

the overprinting of which may indicate a Cretaceous or Tertiary event.

Hydrothermal solutions, which introduced little or no new material, but altered and redistributed existing minerals, could account very satisfactorily for the type of mineralization found in the Lizard, in which the mineral composition of veins is closely related to the chemistry of the country rock. If some means can be found of dating other stages of mineralization in the Lizard complex, it may be possible to use the detailed parageneses already established for the mineralization at Dean quarry and at Porthkerris in a comparative study of phases of hydrothermal activity throughout south-west England.

The full text appears in the Miniprint section, pp. M49-59.

REFERENCES*

- Darnley (A. G.), English (T. H.), Sprake (O.), Preece (E. R.), and Avery (D.), 1965. *Mineral. Mag.* **34**, 159-76 [M.A. 17-121].
- Halliday (A. N.) and Mitchell (J. G.), 1976(a). *Earth Planet. Sci. Lett.* **29**, 227-37 [M.A. 77-1290].
- Hosking (K. F. G.), 1964. In Hosking (K. F. G.) and Shrimpton (G. J.) (eds.), *Present views of some aspects of the geology of Cornwall and Devon*. R. geol. Soc. Cornwall, 201-45 [M.A. 17-650].
- Seager (A. F.), 1967-8 [1971]. *Trans. R. geol. Soc. Cornwall*, **20**, pt. 2, 97-113 [M.A. 72-3370].
- 1978. *Mineral. Mag.* **42**, 245-9.

* Additional references are given in Miniprint section.

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Pyroxenes of basic rocks and rodingites from an ophiolite mélange, south-eastern Turkey

ROBERT HALL

Department of Geology, Queen Mary College, London University, London E1 4NS

OPHIOLITIC rocks occur as a tectonic mélange in the Mutki area of the Eastern Taurus Mountains of south-eastern Turkey. They form the upper part of a Tethyan ophiolite-flysch complex, which is thrust southward over sedimentary rocks of the Arabian foreland (Hall, 1976). The tectonic mélange has a matrix of serpentinite and includes blocks of basic volcanics, gabbros, picrites, and rodingites, most of which have suffered metamorphism and metasomatism. The volcanic rocks have been metamorphosed under conditions transitional between the glaucophane-lawsonite schist facies and the greenschist or greenschist-amphibolite transitional facies of Turner (1968). The picrites have escaped any significant metamorphism, while the gabbros have been partially or completely recrystallized under greenschist facies conditions. Both picrites and gabbros have also suffered calcium metasomatism resulting in the alteration of some of the gabbros to rodingites. Pyroxenes from eight separate blocks from the mélange have been analysed by microprobe (fig. 1) to determine if the pyroxene

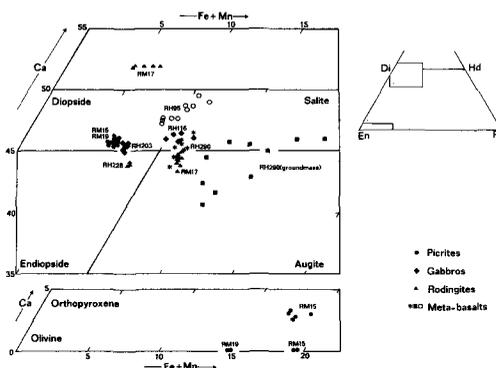


FIG. 1. Composition of clinopyroxenes, orthopyroxenes, and olivines from the mélange rocks.

chemistry is consistent with an igneous origin (as suggested by textural evidence) or if there have been changes due to metamorphism and metasomatism.

None of the blocks examined is completely unaffected by alteration or recrystallization, yet

despite the different metamorphic and metasomatic events affecting the different blocks there is a surprisingly small range in the composition of the clinopyroxenes. There is a trend of iron enrichment and sympathetic decrease in Cr_2O_3 from picrites, through gabbros and rodingites, to meta-basalts, and enrichment in TiO_2 in the meta-basalt groundmass pyroxenes. This pattern of chemical variation, with the textural evidence, is taken to indicate that the clinopyroxenes are igneous in origin, that they have survived metamorphism and metasomatism without re-equilibration, and that most of the basic rocks originated in a single igneous complex.

Two exceptions occur. The pyroxenes of meta-basalt RH95 are separated on the pyroxene quadrilateral (fig. 1) from all the other clinopyroxenes, and their more calcic character is thought to be an original feature. It is possible that the pyroxenes of RH95 crystallized from a melt of different composition from that of the other rocks. Rodingite RM17 contains two chemically and texturally distinct clinopyroxenes. The augite resembles pyroxenes from other basic rocks and is considered to be of igneous origin. The second clinopyroxene is a super-calcic diopside characterized by low Cr, Ti, Na, Mn, and Al, and high Ca and Si. It is intimately intergrown with idocrase and grossular and is interpreted as metasomatic in origin. Its unusual chemistry is probably a reflection of the fluids associated with serpentinization. These are likely to have been similar to calcium hydroxide waters thought to be associated with present-day serpentinization in the western United States (Barnes and O'Neil, 1969).

The chemistry of the original igneous clinopyroxenes should indicate the nature of the original basic magma. Coombs (1963) has suggested the use of pyroxene norms as aids in the discrimination of basaltic types. The norms indicate that the pyroxenes of meta-basalt RH95 are alkalic in character. If, as suggested above, the remaining rocks originated in a single complex their norms indicate that they are more likely to be tholeiitic than alkalic. However, comparison of

the compositions of the clinopyroxenes with those of the Bushveld complex, and of the North Atlantic and Pacific ocean floors, indicate that the mélange pyroxenes tend to be more calcic than those from typical tholeiites. It seems likely that the mélange rocks are transitional between tholeiitic and alkalic basaltic rocks.

Data from thirteen meta-volcanics from the mélange supports suggestions that the elements Ti, Zr, and Y are immobile during low-grade metamorphism, and indicates that the meta-volcanics belong to the group of 'within-plate oceanic basalts' (Pearce and Cann, 1971, 1973), which includes tholeiites and intermediate- and ultra-alkaline rocks from ocean islands.

This work indicates that igneous clinopyroxenes can survive low-grade metamorphism at moderate to high pressures, and may also be resistant to extensive calcium metasomatism under certain conditions. Metasomatic clinopyroxenes are clearly different from those of igneous origin. The range and type of chemical variation in the igneous clinopyroxenes, and the whole-rock trace element data, indicate that most of the basic rocks of the Mutki ophiolitic mélange once formed part of a single igneous complex, but are different from typical ocean-ridge tholeiites.

The full text appears in the Miniprint section, pp. M42-8.

REFERENCES

- Barnes (I.) and O'Neil (J. R.), 1969. *Bull. geol. Soc. Am.* **80**, 1947-60.
 Coombs (D. S.), 1963. *Mineral. Soc. Am. Spec. Pap.* **1**, 227-50.
 Hall (R.), 1976. *Bull. Geol. Soc. Am.* **87**, 1078-88.
 Pearce (J. A.) and Cann (J. R.), 1971. *Earth Planet. Sci. Lett.* **12**, 339-49.
 ——— 1973. *Ibid.* **19**, 290-300.
 Turner (F. J.), 1968. *Metamorphic Petrology*, McGraw-Hill.

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Table 2: Representative X-ray Fluorescence Analyses

| | Groundmass Analyses ^a | | | | | | | | | | Megacryst Analyses | | | | |
|---|----------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|------------------|--------------------|-------|--------|--------|--------|
| | 2* | 4 | 7 | 16 | 45 | 46 | 47 | 52 | 53 | 20c [†] | 20i | 20I | 7c | 7i | 7I |
| SiO ₂ | 69.33 | 68.41 | 70.22 | 68.15 | 68.57 | 68.88 | 69.43 | 69.96 | 67.82 | 64.13 | 62.93 | 61.35 | 65.48 | 63.50 | 62.83 |
| TiO ₂ | 0.37 | 0.61 | 0.43 | 0.57 | 0.44 | 0.53 | 0.50 | 0.44 | 0.60 | 0.23 | 0.47 | 0.61 | 0.39 | 0.33 | 0.54 |
| Al ₂ O ₃ | 15.73 | 14.87 | 14.60 | 14.86 | 15.72 | 14.51 | 14.79 | 14.82 | 15.22 | 17.31 | 18.52 | 17.96 | 17.06 | 18.62 | 18.07 |
| [†] Fe ₂ O ₃ | 0.63 | 0.93 | 0.73 | 1.07 | 0.69 | 1.01 | 0.77 | 0.75 | 0.91 | 0.10 | 0.12 | 0.33 | 0.24 | 0.12 | 0.24 |
| FeO | 1.67 | 2.45 | 1.92 | 2.84 | 1.85 | 2.66 | 2.06 | 1.98 | 2.41 | 0.27 | 0.30 | 0.86 | 0.66 | 0.30 | 0.69 |
| MnO | 0.03 | 0.04 | 0.03 | 0.04 | 0.03 | 0.05 | 0.03 | 0.03 | 0.04 | 0.00 | 0.01 | 0.02 | 0.01 | 0.00 | 0.01 |
| MgO | 1.08 | 1.53 | 1.26 | 1.51 | 1.26 | 1.86 | 1.28 | 1.13 | 1.52 | 0.20 | 0.20 | 0.58 | 0.44 | 0.21 | 0.48 |
| CaO | 2.63 | 3.22 | 2.89 | 3.07 | 3.07 | 3.30 | 3.09 | 2.70 | 3.16 | 0.54 | 1.00 | 1.32 | 0.81 | 0.64 | 0.96 |
| Na ₂ O | 4.69 | 4.41 | 4.68 | 4.36 | 4.67 | 4.30 | 4.33 | 4.33 | 4.49 | 2.13 | 2.43 | 2.24 | 2.04 | 2.13 | 1.98 |
| K ₂ O | 3.78 | 3.07 | 2.60 | 3.11 | 2.83 | 2.20 | 2.94 | 3.50 | 3.05 | 11.76 | 12.02 | 11.42 | 11.45 | 12.47 | 12.36 |
| P ₂ O ₅ | 0.11 | 0.18 | 0.12 | 0.16 | 0.12 | 0.15 | 0.13 | 0.14 | 0.17 | 0.06 | 0.07 | 0.07 | 0.09 | 0.06 | 0.07 |
| BaO | 0.24 | 0.22 | n.a. | 0.20 | 0.20 | 0.18 | 0.21 | 0.21 | 0.21 | 0.65 | 0.61 | n.a. | 0.59 | 0.65 | 0.63 |
| LOI | 0.30 | 0.39 | 0.52 | 0.48 | 0.80 | 0.70 | 0.60 | 0.63 | 0.54 | 2.23 | 1.62 | 2.80 | 1.08 | 1.37 | 1.67 |
| sum | 100.59 | 100.33 | 100.00 | 100.42 | 100.25 | 100.33 | 100.16 | 100.62 | 100.14 | 99.61 | 100.30 | 99.56 | 100.34 | 100.40 | 100.53 |
| Rb(ppm) | 150 | 170 | n.a. | 135 | 110 | 125 | 128 | 145 | 110 | 249 | 247 | n.a. | 255 | 269 | 265 |
| Sr(ppm) | 748 | 625 | n.a. | 860 | 700 | 700 | 680 | 555 | 705 | 1021 | 976 | n.a. | 950 | 1074 | 1017 |
| qr | 20.17 | 21.84 | 24.89 | 21.59 | 21.75 | 25.01 | 24.33 | 23.73 | 20.81 | 5.45 | 0.65 | 1.11 | 7.52 | 1.88 | 1.47 |
| or | 22.34 | 18.14 | 15.36 | 18.38 | 16.72 | 13.00 | 17.37 | 20.68 | 18.02 | 69.49 | 71.03 | 66.01 | 67.66 | 73.69 | 73.04 |
| ab | 39.69 | 37.32 | 39.60 | 36.89 | 39.52 | 36.39 | 36.64 | 36.64 | 37.99 | 18.02 | 20.56 | 18.53 | 17.26 | 18.02 | 16.75 |
| an | 10.71 | 11.71 | 11.15 | 11.79 | 13.57 | 13.79 | 12.24 | 10.67 | 12.37 | 2.29 | 4.03 | 5.10 | 3.43 | 2.76 | 3.92 |
| di | 1.33 | 2.52 | 1.96 | 1.97 | 0.71 | 1.30 | 1.83 | 1.49 | 1.80 | 0.00 | 0.00 | 0.67 | 0.00 | 0.00 | 0.31 |
| ky | 3.86 | 5.13 | 4.25 | 4.95 | 6.75 | 6.99 | 4.45 | 6.22 | 5.42 | 0.50 | 0.10 | 1.35 | 1.40 | 0.52 | 1.17 |
| mt | 1.01 | 1.49 | 1.17 | 1.73 | 1.12 | 1.62 | 1.25 | 1.20 | 1.46 | 0.16 | 0.00 | 0.51 | 0.39 | 0.00 | 0.39 |
| il | 0.70 | 1.16 | 0.82 | 1.08 | 0.84 | 1.01 | 0.95 | 0.84 | 1.14 | 0.44 | 0.33 | 1.14 | 0.74 | 0.61 | 1.03 |
| ap | 0.25 | 0.42 | 0.28 | 0.37 | 0.28 | 0.35 | 0.30 | 0.32 | 0.39 | 0.14 | 0.16 | 0.16 | 0.21 | 0.14 | 0.16 |

