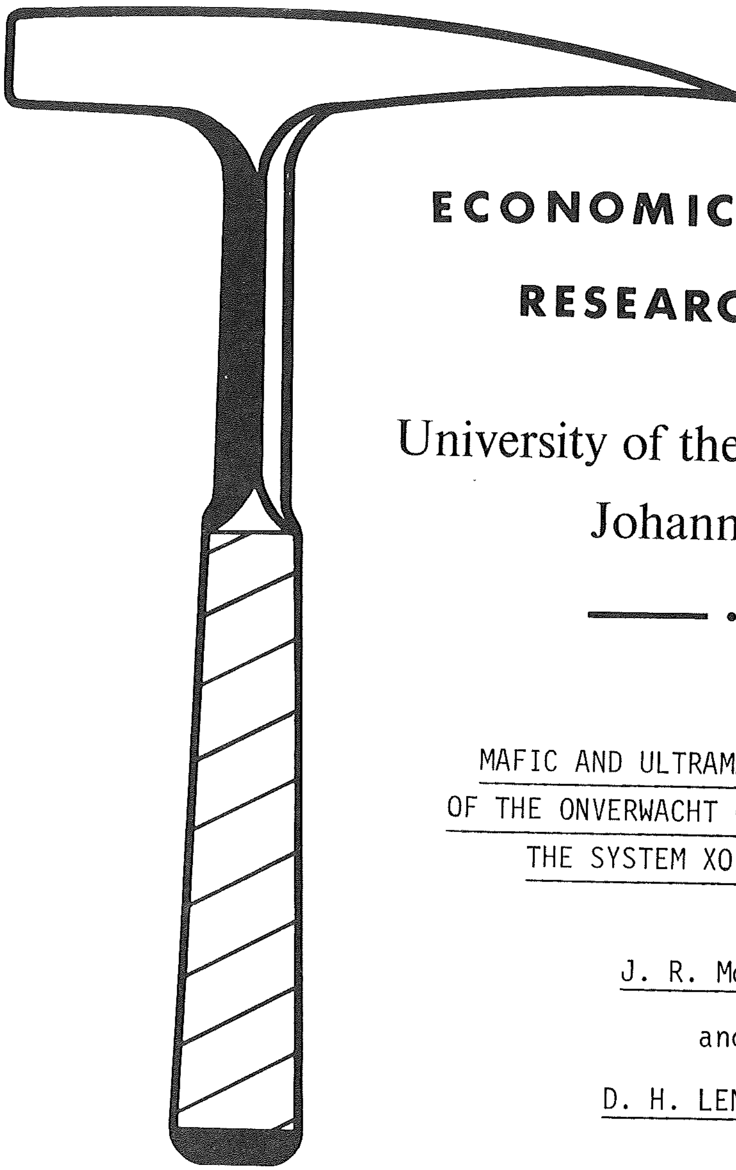

ECONOMIC GEOLOGY RESEARCH UNIT

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MAFIC AND ULTRAMAFIC EXTRUSIVES OF THE ONVERWACHT GROUP IN TERMS OF THE SYSTEM $XO-YO-R_2O_3-ZO_2$

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INFORMATION CIRCULAR No. 80

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ABSTRACT

Evolutionary trends among the mafic and ultramafic extrusives of the Onverwacht Group are revealed in subprojections within the $XO-YO-R_2O_3-ZO_2$ tetrahedron. The parental magma of the Onverwacht Group had a composition close to that of the ultramafic rocks occurring at the base of the pile. Polybaric olivine and orthopyroxene fractionation were important in controlling the development of mafic and ultramafic komatiite extrusives and associated tholeiitic basalts occurring at stratigraphically higher levels.

The development of the parental magma is satisfactorily accounted for by partial melting of a four phase peridotite mantle at depths of 90-100 km or more. The accumulation and preservation of 15000 m of mantle derived material requires the presence of a pre-Onverwacht floor. Attention is drawn to the presence of nepheline normative extrusives in the upper formations of the Onverwacht Group.

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MAFIC AND ULTRAMAFIC EXTRUSIVES OF THE ONVERWACHT GROUP IN TERMS OF THE SYSTEM $XO-YO-R_2O_3-ZO_2$

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INTRODUCTION

Viljoen and Viljoen (1969, a-h) have detailed the geology and geochemistry of the mafic and ultramafic volcanic rocks of the Barberton Mountain Land, and, as a result of their studies, were able to recognise, mainly on the grounds of chemical composition, several major classes of extrusive rocks within the Onverwacht volcanic pile. These include : (i) extrusives of ultramafic nature (ultramafic komatiites); (ii) high-magnesian basalts characterised by high Ca/Al ratios, which are divided into three groups designated the Barberton-, Badplaas-, and Geluk-type basaltic komatiites; and (iii) tholeiitic-type basalts. Within the Onverwacht pile, the above extrusives alternate with less abundant felsic volcanic materials and sediments. However, if only the mafic and ultramafic rock types are considered, it has been shown (Viljoen and Viljoen, 1969c, Figure 3; 1969e, p. 114) that, while all types of extrusive alternate with one another throughout the pile, ultramafic and basaltic komatiites are more abundant in the lower (Sandspruit, Theespruit, and Komati) formations and tholeiitic-type basalts predominate in the upper (Hooggenoeg, Kromberg, and Swartkoppie) formations.

