnet is an andradite or uvarovite.

Neither garnet species could be investigated satisfactorily by X-ray diffractometry. The 220 reflections at 4.26 Å and 4.21 Å, for andradite and uvarovite respectively, were not recorded. Relative intensities of reflections identified differ markedly from those given for hibschite and hydrogrossular by Pabst (1937, 1942).

Xonotlite occurs at the gabbro-xenolith-serpentinite contacts at Wairere, and forms a compact crust from 1 mm to 1 cm thick, separating the slickensided rodingite from the serpentinite. The only other known New Zealand occurrence of xonotlite is that described by Coombs and Lauder (1960) filling joints and fracture zones in a basic sill at the Acheron River, Canterbury.

Specimens collected (17903) are white, sometimes pink or pale green and are extremely tough. The mineral breaks into splinters, which have a pearly lustre on the fractured surfaces. More weathered specimens have a chalky appearance. Physical properties, $\alpha = 1.582$, $\beta = 1.582$, $\gamma = 1.592$, $\gamma - \alpha = 0.010$, $2V$ low, $D = 2.71 \pm 0.03$, $H = 6$, are comparable to those recorded by Shannon (1925) and by Coombs and Lauder (1960).

The X-ray powder diffraction pattern is similar to those obtained from samples from Pueblo, Mexico, and the Isle Royal, Michigan, by Schaller (1950). An additional weak peak at 3.51 Å cannot be explained satisfactorily.

An analysis gave: SiO_2 47.82, Fe_2O_3 0.86, FeO 0.08, MnO 0.72, MgO 3.16, CaO 42.64, H_2O^+ 4.12, H_2O^- 0.46 % SrO 150 ppm. TiO_2 , Al_2O_3 , BaO , and CO_2 were not detected. These results approximate those given by Shannon (1925) for compact xonotlite from Leesburg, Virginia. Since xonotlite has a typical defect lattice, considerable variation in the amount of lattice-held water and some polytypism can be expected (Eitel, 1964). The Wairere xonotlite appears to be intermediate between the compact xonotlite of Shannon ($\text{H}_2\text{O}^+ = 6.0$) and coarse or asbestiform varieties described by Shannon and Coombs and Lauder ($\text{H}_2\text{O}^+ = 3.0$). Total CaO and MgO are in approximately the same proportion to SiO_2 as in Shannon's compact xonotlite and manganese and iron (mainly as Fe^{3+}) are probable impurities. Examination of existing analyses suggest that MgO substitution for CaO may be a consistent feature of compact varieties, with substitution of the smaller Mg^{2+} ion for Ca^{2+} affording lattice contraction and a corresponding increase in density.

The formula of the Wairere xonotlite calculated from cation ratios is $(\text{Ca}_{3.326}\text{Mg}_{0.343})\text{Si}_{3.481}\text{O}_{10.443}\text{H}_2\text{O}$ and is close to the ideal formula $3\text{CaSiO}_3 \cdot \text{H}_2\text{O}$ given by Taylor (1955), being almost fully hydrated. More commonly xonotlite has a composi-

tion matching the formula $5\text{CaSiO}_3 \cdot \text{H}_2\text{O}$ (Taylor, 1955) but the other New Zealand occurrence has a composition approximating the formula $6\text{CaSiO}_3 \cdot \text{H}_2\text{O}$ (Coombs and Lauder, 1960).

There may be an excess of Ca and Mg in the Wairere analysis as a result of slight garnet impurities in the specimen but these have not been taken into account in the calculation of the formula.

Two *chlorite* minerals with distinctive optical properties occur in association with the metasomatic rocks at Wairere:

Pennine occurs in the dark sheared serpentinite in contact with the rodingite (17895) but is best developed in veins and vugs in the rodingite (17896). In the serpentinite, pennine is intergrown with serpentine minerals while in the rodingite it usually occurs as radiating clusters of acicular crystals, growing from the walls towards the centre of the cavity. Crystals are colourless and have an anomalous blue-violet interference colour, parallel extinction, and a variable sign of elongation.

An orange to pink chromian chlorite occurs in a prehnite vein within the rodingite in the same specimen (17895) and is well developed in the rodingite and adjacent serpentinite in another specimen (17892). An euhedral grain of chromite, some 4 mm from the rodingite-serpentinite contact (17892), is partly surrounded by a rim of pink chlorite, which has replaced a corroded crystal face and indicates the formation of this mineral by dissolution of chromite. A similar relationship and origin for kochubeite has been described by Challis (1965). Most of the chromian chlorite in section 17892 occurs as large pools in the rodingite, sometimes enclosing the clinopyroxene in a poikilitic manner.

The X-ray powder diffractogram obtained for this mineral identifies it as a chromian chlorite only. According to Lapham (1958), the labelling of all pink chromian chlorites as *kochubeite* is inaccurate. His nomenclature, based on the Cr_2O_3 content on the one hand, and the lattice position of the substituting chromium on the other, affords a consistent identification of chromium-rich chlorites and provides the term *chromian chlorite* for more general application.

Discussion

The petrogenesis of rodingite has been described both as a contact metamorphic process (Turner and Verhoogen, 1960) and as a magmatic process (Cady, Albee, and Chichester, 1963). The formation of rodingite at chilled contacts of diorite or basalt dykes with serpentine (Thayer, 1966) is compatible with neither hypothesis. He writes ' . . . serpentinising solutions remove alkalis and SiO_2 from feldspathic rocks . . . calcium instead of magnesium is introduced into adjoining rocks during serpentinisation and . . . diffusion between serpentinite and country rocks or inclusions is limited to a few inches commonly, and at most to a few feet' (p. 707).