*column headings refer to sample localities of fig. 1

[†]suffixes for megacryst portions used as in table 2

[†]Fe₂O₃/FeO ratio is based on Fe⁺⁺⁺/Fe⁺⁺ ratio (0.34) of a rock sample from the Godani pluton analyzed by C.C. Patel of the Geological Survey of Nigeria (wet chemical analysis)

[†]% weight loss on ignition at 1000°C

[†]wt.% megacrysts in outcrop: 2(11.3%), 4(4.0%), 7(10.6%), 16(2.5%), 45(11.3%), 46(13.2%), 47(3.7%), 52(7.0%), 53(5.4%)

Hall: Pyroxenes from an ophiolite mélange

PYROXENES OF BASIC ROCKS AND RODINGITES FROM AN OPHIOLITE MÉLANGE,

SOUTH-EASTERN TURKEY

Robert Hall

Department of Geology, Queen Mary College,

London University, London E1 4NS

THE Taurus fold-belt is the southernmost of the two major fold-belts forming the Anatolian sector of the Alpine-Himalayan mountain chain. The interior of the Eastern Taurus is occupied by an extensive area of largely pre-Permian metamorphic rocks known as the Bitlis Massif. This is thrust southward over an ophiolite-flysch which is in turn thrust southward over sedimentary rocks of the Arabian foreland. The ophiolite-flysch complex is part of a zone of Tethyan ophiolites that occurs discontinuously throughout the Middle East between Cyprus and Oman (the 'Crescent Ophiolite Peri-Arab' of Ricou, 1971). At the southern margin of the Bitlis Massif near the village of Mutki ophiolites occur as a tectonic mélange which consists of blocks of basic volcanics, gabbros and picrites, radiolarian cherts and other minor sedimentary components, serpentinites and podiform chromite bodies, together with rodingites and silicon-carbonate rocks. All of these blocks are incorporated in a matrix of serpentinite (Hall, 1976).

Pyroxenes are common in the basic rocks of the mélange. Textural evidence suggests that most of them are of igneous origin, despite the complex thermal and structural history of the mélange, which includes several episodes of tectonic mixing, metamorphism and metasomatism. Recent work indicates that igneous clinopyroxene may survive metamorphism, without re-equilibration, under conditions of the greenschist facies (Wallace, 1974, 1975) and glaucophane-lawsonite-schist facies (Schubert and Seidel, 1972; Mevel and Velde, 1976) and therefore microprobe analyses were made to determine if the pyroxene chemistry is consistent with an igneous origin or if there have been changes due to metamorphism and metasomatism.

Petrography of the tectonic blocks

Volcanic rocks occur in the mélange in blocks several kilometres across which have been metamorphosed and deformed and are marginally recrystallised as greenschists or crossite-bearing schists. The greenschists contain assemblages typical of the greenschist facies except for the amphibole which microprobe analysis indicates is hornblende rather than actinolite. Crossite partly replaces hornblende in some greenschists, and is the only amphibole in the crossite-bearing schists. The appearance of either crossite or hornblende seems to be controlled by the bulk-rock Fe₂O₃/FeO ratio, as shown by Ernst et al. (1970) for similar rocks from the Santagawa terrain. The cores of the blocks are meta-basalts, interbedded with radiolarian cherts, which frequently have agglomeratic textures and contain both lithic and mineral fragments. Mineral assemblages in the meta-basalts are clinopyroxene + albite + chlorite + sphene + opaque ± crossite. The petrography and mineralogy of the volcanic rocks (Hall, 1974) suggests that they have been metamorphosed under conditions trans-

sitional between the glaucophane-lawsonite schist facies and the greenschist or greenschist-amphibolite transitional facies of Turner (1968). Metamorphic pyroxenes crystallised under these conditions are likely to be green sodic pyroxenes with compositions between omphacite and aegirine-augite (Essene and Fyfe, 1976; Brown, 1974; Newton and Fyfe, 1976). In one meta-basalt a green clinopyroxene, whose optical properties indicate aegirine-augite, occurs in a cavity as sub-idioblastic elongate prisms intergrown with albite and an opaque phase. This pyroxene is interpreted as metamorphic in origin. All the other clinopyroxenes in the meta-basalts appear to be igneous relics. Colourless euhedral phenocrysts up to 2 mm in length occur both in and between lithic fragments, often with a groundmass of pink granular pyroxene. Crossite, when present, nucleates on the clinopyroxene, and epidote, actinolite and carbonate occur as late metamorphic vein-filling phases.

Gabbros and picrites occur as blocks usually less than three hundred metres across. The picrites often have a marked mineralogical layering, and consist of cumulus olivine, with clinopyroxene and plagioclase as intercumulus phases. Orthopyroxene occurs in some samples. These rocks have escaped any significant metamorphism; olivine is partly serpentinised, but the pyroxenes are generally quite fresh. The gabbros have been metamorphosed, but under different conditions to those prevailing during the metamorphism of the volcanic rocks. They are partially altered to actinolite + chlorite + albite assemblages; plagioclase is always altered, but usually a relict igneous texture is preserved, often with clinopyroxene. Olivine (F₀) occurs in one sample. Where completely recrystallised, assemblages are typical of the greenschist facies, and in contrast to the meta-volcanics crossite is absent, while actinolite rather than hornblende is the characteristic amphibole. In addition, the gabbros and picrites always show some signs of calcium metasomatism while the meta-volcanics do not. In the picrites and many of the gabbros this metasomatism has resulted in an alteration of the original plagioclase to a fine-grained intergrowth of grossular, prehnite and clinozoisite. In some blocks alteration is more extensive and clinopyroxene may coexist with such minerals as grossular, prehnite, and idocrase. Although these rocks often have a gabbroic appearance, and correspond to the 'rodingites' of some authors (see review by Coleman, 1967) it is difficult to be certain if the clinopyroxene is a relict igneous phase, or is of metasomatic origin. This problem is complicated because these rocks almost always show some signs of cataclasis, and may be extensively mylonitised.

Pyroxene compositions

Eight rocks containing clinopyroxene were selected for study: two meta-basalts (RM9, RM290), two gabbros (RM116, RM203), two rodingites (RM228, RM17) and two picrites (RM5, RM19). Each sample is from a separate block in the mélange. Mineral analyses were made using the Microscan V microprobe at University College London, operated at an accelerating voltage of 20 kV with a specimen current of approximately 2 × 10⁻⁸ amp. All pyroxenes were analysed for Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K and Cr. Pure metal standards were used for Ti, Mn and Cr, and natural silicate standards for the other elements. The raw data were reduced using the EM-10-NPL computer programme (Wason et al., 1969).

The compositions and structural formulae of the analysed pyroxenes are presented in Tables 1 to 3. None of the pyroxenes was zoned with respect to Ca, Mg or Fe, and with the exception of groundmass pyroxenes from meta-basalt RM290, and rodingite RM17 which contains two chemically distinct clinopyroxenes, there is very little compositional variation between different grains in the same rock (Fig. 1).