Features which invite comment and which may be important in unravelling the genetic relationships among the Onverwacht extrusives include the following (Viljoen and Viljoen, 1969c; 1969e) : (a) the occurrence of more magnesia-rich ultramafic komatiites in the stratigraphically higher Komati, Hooggenoeg, and Kromberg formations compared with those of the lowermost Sandspruit formation; (b) the greater development of the most magnesian type of basaltic komatiite (Geluk-type) at higher stratigraphic levels than the less magnesian Barberton- and Badplaas-types; (c) the volumetric decrease in the amount of extrusive material in the upper portion of the pile compared with the lower; (d) the high Ca/Al ratios of the ultramafic and komatiite-type basalts; (e) the higher Ca/Al ratios of the lowermost (Sandspruit) ultramafic extrusives compared with those of the overlying Komati, Hooggenoeg, and Kromberg formations; and (f) the departure of the komatiite sequence from the evolutionary trend of other ultramafic-mafic series, as evidenced by their $MgO-CaO-Al_2O_3$ ratios.

Consideration of the mafic and ultramafic extrusives of the Onverwacht group in terms of the system $XO-YO-R_2O_3-ZO_2$ reveals as yet unrecognised evolutionary trends and throws new light on the possible origins and relationships of the ultramafic and basaltic komatiites.

THE SYSTEM $XO-YO-R_2O_3-ZO_2$

A. General

The problem of the graphical representation of phase relations in complex basalt systems has been considered by O'Hara (1968a) and Jamieson (1969, 1970). O'Hara has devised a scheme in which the oxides of basic rocks are expressed in terms of four components. Jamieson (1969) suggested that the four components be re-labelled XO, YO, R_2O_3, and ZO_2 instead of C, M, A, and S, as originally proposed by O'Hara (1968a), to enable a distinction to be made between natural and synthetic systems to which the latter nomenclature is applied. If the four components are taken as representing the corners of a tetrahedron, it is possible to project the position of a point (rock analysis) within the tetrahedron into any of a number of planes cutting the tetrahedron. Study of the positions of analysed rocks, together with the positions of experimentally determined phase boundaries in selected projection planes, permits a description and prediction of the crystallisation paths of analysed basaltic rocks.

The rules for the construction of the projections are given by O'Hara (1968a). Figure 1 illustrated the positions of the subprojection planes within the tetrahedron as employed in the present discussion. Phase boundary curves and the positions of the ternary pseudo-invariant points are after O'Hara (1968a) and Jamieson (1970).

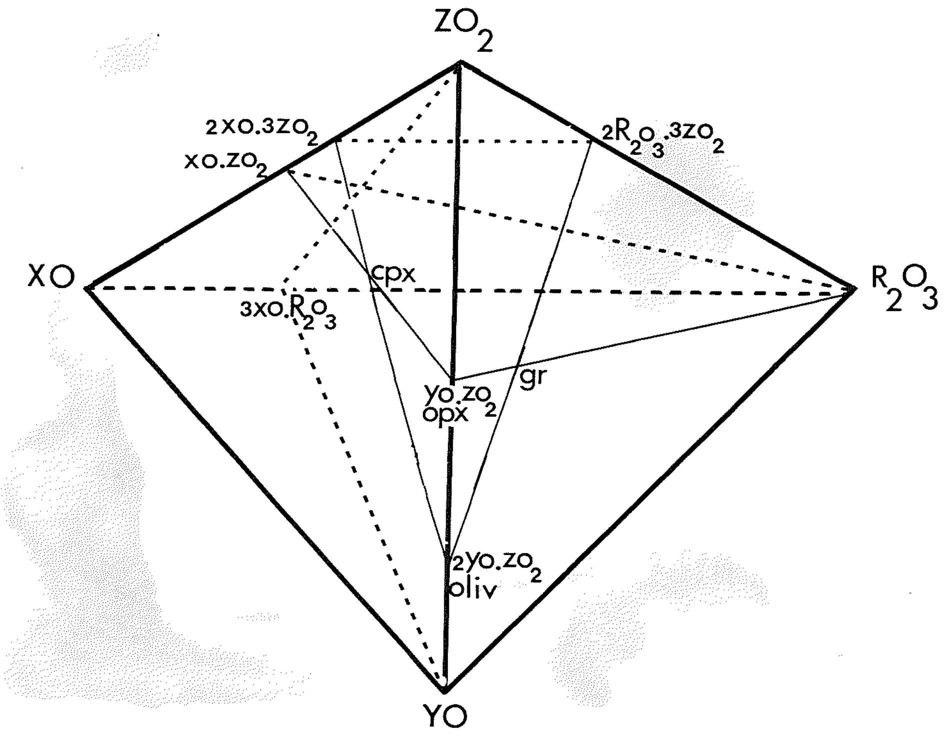

Figure 1 : Projection Planes in the Tetrahedron $XO-YO-R_2O_3-ZO_2$.

