SOME ASPECTS OF THE MINERAL CHEMISTRY AND PETROLOGY OF THE GARNETIFEROUS ULTRAMAFIC XENOLITHS IN THE KIMBERLITES OF SOUTHERN AFRICA

by

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CONTENTS

SUMMARY

This thesis is concerned with the mineralogy and petrology of the ultramafic xenoliths that occur in kimberlite and which are believed to have been derived from the Upper Mantle of the Earth. For purely geographical reasons, it has been necessary to confine experimental studies to samples obtained from the kimberlites of Southern Africa, but it is duly recognised that similar materials occur in the U.S.S.R.

The mineral chemistry of these rocks has been the main object of study, and of the many phases that occur, particular attention has been paid to the garnets. In consequence, the garnetiferous xenoliths have been more closely studied than non-garnetiferous ultramafic nodules.

The main contributions of the candidate are :-

1) The compilation of the occurrences of all known types of ultramafic xenoliths in the kimberlites of Southern Africa, and recognition of the association between these rock types.
2) Equations for checking the compatibility of mineral analyses with analyses of their host rocks have been formulated, and used to demonstrate that garnets are very frequently chemically heterogeneous.
3) A scheme for recalculation of analyses of garnet into end-member molecules has been devised, the aim of which has been to allocate the maximum percentage of cations to garnet molecules.

4)/.....

4) The chemistry of garnets from a very large number and variety of ultramafic xenoliths has been investigated. The compatibility of the results with the current hypotheses of the nature of the Upper Mantle and genesis of ultramafic xenoliths has been considered, and inconsistencies have been noted.

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My colleagues, Mr. G.W. BERG, Mr. A.J. ERLANK, Dr. J.J. GURNEY, Dr. M. MATHIAS, and Mr. J.C. SIEBERT have provided specific assistance, which has been acknowledged separately. However, I would here like to thank them all for their cooperation and stimulating conversation.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

(a) HISTORICAL SURVEY

For many decades geologists have believed that the problems of the origin of basalt and the nature of the Upper Mantle are intimately related. Whilst great volumes of basalt are amenable to examination at the earth's surface, and have been extensively studied, e.g. POLDERVAART and HESS (1968), material from the Upper Mantle is rare. It is not surprising, therefore, that much information about that zone of the Earth has had to be obtained indirectly through geophysical measurements and high-pressure geochemical experiments. These studies have indicated that the composition of the Upper Mantle is ultrabasic, and that its mineralogy is like that of the xenoliths that occur in a number of basic and ultrabasic rocks. The pressure that is necessary for the formation of diamond can only occur in the Upper Mantle and deeper earth zones, unless one postulates the existence of places of over-pressure as could eventuate when shock waves are operative, DAVIDSON (1967b). Thus the ultramafic xenoliths that occur in kimberlite in association with diamond are those most likely to have come from the Upper Mantle.

Possibly the earliest description of an ultramafic xenolith in kimberlite was that of COHEN (1879), who described a kyanite-eclogite from Jagersfontein Mine, O.F.S. in a paper professing that his ideas on the origin of diamond had been plagiarised. BONNEY and RAISIN (1891) (1895) much later published descriptions of samples collected from Kimberley, and STELZNER (1893), BONNEY (1897) and LACROIX (1898) subsequently described specimens from NEWLANDS, C.P., DE BEERS, C.P. and MONASTERY, O.F.S., mines respectively. Little interest in these rocks seems to have been raised until BONNEY (1899a, b, c) announced the discovery of a diamond-bearing eclogite at NEWLANDS MINE, C.P., which was rapidly followed by a second discovery published by BECK (1899).

In the next decade considerable attention was paid to the description of existing diamond mines, e.g. WILLIAMS (1902), GRAICHEN (1903), KYNASTON and HALL (1904) HARGER (1905), and to exploration for new kimberlite occurrences. Much of the latter was carried out by the Geological Commission of the Cape of Good Hope as part of the routine geological survey of that province. The most active geologist in this field was A.L. DU TOIT, whose various reports, (1906)(1907)(1908)(1913) and ROGERS and DU TOIT (1909), contained much information about the ultrabasic xenoliths located in kimberlite occurrences, which were subsequently ignored until this present study was undertaken.

Most papers published in the first decade of the 20th Century, which dealt with ultramafic xenoliths, concentrated on the various types of eclogite, e.g. BECK (1906)(1907), JOHNSON (1907)(1908)(1910), SCHWARZ (1907), CORSTORPHINE (1908)(1911), MENNELL (1908), and MELVILL (1909). A significant departure from this trend was the dissertation by WAGNER (1909) which, together with his paper on the kimberlites of the Pretoria District T.V. (1911), was subsequently enlarged into his classic

book/.....

book, "The Diamond Fields of Southern Africa" (1914).

In 1911, DRAPER published an account of the diamond deposits of Brazil, which had been discovered in 1868, but not recorded in English until this time. This brief report is still the only information publicly available on these kimberlites.

During the second and third decades of this century, WAGNER published a number of papers (1916a, b) (1921)(1926)(1928)(1929a, b) elaborating on some aspects discussed in his book, and proposing various genetical hypotheses. Other than his book, neither he nor any other worker provided information of much importance during this period.

Undoubtedly the next major publication was the two volume book of A.F. WILLIAMS (1932), which, like WAGNER's (1914) book, consolidated information and ideas published in a variety of journals and reports. WILLIAMS enlarged on many aspects mentioned by WAGNER eighteen years before, but his most valuable contribution was the detailed petrography of the ultramafic xenoliths. Having worked in many diamond mines, WILLIAMS had been able to make an excellent collection of nodules, many of which he figured either as hand specimens or thin sections in his copiously illustrated book. A large number of these specimens were subsequently presented by his heirs to the University of Cape Town, and have been the mainstay of this present investigation.

The fourth decade was marked by little further progress in this field, except for descriptive works of the kimberlites in TANZANIA by TEALE (1932) and WILLIAMS (1939), in the CONGO by VERHOOGEN (1938), and in RHODESIA by MACGREGOR et al. (1937). HOLMES and PANETH (1936) showed that some of the kimberlites of South Africa had radiogenic ages corresponding to the Lower Cretaceous period, but their data from ultramafic xenoliths was confusing.

No publications of importance appeared in the 1940s, but the discovery of kimberlite in the U.S.S.R. in 1954 - DAVIDSON (1957), and the synthesis of diamond in 1955 - BUNDY et al. (1955), led to renewed interest in this aspect of geology. Most of the publications in the late 1950s relate to the kimberlites and ultramafic xenoliths of the U.S.S.R., and the three Russian geologists who emerged as the most active in this field were A.P. BOBRIEVICH, G.I. SMIRNOV and V.S. SOBOLEV, who often published together in various author combinations. Nearly all of the types of ultramafic xenolith that had been recorded from Southern African kimberlites were discovered in Siberia, and through the work of these men, the Russians took the lead in research on kimberlite and its inclusions. Unfortunately most of their work has been published in the Russian language and, to keep in touch with Soviet progress, western geologists have been largely dependent upon the excellent summaries by C.F. DAVIDSON (1957)(1964)(1967a).

The post-Second/.....

The post-Second World War developments in geophysical techniques led to renewed interest in the structure of the earth, and in 1961 the International Upper Mantle Project was commenced. This world-wide attempt to cooperate on a single project necessitated exploitation of their natural skills and resources by the various contributing countries, and it is not surprising, therefore, that a major portion of the South African contribution should be modern studies of the rocks most likely to have come from the Upper Mantle. Scientists in some other countries have also acquired specimens of these ultramafic xenoliths, and in the last decade there have been very many publications dealing with them. The number of publications of this sort, combined with those of the relevant aspects of geophysics and experimental geochemistry, are more than twice as numerous as all of those previously published on these topics.

During the last ten years, a number of groups of workers have emerged as being very active in this field. In the U.S.S.R., A.P. BOBRIEVICH, I.K. KUZNETSOVA, V.A. MILASHEV, V.S. SOBOLEV, and his son, N.V. SOBOLEV, are the most eminent. In the United Kingdom, P.G. HARRIS had a team at the University of LEEDS in the early 1960s, of whom J.B. DAWSON and P.H. NIXON made significant contributions, using samples from LESOTHO. C.F. DAVIDSON attracted J.B. DAWSON to ST. ANDREW'S UNIVERSITY, and formed a formidable team, who argued for a crustal origin for many of the ultrabasic xenoliths in kimberlite. M.J. O'HARA joined this field of research whilst studying at the University of Cambridge, and, after a brief period at the Geophysical Laboratory, Washington, he moved to the University of Edinburgh. There, O'HARA collaborated with E.P.L. MERCY and together they have produced many papers, applying the results of high pressure research to petrogenic theory.

F.R. BOYD, I. KUSHIRO, I.D. MACGREGOR, A.E. RINGWOOD and H.S. YODER, Jr. have all worked on this topic at the Geophysical Laboratory, Washington, and, like M.J. O'HARA, are still active in this field. A.E. RINGWOOD moved to the Australian National University, Canberra, and established a team of whom D.M. GREEN, T.H. GREEN, J.F. LOVERING and A. MAJOR have made significant contributions. G.C. KENNEDY of the University of California has also led a team working in experimental geochemistry related to problems of the Upper Mantle, and from Poland, K. SMULIKOWSKI has published a number of interesting papers. Much of this newer work has been discussed by various authors in the book "Ultramafic and related rocks" (1967), edited by P.J. WYLLIE.