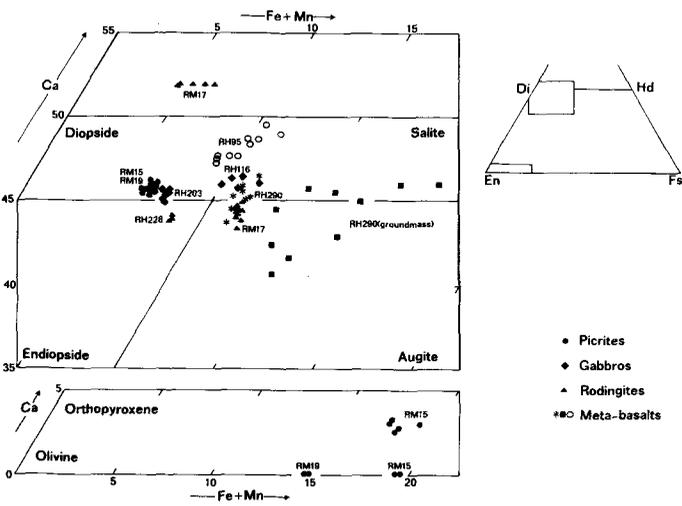


Fig. 1. Compositions of clinopyroxenes, orthopyroxenes, and olivines from the mélangé rocks.

Picrites (RM5, RM2). The clinopyroxenes from both the picrites are diopsides with a high Cr_2O_3 , relatively low Al_2O_3 , and low TiO_2 . Fig. 1 shows the compositions of coexisting clinopyroxenes, olivines and orthopyroxenes in these rocks. In RM9 diopside coexists with olivine (For_{60}) and altered plagioclase, while in RM5 compositionally identical diopside coexists with olivine (For_{70}), bromite (Br_{93-90}) and altered plagioclase. In both rocks the olivine was the first mineral to crystallise (in RM9 olivine is a cumulus phase), and the diopside was later. It is not clear from the textures whether the few grains of orthopyroxene (4 modal percent) represent a cumulus phase or crystallised at the same time as the diopside. In the Bushveld intrusion (Atkins, 1969) compositionally similar diopside of the Basal Series is an intercumulus phase coexisting with cumulus orthopyroxene more magnesian (En_{83-85}) than that of RM5. This suggests that the two pyroxenes of RM5 may have crystallised together as intercumulus phases.

Gabbros (RH16, RH203) and rodingites (RH228, RM17). In the two gabbros igneous textures are well-preserved and the clinopyroxene appears to be unaffected by alteration. The clinopyroxenes are diopsides and salites and are similar to the diopsides from the picrites except in having higher total iron, and lower MgO and Cr_2O_3 . In the rodingites calcium metasomatism has been more extensive. The plagioclase of RH228 has been completely replaced by coarse-grained prehnite although a gabbroic texture is preserved, while in RM17 clinopyroxene coexists with idocrase and grossular and the rock has a cataclastic fabric. Both rocks are veined by these calcium aluminum silicates. No orthopyroxene nor exsolved lamellae of Ca-poor pyroxene have been observed in any of the gabbros or rodingites. The clinopyroxenes from RH228, which are endiopsides, are less calcic than those of gabbro RH203 although otherwise similar. In RM17 two chemically and texturally distinct clinopyroxenes coexist. Augite, similar in composition to the salite of gabbro RH16, but slightly less calcic, occurs as equidimensional anhedral grains up to 1 mm across which are often cracked or broken. The second clinopyroxene occurs mainly as elongate prisms, often bent, and less than 0.5 mm in length, which are intimately intergrown with idocrase and grossular. This pyroxene has much higher CaO (plotting outside the pyroxene quadrilateral, Fig. 1), lower total iron and Al_2O_3 , and much lower MnO, Na_2O , Cr_2O_3 , TiO_2 than the first pyroxene. It is referred to below as super-calcic diopside.

Meta-basalts (RH95, RH290). Compositions of phenocrysts from RH290 resemble those of the salites and augites from gabbro RH16 and rodingite RM17 except in having higher TiO_2 and slightly higher Na_2O , and pyroxene analyses from the three rocks overlap on the pyroxene quadrilateral (Fig. 1). The large area of scatter of groundmass pyroxenes from RH290 may partly reflect the problems of analysis of very small grains (less than 0.15 mm in length) with the microprobe. They are less well polished than the phenocrysts, and their small size means that the problem of returning to exactly the same point during the analysis is likely to be more significant than for the large, compositionally homogeneous and well-polished grains of the picrites, gabbros and rodingites. This difficulty is reflected in the totals of the analyses, which are often slightly lower than those of the larger grains. Despite this the analyses are believed to give a reasonable indication of composition and variation of groundmass pyroxenes. They have consistently higher total iron than coexisting, more homogeneous, phenocrysts, and slightly higher TiO_2 , as suggested also by their pinkish colour. Clinopyroxenes from RH95 are similar to the phenocrysts of RH290 in most respects, having higher TiO_2 than the clinopyroxenes from the picrites, gabbros and rodingites, but they are distinguished from all the other analysed clinopyroxenes, except the super-calcic diopside, by a higher proportion of the Ca end-member and are clearly separated on the pyroxene quadrilateral (Fig. 1). This difference has been confirmed by repetition of the analyses.

Discussion of the pyroxene chemistry

Since none of the blocks in the mélangé is completely unaffected by alteration or recrystallisation it is unreasonable to assume a particular origin for the pyroxenes. However, despite the different metamorphic and metasomatic events affecting the different blocks there is a surprisingly small range in the composition of the clinopyroxenes and this is most easily explained by postulating that they are of igneous origin and have suffered little or no post-crystallisation change. Moreover, in the picrites igneous textures are preserved, two pyroxenes coexist with only partially serpenfinised cumulus olivine and all three minerals have very similar compositions to those of cumulate assemblages in the Basal Series of the Bushveld complex (Atkins, 1969). The pyroxenes are compositionally homogeneous, and the clinopyroxenes have very high Cr_2O_3 typical of early-formed igneous clinopyroxenes. Despite the greenschist facies metamorphism the pyroxenes of the gabbros are chemically similar to those of the picrites and the differences (higher iron and lower MgO and Cr_2O_3) are exactly those to be expected from pyroxenes of more fractionated igneous rocks. A metamorphic origin is unlikely since metamorphic pyroxenes are unknown under conditions of the greenschist facies. The meta-basalts have also suffered low-grade metamorphism, but of a higher pressure type and metamorphic pyroxenes are known from rocks recrystallised under these conditions. However, the pyroxenes of meta-basalt RH290 are chemically quite different from such metamorphic pyroxenes (Essene and Pye, 1967), having much lower Na_2O and higher TiO_2 . In addition, the rock has a relic igneous texture with phenocryst and groundmass pyroxenes,

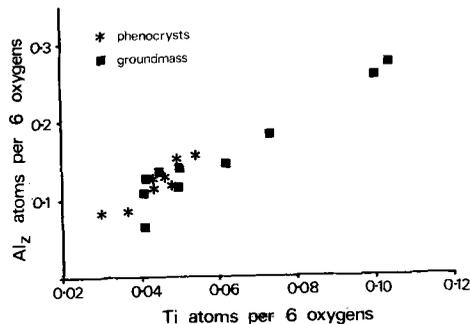


Fig. 2. Variation in Al_2 with Ti content of clinopyroxenes from meta-basalt RH290.

there is a nonparallel overlap of the phenocrysts of RH290 and pyroxenes from gabbro RH16 despite their different metamorphic histories, and there is a distinct compositional separation (fig. 1) of phenocryst and groundmass pyroxenes with the latter having higher total iron and TiO₂; all these features indicate an igneous origin for the pyroxenes. A plot of Al₂ against Ti for pyroxenes from RH290 (fig. 2) shows a good correlation supporting the substitution $Ti_y + 2Al_2 \rightleftharpoons Mg^{2+} + 2Si_2$, typical of igneous pyroxenes (Le Bas, 1962).

Metasomatism appears to have had no effect on the original igneous clinopyroxene chemistry. Although calcium metasomatism has been more extensive in the rodingites their clinopyroxenes (except for the super-calcic diopside, see below) are actually less calcic than those of the gabbros. Phenocrysts from meta-basalt RH290 overlap in composition with pyroxenes from gabbro RH16 and rodingite RMT despite the fact that the meta-basalts have not been affected by the calcium metasomatism. The relict gabbroic textures of many of the rodingites, and the similarity of clinopyroxene compositions from rodingites to those from rocks less affected or unaffected by metasomatism, indicates the igneous origin of the rodingite endopside and augites.

The effect of the metasomatism in RH17 has been to produce a second, texturally distinct, clinopyroxene which is clearly chemically different from the augite interpreted as igneous in origin. This super-calcic diopside is characterized by low Cr, Ti, Ne, Mn and Al, and high Ca and Si. The explanation for this distinctive chemistry probably lies with the fluids responsible for the metasomatism. Barnes and O'Hell (1969) have suggested that these fluids may be similar to unusual calcium hydroxide waters issuing from partly serpentinized alpine-type ultramafic bodies of the western United States. These fluids probably result from the process of serpentinization of the ultramafics and are supersaturated with respect to diopside. They would be incapable of dissolving the calcium-rich igneous pyroxenes from blocks in the mélange, but would precipitate diopside, whose chemistry would reflect the small amounts of Cr, Ti, etc. in solution. In view of this, and the compositional homogeneity of pyroxenes from blocks showing varying amounts of alteration, it seems reasonable to suggest that the calcium metasomatism has resulted in no change in the chemistry of the clinopyroxenes of igneous origin, while causing the precipitation of the super-calcic diopside intergrown with ilcaorase and grossular.

The pyroxenes of meta-basalt RH95 are separated on the pyroxene quadrilateral (fig. 1) from all the other clinopyroxenes. Their chemistry indicates that they are not of metamorphic origin (as with pyroxenes from RH290 Na₂O is too low, and TiO₂ too high), and since none of the meta-basalts is affected by the calcium metasomatism the high proportion of the Ca end-member in the pyroxenes is thought to be an original feature. There is greater scatter for these analyses than for those from any other rock, but in view of their general similarities to the pyroxenes from gabbro RH16 and phenocrysts from meta-basalt RH290, and the compositional homogeneity of individual grains, it is suggested that the pyroxenes from RH95 crystallised from a melt of different composition from that of the other rocks.

The evidence for an igneous origin for most of the clinopyroxenes, their trend of iron enrichment and systematic decrease in Cr₂O₃ from picrites, through gabbros and rodingites (metasomatised gabbros) to meta-basalts, and enrichment in TiO₂ in the meta-basalt groundmass pyroxenes, indicates that all the basic rocks, with the possible exception of RH95, originated in a single igneous complex. The very small range in composition of the clinopyroxenes, and their calcic character support this conclusion. It is extremely unlikely that random sampling of several chemically unrelated basic complexes, would result in the range and type of chemical variation described here.