XO = (mol. prop. $Ca-3\ 1/3P_2O_5+2Na_2O+2K_2O$)X56.08

YO = (mol. prop. $FeO+MnO+NiO+TiO_2$)X40.31

R_2O_3 = (mol. prop. $Al_2O_3+Cr_2O_3+Fe_2O_3+Na_2O+K_2O-TiO_2$)X101.96

ZO_2 = (mol. prop. $SiO_2-2Na_2O-2K_2O$)X60.09

B. Clinopyroxene Projection

Figure 2 is a projection from, or towards, clinopyroxene into the plane $3XO.R_2O_3-YO-ZO_2$. The ultramafic komatiites of the Onverwacht sequence plot within the primary phase volumes of olivine at 30kb. and lie along a well-defined olivine control line that passes close to the projected compositions of garnet lherzolites which have been proposed as being representative of mantle compositions in depth (O'Hara, 1968a; 1970). Away from the olivine point the control line passes into the field occupied by the Badplaas komatiites which, together with the Barberton and Geluk komatiites, lie in the primary phase volume of orthopyroxene at pressures of 30kb. and less, and close to a control line linking their composition fields to the orthopyroxene point. Most of the metatholeiites cluster close to the ternary pseudo-invariant point applicable to 5 kb. pressure.

C. Olivine Projection

Figure 3 is a projection from, or towards, olivine into the plane $XO.ZO_2-YO.ZO_2-R_2O_3$. The ultramafic rocks lie on, or close to, a control line passing through the orthopyroxene point and the projection positions of the garnet lherzolites. Attention is drawn to the fact that the apparent position of the Onverwacht ultramafics within the primary phase volume of orthopyroxene is a feature of this projection. Both Figures 2 and 4 show that these points lie within the primary phase volume of olivine, from which point this projection plane is viewed. The remainder of the analyses show a radial displacement away from the orthopyroxene point, with the metatholeiites and Barberton komatiites closely approaching the low-pressure phase boundaries established by Jamieson (1970) for Hawaiian tholeiites. In Figure 3 the displacement away from the orthopyroxene point is somewhat exaggerated by distortion effects inherent in this projection.

D. Orthopyroxene Projection

Figure 4 is a projection from, or towards, orthopyroxene into the plane $2XO.3ZO_2$-$YO.ZO_2$-$2R_2O_3.3ZO_2$. The projected points all show progressive displacement away from the olivine point. The ultramafic komatiites lie within the primary phase volume of olivine at, or above, 30kb., while the majority of the remaining points appear to lie within the olivine volume only at pressures less than 10kb. The close agreement of the ultramafic komatiites with the line drawn through the garnet lherzolite composition is again apparent.

POSSIBLE GENETIC RELATIONSHIPS OF THE ONVERWACHT MAFIC AND ULTRAMAFIC EXTRUSIVES

A. Ultramafics

The locus of liquid compositions derived from the melting of four-phase peridotite (clinopyroxene, garnet, orthopyroxene, olivine) has been depicted by O'Hara (1968a; 1970) and it is apparent that the path of evolution and composition of such a liquid in progressive melting is controlled by the composition of the parent material, the degree of melting, and the pressure at which melting takes place. For example, in Figure 3, in which the plane of projection is viewed "from below" from the olivine point, the first liquid to form from a garnet lherzolite at 30kb. will have the composition represented by the ternary pseudo-invariant point at 30kb. The composition of this liquid will remain at the ternary pseudo-invariant point until one of the phases of the peridotite is exhausted. If the composition of the starting material lies to the alumina-rich side of the line joining the pseudo-invariant point to the orthopyroxene point (as in the case of garnet lherzolite), the first phase to disappear is clinopyroxene. The liquid then migrates along the garnet-orthopyroxene phase boundary until garnet disappears at a point determined by the intersection of the garnet-orthopyroxene phase boundary and a line through the composition of the starting material to the orthopyroxene point.

After the disappearance of garnet, the liquid advances along the latter line which is situated on the phase boundary between orthopyroxene and olivine. Once the liquid reaches the projected position of the starting material, its behaviour can no longer be followed in Figure 3, as at this point orthopyroxene is used up and, with further melting, the liquid advances towards the olivine projection point, becoming richer in olivine until the composition of the starting material is reached. The behaviour of the liquid may be studied in similar fashion for various pressures in Figures 2 and 4, bearing in mind the orientation of the projection plane. From the foregoing, it is apparent that any liquid formed by partial melting of olivine-rich mantle material must be in equilibrium with olivine at its pressure of formation (O'Hara, 1968a).

In all three projections (Figures 2, 3, and 4), the Onverwacht ultramafic komatiites lie on, or near, control lines passing through the points representing garnet lherzolite compositions. Moreover, the ultramafic komatiites project within the primary phase volume of olivine at pressures of 30kb. (or above). They, therefore, fulfil the requirements for the composition of magma derived from advanced partial melting of garnet lherzolite at depths of 90-100 km (or more). If this is accepted, then it follows that there is a strong likelihood for the presence of a mantle not dissimilar to present-day postulates, more than 3,200 m.y. ago (Allsopp and others, 1962).

