Explor. Mining Geol., Vol. 1, No. 4, pp. 371-381, 1992
Printed in the U.S.A.

0964-1823/92 $5.00 + .00

Pergamon Press Ltd.

Contrasting Kimberlites and Lamproites

BARBARA H. SCOTT SMITH
2555 Edgemont Boulevard, North Vancouver, British Columbia, Canada, V7R 2M9

Received February 28, 1992, accepted July 14, 1992

Abstract — During the last two decades lamproites have joined kimberlites as the only two known primary sources of economic quantities of diamonds. This paper contrasts the petrography, primary and xenocrystic mineralogy and pipe geology of these petrogenetically separate rock types. The petrographic discrimination of kimberlites and lamproites from each other, as well as other rock types found during diamond prospecting, is discussed. Kimberlites and lamproites can be classified texturally and mineralogically. Such classifications highlight the differences between, and among, lamproites and kimberlites. The implications of these differences for diamond exploration programs are discussed, with particular emphasis on the application of petrography.

Introduction

Kimberlite was the term coined in the late 19th century to describe the host rock of diamond at the type locality, Kimberley, South Africa (Lewis, 1887, 1888). Innumerable kimberlites are now known worldwide; some of them contain economic quantities of diamond (e.g. South Africa, Botswana and Russia) while many are barren. Jennings (1989) suggests that less than 3% of the known kimberlites can be considered to be commerical. Kimberlite was thought to be the only important primary source of diamond for approximately a century. Until the late 1970s, lamproites were thought to be only academic curiosities. Some workers (e.g. Wade and Prider, 1940), however, did comment on certain similarities between lamproites and kimberlites and, hence, inferred a potential for lamproites to carry diamonds.

The term lamproite was introduced by Niggli (1923) for leucite-bearing rocks from southeast Spain and Wyoming which had some unusual geochemical characteristics. Wade and Prider (1940) used the term lamproite (as defined by Troger, 1935) to embrace rock types found in the West Kimberley area of Western Australia. All the lamproites described by Wade and Prider (1940) form distinct topographic features. Subsequently in the late 1970s, additional pipes, which have little or no relief, were discovered in the same area, but only as the result of a major diamond exploration program (Atkinson et al., 1984; Jaques et al., 1984, 1986). Some of these bodies are diamondiferous. In 1979, the Argyle pipe was discovered in the East Kimberley area which, in terms of grade, is the richest known primary diamond deposit in the world with some parts of the body having grades greater than 500 carats/100 tonnes (Madigan, 1983; Boxer et al., 1989). All the initial new discoveries in Western Australia resulted from classic stream sampling for "kimberlite indicator minerals" (Atkinson, 1989).

In addition to kimberlite, lamproite, therefore, is now known to be a second important primary source of diamond. Both rock types are products of continental intraplate alkaline volcanism. When compared to other alkaline rocks, they are relatively small in volume but, as a result of their economic importance, the nature of kimberlites and lamproites is much better understood.

Various aspects of the geology of kimberlites and lamproites are outlined here to show that they are distinctly different rock types. Recent reviews of the nature of kimberlites and lamproites are given by Mitchell (1986) and Mitchell and Bergman (1991), respectively. Other useful reviews are Mitchell (1991a) and Geological Survey of Canada (GSC) open file report (1989).

It is not possible to make this review particularly relevant to Canada. Innumerable kimberlites are known worldwide, for example, approximately 450 kimberlite bodies are known in South Africa alone (Skinner, 1989). In contrast, confirmed kimberlites occur at only seven localities in Canada (Fig. 1), although some of these occurrences do comprise several bodies (further details are given in the GSC Open File Report, 1989). The kimberlites in Canada are either barren or poorly diamondiferous and, so far, none have proven to be economic. As a result, most of these kimberlites are poorly documented. In contrast to kimberlites, only a few lamproites are known worldwide and none of these are in Canada. It has been suggested that the bodies, which occur near Golden in British Columbia, may be lamproites (GSC Open File Report, 1989) but this has not yet been confirmed (McCallum, 1991b). Confining or concentrating a review on Canadian occurrences, therefore, would not be particularly meaningful. Additional kimberlites, as well as several lamproites, however, are known to occur in the United States and Greenland. These include two marginally economic bodies. The Sloan kimberlites in northeast Colorado include one body that is 8 ha in size with reported grades of 8 to 20 carats/100 tonnes (Shaver, 1988; McCallum, 1991a; McCallum and Waldman, 1991). The most highly diamondiferous body (up to 46 carats/100 tonnes; McCallum and Waldman, 1991) known to date in North America occurs at George Creek in the same area