Chemical affinities of the rocks

Basic igneous rocks of ophiolite complexes are commonly extensively altered and much discussion (see for example Miyashiro, 1973, 1975a, 1975b; Moores, 1975; Gass et al., 1975; Church and Colish, 1976) has drawn attention

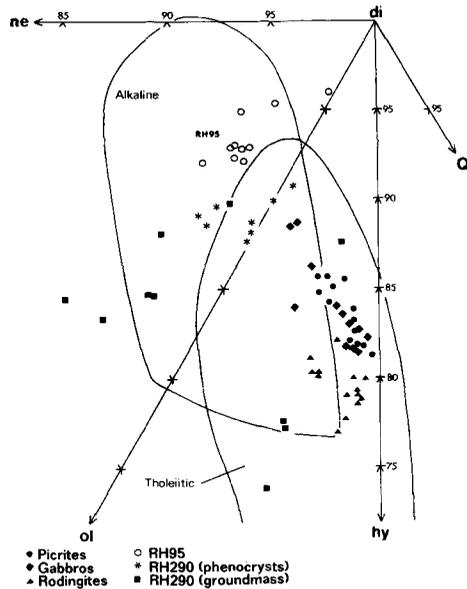


Fig. 3. Compositions of igneous clinopyroxenes from the mélange rocks in molecular percentages of normative components ne - di - ol - Q. Symbols as in fig. 1. Fields of alkaline and tholeiitic basaltic rocks from Coombs (1963).

to the difficulties of using bulk-rock major element analyses to determine their original chemical histories. If the igneous clinopyroxenes have survived unchanged, as argued above, their chemistry should indicate the nature of the original basic magma. Coombs (1963) has suggested the use of the pyroxene norms as aids in the discrimination of basaltic types, and Vallance (1974) believes that the norms are the most useful discriminants in altered mafic rocks. In fig. 3 the normative compositions of the igneous clinopyroxenes from the mélange are plotted on a ne - di - ol - Q diagram with fields of alkaline and tholeiitic basaltic rocks from Coombs (1963). All the pyroxenes from the picrites, gabbros and rodingites fall very clearly within the field of tholeiitic rocks, and most fall outside the alkaline basalt field. The pyroxenes from the meta-volcanic rocks are mostly nepheline normative. Those from RH95 plot outside the tholeiitic field, and nine of the ten analyses fall within the alkaline basalt field. The pyroxenes from RH290 scatter more widely; the phenocryst pyroxenes cluster in the area of overlap of alkaline and tholeiitic basalts while the groundmass pyroxenes are widely scattered. It should be noted that in the microprobe analyses total iron is expressed as Fe²⁺. Fe³⁺ is unlikely to be large in any of the analyses, but its effect would be to make the norms more tholeiitic. Q would appear instead of ol, and hy would increase.

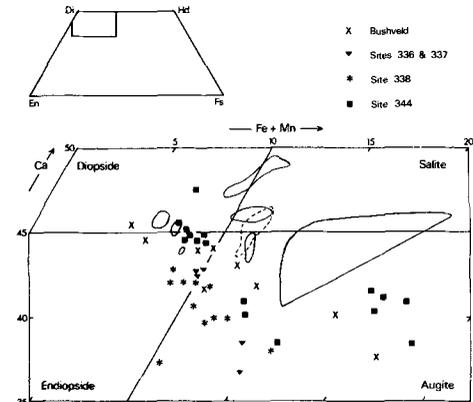


Fig. 4. Comparison of compositions of igneous clinopyroxenes from the mélange rocks with those of tholeiitic rocks from the Bushveld Complex (Atkins, 1969) and North Atlantic (DSDP Leg 30, Sites 336, 337, 339 and 344, Ridley et al., 1976). Fields of mélange pyroxenes from fig. 1.

The norm plot supports the suggestion made above that the pyroxenes of RH95 are chemically different from those of the other rocks and suggests that they are alkalic in character. Assuming the other rocks originated in a single complex, as argued above, the norm plot indicates that they are more likely to be tholeiitic than alkalic. This conclusion is supported by the coexistence of ortho- and clinopyroxene in some of the picrites.

Comparison of the compositions of the clinopyroxenes from the mélange rocks with those of tholeiitic rocks of the Bushveld Complex (Atkins, 1969) and the North Atlantic (DSDP Leg 30, Ridley et al., 1976) indicates a reasonable similarity (fig. 4), although the mélange pyroxenes tend to be more calcic. They are certainly more calcic than pyroxenes from the Pacific (fig. 5) considered to be "unquestionably ocean-ridge tholeiitic basalts" (DSDP Leg 33, Jackson et al., 1976), and also more calcic than pyroxenes from Hawaiian tholeiites (Foster et al., 1973). Similar pyroxenes to those of the mélange rocks occur in the Solafa volcanics of New South Wales (fig. 5) which Barron (1976) has concluded belong to a suite of calc-alkaline rocks.

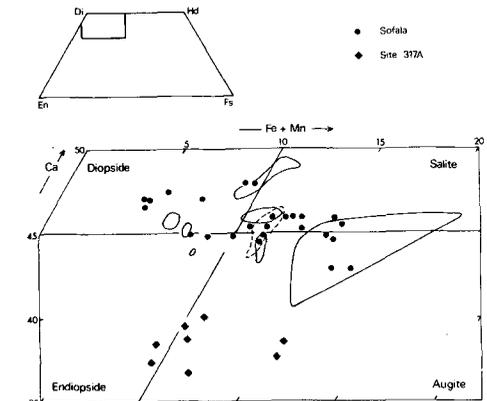


Fig. 5. Comparison of compositions of igneous clinopyroxenes from the mélange rocks with those of tholeiitic rocks from the Pacific (DSDP Leg 33, Site 317A, Jackson et al., 1976) and calc-alkaline volcanics from Solafa, New South Wales (Barron, 1976). Fields of mélange pyroxenes from fig. 1.

Kushiro (1960) and Le Bas (1962) have suggested the use of Al and Ti contents of the clinopyroxene as indicators of the alkalinity of the parent

magma, but recent work (Barberi et al., 1971; Gibb, 1973) has indicated that this approach may be unreliable. The Al and Ti contents probably reflect the silica activity of the melt, and the conditions under which the pyroxenes crystallised, and are not diagnostic of parental magma type. Consequently, Barberi et al. (1971) cast doubt on the reliability of clinopyroxene compositions in determining the affinities of basaltic volcanic rocks. Despite this, Nisbet and Pearce (1977) have used discriminant analysis in an attempt to relate clinopyroxene compositions to basalt types from different tectonic settings. They claim that results of this

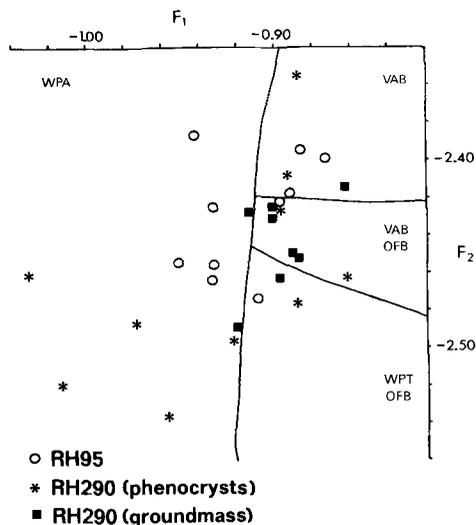


Fig. 6. Plot of discriminant functions F_1 and F_2 for pyroxene analyses from meta-basalts RH95 and RH290 from the mélange. Symbols as in fig. 1. Fields of magma types are from Nisbet and Pearce (1977): ocean-floor basalts (OFB), volcanic arc basalts (VAB), within-plate tholeiitic basalts (VAB), within-plate tholeiitic basalts (WPT), and within-plate alkalic basalts (WPA).

technique are consistent with those obtained using immobile trace elements from rocks which indicate that spilitised lavas from Othris, Greece resemble basalts and basaltic andesites from present-day island arcs. On the other hand, Hynes (1976, 1975) has used clinopyroxene norms to support his argument that the Othris rocks were not formed in an island arc, but are similar to ocean-ridge tholeiites. A plot of the discriminant functions F_1 and F_2 (Nisbet and Pearce, 1977) for pyroxene analyses from the two meta-basalts of the mélange fails to indicate their affinities since the points scatter in all of the four basalt fields (Fig. 6).

All this demonstrates the difficulties of using clinopyroxene analyses to determine unambiguously the nature of the parent magmas. It may be that the mélange rocks are transitional between tholeiitic and alkalic basaltic rocks. This would explain the general similarities, and the Ca-rich character, of the clinopyroxenes compared to those of tholeiitic rocks. It would explain the presence of orthopyroxene in some of the plerites, while accounting for its absence, and the absence of exsolved Ca-poor lamellae in clinopyroxene, in the gabbros.

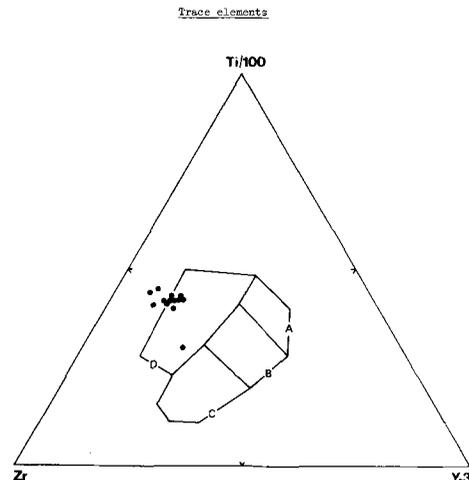


Fig. 7. Ti - Zr - Y discrimination diagram for meta-volcanic rocks from the mélange. Basalt fields from Pearce and Cann (1973): within-plate basalts plot in field D, ocean-floor basalts plot in field B.

In the context of the pyroxene data it is interesting to consider the affinities of the basic rocks as revealed by the trace element data from whole rocks. Pearce and Cann (1971, 1973) have argued that the elements Ti, Zr and Y appear to be immobile during alteration and low-grade metamorphism, and may be used to distinguish between basic volcanic rocks formed in different tectonic settings. Data from thirteen meta-volcanic rocks from the mélange is plotted on a Ti - Zr - Y diagram (Fig. 7). Only four of the rocks are meta-basalts (i.e. contain relict clinopyroxene); the remainder are greenschist or crossite-bearing greenschists. Twelve of the thirteen samples cluster very closely, which suggests that these elements have been effectively immobile during metamorphism. The twelve samples plot in, or close to, the field of 'within-plate basalts' which includes both continental and oceanic rocks. Geological considerations (Hall, 1976) indicate the oceanic nature of the mélange rocks, which must therefore be compared to 'within-plate oceanic-basalts' which include tholeiites, and intermediate- and ultra-alkaline rocks from ocean islands (Pearce and Cann, 1973). Therefore, although this method provides no unambiguous solution to the nature of the mélange rocks, it supports the conclusions drawn from the pyroxene analyses which indicate that they are not typical ocean-ridge tholeiites.