South African research has been pursued at three main centres. At the University of Potchefstroom, Professor P.B. Ackermann has had two students working on the kimberlites of the Barkly West District, C.P., BOSCH (1963), and SCHUTTE (1967), whilst at the Bernard Price Institute, H.L. ALLSOPP and L.O. NICOLAYSEN have been active. However, these groups have not had collections of the size and quality of that at the University of Cape Town.

In 1964/.....

In 1964 Professor L.H. Ahrens founded a team to study these rocks and the initial work has to be carried out on the specimens of the collection made by A.F. WILLIAMS (1932). Mr. G.W. BERG greatly enlarged this collection, and, like Dr. J.J. GURNEY, his work has been mainly concerned with the bulk chemistry of the ultramafic xenoliths and their host kimberlite. The latter recently completed his initial project - GURNEY (1968), but the results of the former are not yet available. Meanwhile, these workers have published two papers on various aspects of their studies, GURNEY, BERG and AHRENS (1966) and BERG (1968). Independently, AHRENS, CHERRY, and ERLANK (1967) have studied the Th - U relationships in zircons that occur in some kimberlites.

When I joined the group in 1966, little of this information was available. There were no modern studies of the constituent minerals of the ultramafic xenoliths, and consequently this topic was assigned to me. I chose to commence with the garnets, for they are frequently present in the xenoliths, and I had previously worked with metamorphic garnets and had found them to be most useful indicators of the chemistry of their host rocks. It soon became obvious that joint work with Dr. M. MATHIAS, who had an interest in this project through supplying mineralogical data to Mr. G.W. BERG, was going to be the most expeditious way to tackle this study. At times, Mr. J.C. SIEBERT, who recently completed an M.Sc. thesis (1968), has collaborated in this work. All of us have made additions to the rock collection at the University of Cape Town, such that it is now one of the largest and most representative of the ultramafic xenoliths that occur in kimberlite. From the publications so far issued, most institutions in other countries appear to have collections biased towards eclogites. The collection, which has been studied for this thesis, is believed to be free of any such strong bias.

(b) THESIS FORMAT

This thesis is presented in the form of a number of chapters, each of which consists entirely or partly of a published paper, or a manuscript which has been submitted for publication. The whole constitutes a unified study, which could have been presented in many ways. The order of presentation is not always chronological as far as publication date is concerned, but it is hoped that it introduces the reader to the data in a manner from which he is best able to gather the current state of knowledge.

The literature relevant to each chapter is given with that chapter, as are the acknowledgements. The final manuscript contains much new information, but it also presents the current interpretation of all the data presented in this thesis.

Several/.....

Several of the papers and manuscripts contained in this thesis have been written under joint authorship, and accordingly, each is preceded by a short account of my specific contribution. In each case a signed statement by a co-author has been included to verify my assessment of my contribution.

The appendix contains listings of all the computer programmes which I have written for the work contained in this thesis. The computer language is Manchester Auto Code, and the programmes were run on an I.C.T. 1301 digital computer. Two of these programmes have been approved and incorporated in the file of standard mathematical computer programmes of the Computer Centre, University of Cape Town.

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CHAPTER 2

THE NATURE AND OCCURRENCES OF NON - ECLOGITIC ULTRAMAFIC XENOLITHS IN THE KIMBERLITES OF SOUTHERN AFRICA.

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CONTENTS

ABSTRACT

Descriptions are given of the non-eclogitic ultramafic xenoliths that occur in kimberlite. The localities in Southern Africa at which such rocks have been found are listed with the rock types that occur. Thirty-one of these 64 localities have been visited, specimens in older collections have been examined, and the mineral assemblages, which can be confirmed, are recorded.

The garnet-lherzolite assemblage, olivine-orthopyroxene-clinopyroxene-garnet, which is frequently assumed to be most similar to the material in the Upper Mantle, occurs at more localities than the other assemblages. Olivine-orthopyroxene, olivine-orthopyroxene-clinopyroxene, and olivine-orthopyroxene-garnet are almost as common, and these lherzolites and harzburgites are often found in the same kimberlite occurrence.

Xenoliths consisting of garnet-spinel, and olivine-orthopyroxene-clino-pyroxene-amphibole, are newly recorded. Foliated xenoliths are figured for the first time.

INTRODUCTION

This paper describes the non-eclogitic ultramafic xenoliths that are found in kimberlites, and contains a compilation of all available records of their occurrence in Africa south of the equator. It is complementary to a similar paper by RICKWOOD, GURNEY and WHITE-COOPER (in press), which deals with the eclogitic inclusions.

The relevant literature is both voluminous and sometimes difficult to obtain, and thus it is hoped that future workers in this field will find it beneficial to have a modern compilation. Mineral assemblages, reported or observed, form the basis of the following sections, as no reliance has been placed on rock names which are variously applied.

In order to verify as many of the published accounts as possible, the author has had to utilise information provided by colleagues, as well as that for which he is responsible. Microscopic data has been provided by Dr. M. Mathias and Mr. J.C. Siebert, and Mr. G.W. Berg, Dr. J.J. Gurney, Mr. J.C. Siebert and Mr. D.R. White-Cooper (Anglo American Corporation, Ltd.) have supplied specimens and field evidence. Other specimens have been obtained from the collection of the late A.F. Williams, who described many of them in his classic volumes (1932).

No attempt has been made to provide a petrological interpretation of the data recorded here, for that will appear in a separate publication under joint authorship with Dr. M. Mathias and Mr. J.C. Siebert.

In this paper, "we" refers to some combination of the author and his co-workers. The following abbreviations are used throughout this work :-

ol = olivine, opx = orthopyroxene, cpx = clinopyroxene, gt = garnet,
amph = amphibole, graph = graphite, zr = zircon, il = ilmenite, py = pyrite,
serp = serpentine, spin = spinel, ap = apatite.
C.P. = Cape Province, O.F.S = Orange Free State, T.V. = Transvaal.

THE NATURE OF THE XENOLITHS

Rocks consisting of 25 different mineral assemblages are listed in the appendix. Most of these xenoliths have similar external features, but the ilmenite-rich and spinel-rich rocks differ from the rest.

Most of the xenoliths occur as rounded boulders frequently flattened in one direction, so having a shape which may be called an ellipsoid of revolution.

Some/....

Some are so thin in one direction that they are better described as being discoidal, (Fig. 1). Specimens with a diameter as large as 30" (75 cm) have been found, but commonly they are less than one-third of that size.

These rocks have an abraided exterior, but it is very rare for the surface to be polished, (Fig. 2), a feature which is common in eclogites. Banding as found in eclogites is very rare, and only two of our specimens show foliation, (Fig. 3). Some peridotitic and pyroxenitic xenoliths have rims in which the constituent minerals appear to be altered, (Fig. 4). In some cases it is most likely that this alteration is due to some kind of reaction with the surrounding kimberlite, for one xenolith collected from 2500 feet below surface has a pronounced alteration rim and yet is enclosed by fresh rock.

Bimineralic garnet-spinel rocks are very rare and small, and their irregular shape may well be due to fragmentation of larger masses. In some kimberlites, bimineralic nodules, rich in ilmenite, occur and frequently the two phases are intergrown in textures which have been termed eutetic, WILLIAMS (1932, Plates 122, 123).

COMMON ASSEMBLAGES

The assemblage ol-opx-cpx-gt is the one which is recorded at most (22) locatities, of which 16 are here confirmed. This accords well with the assumption of many writers that this is the material of which most of the Upper Mantle is composed.

The distinction between lherzolite and harzburgite (or the garnetiferous varieties) is made on the presence or absence of clinopyroxene. In many of the lherzolites which we have examined, clinopyroxene is present in very small amounts and could easily have been missed had unfortunately orientated thin sections been examined. Thus it is necessary to remember that records of ol-opx-gt assemblages can easily be erroneous. Such errors are unlikely to be associated with garnet, even though it is often present in small amounts, for it is a most conspicuous phase, both in hand specimen and thin section. Ol-opx-cpx has been recorded at 19 localities, and the two harzburgite assemblages ol-opx, and ol-opx-gt are present in 19 and 17 localities, respectively. At many of these places the harzburgites and lherzolites occur together and in these instances, the above comments are particularly pertinent.

Pyroxenites consisting of opx-cpx and opx-cpx-gt occur in relatively few localities (6 and 9 respectively), and they are usually rare in these kimberlites.

Ol-cpx/.....

Ol-cpx and ol-cpx-gt are similarly uncommon, having been reported from 5 and 3 localities respectively. The former assemblage has been confirmed at two localities, and in both instances the rocks have been dunites with 98% olivine. Likewise two rocks with ol-cpx-gt have been examined. One, AAB 1053 (SIEBERT 1968) contains 77% olivine, and another LBM 36 (MATHIAS and RICKWOOD - In Press) has roughly equal proportions of these three phases. Alteration of peridotites often leaves clinopyroxene and garnet remnants in a mass of serpentine, and in many cases the primary mineralogy is not ascertainable. It is a common assumption that the presence of serpentine indicates primary olivine, and the fact that orthopyroxene also alters easily is often overlooked. For records other than those substantiated here, it is necessary to remember that the primary assemblages may have been estimated from altered rocks and may well be inaccurate. In our experience these assemblages are very rare.