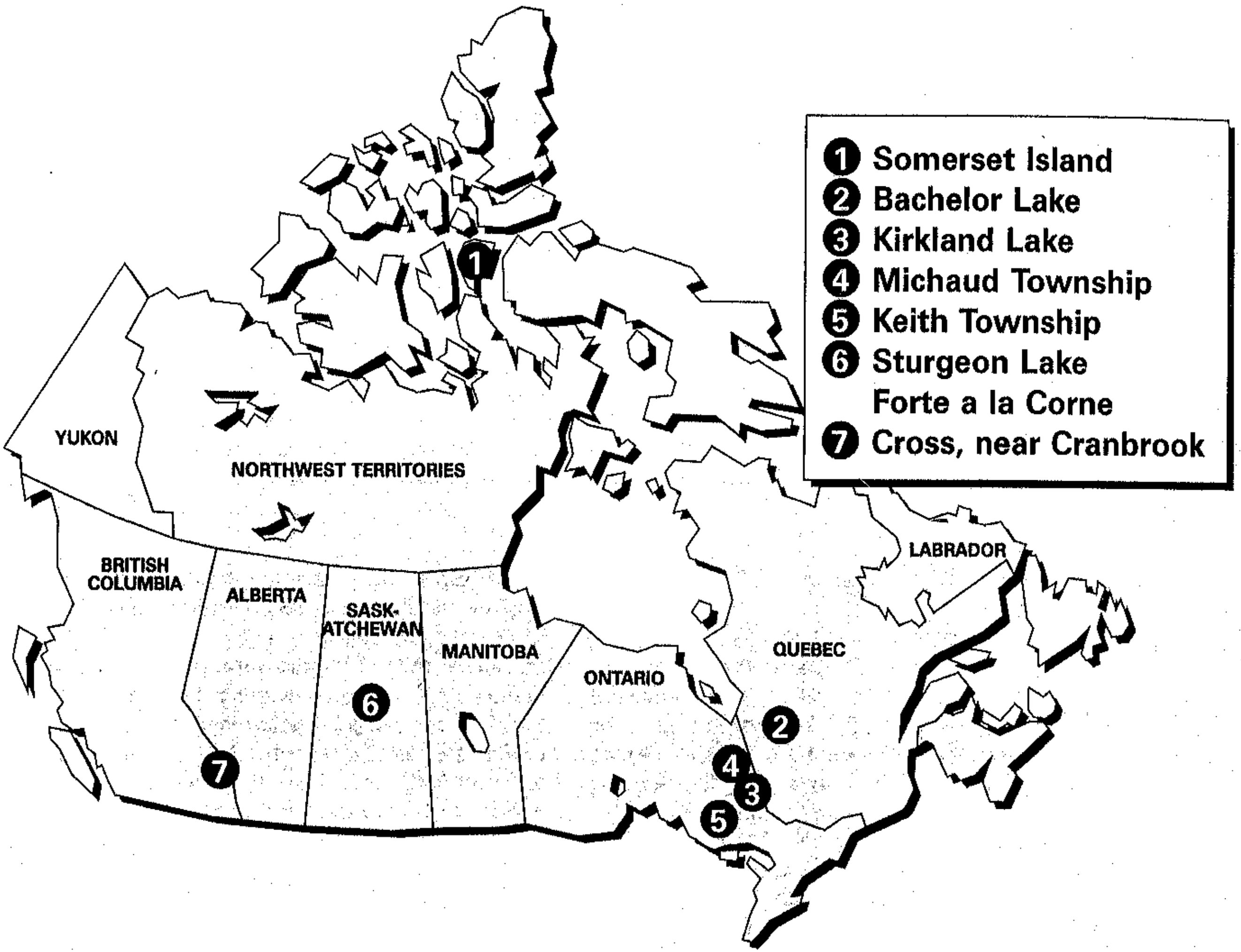

Fig. 1. Occurrences of kimberlite provinces in Canada. Note that no bona fide lamproite occurrences are known in Canada.

as Sloan. This body, however, is only a small dyke. At Prairie Creek in Arkansas part of the 28 ha lamproite body, which was mined during the earlier part of this century, has quoted grades of 10 to 20 carats/100 tonnes (Sinkankas, 1959; Hendrix, 1989).