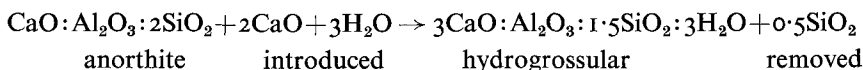
The pseudomorphous replacement of plagioclase by calcium garnet and the occurrence of relict gabbro minerals, such as apatite, within the rodingite suggest that rodingite formation in the Wairere rocks has occurred by replacement of gabbro, as was suggested by Grange (1926) for other New Zealand rodingites, rather than by the crystallization of deuterite calcium-rich liquids, and has possibly resulted in a

slight volume loss. The occurrence of double rodingite zones (fig. 1) in some instances may represent the dislodging of a first-formed rodingite by movement of the xenolith relative to the serpentinite. In such a case it could be argued that apatite, presumed to be a primary mineral of the gabbro, was trapped in partly altered gabbro, which had spalled off the xenolith, more or less concentrically, by movements within the serpentinite mass and then underwent alteration from both sides. The development of garnet, pseudomorphous after plagioclase, and the gradational nature of the rodingite-gabbro contact indicate that rodingite formation occurs by metasomatic alteration of the parent rock, rather than by crystallization from aqueous solutions at the gabbro-serpentinite contact.

A slight enrichment of CaO in gabbro towards the centre of the xenolith, and a less than equivalent decrease in alkalis in the same direction, shown by a comparison of bulk chemical compositions (17250, 17253—table I), together with the crystallization of calcium-rich secondary phases, indicate a source of CaO external to the gabbro and Thayer's suggestion (1966) of supply of calcium from a very large body of serpentinizing peridotite seems a likely explanation. Though the average pyroxene peridotite (Nockolds, 1954) contains less than 3% CaO, extensive calcite veining of serpentinite in the vicinity of the xenoliths demonstrates the possibility of mass transfer of CaO to the gabbro, possibly under the influence of a thermal gradient. Moreover, since plagioclase at the centre of the xenolith has suffered little albitization it seems improbable that albitization of plagioclase near the contact has given rise to the rodingite and the large amounts of prehnite and xonotlite throughout the xenolith. The normal processes of alteration of plagioclase are albitization and saussuritization. Only in ultramafic environments, and then only at serpentinite contacts, do rodingites occur (Thayer, 1966). The evidence of a genetic relationship between rodingites and the serpentinization process seems conclusive.

Since most of the MgO in excess of that required for serpentinization is removed in solution (Thayer, 1966), the MgO deficiency in the contact gabbro is unlikely to be balanced in another part of the system. The 3.16% MgO in xonotlite could have been derived from the gabbro but could also have been derived from the serpentinizing peridotite—that is, from the same source as the CaO.

The formation of magnesium aluminium chlorites in the serpentinite adjacent to the xenolith contact accompanying a slight decrease in alumina towards the gabbro contact is believed to represent in part a loss of alumina from the gabbro. Coleman (1966) has suggested the equation below to explain the breakdown of plagioclase to hydrogrossular, which is based on the assumption that ferromagnesians alter to chlorite (and tremolite-actinolite).



While there is petrographic evidence that ferromagnesians are chloritized, it seems doubtful, because of the extent of alteration, that the considerable amount of chlorite that appears to have formed adjacent to the serpentinite could all be derived from the breakdown of ferromagnesian minerals in the gabbro.

The occurrence of chromian chlorites within the rodingite can be explained by postulating a metasomatic transfer of chromium from the serpentinite to the rodingite. Evidence for such a transfer is incomplete. In thin section 17895 a little chromian chlorite can be seen in a prehnite vein transecting the gabbro. In thin section 17893 a chrome spinel in the serpentinite some 2 mm from the rodingite contact is surrounded by faintly orange chlorite or serpentine and the same material occurs in veins nearer to the contact.

The interpretation of grain size in a metasomatic rock is difficult. The fine-grained rodingite adjacent to the contact might result from either rapid replacement of gabbro by rodingite or the cooling of hydrothermal solutions outside the limits of the original gabbro-serpentinite contact, where the formation of garnet was not controlled by the habit of primary plagioclase.

It is apparent from earlier discussion that the formation of rodingite and xonotlite depends on the supply of CaO from serpentinitization. It is probable that the serpentinitization, formation of rodingite, and crystallization of xonotlite followed in quick succession.

Slickensiding and grooving on the xenolithic surface may predate the metasomatism. Assuming that to be the case, the stability range of xonotlite places a temperature limit on the metasomatic processes. Buckner, Roy, and Roy (1960) show xonotlite to be stable between 260° and 400 °C at 5000 lb. in⁻² confining pressure and 220° and 470 °C at 3000 lb. in⁻² confining pressure. This range may vary with the SrO content of the xonotlite. The present mineral has a SrO content of 150 ppm and, assuming reasonably uniform temperature throughout the intrusion, the temperature of the metasomatic processes including serpentinitization was between 220° and 470 °C. The higher-pressure regime probably applied since field evidence suggests that emplacement of the serpentinite was effected by strong tectonic compression (O'Brien, 1970).

A pressure-independent geothermometer is found in the hydration states of hydrogrossular (Yoder, 1950; Carlson, 1956). An examination of the Wairere hydrogrossular by Coleman (1966) indicates the temperature of formation of the garnet to be in the range of 430 to 580 °C and allowing for error in determinative methods the temperature range of the metasomatic processes is concluded to be in the range 430 to 470 °C.

The widespread occurrence of aragonite on shear planes throughout the Wairere serpentinite cannot be regarded as an absolute pressure indicator (O'Brien, 1970). Nor can an estimate of pressure be made from the probable thickness of overburden, because tectonic stresses were dominant during emplacement and alteration of the mass, and there is no evidence to suggest at what level in the crust the metasomatic processes occurred.

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