Viljoen and Viljoen (1969c; 1969e) noted the more magnesian character of the stratigraphically higher ultramafic komatiites of the Komati, Hooggenoeg, and Kromberg formations, as compared with the Sandspruit ultramafic komatiites at the base of the Onverwacht pile. In Figure 2, the more magnesian nature of the Komati, Hooggenoeg, and Kromberg ultramafic komatiites is clearly displayed

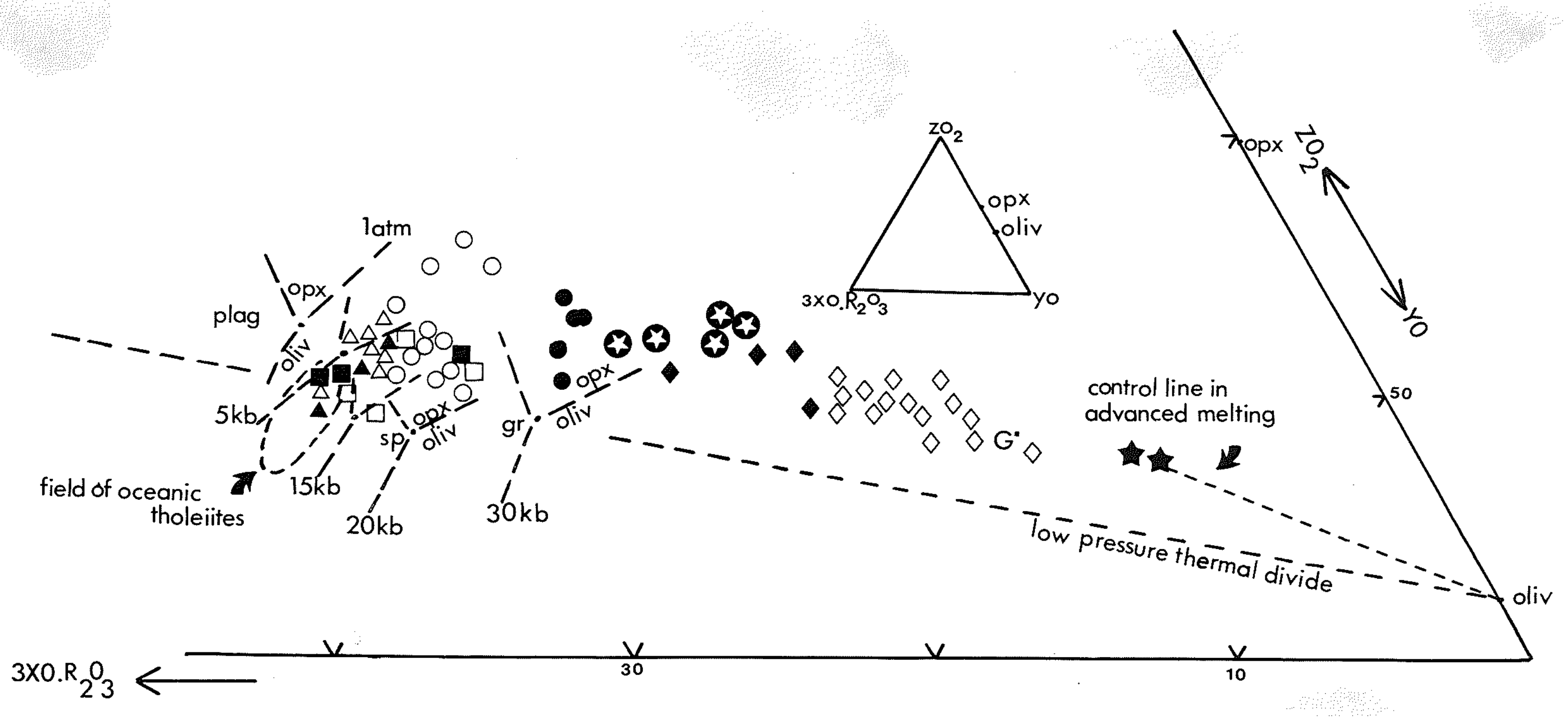

Figure 2 : Projection from, or towards, clinopyroxene into the plane $3XO.R_2O_3$-YO-ZO_2. Ornamentation is as follows : filled stars, garnet lherzolite in kimberlite and average garnet lherzolite in kimberlite (Ito and Kennedy, 1967; Cohen and others, 1967); open diamonds, ultramafic komatiites from Komati, Hooggenoeg, and Kromberg formations (Viljoen and Viljoen, 1969d, e, pp. 92, 148); filled diamonds, ultramafic komatiites from Sandspruit formation (Viljoen and Viljoen, 1969c, p. 72); circled stars, basaltic komatiites, Geluk-type (Viljoen and Viljoen, 1969c, p. 76); filled circles, basaltic komatiites, Badplaas-type (Viljoen and Viljoen, 1969c, p. 75); open circles, basaltic komatiites, Barberton-type (Viljoen and Viljoen, 1969c, p. 74); open triangles, metatholeiites, lower Onverwacht (Viljoen and Viljoen, 1969c, p. 78); filled triangles, metatholeiites, Hooggenoeg formation (Viljoen and Viljoen, 1969e, p. 142); open squares, metabasalts, Hooggenoeg formation (Viljoen and Viljoen, 1969e, p. 144); filled squares, metabasalts, Kromberg formation (Viljoen and Viljoen, 1969e, p. 146); point labelled G, peridotitic komatiite (Green, 1972). Field of oceanic tholeiites after O'Hara (1968b). Phase boundaries are after O'Hara (1968a, Figures 4-6) and Jamieson (1970). Clustering of projected analyses in the low-pressure region prevents use of all available analyses. Abbreviations used : cpx.-clinopyroxene, opx.-orthopyroxene, oliv.-olivine, gr.-garnet, sp.-spinel, plag.-plagioclase.