Kimberlites

Petrography

Kimberlites are petrographically complex. They are hybrid rocks typically containing mantle-derived xenoliths and xenocrysts as well as a range of primary phases crystallized from a kimberlite magma, which may itself be derived from several mantle sources (Clement, 1982). Kimberlites also often contain abundant crustal derived material. Some kimberlites may contain diamond, but only as a very rare constituent. The contribution of any of these different sources varies widely between kimberlites. Further modal variation can result from magmatic processes such as differentiation. During the last two decades considerable effort has been expended in investigating these rocks. They are now relatively well understood (reviewed by Mitchell, 1986, 1989). Kimberlites contain abundant, relatively large (up to 10 mm) anhedral (often rounded) grains referred to as macarocyrsts (a term devoid of genetic inferences; Clement et al., 1977) set in a finer grained matrix. The origin of the macrocryst suite is still debated although some, and maybe most, of these grains represent xenocrysts derived from mantle-derived xenoliths and megacrysts (>1 cm). These grains are the so-called "kimberlite indicator minerals" recovered from heavy mineral concentrates in stream, loam or soil samples taken during diamond prospecting. In rare instances, aphanitic kimberlites may occur in which macrocrysts may be rare or absent (e.g. Apter et al., 1984). Primary phases in kimberlites comprise: (1) phenocrysts and microphenocrysts which are generally subhedral to euhedral and thought to have crystallized from the kimberlite magma prior to emplacement; they are typically dominated by olivine, but phlogopite may also occur, and (2) minerals which have crystallized more or less in situ to form the fine-grained groundmass (phlogopite, carbonate, serpentine, clinopyroxene, monticellite, apatite, spinels, perovskite, ilmenite and probably melilite). Cores of some of these so-called groundmass minerals, typically (Cr-rich) spinel, ilmenite and phlogopite, may have crystallized at depth but cannot be distinguished from the late stage minerals on the basis of grain size alone (e.g. Apter et al., 1984). All these primary phases display wide modal variations and any one kimberlite does not contain all these minerals. Small xenocrysts may resemble some of these primary phases. For example, euhedral neoblasts of olivine derived from recrystallized mantle peridotites are difficult to distinguish from olivine phenocrysts.

Definition

The following brief definition of kimberlite is modified from Mitchell (1986) and Clement et al. (1984). "Kimberlites are a clan of volatile-rich (CO_2 and H_2O), potassic, ultrabasic rocks. They exhibit a distinctive inequigranular texture resulting from the presence of macrocrysts (and in some instances megacrysts) set in a finer grained matrix. The macrocryst assemblage consists of anhedral grains which are dominated by olivine but include phlogopite, magnesian ilmenite, chromian spinel, magnesian garnet, clinopyroxene and orthopyroxene. The matrix contains phenocrysts of olivine and in some instances phlogopite, together with several of the following groundmass minerals: phlogopite, carbonate (typically calcite), serpentine (commonly Fe-rich), clinopyroxene (typically Al- Ti-poor diopside), monticellite, apatite, spinels (Ti-, Mg-chromite), perovskite and ilmenite. Alteration of macrocrysts and some matrix minerals by deuteric processes, typically serpentinization and carbonatization, is common."

Mineralogical Classification

Hypabyssal kimberlites can be described using the modal mineralogy of the primary groundmass minerals (Skinner and Clement, 1979). A kimberlite may be described as a "diopside phlogopite kimberlite", for example, where phlogopite is the dominant groundmass mineral and diopside is an important accessory mineral (<2/3 modal % of dominant mineral). For the purposes of this mineralogical classification, macrocrystal and phenocrystal olivine are ignored as they are ubiquitous. The five dominant groundmass minerals in most kimberlites are monticellite, phlogopite, diopside, calcite and serpentine. Other minerals typically present in accessory amounts may, in rare instances, be sufficiently abundant to be included as a modifier in a descriptive name, e.g. apatite-bearing carbonate kimberlite.