Conclusions

This work supports the view that igneous pyroxenes can survive low-grade metamorphism at moderate to high pressures. It appears also that they are resistant to extensive cation metasomatism under certain conditions, and that metasomatic clinopyroxenes are chemically distinctive and quite different from igneous clinopyroxenes. The pyroxene chemistry, and whole-rock trace element data, indicate that rocks from the Mutki ophiolite mélange are different in several ways from tholeiites typical of present-day oceanic ridges. The range and type of chemical variation in the igneous clinopyroxenes indicates that most of the basic rocks of the mélange originated in a single igneous complex. Such a conclusion is evident for the layered ophiolite complexes such as those of Cyprus, Hatay and Oman, but where original relationships have been disrupted as in the case of the ophiolite mélanges of the Middle East, this is an important starting point in attempts to unravel their histories. These mélange terranes are probably much more organized than their apparently chaotic appearance would suggest (see for example Norman, 1975; Hall, 1976) and their histories may provide many insights into the processes at destructional plate-margins.

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REFERENCES

- Atkins (F.B.), 1969. *J.Petrol.* **10**, 228-249.
 Barberi (F.), Rizouard (H.), and Varet (J.), 1971. *Contrib. Mineral. Petrol.* **33**, 93-107.
 Barron (B.J.), 1976. *Am.J.Sci.* **276**, 604-636.
 Barnes (I.) and O'Neill (J.R.), 1969. *Bull. Geol. Soc. Am.* **80**, 1947-1960.
 Brown (E.H.), 1974. *Ibid.* **85**, 333-344.
 Church (W.R.) and Coish (R.A.), 1976. *Earth Planet. Sci. Lett.* **21**, 8-14.
 Coleman (R.C.), 1976. *U.S. Geol. Surv. Bull.* **1247**, 49pp.
 Coombs (D.S.), 1963. *Mineral. Soc. Am. Spec. Pap.* **1**, 227-250.
 Ernst (W.G.), Seki (Y.), Onuki (H.), and Gilbert (M.C.), 1970. *Geol. Soc. Am. Mem.* **126**, 276pp.
 Essene (E.J.) and Rye (W.S.), 1967. *Contrib. Mineral. Petrol.* **15**, 1-23.
 Foster (R.V.), Keil (K.), and Burch (T.E.), 1975. *Ibid.* **50**, 182-195.
 Gass (I.G.), Neary (C.R.), Plant (J.), Robertson (A.H.F.), Simonian (K.O.), Seewing (J.D.), Spooner (E.T.C.), and Wilson (R.A.M.), 1975. *Earth Planet. Sci. Lett.* **25**, 236-238.
 Gibb (F.G.P.), 1973. *J.Petrol.* **14**, 203-230.
 Hall (R.), 1974. Unpubl. Ph.D. Thesis, University of London, 351pp.
 — 1976. *Bull. Geol. Soc. Am.* **87**, 1076-1088.
 Hynes (A.), 1974. *Contrib. Mineral. Petrol.* **46**, 233-239.
 — 1975. *Earth Planet. Sci. Lett.* **25**, 213-216.
 Jackson (R.D.), Barger (K.E.), Fabbri (B.P.), and Heropoulos (C.), 1976. In Schlanger (S.O.), Jackson (E.D.) and others, *Initial Reports of the Deep Sea Drilling Project*, **33**, 571-630.
 Kushiro (T.), 1960. *Am.J.Sci.* **258**, 548-544.
 Le Bas (M.J.), 1962. *Ibid.* **260**, 267-288.
 Mason (F.K.), Frost (M.T.), and Reed (S.J.B.), 1969. *Natl. Phys. Lab. (U.K.S.) Rep.* **2**.
 Mevel (C.) and Velds (D.), 1976. *Earth Planet. Sci. Lett.* **30**, 158-164.
 Miyashiro (A.), 1973. *Ibid.* **19**, 218-224.
 — 1975a. *Ibid.* **25**, 217-222.
 — 1975b. *Ibid.* **25**, 227-235.
 Moores (E.M.), 1975. *Ibid.* **25**, 223-226.
 Newton (R.C.) and Pye (W.S.), 1976. In *The Evolution of the Crystalline Rocks* (Sizley (D.K.) and Macdonald (R.), eds.) Academic Press.
 Nisbet (E.G.) and Pearce (J.A.), 1977. *Contrib. Mineral. Petrol.* **63**, 149-160.
 Norman (T.), 1975. *Proc. 50th Anniv. Earth Sci. Congr. Ankara 1975*, 78-95.
 Pearce (J.A.) and Cann (J.R.), 1971. *Earth Planet. Sci. Lett.* **12**, 339-349.
 — 1973. *Ibid.* **19**, 299-300.
 Ricou (L.E.), 1971. *Bev. Geogr. Phys. Geol. Dynam.* **13**, 327-349.
 Ridley (W.I.), Perfit (M.R.), and Adams (N.L.), 1976. In Talwani (M.), Udintsev (G.) et al., *Initial Reports of the Deep Sea Drilling Project*, **35**, 731-739.
 Schüber (W.) and Seidel (E.), 1972. *Z. Deutsch. Geol. Gesell.* **123**, 371-384.
 Turner (F.J.), 1966. *Metamorphic Petrology*, McGraw-Hill.
 Vallance (T.G.), 1974. *J.Petrol.* **15**, 79-96.
 — 1975. In *Spillitee* (Amstutz (G.C.) ed.) Springer-Verlag.
 For fig. 1 see the synopsis (this vol.).

M46

Table 1. Electron microprobe analyses and structural formulae of pyroxenes from picrite blocks in the mélange. Total iron as FeO.

| | RM19/1 | RM19/2 | RM19/3 | RM19/5 | RM19/6 | RM19/7 | RM19/8 |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|
| SiO ₂ | 52.86 | 53.37 | 52.66 | 53.39 | 53.05 | 52.87 | 52.77 |
| Al ₂ O ₃ | 2.92 | 2.40 | 2.77 | 2.64 | 2.63 | 2.63 | 2.71 |
| TiO ₂ | 0.27 | 0.20 | 0.19 | 0.20 | 0.20 | 0.21 | 0.22 |
| Cr ₂ O ₃ | 0.87 | 0.97 | 1.00 | 1.03 | 0.93 | 0.93 | 0.96 |
| FeO | 3.92 | 3.79 | 3.80 | 3.68 | 3.96 | 4.02 | 3.97 |
| MnO | 0.13 | 0.11 | 0.12 | 0.12 | 0.13 | 0.13 | 0.13 |
| MgO | 16.53 | 16.93 | 16.68 | 16.75 | 16.58 | 16.61 | 16.44 |
| CaO | 22.37 | 22.14 | 22.11 | 22.07 | 22.00 | 22.02 | 22.01 |
| Na ₂ O | 0.17 | 0.16 | 0.20 | 0.17 | 0.19 | 0.16 | 0.20 |
| K ₂ O | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| Total | 100.04 | 100.07 | 99.53 | 100.05 | 99.68 | 99.58 | 99.41 |

Ionic ratios to 6 oxygens

| | | | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|-------|
| Si | 1.928 | 1.943 | 1.930 | 1.942 | 1.940 | 1.937 | 1.936 |
| Al ^{iv} | 0.072 | 0.057 | 0.070 | 0.058 | 0.060 | 0.063 | 0.064 |
| Al ^{vi} | 0.054 | 0.046 | 0.050 | 0.056 | 0.054 | 0.050 | 0.054 |
| Ti | 0.007 | 0.005 | 0.005 | 0.005 | 0.006 | 0.006 | 0.006 |
| Cr | 0.025 | 0.028 | 0.029 | 0.030 | 0.027 | 0.027 | 0.028 |
| Fe ²⁺ | 0.120 | 0.115 | 0.116 | 0.112 | 0.121 | 0.123 | 0.122 |
| Mn | 0.004 | 0.003 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| Mg | 0.899 | 0.919 | 0.911 | 0.908 | 0.904 | 0.907 | 0.899 |
| Ca | 0.874 | 0.864 | 0.868 | 0.860 | 0.862 | 0.864 | 0.865 |
| Na | 0.012 | 0.011 | 0.014 | 0.012 | 0.013 | 0.011 | 0.014 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| Sum X+Y | 1.995 | 1.992 | 1.998 | 1.987 | 1.991 | 1.993 | 1.992 |

Cations - atomic per cent

| | | | | | | | |
|-------|------|------|------|------|------|------|------|
| Mg | 47.4 | 48.3 | 48.0 | 48.2 | 47.8 | 47.8 | 47.6 |
| Fe+Mn | 6.5 | 6.2 | 6.3 | 6.1 | 6.6 | 6.7 | 6.7 |
| Ca | 46.1 | 45.4 | 45.7 | 45.7 | 45.6 | 45.5 | 45.8 |

Table 1 (continued).

| | RM15/5 | RM15/6 | RM15/7 | RM15/8 | RM15/9 | RM15/10 |
|--------------------------------|--------|--------|--------|--------|--------|---------|
| SiO ₂ | 55.81 | 55.74 | 52.51 | 52.43 | 52.69 | 52.83 |
| Al ₂ O ₃ | 1.25 | 1.39 | 2.76 | 3.14 | 2.80 | 2.50 |
| TiO ₂ | 0.16 | 0.18 | 0.15 | 0.17 | 0.18 | 0.15 |
| Cr ₂ O ₃ | 0.10 | 0.17 | 1.10 | 1.12 | 0.92 | 0.97 |
| FeO | 11.59 | 11.50 | 3.79 | 3.86 | 3.97 | 4.01 |
| MnO | 0.21 | 0.30 | 0.15 | 0.14 | 0.13 | 0.13 |
| MgO | 29.42 | 28.99 | 16.62 | 16.52 | 16.77 | 16.78 |
| CaO | 1.29 | 1.39 | 22.30 | 22.26 | 22.25 | 22.19 |
| Na ₂ O | 0.01 | 0.01 | 0.16 | 0.18 | 0.17 | 0.19 |
| K ₂ O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 99.94 | 99.67 | 99.34 | 99.82 | 99.88 | 99.75 |