No confirmation can be given of any of the 5 records of il-opx rocks, but one of the 6 il-cpx assemblages has been seen. These are not common xenoliths and have unusual intergrowth textures, which are frequently called eutectics, e.g. WILLIAMS (1932).

The first records of garnet-spinel rocks appear in this work, and these specimens will be discussed more fully in a paper that is in preparation.

RARE ASSEMBLAGES RECORDED AT ONLY ONE LOCALITY

Of the 25 rock types which have been listed in the appendix, no less than 12 have been found at only one locality. These are :-

1.	Ol-Gt	FRANK SMITH, C.P.	SCHUTTE (1967 p.20) SIEBERT (1968)
2.	Cpx-Gt	FRANK SMITH, C.P.	SCHUTTE (1967 p.17)
3.	Opx-Ap	DE BEERS, C.P.	WAGNER (1914 p.133)
4.	Ol-Cpx-Amph	DE BEERS. C.P.	WILLIAMS (1932, pp 356-7, Plate 133)
5.	Ol-Cpx-Zr	BULTFONTEIN, C.P.	WILLIAMS (1932 Plate 127)
6.	Ol-Opx-Cpx-Amph	MONASTERY, O.F.S.	
7.	Ol-Opx-Il-Graph	THABA PUTSOA, LESOTHO	DAWSON (1960, p.120)
8.	Ol-Cpx-Pyrite-Graph	PREMIER, T.V.	WILLIAMS (1932, p.387)
9.	Ol-Cpx-Gt-Il	MABUKI, TANZANIA	WILLIAMS (1939, p.13)
10.	Opx-Cpx-Gt-Amph	MONASTERY, O.F.S.	ROGERS & DU TOIT (1904, p.77)
11.	Il-Ol	MOFFAT, RHODESIA	ZEALLEY (1917, p.9, 11)
12.	Il-Gt	MONASTERY, RHODESIA	WAGNER (1914 p.132)

Confirmation can be given of assemblage 1, and of assemblage 6 which is here recorded for the first time. The fact that ilmenite-serpentine has been confirmed at Monastery Mine, O.F.S., makes ZEALLEY's (1917, p.9,11) report of ilmenite-olivine at Moffat, Rhodesia seem reasonable.

SCHUTTE/.....

SCHUTTE (1967, p.17) did not classify his cpx-gt rock with the rest of his eclogites, having preferred to call it a clinopyroxenite. This may well be exsolved garnet in clinopyroxene and be a fragment from a larger xenolith with more phases.

Assemblage 4 must be considered uncertain for there is no amphibole in our portion of the rock to which WILLIAMS (1932, p.356-7, Plate 133) referred.

Omitted from this list are the bronzite-smaragdite-phlogopite xenoliths - DUTOITSPAN, C.P. - WAGNER (1914, p.133), because this assemblage is not one which is normally primary. Likewise several rocks recorded from Jagersfontein, O.F.S are excluded, i.e. a doubtful three pyroxene assemblage hypersthene-enstatite-diopside-vaalite-serpentine - HARGER (1905, p.125), and an olivine-enstatite-garnet-graphite-pyrrhotite-mica-zircon rock - WAGNER (1916a, pp.54-55) in which the last four phases are probably minor in quantity. The only described xenolith from the kimberlite at WIMBLEDON SIDING, C.P. contained serpentinised olivine, mica and a mineral dubiously identified as kyanite - DU TOIT (1906, p.161).

ROGERS and DU TOIT (1904, pp. 77-78) mentioned two rocks each with two clinopyroxenes as occurring at Monastery Mine, O.F.S., and these are also considered doubtful identifications.

THE COMPILATION

Those papers, in which the assemblages of primary minerals in the xenoliths are given, have been most important for this study. Rock terms have no universal application, and accordingly it is dangerous for someone else to infer the assemblage seen by the geologist who uses the terms. However, it has seemed worthwhile to list these names for they do at least give some idea of the xenolith type. These latter records have not been used for the main part of the paper. The appendix contains some localities for which the best available information indicates nothing more than that xenoliths of ultrabasic or cognate nature have been discovered. Such localities have been excluded from the paper on eclogite xenoliths, for eclogites are conspicuous rocks which are well-known and are recorded by name.

References to nodules which are xenocrysts or single phase aggregates have not been included, but it should be noted that some workers apply names such as clinopyroxenite to nodules which are not 100% clinopyroxene, e.g. SCHUTTE (1967). Some assemblages, which should have been included in this paper, may have been unintentionally excluded for reasons such as this.

Phlogopite/.....

Phlogopite, or some similar brown mica, was found by SIEBERT (1968) in 93 of the 128 peridotites and pyroxenites which he examined microscopically. The rôle of this mineral is uncertain. There are cases where it is definitely of secondary origin, e.g. HOLMES (1936, p.399), but there are others where it could be primary. WILLIAMS (1932, p.356 et.seq) claimed to be able to distinguish between these two origins, whereas SIEBERT (1968) always listed this phase under the heading of secondary minerals. Recent work by GURNEY (1968) appears to indicate that it may have originated in either way, but from microscopic investigation alone, it would be presumptious to decide the origin of phlogopite in each nodule. For the present work, it has been disregarded, and accordingly phlogopite may be found in association with any combination of the five main primary phases: olivine, orthopyroxene, clinopyroxene, garnet and ilmenite.

Whilst in only one case is there evidence that the orthopyroxene in these nodules is not enstatite (it is then hypersthene), it is quite clear from chemical analyses that the clinopyroxene is not always true diopside. To avoid difficult decisions of terminology without adequate chemical evidence, I have adhered to the terms ORTHOPYROXENE and CLINOPYROXENE throughout this work. For similar reasons, minerals of the GARNET and OLIVINE groups are called by those collective names.

All available literature relating to the kimberlite occurrences in the African countries south of the equator has been consulted. In addition, letters were sent to the directors, or their equivalent office-bearers, of the Geological Surveys in each of these countries, asking for any data relevant to this work. Many of the replies received are quoted in the appendix, but not all of the directors replied, and so for some countries up-to-date information is lacking. Whilst every endeavour has been made to present a complete and accurate compilation, it would be too much to expect that this has been achieved. I would welcome notification of any errors or omissions, and would particularly appreciate being sent samples of rocks not recorded for any specific locality.

All localities mentioned in the appendix are shown in Fig. 5.

ACKNOWLEDGEMENTS

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Information/.....

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APPENDIX

KIMBERLITE OCCURRENCES WITH NON-ECLOGITIC ULTRAMAFIC XENOLITHS

(a) Countries with no known kimberlite.

The following countries lie within the geographical boundaries of this study and are not known to contain any kimberlite.

BURUNDI (Pers. Comm. Directeur du Départment de Geologie et Mines - 20/2/69)
CONGO (BRAZZAVILLE)
MALAGASY REPUBLIC (Pers. Comm. Chéf du Service Géologique - 17/1/69)
MOCAMBIQUE
RWANDA
SWAZILAND (Pers. Comm. Director, Geological Survey - 17/1/69).

(b) Countries with kimberlite and no reported non-eclogitic ultramafic xenoliths.

ANGOLA.

Kimberlite occurs within the Lucapa graben of N.E. Angola in the Chicapa and Luachimo River valleys, de KUN (1965, p.449-450), DAWSON (1967, p.249). More than 50 occurrences have been located but no details are available of their xenolith content. In a general statement de KUN (1965, p.450) mentioned nodules, "... of hornblende-garnet pyroxenites carrying ilmenite. Rarer nodules consist of pyroxene hornblendite", in the basaltic kimberlite of the Camafuca. This information was almost certainly derived from the Memoire written by REAL (1959), from which it appears that the former xenoliths are more similar to eclogite than pyroxenite, and that the latter are amphibolites.

BOTSWANA

Recent discoveries of large kimberlite pipes in an area west of Francistown have been widely publicised in South African newspapers. At the present time no ultramafic xenoliths have been reported from them. (Pers. Comm. Mr. C.D. Hallam),

GABON

Kimberlite dykes occur near the Bendolo River adjacent to alluvial diamond deposits, CHOUBERT (1946), but no ultramafic xenoliths are recorded.

KENYA

Kimberlite has recently been discovered near the border with Tanzania, (Pers. Comm. Dr. E.P. Saggerson 14/1/69), but no "undisputed mantle peridotite nodules" have been found. (Pers. Comm. Commissioner of Geological Survey and Mines, Uganda, 18/1/69).

MALAWI

Five occurrences of kimberlite are known in the Livingstonia area of Northern Malawi, but no ultrabasic inclusions have so far been found in them. (Pers. Comm. Director, Geological Survey Department, 18/1/69).

UGANDA

Kimberlite has recently been discovered but no ultramafic xenoliths of "undisputed mantle peridotite" have been found. (Pers. Comm. Commissioner of Geological Survey and Mines, 18/1/69).

ZAMBIA

In 1961, kimberlite was discovered in the mid-Luangwa valley area, but no xenoliths have been reported. (Pers. Comm. Acting Director, Geological Survey, 17/1/69; and J.B. Hawthorne, Anglo American Corporation, Ltd., 10/2/69).

(c) Countries with kimberlite containing non-eclogitic ultramafic nodules.

In the following section all latitudes and longitudes are approximate, having been measured on the most detailed maps available. In some instances these were both old and drawn to a small scale.

Localities of kimberlite reported to contain either ultrabasic or cognate xenoliths are included in this paper, for it is believed that authors usually take special care to mention the presence of the conspicuous eclogites.