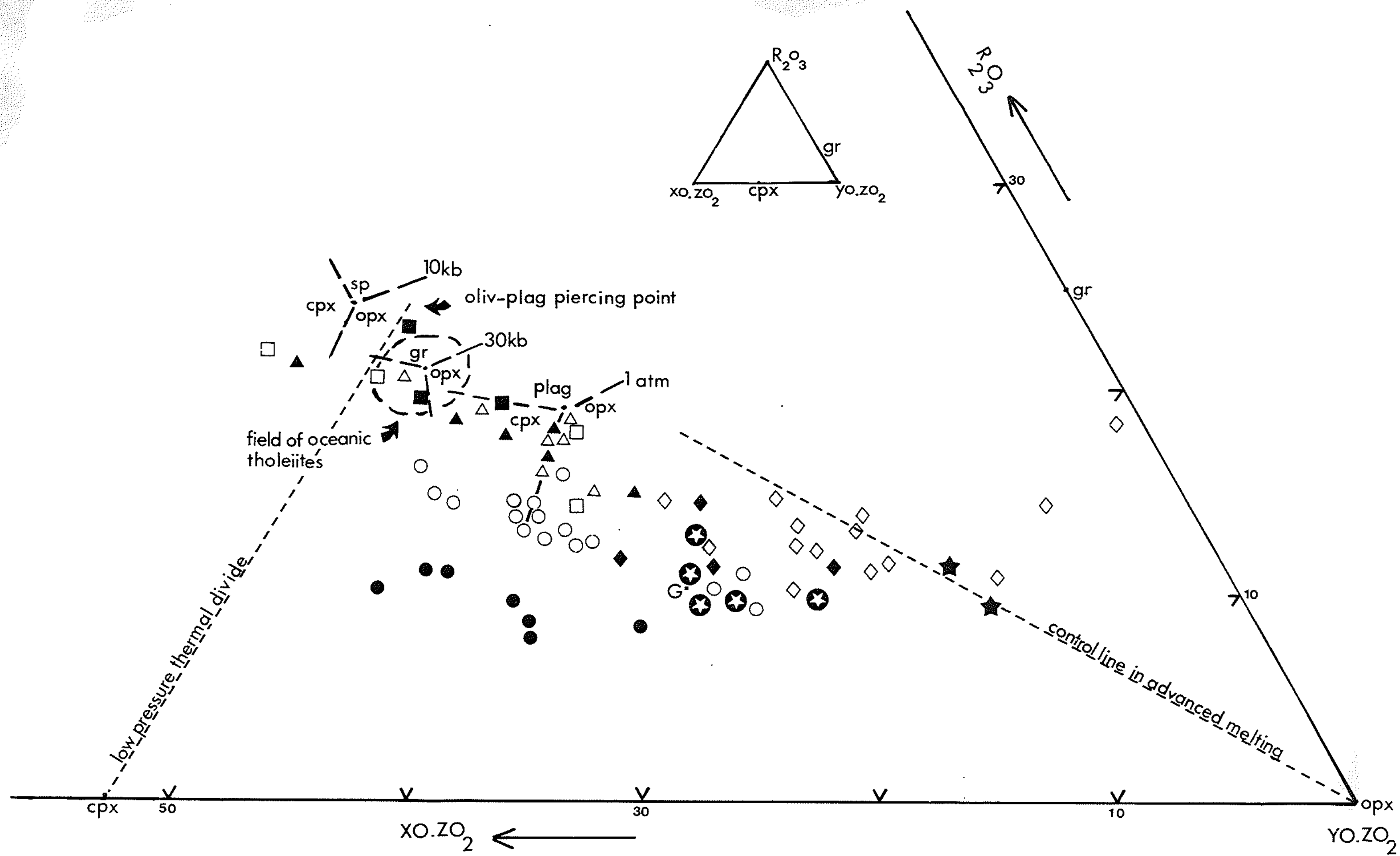

Figure 3 : Projection from, or towards, olivine into the plane $XO.ZO_2$-$YO.ZO_2$-R_2O_3. Ornamentation as for Figure 2.