Geology and Textural Classification

Composite kimberlite pipe models (Hawthorne, 1975; modified by Mitchell, 1986) and kimberlite-specific textural-genetic classifications (Clement, 1982; Clement and Skinner, 1985; Clement and Reid, 1989; modified by Mitchell, 1986, 1989) note three dominant zones: crater, diatreme and hypabyssal (Fig. 2), each resulting from markedly different modes of emplacement. Craters have been preserved only in a few areas (e.g. Botswana, Tanzania) where erosion has been minimal (e.g. Mannard, 1962). In these areas of Africa the rocks are generally extensively altered. Fresher exposures are becoming available as a result of mining, but few modern investigations are published. Down rafted blocks of previously formed crater-facies kimberlite do occur in some diatremes (Clement, 1982). The nature of kimberlite craters (and the upper parts of the diatreme), therefore, is not well understood. Craters appear to be shallow, basin-like structures less than 1500 m in diameter. They are commonly less than 150 m deep but depths range up to 300 m. Craters may be infilled with extrusive volcaniclastic deposits including primary pyroclastics as well as reworked material which may include epiclastic kimberlite. Extrusive volcaniclastic deposits may occur below the flared crater in the top of the steep-sided part of the pipe and also outside the crater (e.g. tuff rings as discussed by Mitchell, 1986) but there is little available evidence.

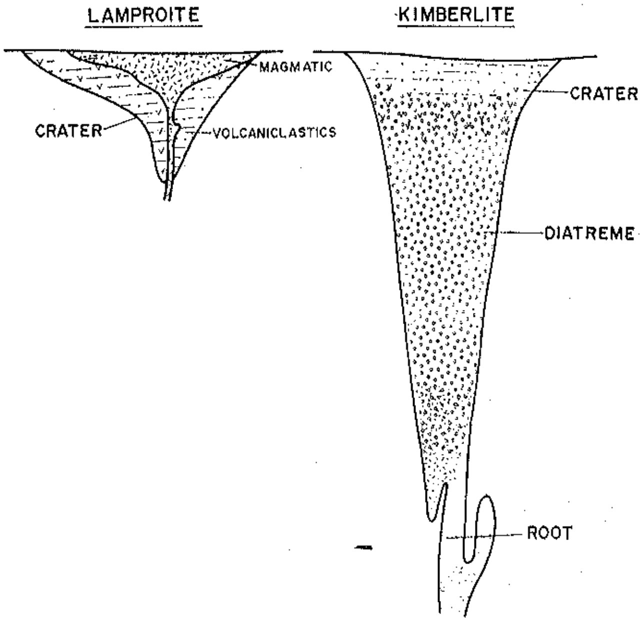

Fig. 2. A comparison of schematic simplified geological models of lamproite and kimberlite pipes (modified after Scott Smith and Skinner, 1984b). Not to scale.

Kimberlite diatremes are steep-sided (75 to 85 degrees) bodies typically less than 1000 m in diameter and less than 2000 m deep. Single intrusions are typically circular in plan. The diatreme zone of kimberlites is infilled mainly with structureless tuffisitic kimberlite breccias which are the end products of complex fluidized intrusive systems. They are characterized by fragmental textures resulting from the presence of rounded juvenile lapilli-like structures (termed pelletal lapilli by Clement and Skinner, 1985) as well as abundant xenoliths dominated by angular fragments of country rock. The inter-clast matrix is typically composed of serpentine and microlitic clinopyroxene that are quench products from kimberlitic fluids. Carbonate is typically absent from this matrix, probably reflecting degassing during diatreme formation.

Diatremes grade with depth into complex irregular root zones. Root zones, as well as dykes and sills, consist of hypabyssal kimberlite that most commonly displays a macrocrystic texture. The groundmass may be uniform or segregationary. In extreme cases they may develop globular