Each observation listed is supported by references. Where there is more than one literature account, the earliest and most recent are included. In rare cases, a third reference has been retained because it is of particular interest. Assemblages not followed by a reference are recorded here for the first time.

Assemblages followed by the reference SIEBERT (1968) can be considered confirmed.

The localities visited by myself and/or one or more of my colleagues or Mr. D.R. WHITE-COOPER have been marked with an asterisk.

CONGO RÉPUBLIQUE

Kimberlite occurs on the Kundelungu Plateau, Katanga - VERHOOGEN (1938), and in the central region near Bakwanga - FIEREMANS (1966). Near Bakwanga are a series of kimberlites which contain nodules composed largely (90-95%) of diopside with minor garnet ± hornblende ± magnetite ± biotite. These diopsidites - FIEREMANS (1966, pp. 64-69) are sometimes calcified and/or silicified. In a general statement about the Congo, WAGNER (1914, p.103) recorded the presence of eulysite xenoliths in the kimberlite; by which he meant the assemblage ol + opx + cpx + gt.

LESOTHO

Most of the known occurrences of kimberlite in Lesotho were numbered by Col. J. Scott in a series of reports to the Public Works Department, Maseru, over the period 1955 - 1963. These numbers are quoted here, and were obtained from the most recent compilation of kimberlite occurrences in Lesotho, MEATON (1966).

KAO/.......

KAO (29°01'S, 28°38'E) (Scott No. 1).

Ol - Opx - Gt DAWSON (1960, p.120)

Ol - Opx - Cpx - Gt DAWSON (1960, p.120) (1962, p.554), NIXON et al. (1963, p.1099).

There are two pipes, the larger is usually called Kao 1 and the smaller Kao 2; the latter is 1/4 mile N W of Kao 1. Both of the above authors described the garnet-lherzolites as occurring at Kao, but Dawson also wrote of them existing at Kao 1 as well as Kao. Both peridotite and pyroxenite have been reported from Kao 1, as well as Kao 2, DAWSON (1960, p.40, p.50), O.G.S. (1963, p.91-2).

KHABOS DYKE (28°50'S, 28°16'E) (Scott No. 73).

"There are a few rounded ultrabasic inclusions" O.G.S. (1963, p.86).

KOENANENG (KHOELIBANNA) (28°47'30"S, 28°12'30"E) (Scott No. 95).

Two pipes 600 yards apart are described, ".... and there are occasional xenoliths of peridotite", O.G.S. (1963, p.87). Earlier, DAWSON (1960, p.25) had recorded the presence of garnet-peridotite nodules, sometimes carbonated, and "altered pyroxenite" now consisting of phlogopite and with brown amphibole in the core of the xenolith.

* LEMPHANE (28°57'S, 28°35'E) (Scott No. 3)

One garnet-peridotite xenolith was collected from Lemphane by G.W. Berg and Dr. B. Harte in 1968. The specimen is very decomposed but the garnets have been studied by MATHIAS and RICKWOOD (In Press). This was the only ultramafic xenolith to be seen.

LETSENG-LA-TERAI (29°00'S, 28°40'E) (Scott No. 40).

"... a few of garnet-peridotite (B25) in places". O.G.S. (1963, p.99). This locality was visited by a joint University of Cape Town-University of Edinburgh expedition in 1968, but Police intervention prevented us from examining either the kimberlite or its contents.

* LIPELANENG (28°46'12"S, 28°14'30"E) (Scott No. 99).

STOCKLEY (1947, p.84) recorded peridotite xenoliths and the O.G.S. (1963, p.90) listed "unaltered dunite, peridotite and other ultrabasic rocks containing varying proportions of plagioclase, enstatite and olivine". Specimens were taken from here in 1968 and are awaiting detailed study, but peridotites are certainly present.

LIQHOBONG (28°59'20"S, 28°36'40"E) (Scott No. 2).

Ol - Opx - Cpx - Gt DAWSON (1960, p.120) (1962, Fig.3) NIXON et al. (1963, p.1097, Fig.2)

Dunite has also been recorded by the O.G.S. (1963, p.94), but it is not known whether this was found at the same small pipe 500 yds. S.W. of the main pipe, as were DAWSON'S (1960, p.64) peridotite, pyroxenite and garnet-peridotite.

MALIBAMATSO PIPE (29°01'40"S, 28°33'E) (Scott No. 26).

Ol - Opx - Cpx - Gt DAWSON (1960, p.120) (1962, p.554), NIXON et al. (1963, p.1099, 1118).

Both pyroxenite/.....

Both pyroxenite and garnet-peridotite xenoliths have been recorded by DAWSON (1960, p.55).

* MATSOKU (BUCKMANN'S) PIPE (29°05'S, 28°44'E) (Scott No. 21).

Ol - Opx	MATHIAS & RICKWOOD (In press)
Ol - Opx - Cpx	" " "
Ol - Opx - Gt	" " "
Opx - Cpx - Gt	" " "
Ol - Cpx - Gt	" " "
Ol - Opx - Cpx - Gt	" " "

Prior to the recent collection and description of the above xenoliths, MATHIAS & RICKWOOD (In Press), a garnet-peridotite xenolith had been recorded by DAWSON (1968, p.506). One of the above rocks is a dunite with very minor orthopyroxene, and another is a unique olivine-clinopyroxene-garnet rock with chromiferous phases.

MOTAI (28°58'S, 28°48'E) (Scott No. 37).

The O.G.S. report (1963) stated p.97, "The kimberlite contains .... also a notable amount of ultrabasic xenoliths with abundant garnet, olivine and chrome diopside", but it is not clear whether the mineral assemblage consists of all these phases or whether it is restricted to them. Earlier, p.41, mention was made of the "numerous small cognate xenoliths".

NGOPETŠOEU (29°33'S, 27°47'E) (Scott No. 126).

STOCKLEY (1947, p.85) recorded the presence of pyroxenite xenoliths and the O.G.S. reported, "There are also many inclusions of dunite and peridotite with chrome-diopside....." (1963, p.101)

QAQA (29°0'30"S, 28°52'E) (Scott No. 38)

DAWSON (1960, p.77) reported the discovery of a garnet-peridotite xenolith in prospecting pit A.

ROBERT (29°09'S, 29°01'E) (Probably Scott No. 48).

Ol - Opx - Cpx

One xenolith in kimberlite has been kindly supplied by Mr. A.O. Thompson.

SEKAMENG, (SIKHAMING, SEKHAMENG) (28°48'S, 28°16'E) (Scott No. 72X).

DAWSON (1960, p.23) recorded peridotite, garnet-peridotite and pyroxenite nodules from this locality and NIXON et al.(1963, p.1100, 1104) referred to specimen E.10 as an altered garnetiferous ultrabasic xenolith.

This locality near Butha Buthe should not be confused with one of the same name in the southern part of Lesotho near Kolo Mountain. The co-ordinates cited above have been taken from MEATON (1966, p.81) and agree well with the position shown on STOCKLEY's (1947) map; the figures given by DAWSON (1962) appear to be in error.

THABA PUTSOA (28°55'S, 28°39'E) (Scott No. 6).

Ol - Opx - Gt	DAWSON (1960, p.120), NIXON et al (1963, p.1099, 1118)
Ol - Opx - Cpx - Gt	DAWSON (1960, p.120)(1962, p.554), NIXON et al. (1963, p.1093, 1099, 1118).

Ol/.....

Ol - Opx - Graph - Il DAWSON (1960, p.120)

Il - Cpx DAWSON (1960, p.137)

In addition to the above records, the O.G.S. (1963, p.96) stated, "There are numerous rounded inclusions, often shattered, of pyroxenite and garnet peridotite". This information appears to have been obtained from DAWSON (1960, p.66). The harzburgite containing graphite and ilmenite appears to be unique; the diopside-ilmenite rock is not an intergrowth, but consists of pyroxene inclusions in an ilmenite nodule.

RHODESIA

* COLOSSUS, ROBIN'S FARM, 29 m. N. BULAWAYO (19°47'30"S, 28°52'30"E).

Ol - Opx - Gt MENNELL (1910, p.373), MACGREGOR et al. (1937, p.66).

Ol - Opx - Cpx - Gt MACGREGOR et al. (1937, p.66)

Il - Opx MACGREGOR et al. (1937, p.66)

Il - Cpx MACGREGOR (1915, p.1-3)

'Peridotite' boulders were first recorded by MENNELL (1910, p.373). ZEALLEY subsequently noted nodules of pyroxene and olivine (1914, p.2), a eulysite (1917, p.6), by which one infers the assemblage garnet-olivine-clinopyroxene, and flattened 'boulders consisting of corroded-looking hypidiomorphic pale pyroxene, altering to bastite in a fine black ground with few garnets' - (1917, p.6). MACGREGOR et al. (1937, p.65-6) also recorded xenoliths of olivine and an unspecified pyroxene, but they did note that boulders of ol-opx-cpx-gt were less common than those with ol-opx-gt. A xenolith of the former assemblage was the only one to be found during a visit in 1968; in it the orthopyroxene has not been positively identified and the rock as a whole is of unusual appearance.

Nodules consisting of ilmenite intergrown with an unspecified pyroxene were recorded by ZEALLEY (1914, p.3) (1917, p.6, 11), but MACGREGOR (1915, p. 1-3) specified diopside although in a later publication, MACGREGOR et al. (1937, p.66) he only stated that enstatite-ilmenite intergrowths were fairly common.