Ionic ratios to 6 oxygens

| | | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|
| Si | 1.977 | 1.979 | 1.926 | 1.918 | 1.926 | 1.934 |
| Al ^{iv} | 0.023 | 0.021 | 0.074 | 0.082 | 0.074 | 0.066 |
| Al ^{vi} | 0.029 | 0.037 | 0.046 | 0.054 | 0.047 | 0.042 |
| Ti | 0.004 | 0.005 | 0.004 | 0.005 | 0.005 | 0.004 |
| Cr | 0.003 | 0.005 | 0.032 | 0.032 | 0.027 | 0.028 |
| Fe ²⁺ | 0.243 | 0.241 | 0.116 | 0.118 | 0.121 | 0.123 |
| Mn | 0.009 | 0.009 | 0.005 | 0.004 | 0.004 | 0.004 |
| Mg | 1.533 | 1.534 | 0.909 | 0.901 | 0.914 | 0.916 |
| Ca | 0.049 | 0.053 | 0.877 | 0.873 | 0.872 | 0.870 |
| Na | 0.001 | 0.001 | 0.011 | 0.013 | 0.012 | 0.013 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| Sum X+Y | 1.992 | 1.985 | 1.999 | 2.000 | 2.001 | 2.001 |

Cations - atomic per cent

| | | | | | | |
|-------|------|------|------|------|------|------|
| Mg | 79.5 | 79.2 | 47.7 | 47.5 | 47.8 | 47.9 |
| Fe+Mn | 18.0 | 18.1 | 6.3 | 6.5 | 6.6 | 6.6 |
| Ca | 2.5 | 2.7 | 46.0 | 46.0 | 45.6 | 45.5 |

Table 2. Electron microprobe analyses and structural formulae of pyroxenes from gabbro blocks in the mélange. Total iron as FeO.

| | RM19/9 | RM19/10 | RM15/1 | RM15/2 | RM15/3 | RM15/4 |
|--------------------------------|--------|---------|--------|--------|--------|--------|
| SiO ₂ | 53.36 | 52.83 | 55.30 | 55.10 | 55.89 | 56.16 |
| Al ₂ O ₃ | 2.67 | 2.92 | 1.26 | 1.25 | 1.20 | 1.17 |
| TiO ₂ | 0.26 | 0.15 | 0.15 | 0.15 | 0.25 | 0.22 |
| Cr ₂ O ₃ | 0.87 | 1.01 | 0.08 | 0.07 | 0.03 | 0.04 |
| FeO | 3.97 | 3.70 | 11.97 | 12.11 | 11.22 | 11.16 |
| MnO | 0.12 | 0.11 | 0.34 | 0.31 | 0.31 | 0.34 |
| MgO | 16.66 | 16.49 | 28.30 | 28.62 | 29.47 | 29.27 |
| CaO | 22.24 | 22.21 | 1.49 | 1.54 | 1.54 | 1.59 |
| Na ₂ O | 0.18 | 0.16 | 0.03 | 0.01 | 0.02 | 0.02 |
| K ₂ O | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| Total | 100.33 | 99.58 | 98.92 | 99.17 | 99.93 | 99.97 |

Ionic ratios to 6 oxygens

| | | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|
| Si | 1.939 | 1.933 | 1.984 | 1.975 | 1.978 | 1.985 |
| Al ^{iv} | 0.061 | 0.067 | 0.016 | 0.025 | 0.022 | 0.015 |
| Al ^{vi} | 0.053 | 0.059 | 0.037 | 0.027 | 0.028 | 0.034 |
| Ti | 0.007 | 0.004 | 0.004 | 0.004 | 0.007 | 0.006 |
| Cr | 0.025 | 0.029 | 0.002 | 0.002 | 0.001 | 0.001 |
| Fe ²⁺ | 0.121 | 0.113 | 0.359 | 0.363 | 0.332 | 0.330 |
| Mn | 0.004 | 0.003 | 0.010 | 0.009 | 0.009 | 0.010 |
| Mg | 0.902 | 0.899 | 1.513 | 1.529 | 1.554 | 1.542 |
| Ca | 0.866 | 0.871 | 0.057 | 0.059 | 0.058 | 0.060 |
| Na | 0.013 | 0.011 | 0.002 | 0.001 | 0.001 | 0.001 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| Sum X+Y | 1.991 | 1.991 | 1.985 | 1.995 | 1.991 | 1.985 |

Cations - atomic per cent

| | | | | | | |
|-------|------|------|------|------|------|------|
| Mg | 47.7 | 47.7 | 78.0 | 78.0 | 79.5 | 79.4 |
| Fe+Mn | 6.6 | 6.2 | 19.0 | 19.0 | 17.5 | 17.5 |
| Ca | 45.8 | 46.2 | 3.0 | 3.0 | 3.0 | 3.1 |

| | RM16/1 | RM16/4 | RM16/6 | RM16/7 | RM16/8 | RM203/1 |
|--------------------------------|--------|--------|--------|--------|--------|---------|
| SiO ₂ | 51.85 | 52.42 | 51.16 | 52.84 | 51.97 | 53.64 |
| Al ₂ O ₃ | 2.87 | 2.77 | 3.99 | 2.91 | 2.76 | 1.88 |
| TiO ₂ | 0.44 | 0.32 | 0.35 | 0.34 | 0.41 | 0.19 |
| Cr ₂ O ₃ | 0.32 | 0.28 | 0.35 | 0.36 | 0.29 | 0.33 |
| FeO | 6.96 | 6.21 | 6.37 | 5.90 | 6.33 | 4.45 |
| MnO | 0.21 | 0.18 | 0.17 | 0.18 | 0.20 | 0.13 |
| MgO | 14.73 | 15.22 | 14.67 | 15.24 | 14.74 | 16.73 |
| CaO | 22.34 | 22.59 | 21.48 | 22.00 | 22.19 | 22.28 |
| Na ₂ O | 0.19 | 0.19 | 0.20 | 0.23 | 0.18 | 0.21 |
| K ₂ O | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| Total | 99.91 | 100.18 | 98.75 | 100.00 | 99.07 | 99.84 |

Ionic ratios to 6 oxygens

| | | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|
| Si | 1.922 | 1.930 | 1.908 | 1.941 | 1.935 | 1.961 |
| Al ^{iv} | 0.078 | 0.070 | 0.092 | 0.059 | 0.065 | 0.039 |
| Al ^{vi} | 0.047 | 0.050 | 0.084 | 0.067 | 0.056 | 0.042 |
| Ti | 0.012 | 0.009 | 0.010 | 0.009 | 0.011 | 0.005 |
| Cr | 0.009 | 0.008 | 0.010 | 0.010 | 0.009 | 0.010 |
| Fe ²⁺ | 0.216 | 0.191 | 0.199 | 0.181 | 0.197 | 0.136 |
| Mn | 0.007 | 0.006 | 0.005 | 0.006 | 0.006 | 0.004 |
| Mg | 0.814 | 0.835 | 0.815 | 0.834 | 0.818 | 0.912 |
| Ca | 0.887 | 0.891 | 0.858 | 0.866 | 0.885 | 0.873 |
| Na | 0.014 | 0.014 | 0.014 | 0.016 | 0.013 | 0.015 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| Sum X+Y | 2.006 | 2.004 | 1.997 | 1.990 | 1.995 | 1.996 |

Cations - atomic per cent

| | | | | | | |
|-------|------|------|------|------|------|------|
| Mg | 42.3 | 43.4 | 43.4 | 44.2 | 42.9 | 47.4 |
| Fe+Mn | 11.6 | 10.2 | 10.9 | 9.9 | 10.7 | 7.3 |
| Ca | 46.1 | 46.3 | 45.7 | 45.9 | 46.4 | 45.4 |

Table 2 (continued).

| | RH203/2 | RH203/3 | RH203/4 | RH203/5 | RH203/6 | RH203/7 |
|--------------------------------|---------|---------|---------|---------|---------|---------|
| SiO ₂ | 53.59 | 53.58 | 53.30 | 53.46 | 53.58 | 53.81 |
| Al ₂ O ₃ | 1.86 | 1.84 | 1.88 | 1.92 | 2.02 | 1.99 |
| TiO ₂ | 0.17 | 0.17 | 0.18 | 0.19 | 0.20 | 0.19 |
| Cr ₂ O ₃ | 0.35 | 0.36 | 0.29 | 0.35 | 0.36 | 0.35 |
| FeO | 4.47 | 4.40 | 4.48 | 4.44 | 4.49 | 4.33 |
| MnO | 0.13 | 0.17 | 0.14 | 0.14 | 0.14 | 0.14 |
| MgO | 16.76 | 16.77 | 16.80 | 16.69 | 16.54 | 16.52 |
| CaO | 22.12 | 22.22 | 22.00 | 22.27 | 22.24 | 22.22 |
| Na ₂ O | 0.19 | 0.15 | 0.19 | 0.24 | 0.19 | 0.22 |
| K ₂ O | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| Total | 99.64 | 99.66 | 99.26 | 99.71 | 99.76 | 99.77 |
| Ionic ratios to 6 oxygens | | | | | | |
| Si | 1.962 | 1.962 | 1.960 | 1.958 | 1.960 | 1.966 |
| Al ^{iv} | 0.038 | 0.038 | 0.040 | 0.042 | 0.040 | 0.034 |
| Al ^{vi} | 0.043 | 0.041 | 0.041 | 0.041 | 0.047 | 0.052 |
| Ti | 0.005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.005 |
| Cr | 0.010 | 0.010 | 0.008 | 0.010 | 0.010 | 0.010 |
| Fe ²⁺ | 0.137 | 0.135 | 0.138 | 0.136 | 0.137 | 0.132 |
| Mn | 0.004 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 |
| Mg | 0.915 | 0.915 | 0.921 | 0.911 | 0.902 | 0.900 |
| Ca | 0.868 | 0.872 | 0.867 | 0.874 | 0.872 | 0.870 |
| Na | 0.013 | 0.011 | 0.014 | 0.017 | 0.013 | 0.016 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| Sum X+Y | 1.994 | 1.994 | 1.997 | 1.999 | 1.992 | 1.989 |
| Cations - atomic per cent | | | | | | |
| Mg | 47.6 | 47.5 | 47.7 | 47.3 | 47.1 | 47.2 |
| Fe+Mn | 7.3 | 7.3 | 7.4 | 7.3 | 7.4 | 7.2 |
| Ca | 45.1 | 45.2 | 44.9 | 45.4 | 45.5 | 45.6 |

Table 3 (continued).