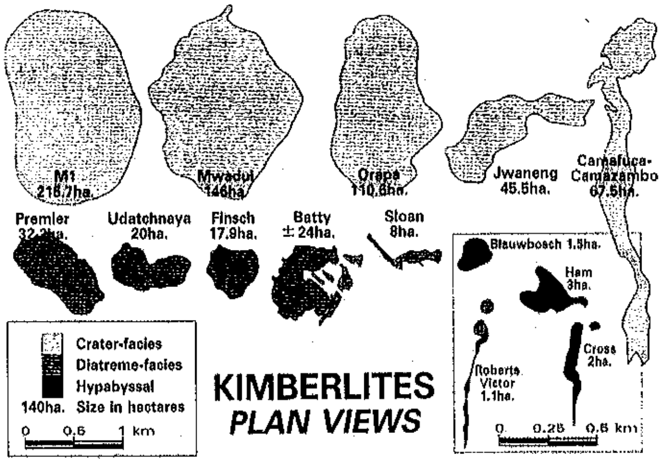

Fig. 3. Plan views of selected kimberlites sub-divided according to the facies exposed at surface (from Jennings, 1989; Chapman, 1980; Shaver, 1988; Wagner, 1914; Meeks, 1979; Jago and Mitchell, 1985; Kjarsgaard, publ. comm., 1991; unpublished information).

segregationary textures (Clement and Skinner, 1985) which should not be confused with volcaniclastic kimberlite. Kimberlite breccias (>15% xenoliths >4 mm in size) are common. Bona fide extrusive magmatic kimberlites, i.e. lavas, are not known.

Known kimberlites are obviously exposed at different levels of erosion within the kimberlite pipe (Hawthorne, 1975). Figure 3 includes plan views for a selection of kimberlites worldwide (M1, Orapa and Jwaneng in Botswana, Mwadui in Tanzania, Camafuca-Camazambo in Angola, Premier, Finsch, Blauwbosch and Roberts Victor in South Africa, Udatchnaya in Siberia, Batty, Ham and Cross in Canada, Sloan in the United States). This figure includes bodies for which the most detailed information is available which are, in turn, mostly mines. The variations in size and shape reflect the main features of the kimberlite model (Fig. 2). The larger bodies (up to 216 ha, Fig. 3), with minimal erosion, are exposed within the crater. Some of these craters may be composite bodies such as Jwaneng which is considered to represent three intrusions which have coalesced at surface (Clement, 1982). Kimberlites exposed within the diatreme zones are typically between 5 ha and 30 ha in size at surface. Until recently (see below) Batty in Somerset Island was the largest known kimberlite in Canada (Fig. 3). It is barren and detailed information is not available. It is reported to comprise diatreme-facies material (i.e. tuffisitic kimberlite; B. Kjarsgaard, public comm. in poster session of CIM Geological Society 1st Annual Field Conference, Saskatoon, September 1991). Sloan, the only sizeable and reasonably diamondiferous kimberlite in North America comprises the lower parts of the diatreme, approaching the root zone, where the geology becomes more complex (Fig. 3). Smaller hypabyssal kimberlites in both root zones and dykes have produced many successful small mines, such as Blauwbosch and Roberts Victor, shown in Figure 3. Geologically equivalent, but barren, examples of root zones occur in Canada, such as Cross in British Columbia and Ham on Somerset Island (Fig. 3).

Lamproites

Petrography

Lamproites include diverse rocks displaying a wide range of modal mineralogies, which is particularly noteworthy considering the small number of lamproites known. Each province also is different, exhibiting its own variations on a theme. Lamproites also have unusual mineralogies which is a reflection of their unusual magma compositions (e.g. Mitchell and Bergman, 1991). Macrocrysts of olivine and other mantle derived minerals occur in some, but not all, lamproites.

Definition

This brief definition is modified from Mitchell (1985) and Scott Smith and Skinner (1984 a,b). "The lamproite clan are a group of ultrapotassic mafic rocks characterized by the presence of one or more of the following primary phenocrystal and/or groundmass constituents with widely varying modal abundances: titanian, alumina-poor phlogopite, Fe-rich leucite, titanian potassic richterite, forsteritic olivine, diopside, Fe-rich sanidine and titanian tetraferriphlogopite. Minor and accessory phases include priderite, apatite, wadeite, perovskite, spinel, ilmenite, shcherbakovite, armalcolite and jeppeite. Glass may be an important constituent of rapidly chilled lamproites." This definition is augmented by many other mineral and whole-rock geochemical criteria (Mitchell and Bergman, 1991). Mantle-derived xenocrysts including olivine, chromite and pyrope garnet may also be present. Other phases such as analcime, barite, zeolite and carbonate are typically secondary.