MOFFAT, FREIS FARM, 48 m. N.E. BULAWAYO (19°35'S, 29°2'30"E).

Opx - Cpx ZEALLEY (1917, p.9)

Il - Ol ZEALLEY (1917, p.9, 11)

Il - Serp ZEALLEY (1917, p.9, 11)

Pyroxenites were recorded by HARRISON (In Press), but most confusion surrounds the ilmenite nodules. ZEALLEY (1917) writes about them in three places successively as 'intergrowth of ilmenite and serpentine (? olivine)', p. 9; 'olivine (or pyroxene) included in irregular grains of ilmenite', p. 9; 'The ilmenite - pyroxene and ilmenite - ? olivine (perhaps only serpentinised pyroxene) nodules are a kind of intergrowth, perhaps comparable to the graphic intergrowth of pyroxene-ilmenite at Colossus', p.11.

It has not been possible to visit this remote locality to try and sort out this muddle.

* WESSELS, WESSELS FARM, 32 m. N. BULAWAYO (19°48'40"S, 28°58'08"E).

Il - Cpx MACGREGOR (1915, p. 1)

ZEALLEY/.....

ZEALLEY (1917, p.4) and MACGREGOR et al.(1937, p.65) have both recorded rare inclusions of peridotite, but in neither case was the mineral assemblage mentioned. Likewise, they both -(p.2) and (p.65) respectively - refer to ilmenite-pyroxene intergrowths, the pyroxene having earlier been identified by MACGREGOR (1915, p.1) as diopside.

SOUTH AFRICA

A. Cape Province

ABBOTSFORD, EAST GRIQUALAND (30°27'40"S, 28°50'E).

DU TOIT (1929, p.26) wrote "...while lumps of ultrabasic rock are present,...." This locality has not been visited.

BEESTPAN - See MARKT

* BELLSBANK, (WESTERN FISSURE), NEAR BARKLY WEST (28°3'30"S, 24°23'E).

Two series of kimberlite dykes occur on this farm and SCHUTTE (1967) has distinguished them as the BELLSBANK or MAIN FISSURES (Western) and the BOBBEJAAN (Eastern) fissures. However, in only one place (p.12-13) did he state the xenoliths which occur in each set of kimberlite dykes and here he only used rock names. Thus mineral assemblages given throughout the rest of his thesis could be of xenoliths from either or both of these places. Accordingly in this section, the xenoliths described as occurring in the BELLSBANK dykes are both those specifically stated as being from this source and those which occur somewhere on the BELLSBANK farm. Those xenoliths listed under the heading BOBBEJAAN definitely derive from that dyke series. Most of the xenoliths from BELLSBANK FARM which have been examined by myself, and my colleagues, have been included here, for we generally failed to distinguish between the two dyke series whilst we were collecting.

Ol - Opx   SCHUTTE (1967, p.12, 20) SIEBERT (1968)
Cpx - Opx   SCHUTTE (1967, Plate XA)
Gt - Spinel

SCHUTTE (1967, p.12, 20) lists dunite, orthopyroxenite and clinopyroxenites from BELLSBANK, but his useage of these terms is not clear, and they are certainly not restricted to monomineralic rocks. The clinopyroxene-orthopyroxene assemblage that he illustrates in Plate XA is stated in the caption as coming from BELLSBANK, but in the text he describes it under the heading MITCHEMANSKRAAL.

A garnet-spinel rock was recently discovered by Mr. D.R. White-Cooper; no other phases co-exist.

* BOBBEJAAN (EASTERN FISSURES) NEAR BARKLY WEST (28°05'S, 24°24'E).

Ol - Opx
Ol - Opx - Cpx   SCHUTTE (1967, p.13)
Gt - Spinel

SCHUTTE (1967, p.13) lists lherzolite at this locality and from p.11 it can be assumed that he meant an olivine-enstatite-diopside assemblage. This we also found in 1967 as also olivine-enstatite rocks and a rare garnet-spinel rock.

BULTFONTEIN/...

* BULTFONTEIN, KIMBERLEY (28°46'S, 24°48'E).

Ol - Opx DU TOIT (1906, p.162), SIEBERT (1968)

Ol - Cpx WILLIAMS (1932, p.356-7, Plate 132), SIEBERT (1968)

Opx - Cpx SIEBERT (1968)

Opx - Gt

Ol - Opx - Cpx DU TOIT (1906, p.161, 164-5), SIEBERT (1968).

Ol - Opx - Gt WILLIAMS (1932, p.356-7)

Opx - Cpx - Gt SIEBERT (1968)

Ol - Cpx - Gt DU TOIT (1906, p.164)

Ol - Cpx - Zr WILLIAMS (1932, Plate 127)

Ol - Opx - Cpx - Gt DU TOIT (1906, p.163-4), RASTALL (1907, p.285-6), SIEBERT (1968).

The ninth of these assemblages is the only zircon-bearing xenolith recorded in kimberlite where zircon is a major constituent. We can confirm all other assemblages except ol - cpx - gt, for we have collected extensively from the dumps of this mine. One of our xenoliths consists of orthopyroxene exsolving garnet.

CLARKTON, EAST GRIQUALAND, (30°00'30"S, 29°21'30"E).

Ol - Opx - Cpx - Gt DU TOIT (1913, p.1000 (1929, p.27).

DU TOIT (1913, p.100) also gives brief mention to the occurrence of "Lherzolite, saxonite, and other types of ultrabasic rocks". We have not visited this locality.

* DE BEERS, KIMBERLEY (28°44'10"S, 24°47'E).

Ol - Opx DU TOIT (1906, p.161-2), SIEBERT (1968).

Opx - Cpx WAGNER (1914, p.133)

Opx - Ap WAGNER (1914, p.133)

Ol - Opx - Cpx WILLIAMS (1932, p.101), SIEBERT (1968)

Ol - Opx - Gt DU TOIT (1906, p.162-3), SIEBERT (1968)

Opx - Cpx - Gt

Ol - Cpx - Amph WILLIAMS (1932, p.356-7, Plate 133)

Ol - Opx - Cpx - Gt DU TOIT(1906, p.163), SIEBERT (1968)

We have not confirmed the assemblage opx - cpx which WAGNER (1914, p.133) reported to be accompanied by phlogopite, nor have we seen his unique bronzite-phlogopite - apatite rock. Our sample of WILLIAMS (1932) Ol - Cpx - Amph rock contains orthopyroxene and no amphibole.

* DUTOITSPAN, KIMBERLEY (28°45'30"S, 24°48'E).

Ol - Opx DU TOIT (1906, p.162), SIEBERT (1968).

Ol - Opx - Cpx SIEBERT (1968)

Ol - Opx - Gt

Ol - Opx - Cpx - Gt WAGNER (1914, p.135), SIEBERT (1968).

Compared to the other mines at Kimberley, the number of different mineral assemblages found as xenoliths at Dutoitspan are few. In addition to the above, WILLIAMS (1932, p.304) recorded that pyroxenites were fairly abundant and WAGNER (1914, p.133) listed a unique bronzite-smaragdite-phlogopite nodule. There are several accounts of bimineralic nodules with phlogopite as/...

as one phase, e.g. WILLIAMS (1932, p.358-9, Plate 116).

* EXCELSIOR, BARKLY WEST (28°12'S, 24°30'30"E).

Ol - Opx - Cpx - Gt SIEBERT (1968)

This is the only ultramafic xenolith recorded from here other than eclogite.

* FRANK SMITH - WELTEVREDEN, BARKLY WEST (28°15'S, 24°30'20"E).

At this locality there are two blows on one kimberlite dyke. For many years they were mined separately, but to-day one company works both and operates one processing plant. All assemblages given below could have come from either of these blows.

Ol - Opx SCHUTTE (1967, p.12, Plates V and X).
Ol - Gt SCHUTTE (1967, p.20), SIEBERT (1968)
Cpx - Gt SCHUTTE (1967, p.17)
Ol - Opx - Cpx SIEBERT (1968)
Ol - Opx - Gt SCHUTTE (1967, p.12, Plates 8B, 11A), SIEBERT (1968)
Ol - Opx - Cpx - Gt SIEBERT (1968)
Il - Cpx WILLIAMS (1932, p.35, Plate 123).

Only the Cpx - Gt assemblage has not been confirmed. SCHUTTE (1967, p.17) recorded Cpx - Gt - Phlogopite - Il as 'clinopyroxenite', and he also noted garnetites and orthopyroxenites here which could yield other mineral combinations.

GANSFONTEIN, NEAR BEAUFORT WEST (31°46'S, 22°34'E).

Ol - Opx ROGERS (1910, p.56)
Ol - Cpx - Gt ROGERS (1910, p.56)

The only record of xenoliths at this locality has been that of ROGERS (1910, p.56), who noted a strange biotite-ilmenite and minor enstatite and olivine rock (No. 2640) in addition to the above. This locality has not been visited recently.

HLANGWINI LOCATION, EAST GRIQUALAND (30°06'30"S, 29°01'E).

The sole description of xenoliths read ".... parts are full of small holocrystalline ultra-basic inclusions..." DU TOIT (1913, p.101).

* KAMFERSDAM, KIMBERLEY (28°41'30"S, 24°44'E).