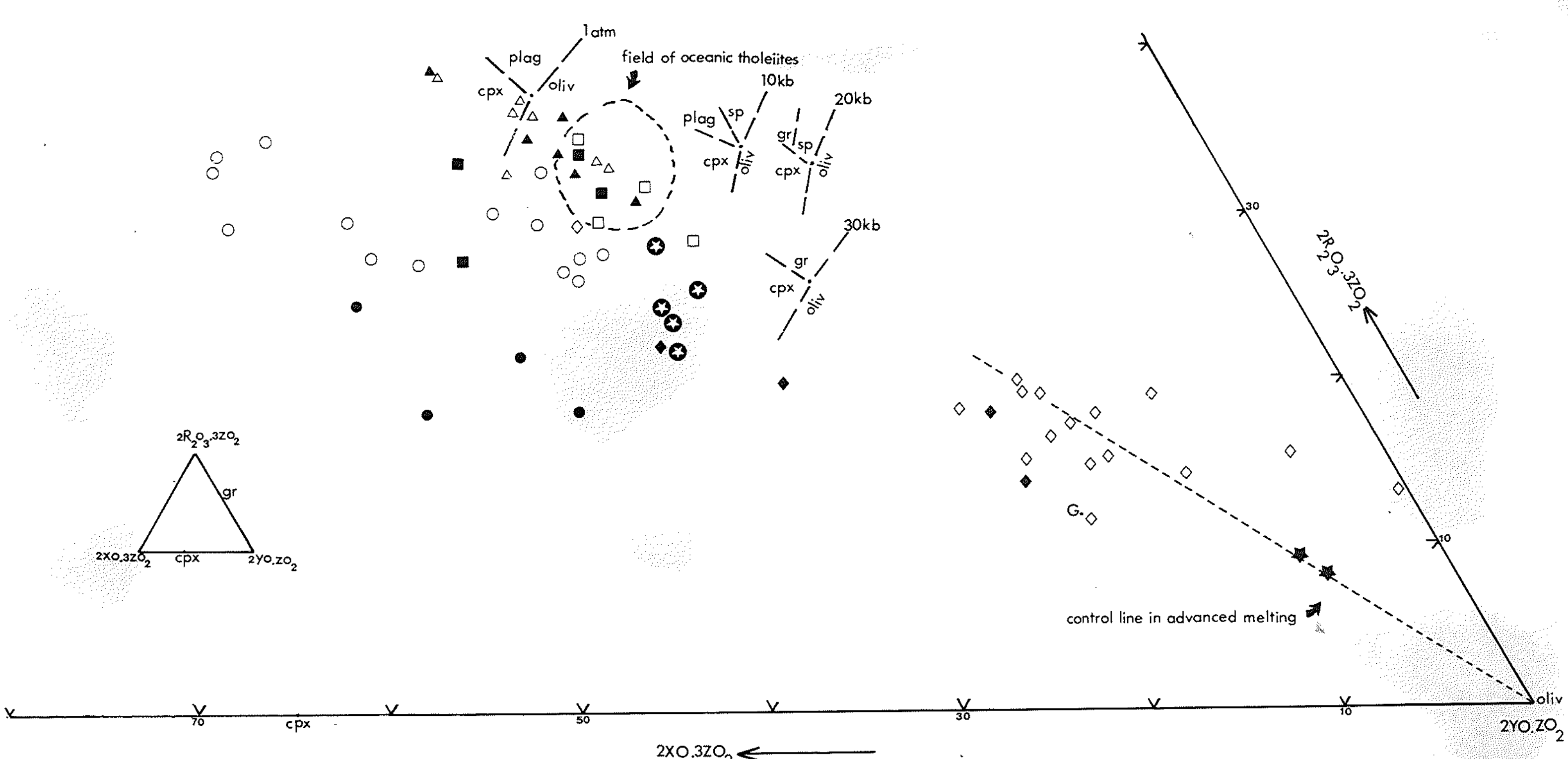

Figure 4 : Projection from, or towards, orthopyroxene into the plane $2(XO).3ZO_2$-$2(R_2O_3).3ZO_2$-$YO.ZO_2$. Ornamentation as for Figure 2.

by their position closer to the olivine point, relative to the Sandspruit ultramafic komatiites. This distribution, coupled with the stratigraphic relationships, is indicative of the initial development and eruption of a magma having a composition falling within the field covered by the Sandspruit rocks. Enrichment of portions of this magma by settled olivine from ascending material of similar composition would give rise to compositions projecting in the field of the Komati, Hooggenoeg, and Kromberg ultramafic komatiites which, on eruption, would, of necessity, occupy a stratigraphically higher position than the initial Sandspruit ultramafic komatiites. In this respect, the abundance of euhedral olivine microphenocrysts characteristic of the stratigraphically higher ultramafic komatiites illustrated by Viljoen and Viljoen (1969d, pl. IVa, VIIa; 1969e, pl. XIIa) is significant.

From experimental considerations Green (1972) has concluded that the extrusion temperature of an Onverwacht 'peridotitic komatiite' (Green, 1972, Table 1, No. 7) was in the range 1600-1650°C. In Figures 2, 3, and 4 this rock shows close agreement with the positions of the ultramafic komatiites occurring above those of the Sandspruit Formation. It is, therefore, similar to ultramafic rocks which are believed to have been enriched in olivine by crystal settling at depth and which reached surface in the form of a magma carrying olivine phenocrysts or microphenocrysts.

The appearance of ultramafics having the compositions indicated in Figures 2, 3, and 4 at the surface requires very rapid upward movement of the melt. Problems associated with such movement are, as yet, not understood, but the situation is not unique to the Onverwacht sequence in that Clarke (1970) has found that the basalts at the base of certain flows in Greenland have compositions entirely compatible with their having been derived as primary undifferentiated melts of the mantle at depths of 90-100 km (30kb.).