Mineralogical Classification

To replace archaic and confusing terminology, it is now generally accepted that lamproites should be classified according to their modal mineralogy following a scheme similar to that for kimberlites (Scott Smith and Skinner, 1984 a,b; Mitchell and Bergman, 1991). In lamproites no mineral is truly ubiquitous or in reasonably constant proportions, so none are excluded from the mineralogical classification (in contrast to olivine in kimberlites). This classification is best applied to magmatic rocks. Six major sub-divisions of lamproites can be made according to the six most dominant minerals: leucite, phlogopite, amphibole, clinopyroxene, olivine and sanidine. Glass may also be abundant. Further sub-divisions use a modifier to reflect the presence of other modally significant phases (e.g. leucite phlogopite lamproite which is equivalent to the historically used term fitzroyite). Mitchell (1985) has suggested that the classification should be modified to take into account the habit of the phlogopite; phlogopite lamproite for those with phenocrystal phlogopite and madupitic lamproite where the phlogopite has a poikilitic groundmass habit. Perhaps a similar sub-division should be devised to cater for variations in the habit of other minerals such as olivine.

Geology and Textural Classification

Most lamproites comprise craters (Fig. 2) which are irregular, asymmetric, often relatively shallow (<300 m) and range in size up to 1500 m in diameter (or 124 ha; Fig. 4). The plan views of a selection of lamproites worldwide are shown in Figure 4 (Calwynyardah, Ellendale 4, 6 and 9 from the West Kimberley and Argyle from the East Kimberley, both in Western Australia, Kapamba in Zambia, Prairie Creek in Arkansas and Zirkel in Wyoming, the United States, Majhgawan in India). Except for Zirkel in the inset, all the bodies illustrated in Figure 4 are diamondiferous. Composite craters occur. For example, Ellendale 4 and 9 both comprise two coalesced craters (Fig. 4). Lamproite craters are infilled with extrusive volcaniclastic material, typically well bedded ash and lapilli tuffs, which are predominantly of pyroclastic origin (as illustrated, for example, in Figure 2.5 of Smith and Lorenz, 1989). Some of these rocks have been interpreted as base surge deposits. Volcaniclastic deposits probably also occur outside the crater but these have not been preserved. Reworking of the volcaniclastic deposits is also important. Bedding is common and may result from primary volcanic or secondary processes. Many of the volcaniclastic rocks examined from lamproite pipes comprise extremely variable proportions of both accidental and juvenile lapilli. The latter are typically glassy to scoriaceous. In many instances (e.g. parts of Argyle, Ellendale A and B, Kapamba P1, Prairie Creek) the xenolithic material consists mainly of single grains of quartz. In these cases, when juvenile material is rare or absent, the volcaniclastic rocks may resemble a sandstone. The volcaniclastic rocks in lamproite craters are often, but not always, intruded by magmatic lamproite that forms ponded lava lakes or domes (Figs. 2 and 4). Lamproite lavas are rare, except at the Leucite Hills in Wyoming. Zirkel, the largest of the bodies in the Leucite Hills which is shown in Figure 4, is the largest known lamproite. This, and other bodies in the Leucite Hills province, are formed by one or more lava flows. Associated volcaniclastic deposits, including cinder cones, are present. Lamproite dykes and sills occur also. In contrast to kimberlites, the textural varieties of rocks found in lamproites are similar to those of many other volcanic rocks, so existing terminology can be applied (e.g. Fisher and Schminke, 1984).

Summary

The definition of kimberlites and lamproites is based on their petrographic mineral assemblages (Table 1) which are augmented by both mineral and whole rock compositions. Both kimberlites and lamproites can be usefully classified both texturally and mineralogically using modal abundances: for example, hypabyssal monticellite kimberlite or phlogopite lamproite lapilli tuffs. Kimberlites and lamproites display markedly different modes of emplacement resulting in different pipe morphologies (Fig. 2). The differences between, and among, lamproites and kimberlites reflect different mantle sources, different petrogeneses and different near surface processes (see Mitchell, 1986; Mitchell and Bergman, 1991, for more detailed discussions).