Ol - Opx
Ol - Opx - Cpx SIEBERT (1968)
Ol - Opx - Gt SIEBERT (1968)
Ol - Cpx - Gt SIEBERT (1968)
Ol - Opx - Cpx - Gt SIEBERT (1968)

The fourth of these assemblages relates to a dunite with about 77% olivine, and is not therefore an olivine-eclogite such as SCHUTTE (1967) has described from Bellsbank. Indeed, RICKWOOD, MATHIAS and SIEBERT (1968) demonstrated that the properties of the garnet in this rock were dissimilar to those of garnets in eclogites.

* KIMBERLEY MINE (BIG HOLE) (NEW RUSH) (COLESBERG KOPJE) (28°44'15"S, 24°46'E)

Ol - Opx BECK (1907, p.293)

Opx - Cpx DU TOIT (1906, p.160)

Ol - Opx - Gt SIEBERT (1968)

Ol - Opx - Cpx - Gt

Accounts of xenoliths from the most famous type locality of kimberlite are the three cited above and the following generalities :

(a) "Peridotites must be extremely rare, for after a prolonged search I obtained only one specimen", DU TOIT (1906, p.136).

(b) "Peridotites and pyroxenites present by scarce", WILLIAMS (1932, p.304). We now possess two of the four mineral assemblages yet found.

LEKKERFONTEIN, 20 m. N.E. PHILIPSTOWN (30°21'S, 24°38'E).

Il - Opx KEYSER (1940, p. 71 - 72).

KEYSER (1940 p.75) recorded a serpentinised peridotite with olivine altered to serpentine and biotite altered to chlorite, together with an 'altered eclogite', in which he described purple and pink garnets. These garnets are more the colour of those that occur in peridotites and pyroxenites rather than in eclogites. The above coordinates were published by KEYSER (1940).

* MARKT (BEESTPAN), 60 m. S.S.W. PRIESKA (30°15'S, 22°22'E).

Ol - Opx

Ol ? - Opx - Cpx

Rocks with the above assemblages were collected in 1967. Three of them had recognisable ortho and clino-pyroxenes set in serpentine and it is inferred that the latter came from olivine.

* MELTON WOLD, VICTORIA WEST DISTRICT, (31°27'S, 22°47'E).

Ol - Opx - Cpx

Ol - Opx - Gt

Ol - Opx - Cpx - Gt.

A series of decomposed xenoliths of characteristic pancake shape were obtained in 1967; the above assemblages were still recognisable.

* MITCHEMANSKRAAL (-DOORNKLOOF-SOVER) FISSURES, BARKLY WEST (28°10'S, 24°30'E).

Ol - Opx - Cpx - Gt SCHUTTE (1967, p.13, 21).

In the only non-eclogitic ultramafic xenolith found here, SCHUTTE recorded the above minerals and noted that the total pyroxene content exceeded 90%. He also described dunite, clinopyroxenite and orthopyroxenite as being present. We only found eclogites.

NEW BRISTOL, EAST GRIQUALAND (29°59'20"S, 29°18'30"E).

Opx - Cpx - Gt DU TOIT (1913, p.101)

DU TOIT (1913, p. 101) wrote, "A few small boulders of ultrabasic rocks were found, one being a very handsome bronzite - chrome diopside - garnet rock".

* NEWLANDS, BARKLY WEST (28°21'S, 24°24'E).

Ol - Opx BECK (1907, p.295)

Opx - Gt BONNEY (1899, p.179-180)

Ol - Opx/.....

Ol - Opx - Cpx BONNEY (1900, p.475-6), BECK (1907, p.295).
Opx - Cpx - Gt GRAICHEN (1903,p.451), BECK (1907, p.298).
Ol - Opx - Cpx - Gt BONNEY (1900, p.476-7)

This mine has been visited by G.W. Berg, who did not discover any of the above xenoliths; (Pers. comm. 8/1/69). BECK (1907, p.298) described a rock consisting of garnet, clinopyroxene and an orthopyroxene mixture of enstatite and bastite in which the orthopyroxene was a major component. This rock type is thus distinct from the enstatite-eclogites, which he also mentions (p.296-7), for in these the orthopyroxene is present in minor quantities. Clearly, this rock type forms a link between eclogites and pyroxenites and any sub-division is artificial. Since it has been convenient to discuss the occurrences of eclogite separate from the remaining ultramafic rock xenoliths, RICKWOOD, GURNEY and WHITE-COOPER (1969), such a false subdivision has been unavoidable.

NOENIPUT (WITKOP) 90 m. N.W. OF UPINGTON (27°32'S, 20°11'E).

Ol - Cpx - Gt ROGERS (1907, p.91)

This is one of the two xenoliths found here; the other is an eclogite.

POSTMASBURG MINE, FARM BLINKKLIP M. 69, 2¼ m. E.N.E. POSTMASBURG, (28°19'10"S, 23°06'E).

Ol - Opx - Gt WILLIAMS (1932, Plate 136)

Our portion of this rock does not contain recognisable olivine or orthopyroxene. WILLIAMS described it as being "almost completely altered to chalcedony". (1932,caption to Plate 136).

ROBERTDALE, EAST GRIQUALAND (36°06'55"S, 28°49'45"E).

....."there is an abundance of ultrabasic xenoliths, some carrying chrome diopside...." DU TOIT (1929, p.27).

SANDDRIFT, 18 m. N.E. PRIESKA (29°30'40"S, 22°56'E).

"Boulders of peridotite" have been recorded by DU TOIT (1907, p.185-6), but nothing similar could be found in 1967 by Mr. F.W. SCHUMANN.

* SECRETARIS, 17 m. W. OF KIMBERLEY (28°42'30"S, 24°30'30"E).

Ol - Opx - Gt WILLIAMS (1932, p.401, Plate 139).

The only recognisable minerals in our portion of the above xenolith were garnet and antigorite (confirmed by X-ray diffraction). HARGER (1905, p.125) recorded garnet-pyroxenite xenoliths. MR. D.R. WHITE-COOPER found no ultrabasic xenoliths when he visited this locality in 1969, and he reported that samples in the Kimberley Museum labelled "eclogite" are "garnet-pyroxene peridotites". - (Pers. Comm. 3/2/69).

SIBI, EAST GRIQUALAND. TWO PIPES. (30°09'55"S, 28°47'45"E)(30°10'S, 28°47'45"E).

DU TOIT (1929, p.27) mentioned ".....cognate ultrabasic rocks....." were in the larger and more southerly of two pipes 150 yards apart, and "....some cognate xenoliths....." were in the northern pipe.

* SYDNEY-ON-VAAL, BARKLY WEST, (28°29'S, 24°17'E).

Ol - Opx

A core supplied by D.R. WHITE-COOPER contained a portion of a very altered olivine-orthopyroxene xenolith.

TAYLOR's KOPJE, KIMBERLEY (28°44'20"S, 24°44'E).

Ol - Opx - Cpx DU TOIT (1906, p.161)

This is the only xenolith on record apart from a mica-diopside nodule also described by DU TOIT (1906, p.160).

* WESSELTON, (FORMERLY KNOWN AS PREMIER), KIMBERLEY (28°46'S, 24°50'E).

Ol - Opx	SIEBERT (1968)
Ol - Cpx	WILLIAMS (1932, p.356-7)
Ol - Opx - Cpx	HOLMES (1936, p.397-8), SIEBERT (1968)
Ol - Opx - Gt	SIEBERT (1968)
Opx - Cpx - Gt	SIEBERT (1968)
Ol - Opx - Cpx - Gt	WILLIAMS (1932, p.356-7), SIEBERT (1968)

WILLIAMS (1932, p.356-7) listed the minerals olivine, diopside and phlogopite in specimen 153, the only known xenolith from this locality with this assemblage. Earlier (p.304) he had stated "...pyroxenites present, but scarce". We have examined one, 152, in which WILLIAMS (1932, p.356-7) recorded olivine, but which we have not found in the thin section available.

WEST END, 1 m. N.N.E. POSTMASBURG, (28°19'20"S, 23°04'30"E).

WILLIAMS (1932, p.305) referred to "...fine specimens of cognate xenoliths ....", but no details were given.

WIMBLEDON SIDING, 7 m. S.S.W. OF KIMBERLEY (28°49'S, 24°43'E).

DU TOIT (1906, p.143) mentioned that the two oval-shaped bodies contain peridotite xenoliths. He subsequently described one (p.161) as consisting of serpentinised olivine - mica - ? kyanite. His identification of kyanite was uncertain.

B. Orange Free State

* BLAAUBOSCH MINE, 15 m. W. OF BOSHOF (28°33'30"S, 25°27'E).

Ol - Opx

The above assemblage occurs in a greatly serpentinised xenolith that I found in 1969. It is the only xenolith on record to substantiate WILLIAMS (1932, p.305) claim to their presence.

* CROWN (LACE) MINE, 18 m. N.W. KROONSTAD (27°27'S, 27°06'E).

In writing about Newlands, Crown and Roberts-Victor mines, WILLIAMS (1932, p.305) stated, "None of these three mines has produced many of the more common peridotite and pyroxenite nodules". Some of these do occur at Roberts-Victor, and thus the inference is that some varieties are also present at Crown Mine. Mr. D.R. WHITE-COOPER did not find any during a recent visit.

* JAGERSFONTEIN (29°46'S, 25°25'E).

Ol - Opx	WILLIAMS (1932, p. 358-9), SIEBERT (1968)
Ol - Cpx	WILLIAMS (1932, p. 360-1)
Opx - Cpx	WAGNER, (1914, p.133), HOLMES & PANETH (1936, p.390)
Ol - Opx - Cpx	SIEBERT (1968)

Ol - Opx /.........