B. Komatiites

A melt plotting in the Sandspruit ultramafic komatiite field of Figure 2 would, on slow ascent, at first crystallise only olivine, due to the expansion of the primary phase volume of olivine with falling pressure (O'Hara, 1968a). Subtraction of early olivine gives rise to compositions progressively displaced from the olivine point, and reference to Figure 2 shows that the composition field of the Badplaas komatiites lies on the extension of such a control line and that, at approximately 30kb., the control line strikes the phase boundary of olivine and orthopyroxene, at which stage olivine is joined by orthopyroxene on the liquidus. Attention has already been drawn to the control line linking the basaltic komatiites to the orthopyroxene point, and it would appear that the subtraction of both orthopyroxene and olivine from Sandspruit-type magma is responsible for the change to the composition of the Badplaas komatiite. It is considered very likely that the composition of the appropriate melt remained on, or close to, the olivine-orthopyroxene phase boundary during the movement of the latter away from the olivine point with decrease in pressure during ascent. Fractionation of orthopyroxene and olivine from Badplaas komatiite compositions would give rise to residual liquids displaced into the field of the Barberton komatiites, while the material enriched in the fractionated products would be displaced into the field of the more magnesian Geluk komatiites. Significantly, the Geluk komatiites attain their maximum development stratigraphically above the Barberton and Badplaas komatiites, and contain an average of 42 percent normative hypersthene, compared to 24 and 28 percent for the Barberton and Badplaas komatiites, respectively.

In Figure 3, the radial displacement of the basaltic komatiites away from the orthopyroxene point, but unassociated with the melting control line, is again indicative of the fractionation of this mineral in the basaltic komatiite sequence, and suggests derivation from melts formed at pressures in excess of 40kb. (O'Hara, 1970, p. 241, Figure 5). Seen from the orthopyroxene point, the trends are not displayed, and Figure 4 is of limited use in examining the komatiite sequence.

From the foregoing, it is apparent that the basaltic komatiites are not in equilibrium with olivine at the same pressures at which the ultramafic komatiites show this relationship. It is therefore not possible for the basaltic komatiites to represent unmodified partial melts of the mantle at 90-100 km or more. It is possible that the Badplaas komatiites could represent unmodified partial melts at pressures between 20 and 30kb., but this hypothesis ignores the clear evolutionary trend linking the ultramafic and basaltic komatiites.

At this stage, it is tempting to try to find an explanation for the much discussed high Ca/Al ratios of the basaltic komatiites and associated ultramafics. As discussed earlier, fractionation is dominated by olivine and orthopyroxene in the initial stages, and, while the latter mineral is aluminous at elevated pressure, consideration of its fractionation would not affect the Ca/Al ratios of the ultramafic komatiites. A more attractive approach would seem to seek a mechanism which would set its stamp on the ultramafics in such a way that they and their derivatives would retain this characteristic. Garnet fractionation at depth would appear to provide a possible mechanism whereby alumina could be abstracted from a melt of Sandspruit-type. O'Hara (1968b, p. 684) has indicated that, at pressures in excess of 30kb., the ternary pseudo-invariant point of Figure 2 will probably move from its indicated position towards the olivine-orthopyroxene join. If this is the case, a magma in the Sandspruit field may come into contact, perhaps briefly, with the olivine-garnet phase boundary at some elevated pressure. Crystallisation of garnet would increase the Ca/Al ratio of the melt, and, as no Ca-bearing phases appear to be important until the tholeiitic compositions are reached, this ratio would be identifiable throughout the ultramafic and basaltic komatiite sequence. Olivine accumulation is believed to have been important in the development of the ultramafic komatiites of the Komati, Hooggenoeg, and Kromberg formations, and the accumulation of garnet must therefore be equally important. While possibly having lost garnet in the same way as the Sandspruit magmas, the overlying ultramafics would also have become recipients at depth for garnet derived from the Sandspruit melts, and, in this respect, it is interesting to note that the Ca/Al ratios of the stratigraphically higher ultramafic komatiites are lower than those of the Sandspruit rocks (Viljoen and Viljoen, 1969c). Garnet fractionation may therefore be the reason for the trend shown by the komatiite sequence in the CaO-Al_2O_3-MgO plot of Viljoen and Viljoen (1969c, Figure 4b).

C. Metatholeiites

Consideration of the projection fields of metatholeiites and metabasalts (Viljoen and Viljoen, 1969e) in Figures 2 and 3 shows that considerable overlap occurs between these rocks and some Barberton-type komatiites. Figure 2 shows that the metatholeiites and metabasalts approach the 5kb. ternary pseudo-invariant point along a control line indicating the importance of orthopyroxene fractionation in their evolution. Figure 3 reveals that many of the metatholeiites, metabasalts, and Barberton-type komatiites approach the cotectic curve between orthopyroxene and clinopyroxene, while a lesser number plot close to the clinopyroxene-plagioclase boundary. The latter basalts would be expected to show the appearance of olivine followed by clinopyroxene and plagioclase, while the former would show the sequence olivine, orthopyroxene, clinopyroxene, with plagioclase possibly appearing in compositions close to the pseudo-invariant point. Destruction of the primary mineral assemblages of the Onverwacht rock-types by low-grade metamorphism, however, precludes the confirmation of the foregoing by thin-section analysis. The position of the points relative to the low-pressure cotectic curves appears to have been controlled by the amount of orthopyroxene fractionation during ascent, which is, in turn, a feature of the rate of rise of the melt. As a result of lack of experimental data on the Onverwacht rocks, the atmospheric pressure pseudo-invariant points employed are those determined for Hawaiian lavas (Jamieson, 1970), and this may account for the pressure discrepancy evidenced between Figures 2 and 3. However, there appears to be little doubt that the metatholeiites, metabasalts, and some Barberton-type komatiites closely approach cotectic equilibrium involving three phases at low pressure. These extrusives could have attained this condition by melting of four-phase peridotite at depths where pressures approximated 5kb. (15 km) or less. Alternatively, the basalts could have attained their low-pressure compositions via a defined path involving continuous modification of a deep-seated melt by polybaric crystallisation of appropriate phases followed by equilibration in shallow magma chambers prior to eruption. The second alternative is preferred, as the first must, of necessity, ignore the rock-types associated with the metatholeiites and metabasalts in the Onverwacht pile. The smaller volume of the metatholeiites and metabasalts (Viljoen and Viljoen, 1969e), compared with that of the komatiites and ultramafics, is an additional indication of the second alternative.