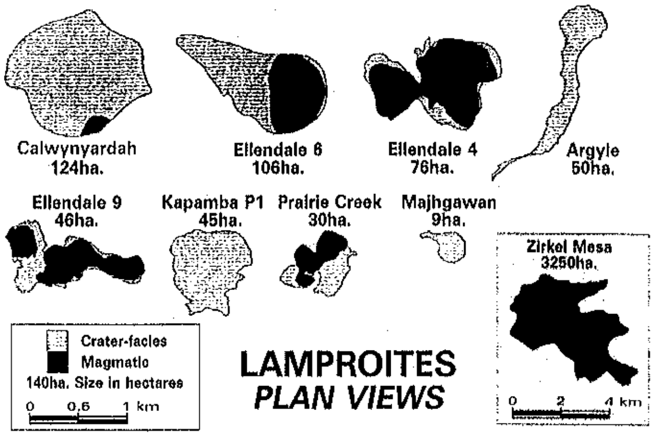

Fig. 4. Plan views of selected lamproites (after Jaques et al., 1984; Scott Smith et al., 1989; Bolivar and Brookins, 1979; Halder and Ghosh, 1974; Smithson, 1959; unpublished information).

Discussion and Implications for Exploration

The emergence of lamproites, in addition to kimberlites, as a second major source of diamonds has considerably increased the importance of petrography in diamond exploration (GSC Open File Report, 1989). Some of the significant differences between lamproites and kimberlites will be discussed below, with particular emphasis on the use of petrography in exploration.

Geology and Textural Classification

Comparing the models for kimberlites and lamproites (Fig. 2) has obvious implications for exploration, for example in the preservation, the determination of ore reserves and the evaluation of any bodies. The differences between the "champagne glass" versus "carrot" shaped pipes (Fig. 1) are the end result of markedly different modes of emplacement of each of the rock types. The different style of volcanism typical of, but not exclusive to, kimberlite, is thought to reflect the CO_2-rich nature of these magmas which is shown by the occurrence of common primary carbonate in hypabyssal kimberlites. Primary carbonate is rare in lamproites. The most obvious difference between the pipe models (Fig. 2) is that kimberlites appear to be much deeper intrusions than lamproites (up to 2000 m) with the development of an extensive diatreme and related root zone below the crater. The diatremes and root zones of kimberlites form the main ore reserve in many diamond mines including all those in South Africa and many in Russia. The equivalent of the kimberlite diatremes with their intrusive breccias and root zones have not been encountered in lamproites. Lamproites, therefore, appear to be much shallower intrusions (<400 m).

Both kimberlite and lamproite pipes have craters. Lamproite craters may be smaller in area than those of kimberlite (compare Figs. 3 and 4). In kimberlites, the crater is limited in extent when compared to the rest of the pipe, but can still comprise extensive ore reserves, such as found in the mines at Orapa, Jwaneng and Mwadui (Fig. 1). In contrast, the crater forms the main part of a lamproite pipe and, there-

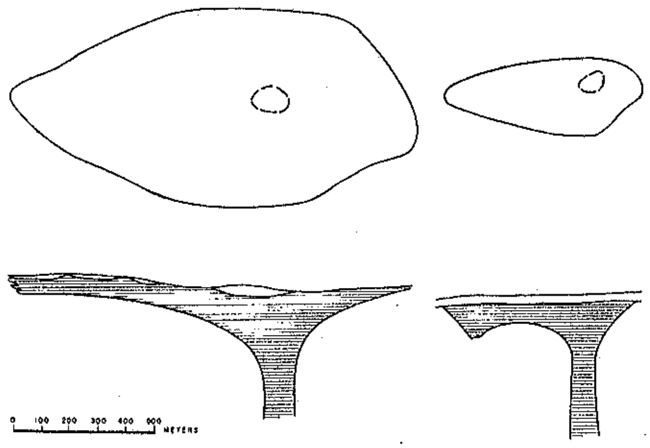

Fig. 5. Plan views (upper) and cross-sections (lower) of two kimberlite bodies in the Mbuji-Mayi (formerly Bakwanga) area of Zaire (after Meyer de Stadelhofen, 1963; Demaiffe et al., 1991). In the plan views, the inner dashed line indicates the size and location of the pipe at depth. In the cross-section, the kimberlite is hatched while the overburden is unshaded.

fore, the only significant potential ore reserve. Both kimberlite and lamproite craters are infilled mainly with pyroclastic and reworked material all of which have extremely complex diamond grade variations, even on a small scale.