Ol - Opx - Gt WILLIAMS (1932, p.345,358-9, 360-1, Plates 41, 46), SIEBERT (1968)

Opx - Cpx - Gt

Ol - Cpx - Gt WAGNER (1914, p.135), WILLIAMS (1932, p.360-1)

Ol - Opx - Cpx - Gt WAGNER (1914, p.135), SIEBERT (1968)

Il - Cpx HARGER (1905, p.128)

Six of the above assemblages are confirmed. Assemblages of Ol - Cpx, Ol - Cpx - Gt were described by WILLIAMS (1932, p.360-1) as being in specimens in our collection. The former (369) contains Ol - Opx - Cpx and the latter (370) does not have olivine. WAGNER (1914, p.135) recorded ol - cpx - gt - phlogopite - graphite in a rock which is not eclogitic. Il - cpx assemblages have not been seen, nor can confirmation be given of the unusual hypersthene - enstatite - diopside - vaalite - serpentine xenolith also recorded by HARGER (1905, p.125). Another strange assemblage is that of ol-enstatite - gt - graphite - pyrrhotite - mica - zircon noted by WAGNER (1916a, p.54-55). Our opx - cpx - gt assemblage exists in a small nodule found by Mr. D.R. WHITE-COOPER, and consists of clinopyroxene and garnet totally enclosed within orthopyroxene.

* KOFFIEFONTEIN (KOFFYFONTEIN) (29°25'S, 24°59'30"E).

Ol - Opx - Cpx HARGER (1911, p.66)

Opx - Cpx - Gt HARGER (1911, p.66)

The latter assemblage is confirmed in xenoliths provided by Mr. D.R. WHITE-COOPER. In addition to these assemblages, HARGER (1911,p.66) stated that there were "many other variations seen in the nodular and boulder form in blue ground", but WILLIAMS (1932, p.304) mentioned that both peridotites and pyroxenites are very rare.

A four-phase assemblage reported by RICKWOOD, MATHIAS and SIEBERT (1968) and SIEBERT (1968), specimen No. WC KOFF, actually came from Poortje and not Koffiefontein.

LEEUWFONTEIN, NEAR REDDERSBURG (29°46'S, 26°28'30"E).

Opx - Cpx - Gt

This assemblage is to be found in xenolith 2525 in the Kimberley Museum.

MONASTERY (MONASTRY) (VILJOEN'S RUSH), 10 m. S. of MARQUARD (28°49'S, 27°25'E).

Ol - Opx	WILLIAMS (1932, Plate 109)
Ol - Cpx	ROGERS & DU TOIT (1904, p.78)
Ol - Opx - Cpx	HARGER (1905, p.125)
Ol - Opx - Gt	LACROIX (1898, p.26)
Ol - Cpx - Gt	ROGERS and DU TOIT (1904, p.78)
Ol - Opx - Cpx - Gt	WILLIAMS (1932 Plate 40), SIEBERT (1968)
Ol - Opx - Cpx - Amph	
Opx - Cpx - Gt - Amph	ROGERS and DU TOIT (1904, p.77)
Il - Opx	HARGER (1905, p.123), WAGNER (1914, p.132)
Il - Cpx	LACROIX (1898, p.23), WAGNER (1914, p.132)
Il - Gt	WAGNER (1914, p.132)
Il - Serp	WILLIAMS (1932, Plate 122)

HARGER (1905, p.125) gave only one mineral assemblage of a xenolith from Monastery, but he also stated the presence of pyroxenites (p.124). Three very unusual assemblages are cited by ROGERS and DU TOIT (1904, p.77-8) - (a) enstatite - garnet - augite - hornblende; (b) bright green augite containing chromium - colourless augite - biotite - olivine - garnet - ilmenite; and (c) olivine - pale green augite - colourless augite - biotite. A peridotite xenolith illustrated by WILLIAMS (1932, Plate 40) has been examined by SIEBERT (1968) and found to contain garnet - olivine - enstatite and diopside. We possess rocks with the assemblages cl - opx, ol - opx - cpx - amph.

This mine is best known for the unusual xenoliths in which ilmenite is intergrown with ortho- or clino-pyroxene. The ilmenite - garnet rock listed above is described as being an aggregate of these minerals; WAGNER (1914, p.132) In the text of his book, WILLIAMS (1932, p.35) referred to an illustration (Plate 122) of specimen 315 as being an eutectic of ilmenite and diopside, the latter having completely altered to serpentine. But, on p.384 he wrote that this serpentine formed after olivine or enstatite, and yet the caption to the photograph states a change from olivine or diopside. Our sample of that rock contains only ilmenite, serpentine and calcite.

JOHNSON (1910, p.31) recorded "numerous examples of a peculiar magnetite - pyroxenite, the two components of which are in graphic intergrowth". It is most likely that he saw ilmenite intergrown with pyroxene.

* <u>NEW ELANDS MINE, 3 m. N. of FARM BLAAUBOSCH (28°30'30"S, 25°29'E).</u>

WILLIAMS (1932, p.305) wrote, "Fine specimens of cognate inclusions have also been found in ....", but we found none in 1967.

<u>PHOENIX MINE, 1 m. N.E. THERON SIDING (28°19'S, 26°46'E).</u>

WILLIAMS' (1932, p. 305) statement just cited was also applied to this mine.

* <u>POORTJE, NEAR KOFFIEFONTEIN (29°26'30"S, 25°06'E).</u>

Ol - Opx - Cpx - Gt RICKWOOD, MATHIAS & SIEBERT (1968), SIEBERT (1968)

In our earlier publications, this rock (WCKOFF) was erroneously reported to have been collected at Koffiefontein; it was supplied by Mr. D.R. WHITE-COOPER.

* <u>ROBERTS VICTOR (ROVIC) (DAMPLAATS) NEAR BOSHOF, (28°28'43"S, 25°33'44"E).</u>

Ol - Opx - Cpx	JOHNSON (1907, p.118), SIEBERT (1968)
Ol - Opx - Gt	
Ol - Opx - Cpx - Gt	JOHNSON (1907, p.118), WILLIAMS (1932, p.360-1, Plate 135), SIEBERT (1968).

JOHNSON (1908, p.113) referred to lherzolite xenoliths and in 1910 (p.19), he added garnet - peridotites. Nobody visiting this locality could fail to notice the paucity of peridotitic nodules and the abundance of eclogites.

One of our samples contains opx - gt and serpentine; the latter has been presumed to be after olivine.

<u>STAR (WYNANDSFONTEIN) 9½ m. N.E. OF THEUNISSEN (28°18'30"S, 26°50'E).</u>

In the only known reference, ALLAN (1961, p.310), indicated the presence of "cognate inclusions".

* VOORSPOED/.....

* VOORSPOED, 18 m. N.N.W. OF KROONSTAD (27°23'30"S, 27°12'E).

Although WILLIAMS (1932, p.305) wrote, "Fine specimens of cognate inclusions have also been found in .....", he had earlier noted (p.35) that HARGER was unable to find any. Mr. D.R. WHITE-COOPER was also unable to find any in 1968.

ZWARTRANDSDAM, NEAR KOFFIEFONTEIN (29°20'S, 25°15'E).

WAGNER (1914, p.135) mentioned the presence of graphite "in a xenolith of lherzolitic composition".

C. Transvaal

DERDEPOORT, EAST OF PRETORIA (25°41'40"S, 28°17'20"E).

Nodules of "hard peridotite" were reported to have been found in yellow ground in No. 4 prospecting pit; Anon. (1912, p.689).

MONTROSE No. 2, ¾ m. N.N.E. OF RAYTON, (25°45'15"S, 28°32'E).

Ol - Opx WAGNER (1911, p.47)

WAGNER stated that these nodular aggregates were fairly common.

* PREMIER MINE 21 m. N.E. OF PRETORIA (25°40'20"S, 28°31'E).

Ol - Opx	WAGNER (1911, p.55)(1914, p.95), WILLIAMS (1932, p. 358-9)
Ol - Opx - Cpx	WAGNER (1911, p. 55)(1914, p.95)
Ol - Cpx - Gt	WAGNER (1911, p.55)(1914, p.95)
Ol - Opx - Cpx - Gt	WAGNER (1914, p.95)
Ol - Cpx - Graphite - Pyrite	WILLIAMS (1932, p.387)
Il - Opx	WAGNER (1911, p.55) (1914, p.95)

WILLIAMS (1932) mentioned pyroxenites twice, once together with peridotites as being scarce, (p.304), and also when referring to a segregation within a pyroxenite (p.358-9). In neither case did he list the minerals present.

Two unusual xenoliths have been discovered here and it has not been possible to substantiate their identity. The olivine - diopside - pyrope rock listed above is not included with eclogites by WAGNER (1911, p.55), and so should be given in this paper. WILLIAMS (1932, p.387) noted a very unusual rock containing olivine - diopside - graphite - pyrite.

Xenoliths of ol - opx, and ol - opx - cpx - gt are in our possession.

• ZONDERWATER (SONDER WATER) NEAR PREMIER MINE (25°41'S, 28°33'E).

Ol - Opx WAGNER (1911, p.48)

In addition to the above, WAGNER also recorded the diopside - phlogopite assemblage. WILLIAMS (1932, Plate 42) illustrated a xenolith in its matrix and referred to the nodule as an "enstatite-peridotite"; this also consisted of olivine and orthopyroxene (Specimen No. 281) and is in our collection.