D. Nepheline Normative Basalts

While the bulk of the Onverwacht basaltic lavas have, in the past, been considered to be tholeiitic in nature, attention is drawn to the analyses which plot to the nepheline normative side of the low-pressure thermal divide or plane of critical undersaturation (Yoder and Tilley, 1962) in Figures 2 and 3. These rocks, which are grouped by Viljoen and Viljoen (1969, p. 142, Table I, No. 3; p. 144, Table II, No. 4) with metatholeiites and Mg-rich metabasalts of the Hooggenoeg formation, show 1.20 and 2.19 percent Ne in the norm, respectively. According to the classification scheme of Irvine and Baragar (1971), the rock with 1.2 percent normative nepheline qualifies for classification as a hawaiite, while the other falls within the alkali basalt field.

While it appears possible from Figure 2 that orthopyroxene fractionation was mainly responsible for carrying these compositions over the olivine gabbro thermal divide, the influence of amphibole fractionation (Yoder and Tilley, 1962) should probably not be entirely ignored. For orthopyroxene fractionation to have been effective fractionation must have taken place at pressures above 8kb., as below this pressure it does not appear possible to breach the thermal divide by simple orthopyroxene fractionation (O'Hara, 1968a, p. 71). It is suggested that more detailed sampling may reveal the presence of additional rocks having alkaline affinities in what has up to now been regarded as a tholeiitic pile.

E. Basaltic Komatiites and Oceanic Tholeiites

Both basaltic komatiites and oceanic tholeiites have had the adjective 'primitive' applied to them (Engel and others, 1965; Viljoen and Viljoen, 1969h, p. 245; and Gale, 1972, p. 26). It is therefore of interest to compare the projection fields of oceanic tholeiites (O'Hara, 1968b) and Badplaas-type komatiites which appear to be 'parental' to the basaltic komatiite sequence. In Figures 2 and 3, the two groups show no correspondence with one another. Both groups, however, share the characteristic of being evolved magmas (O'Hara, 1968b), as neither could represent unmodified mantle melts, except at shallow depths in the case of oceanic tholeiites. O'Hara (1968b) has reviewed this problem and concluded that the oceanic tholeiites evolved from a mantle melt which precipitated olivine only during ascent. In Figure 2, the difference in position between a control line linking the field of oceanic tholeiites to the olivine point is removed from a similar control line passing through the Badplaas komatiite field. If melting commenced at 30kb., the difference in position of the two olivine control lines would be accounted for by a greater degree of partial melting of mantle material to produce the komatiite trend. Alternatively, the komatiite trend could possibly have originated from a more limited melt at greater depth. Considerations based on trace element chemistry have led Gale (1972) to generally similar conclusions. It is, however, suggested that the term 'primitive' be dropped from descriptions of these rocks, as both originated from evolved magmas. In the Onverwacht pile, the only truly 'primitive' magma gave rise to the lowermost Sandspruit ultramafic rocks.

SUMMARY AND CONCLUSIONS

1. Ultramafic extrusives in the Onverwacht pile have compositions consistent with their derivation as advanced partial melts of four-phase peridotite at depths of 90-100 km or more.

2. Extrusives of basaltic komatiite type do not represent direct partial melts of the mantle, but appear to have developed as a result of olivine and orthopyroxene fractionation from magmas of similar composition to those of the Sandspruit ultramafic komatiites. Basaltic komatiites, therefore, formed from an evolved magma, the nature of which was determined by depth of melting and degree of melting of parent material.

3. Orthopyroxene and olivine fractionation controlled the evolution trend of the basaltic komatiite sequence which terminated with the development of tholeiitic basalts.

4. The Onverwacht volcanic pile was built by successive eruptions of magmas to which the Sandspruit ultramafic type was parental. The nature of the erupted material depended on depth from which eruption occurred and rate of rise towards the surface.

5. The accumulation and preservation of some 15000 m (Viljoen and Viljoen, 1969c) of mantle derived volcanics in the Onverwacht pile appears to require the presence of a pre-Onverwacht floor.

6. The occurrence of more magnesia-rich extrusives stratigraphically above less magnesian rocks of similar type appears to be related to crystal settling effects in depth.

7. The reason for the Ca/Al ratios of the extrusive ultramafic and basaltic komatiites can possibly be sought in garnet fractionation at elevated pressures.

8. The extrusives of the Onverwacht pile show evolutionary paths consistent with derivation from a four-phase peridotite mantle +3,200 m.y. ago. There would thus appear to be no reason to expect rocks of komatiite type to be confined to early stages in the earth's history as suggested by Viljoen and Viljoen (1969c). Attention has been drawn to relatively young rocks of basaltic komatiite composition by Gale (1972) and McIver (1972).

9. Attention is drawn to the presence of nepheline normative extrusives in the Onverwacht sequence.

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