| | RM17/9 | RM17/10 | RM17/11 | RM17/1 ^m | RM17/13 ^m | RM17/14 ^m |
|--------------------------------|--------|---------|---------|---------------------|----------------------|----------------------|
| SiO ₂ | 53.33 | 53.17 | 52.74 | 54.69 | 54.57 | 54.85 |
| Al ₂ O ₃ | 1.79 | 1.65 | 1.96 | 1.21 | 1.31 | 1.00 |
| TiO ₂ | 0.23 | 0.23 | 0.21 | 0.00 | 0.00 | 0.01 |
| Cr ₂ O ₃ | 0.28 | 0.15 | 0.46 | 0.00 | 0.01 | 0.00 |
| FeO | 7.12 | 6.94 | 6.92 | 4.05 | 2.92 | 2.99 |
| MnO | 0.22 | 0.22 | 0.21 | 0.08 | 0.09 | 0.08 |
| MgO | 15.41 | 15.49 | 15.24 | 14.92 | 15.50 | 15.52 |
| CaO | 21.66 | 21.64 | 21.78 | 25.83 | 25.73 | 25.87 |
| Na ₂ O | 0.16 | 0.17 | 0.21 | 0.04 | 0.04 | 0.06 |
| K ₂ O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 100.20 | 99.66 | 99.73 | 100.82 | 100.17 | 100.38 |
| Ionic ratios to 6 oxygens | | | | | | |
| Si | 1.963 | 1.967 | 1.953 | 1.990 | 1.988 | 1.995 |
| Al ^{iv} | 0.037 | 0.033 | 0.047 | 0.010 | 0.012 | 0.005 |
| Al ^{vi} | 0.041 | 0.039 | 0.039 | 0.042 | 0.044 | 0.038 |
| Ti | 0.006 | 0.006 | 0.006 | 0.000 | 0.000 | 0.000 |
| Cr | 0.008 | 0.004 | 0.013 | 0.000 | 0.000 | 0.000 |
| Fe ²⁺ | 0.219 | 0.215 | 0.214 | 0.123 | 0.089 | 0.091 |
| Mn | 0.007 | 0.007 | 0.007 | 0.002 | 0.003 | 0.002 |
| Mg | 0.846 | 0.854 | 0.841 | 0.809 | 0.842 | 0.841 |
| Ca | 0.854 | 0.858 | 0.864 | 1.007 | 1.004 | 1.008 |
| Na | 0.011 | 0.012 | 0.015 | 0.003 | 0.003 | 0.004 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| Sum X+Y | 1.993 | 1.995 | 1.999 | 1.986 | 1.985 | 1.985 |
| Cations - atomic per cent | | | | | | |
| Mg | 43.9 | 44.2 | 43.7 | 41.7 | 43.4 | 43.3 |
| Fe+Mn | 11.7 | 11.5 | 11.5 | 6.5 | 4.7 | 4.8 |
| Ca | 44.4 | 44.4 | 44.9 | 51.9 | 51.8 | 51.9 |

Table 3. Electron microprobe analyses and structural formulae of pyroxenes from rodingite blocks in the mRange. Total iron as FeO. (^m metamorphic pyroxenes).

| | RM17/2 | RM17/3 | RM17/4 | RM17/5 | RM17/6 | RM17/7 | RM17/8 | RM17/18 ^m | RM17/19 ^m | RH228/1 | RH228/2 | RH228/3 | RH228/4 |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|----------------------|----------------------|---------|---------|---------|---------|
| SiO ₂ | 53.28 | 52.97 | 53.03 | 53.11 | 53.34 | 52.68 | 53.15 | 54.65 | 54.66 | 53.07 | 52.89 | 52.99 | 53.04 |
| Al ₂ O ₃ | 1.58 | 1.82 | 1.84 | 1.86 | 1.65 | 2.04 | 1.64 | 1.01 | 1.19 | 2.36 | 2.49 | 2.37 | 2.37 |
| TiO ₂ | 0.21 | 0.23 | 0.24 | 0.23 | 0.22 | 0.24 | 0.23 | 0.00 | 0.00 | 0.32 | 0.36 | 0.32 | 0.33 |
| Cr ₂ O ₃ | 0.18 | 0.32 | 0.17 | 0.18 | 0.22 | 0.64 | 0.24 | 0.00 | 0.01 | 0.38 | 0.46 | 0.41 | 0.38 |
| FeO | 6.93 | 6.76 | 7.02 | 7.30 | 6.97 | 7.21 | 7.06 | 3.32 | 3.74 | 4.98 | 5.01 | 5.00 | 4.98 |
| MnO | 0.21 | 0.21 | 0.20 | 0.21 | 0.21 | 0.23 | 0.19 | 0.08 | 0.07 | 0.22 | 0.18 | 0.19 | 0.19 |
| MgO | 15.60 | 15.28 | 15.49 | 15.75 | 15.53 | 15.47 | 15.52 | 15.20 | 15.03 | 16.78 | 16.71 | 16.77 | 16.75 |
| CaO | 21.77 | 21.59 | 21.50 | 21.25 | 21.61 | 21.27 | 21.52 | 25.70 | 25.73 | 21.48 | 21.53 | 21.49 | 21.46 |
| Na ₂ O | 0.16 | 0.20 | 0.19 | 0.18 | 0.20 | 0.17 | 0.17 | 0.04 | 0.03 | 0.28 | 0.29 | 0.28 | 0.29 |
| K ₂ O | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| Total | 99.92 | 99.38 | 99.69 | 100.07 | 99.95 | 99.95 | 99.72 | 100.01 | 100.46 | 99.87 | 99.92 | 99.83 | 99.79 |
| Ionic ratios to 6 oxygens | | | | | | | | | | | | | |
| Si | 1.966 | 1.964 | 1.961 | 1.958 | 1.967 | 1.947 | 1.965 | 1.997 | 1.992 | 1.943 | 1.937 | 1.941 | 1.943 |
| Al ^{iv} | 0.034 | 0.036 | 0.039 | 0.042 | 0.033 | 0.053 | 0.035 | 0.003 | 0.008 | 0.057 | 0.063 | 0.059 | 0.057 |
| Al ^{vi} | 0.035 | 0.044 | 0.042 | 0.039 | 0.039 | 0.036 | 0.037 | 0.041 | 0.043 | 0.045 | 0.044 | 0.044 | 0.045 |
| Ti | 0.006 | 0.006 | 0.007 | 0.006 | 0.006 | 0.007 | 0.006 | 0.000 | 0.000 | 0.009 | 0.010 | 0.009 | 0.009 |
| Cr | 0.005 | 0.009 | 0.005 | 0.005 | 0.006 | 0.019 | 0.007 | 0.000 | 0.000 | 0.011 | 0.013 | 0.012 | 0.011 |
| Fe ²⁺ | 0.214 | 0.210 | 0.217 | 0.225 | 0.215 | 0.223 | 0.218 | 0.101 | 0.114 | 0.152 | 0.153 | 0.153 | 0.153 |
| Mn | 0.007 | 0.007 | 0.006 | 0.007 | 0.007 | 0.007 | 0.006 | 0.002 | 0.002 | 0.007 | 0.006 | 0.006 | 0.006 |
| Mg | 0.858 | 0.844 | 0.854 | 0.865 | 0.854 | 0.852 | 0.855 | 0.828 | 0.816 | 0.916 | 0.912 | 0.916 | 0.914 |
| Ca | 0.861 | 0.858 | 0.852 | 0.839 | 0.854 | 0.842 | 0.853 | 1.006 | 1.005 | 0.843 | 0.845 | 0.844 | 0.842 |
| Na | 0.011 | 0.014 | 0.014 | 0.013 | 0.014 | 0.012 | 0.012 | 0.003 | 0.002 | 0.020 | 0.021 | 0.020 | 0.021 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| Sum X+Y | 1.997 | 1.992 | 1.996 | 1.999 | 1.995 | 1.998 | 1.995 | 1.983 | 1.983 | 2.002 | 2.003 | 2.003 | 2.001 |
| Cations - atomic per cent | | | | | | | | | | | | | |
| Mg | 44.2 | 44.0 | 44.3 | 44.7 | 44.2 | 44.3 | 44.3 | 42.7 | 42.1 | 47.7 | 47.6 | 47.7 | 47.7 |
| Fe+Mn | 11.4 | 11.3 | 11.6 | 12.0 | 11.5 | 12.0 | 11.6 | 5.4 | 6.0 | 8.3 | 8.3 | 8.3 | 8.3 |
| Ca | 44.4 | 44.7 | 44.2 | 43.3 | 44.3 | 43.8 | 44.1 | 51.9 | 51.9 | 43.9 | 44.1 | 44.0 | 44.0 |

M48

Table 4. Electron microprobe analyses and structural formulae of pyroxenes from meta-basalt blocks in the mélange. Total iron as FeO. (P phenocryst pyroxenes; K groundmass pyroxenes).

| | RH290/3 ^P | RH290/4 ^P | RH290/6 ^P | RH290/7 ^P | RH290/8 ^P | RH290/19 ^P | RH290/20 ^P |
|--------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|-----------------------|-----------------------|
| SiO ₂ | 49.09 | 50.91 | 51.05 | 48.91 | 49.65 | 50.53 | 50.10 |
| Al ₂ O ₃ | 3.72 | 1.87 | 1.86 | 3.68 | 2.91 | 3.46 | 3.50 |
| TiO ₂ | 1.76 | 1.05 | 1.30 | 1.93 | 1.66 | 1.57 | 1.57 |
| Cr ₂ O ₃ | 0.49 | 0.36 | 0.28 | 0.35 | 0.35 | 0.33 | 0.34 |
| FeO | 6.99 | 6.87 | 6.83 | 6.67 | 6.55 | 6.59 | 6.95 |
| MnO | 0.16 | 0.13 | 0.19 | 0.13 | 0.14 | 0.08 | 0.10 |
| MgO | 14.65 | 15.52 | 15.67 | 14.81 | 15.19 | 14.77 | 14.73 |
| CaO | 21.37 | 21.73 | 21.16 | 21.85 | 21.80 | 21.70 | 21.28 |
| Na ₂ O | 0.40 | 0.30 | 0.48 | 0.30 | 0.35 | 0.28 | 0.32 |
| K ₂ O | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 98.63 | 98.75 | 98.82 | 98.63 | 98.60 | 99.31 | 98.89 |