D. South West Africa/.....

D. South West Africa

LOUWRENCIA, NEAR GIBEON (25°18'30"S, 17°48'30"E).

Ol - Opx - Cpx - Gt NIXON et al. (1963, p.1093, 1099)

No other details of this locality are available.

MUKORUB (MUKEROP)(MUKOROB) PIPE, 30 m S.E. OF GIBEON (25°30'S, 18°10'E).

Ol - Cpx SCHEIBE (1906, p.14), WAGNER (1916b, p.72)

Ol - Cpx - Gt SCHEIBE (1906, p.14), WAGNER (1916b, p.72)

Gt - Cpx - Mica WAGNER (1914, p.100)

In close proximity to this pipe are a series of dykes which FRANKEL (1957, p.118) described as being olivine melilitite in composition. They contain xenoliths which constitute up to 75% of the rock volume, and amongst them FRANKEL has recorded eclogite, pyroxenite and garnet-ilmenite (p.116) and ilmenite-pyroxene, olivine-enstatite-bronzite and olivine-ilmenite (p.120). These xenoliths he believed to be similar to those found in kimberlite and he concluded that the neighbouring kimberlite and olivine melilitite were related genetically.

TANZANIA

In spite of the finding of over 200 kimberlite bodies in Tanzania, EDWARDS and HOWKINS (1966, p.541), there are only two records of localities with peridotitic xenoliths.

MABUKI (02°57'S, 33°10'E).

Ol - Cpx - Gt - Il WILLIAMS (1939, p.13)

Il - Opx WILLIAMS (1939, p.32, Plate 111, Fig. viii)

The latter are described as intergrowths of ilmenite and enstatite.

SULTAN PIPE (03°43'30"S, 33°25'E).

WILLIAMS (1939, p.21) wrote ".....and ultrabasic garnet-bearing nodules have been found".

CAPTIONS TO ILLUSTRATIONS

FIG. 1. XMW5 - A discoidal, altered, garnet-lherzolite (ol-opx-cpx-gt) from Melton Wold, C.P.

FIG. 2. 152 - Garnet-pyroxenite (opx-cpx-gt), Wesselton Mine. C.P., with polished exterior.

FIG. 3. AA7 - Foliated garnet-harzburgite (ol-opx-gt) from one of the Kimberley Mines, C.P.

FIG. 4. W397 - Garnet lherzolite (ol-opx-cpx-gt) Premier Mine, T.V. Peripheral alteration is revealed by the orthopyroxene crystals which appear white on this photograph.

FIG. 5. A map of the kimberlite localities in Southern Africa which contain non-eclogitic ultramafic xenoliths.

LOCALITY NUMBERS:

CAPE PROVINCE. 1. Gansfontein, 2. Melton Wold, 3. Markt, 4. Sanddrift, 5. Noeniput, 6. West End, 7. Postmasburg, 8. Bobbejaan, 9. Bellsbank, 10. Excelsior, 11. Mitchemanskraal, 12. Frank Smith, 13. Newlands, 14. Sydney-on-Vaal, 15. Secretaris, 16. Lekkerfontein, 17. Abbotsford, 18. Sibi, 19. Robertdale, 20. Hlangwini Location, 21. New Bristol, 22. Clarkton.

Inset map of Kimberley Area:

23. Kamfersdam, 24. Taylor's Kopje, 25. Kimberley Mine ('Big Hole'), 26. De Beers, 27. Du Toitspan, 28. Bultfontein, 29. Wesselton, 30. Wimbledon Siding.

ORANGE FREE STATE:

31. Leeufontein, 32. Jagersfontein, 33. Zwartrandsdam, 34. Poortje, 35. Koffiefontein, 36. Blaaubosch, 37. New Elands, 38. Roberts Victor, 39. Phoenix, 40. Star, 41. Monastery, 42. Crown, 43. Voorspoed.

TRANSVAAL:

44. Derdepoort, 45. Premier, 46. Zonderwater, 47. Montrose No. 2.

LESOTHO:

48. Ngopetšoeu, 49. Koenaneng, 50. Lipelaneng, 51. Sekameng, 52. Khabos.

Inset Map of Maluti Mountains:

53. Thaba Putsoa, 54. Lemphane, 55. Liqhobong, 46. Malibamatso, 57. Kao, 58. Matsoku, 59. Motai, 60. Qaqa, 61. Letseng-la-Terai, 62. Robert.

RHODESIA:

63. Moffat, 64. Wessels, 65. Colossus.

SOUTH WEST AFRICA:

66. Mukorub, 67. Louwrencia.

TANZANIA:

68. Sultan, 69. Mabuki.

FIG. 1. XMW5 - A discoidal, altered, garnet-lherzolite (ol-opx-cpx-gt) from Melton Wold, C.P.

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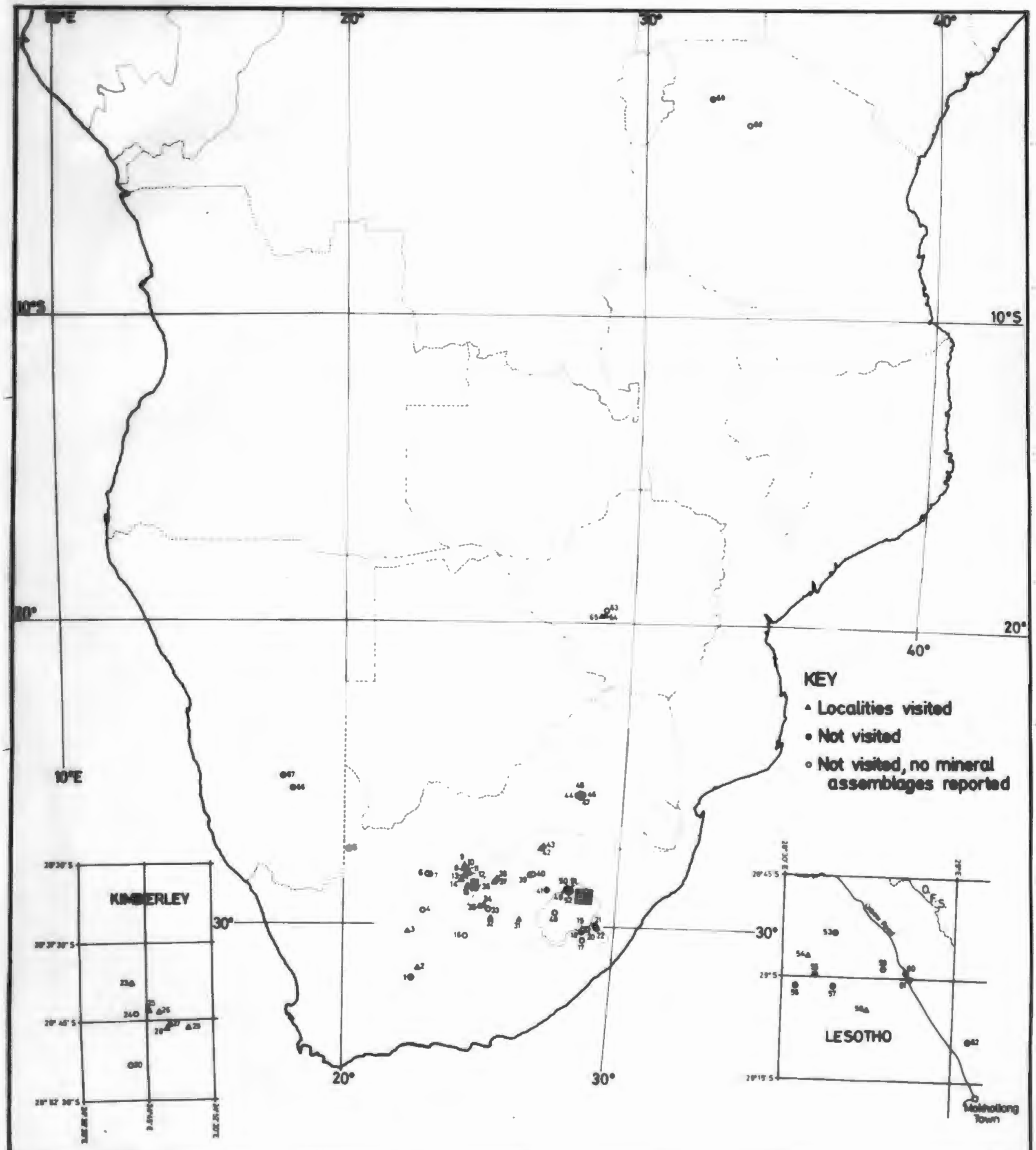

FIG. 5. A map of the kimberlite localities in Southern Africa which contain non-eclogitic ultramafic xenoliths.

C H A P T E R 3

THE NATURE AND OCCURRENCES OF ECLOGITE XENOLITHS IN THE KIMBERLITES OF SOUTHERN AFRICA.

Accepted for publication in

"The Transactions of the Geological Society of South Africa".

Specific observational contributions of my co-authors and myself are clearly indicated in the appendix. In addition, Dr. J.J. GURNEY provided translations of the literature relevant to the Congo République, and assisted me with the writing of the numerous letters requesting information. Otherwise, the initiation of the study, the survey of the literature, and the production of the first draft manuscript, were my responsibilities.

I certify that the above statement by the candidate is a true assessment of his contribution to this paper.

Signed Ph.D.