Ionic ratios to 6 oxygens

| | | | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|-------|
| Si | 1.851 | 1.913 | 1.914 | 1.844 | 1.870 | 1.883 | 1.877 |
| Al ^{iv} | 0.149 | 0.083 | 0.082 | 0.156 | 0.129 | 0.117 | 0.123 |
| Al ^{vi} | 0.017 | 0.000 | 0.000 | 0.008 | 0.000 | 0.035 | 0.032 |
| Ti | 0.050 | 0.030 | 0.037 | 0.055 | 0.047 | 0.044 | 0.044 |
| Cr | 0.015 | 0.011 | 0.008 | 0.010 | 0.010 | 0.010 | 0.010 |
| Fe ²⁺ | 0.220 | 0.216 | 0.214 | 0.210 | 0.206 | 0.205 | 0.218 |
| Mn | 0.005 | 0.004 | 0.006 | 0.004 | 0.004 | 0.003 | 0.003 |
| Mg | 0.823 | 0.869 | 0.876 | 0.832 | 0.853 | 0.820 | 0.823 |
| Ca | 0.864 | 0.875 | 0.850 | 0.883 | 0.880 | 0.866 | 0.854 |
| Na | 0.029 | 0.022 | 0.035 | 0.022 | 0.026 | 0.020 | 0.023 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 1.996 | 1.996 | 2.000 | 1.999 | 2.000 | 2.000 |
| Sum X+Y | 2.023 | 2.026 | 2.026 | 2.025 | 2.026 | 2.003 | 2.008 |

Cations - atomic per cent

| | | | | | | | |
|-------|------|------|------|------|------|------|------|
| Mg | 43.1 | 44.3 | 45.0 | 43.1 | 43.9 | 43.3 | 43.3 |
| Fe+Mn | 11.8 | 11.2 | 11.3 | 11.1 | 10.8 | 11.0 | 11.6 |
| Ca | 45.2 | 44.5 | 43.7 | 45.8 | 45.3 | 45.7 | 45.0 |

Table 4 (continued).

| | RH290/17 ^K | RH290/18 ^K | RH290/22 ^K | RH290/25 ^K | RH95/1 | RH95/2 | RH95/3 |
|--------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|--------|--------|--------|
| SiO ₂ | 46.31 | 47.87 | 51.70 | 49.20 | 48.16 | 48.82 | 50.09 |
| Al ₂ O ₃ | 6.93 | 3.04 | 3.46 | 3.53 | 3.91 | 4.33 | 3.31 |
| TiO ₂ | 3.56 | 1.72 | 1.45 | 1.48 | 2.02 | 1.99 | 1.19 |
| Cr ₂ O ₃ | 0.10 | 0.11 | 0.32 | 0.28 | 0.91 | 0.67 | 0.66 |
| FeO | 9.08 | 8.14 | 10.48 | 8.44 | 6.73 | 6.01 | 5.35 |
| MnO | 0.12 | 0.14 | 0.23 | 0.14 | 0.12 | 0.11 | 0.11 |
| MgO | 12.53 | 14.51 | 11.05 | 13.28 | 13.44 | 13.99 | 14.99 |
| CaO | 20.55 | 21.29 | 20.14 | 21.11 | 23.03 | 22.62 | 22.70 |
| Na ₂ O | 0.38 | 0.41 | 0.97 | 0.44 | 0.44 | 0.39 | 0.60 |
| K ₂ O | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| Total | 99.56 | 97.24 | 99.80 | 97.90 | 98.77 | 98.93 | 99.00 |

Ionic ratios to 6 oxygens

| | | | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|-------|
| Si | 1.746 | 1.846 | 1.938 | 1.878 | 1.826 | 1.835 | 1.873 |
| Al ^{iv} | 0.254 | 0.138 | 0.062 | 0.122 | 0.174 | 0.165 | 0.127 |
| Al ^{vi} | 0.055 | 0.000 | 0.091 | 0.037 | 0.001 | 0.026 | 0.019 |
| Ti | 0.101 | 0.050 | 0.041 | 0.042 | 0.058 | 0.056 | 0.033 |
| Cr | 0.003 | 0.003 | 0.009 | 0.008 | 0.027 | 0.020 | 0.020 |
| Fe ²⁺ | 0.286 | 0.263 | 0.329 | 0.269 | 0.213 | 0.189 | 0.167 |
| Mn | 0.004 | 0.005 | 0.007 | 0.005 | 0.004 | 0.004 | 0.003 |
| Mg | 0.704 | 0.834 | 0.617 | 0.755 | 0.760 | 0.783 | 0.836 |
| Ca | 0.830 | 0.880 | 0.809 | 0.863 | 0.936 | 0.911 | 0.910 |
| Na | 0.028 | 0.031 | 0.071 | 0.033 | 0.032 | 0.028 | 0.044 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 1.984 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| Sum X+Y | 2.011 | 2.065 | 1.975 | 2.012 | 2.031 | 2.018 | 2.032 |

Cations - atomic per cent

| | | | | | | | |
|-------|------|------|------|------|------|------|------|
| Mg | 38.6 | 42.1 | 35.0 | 39.9 | 39.7 | 41.5 | 43.6 |
| Fe+Mn | 15.9 | 13.5 | 19.1 | 14.5 | 11.4 | 10.2 | 8.9 |
| Ca | 45.5 | 44.4 | 45.9 | 45.6 | 48.9 | 48.3 | 47.5 |

RH290/21^P RH290/11^K RH290/12^K RH290/13^K RH290/14^K RH290/15^K RH290/16^K

| | RH95/4 | RH95/6 | RH95/7 | RH95/8 | RH95/10 | RH95/12 | RH95/13 |
|--------------------------------|--------|--------|--------|--------|---------|---------|---------|
| SiO ₂ | 50.66 | 49.01 | 44.71 | 50.03 | 47.86 | 50.00 | 48.85 |
| Al ₂ O ₃ | 3.72 | 4.22 | 6.97 | 2.82 | 5.18 | 3.35 | 2.89 |
| TiO ₂ | 1.70 | 2.18 | 3.57 | 1.45 | 2.59 | 1.71 | 1.57 |
| Cr ₂ O ₃ | 0.36 | 0.22 | 0.20 | 0.18 | 0.20 | 0.15 | 0.21 |
| FeO | 6.88 | 10.00 | 11.42 | 9.00 | 9.95 | 8.41 | 9.22 |
| MnO | 0.12 | 0.16 | 0.21 | 0.20 | 0.13 | 0.35 | 0.35 |
| MgO | 14.12 | 13.08 | 10.42 | 15.08 | 12.14 | 14.53 | 14.79 |
| CaO | 21.66 | 19.58 | 19.97 | 19.29 | 20.22 | 19.73 | 20.01 |
| Na ₂ O | 0.36 | 0.30 | 0.79 | 0.32 | 0.67 | 0.35 | 0.75 |
| K ₂ O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 99.58 | 98.75 | 98.26 | 98.37 | 99.01 | 98.36 | 98.64 |

Ionic ratios to 6 oxygens

| | | | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|-------|
| Si | 1.884 | 1.858 | 1.733 | 1.893 | 1.818 | 1.887 | 1.859 |
| Al ^{iv} | 0.116 | 0.142 | 0.267 | 0.107 | 0.182 | 0.113 | 0.130 |
| Al ^{vi} | 0.047 | 0.046 | 0.052 | 0.019 | 0.051 | 0.036 | 0.000 |
| Ti | 0.048 | 0.062 | 0.104 | 0.041 | 0.074 | 0.049 | 0.045 |
| Cr | 0.011 | 0.007 | 0.006 | 0.005 | 0.006 | 0.004 | 0.006 |
| Fe ²⁺ | 0.214 | 0.317 | 0.370 | 0.285 | 0.316 | 0.265 | 0.293 |
| Mn | 0.004 | 0.005 | 0.007 | 0.006 | 0.006 | 0.004 | 0.011 |
| Mg | 0.783 | 0.739 | 0.602 | 0.850 | 0.687 | 0.817 | 0.839 |
| Ca | 0.863 | 0.795 | 0.830 | 0.782 | 0.823 | 0.798 | 0.816 |
| Na | 0.026 | 0.022 | 0.059 | 0.023 | 0.049 | 0.026 | 0.055 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 1.989 |
| Sum X+Y | 1.995 | 1.994 | 2.030 | 2.012 | 2.013 | 2.000 | 2.066 |

Cations - atomic per cent

| | | | | | | | |
|-------|------|------|------|------|------|------|------|
| Mg | 42.0 | 39.8 | 33.3 | 44.2 | 37.5 | 43.4 | 42.8 |
| Fe+Mn | 11.7 | 17.4 | 20.9 | 15.1 | 17.6 | 14.3 | 15.6 |
| Ca | 46.3 | 42.8 | 45.9 | 40.7 | 44.9 | 42.3 | 41.6 |

Ionic ratios to 6 oxygens

| | | | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|-------|
| Si | 1.878 | 1.878 | 1.839 | 1.865 | 1.858 | 1.850 | 1.908 |
| Al ^{iv} | 0.122 | 0.122 | 0.161 | 0.135 | 0.142 | 0.150 | 0.092 |
| Al ^{vi} | 0.027 | 0.020 | 0.030 | 0.021 | 0.062 | 0.041 | 0.063 |
| Ti | 0.037 | 0.033 | 0.056 | 0.043 | 0.053 | 0.053 | 0.035 |
| Cr | 0.015 | 0.027 | 0.022 | 0.020 | 0.020 | 0.015 | 0.019 |
| Fe ²⁺ | 0.177 | 0.168 | 0.181 | 0.168 | 0.188 | 0.191 | 0.180 |
| Mn | 0.005 | 0.003 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 |
| Mg | 0.819 | 0.838 | 0.798 | 0.835 | 0.748 | 0.749 | 0.762 |
| Ca | 0.909 | 0.902 | 0.894 | 0.903 | 0.889 | 0.923 | 0.893 |
| Na | 0.025 | 0.026 | 0.027 | 0.023 | 0.029 | 0.035 | 0.030 |
| K | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sum Z | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| Sum X+Y | 2.015 | 2.017 | 2.012 | 2.016 | 1.992 | 2.011 | 1.985 |

Cations - atomic per cent

| | | | | | | | |
|-------|------|------|------|------|------|------|------|
| Mg | 42.9 | 43.8 | 42.5 | 43.7 | 40.9 | 40.2 | 41.4 |
| Fe+Mn | 9.5 | 9.0 | 9.9 | 9.0 | 10.5 | 10.4 | 10.0 |
| Ca | 47.6 | 47.2 | 47.6 | 47.3 | 48.6 | 49.4 | 48.6 |