In many but not all instances, lamproite craters are intruded by later magmatic lamproite which forms a lava lake or lava dome. The lava lakes are typically much lower in grade than the volcaniclastic rocks into which they intrude. At Ellendale A and B in Western Australia, for example, the volcaniclastic deposits may be economic while the magmatic material is not (Jaques et al., 1986). At Ellendale 4, the volaniclastic rocks have grades ranging from 1 to 30 carats/100 tonnes. The range in grade partly relates to dilution by xenocrystic quartz. The magmatic lamproite forming the extensive lava lakes (Fig. 4) contains only 0 to 1.5 carats/100 tonnes. Other forms of magmatic lamproites, i.e. lavas, dykes and sills, are also poor in diamond. Extrusive magmatic kimberlite is not known and is notably absent from kimberlite craters (Fig. 3).

The internal geology of kimberlite diatremes is usually relatively simple with fairly uniform diamond grades (Clement, 1982). Below the diatreme, the root zone typically is complex in both shape and internal geology resulting from multiple phases of intrusion during embryonic pipe development. Diamond grades in the petrographically distinct kimberlite types within the root zone can vary considerably (Clement, 1982 and reviewed by Gurney, 1989). For example, different intrusions in the root zone kimberlite of Wessleton Mine, South Africa, vary from 6 to 33 carats/100 tonnes.

The kimberlite and lamproite models presented in Figure 2 are simplified and schematic. One would expect the geology of actual bodies to deviate from these models. An example of a deviation from the kimberlite model may occur at Mbuji-Mayi (formerly Bakwanga) in Zaire where at least two bodies are reported to have shallow champagne-glass or crater-like shapes with a relatively narrow feeder as shown in Figure 5 (Meyer de Stadelhofen, 1963; Demaiffe et al., 1991). The rocks within these bodies include "green kimberlite breccias and tuffs showing graded bedding and cross-bedding" (Demaiffe et al., 1991). Little modern detailed information is available for these bodies, but they are presumed firstly, to be kimberlites from the information given by Demaiffe et al. (1991) and secondly, to be craters which have had no diatreme development.

All documented lamproite craters are limited in depth (<400 m) as summarized in Figure 2. In contrast, the pipe model presented for Argyle suggests that the body may have originally comprised a pipe 1600 m to 1700 m deep (Boxer et al., 1989). Most lamproite pipes have predominantly shallow contacts (Fig. 2). There are, however, a few example of steep sided lamproites. These include Argyle (although its shape has also been affected by post intrusion faulting, Jaques et al., 1986) and Majhgawan (Halder and Ghosh, 1974). Although these steep sided pipes may have some superficial resemblance to a kimberlite diatreme, they are infilled with extrusive volcaniclastic material which is not comparable to the intrusive tuffisitic kimberlite breccias occurring in kimberlite diatremes.

In a model for the Ellendale lamproites, the pipe has been subdivided into crater, diatreme and dyke zones (Smith and Lorenz, 1989). The infillings of the so-called crater and diatreme zones in this model are both similar and comprise extrusive volcaniclastic rocks. This so-called diatreme zone of lamproites, therefore, is not comparable to that of kimberlites and they must not be confused. The recognition of crater, diatreme and root zones is very meaningful for kimberlites because they contain distinctly different rock types resulting from different near surface processes. A similar threefold subdivision is not meaningful for lamproites, where only crater zones and hypabyssal lamproite are required. The crater zone of lamproites, however, include both extrusive volcaniclastic and essentially extrusive magmatic material (Fig. 2). Lamproites do not form diatremes or root zones analagous to those formed by kimberlites and a lamproitic equivalent of tuffisitic kimberlite is not known.

Recognition of Kimberlites and Lamproites

The recognition of kimberlites and lamproites is based on their contrasting petrographic mineral assemblages (Table 1). Kimberlites are composed of essential xenocrysts and phenocrysts, or two generations, of olivine set in a matrix composed of several of the other, primary, minerals listed in Table 1. Lamproites are characterized by one or more of the primary phenocrystal and/or groundmass constituents listed in Table 1. No one mineral is essential in lamproites but phlogopite is usually present. Glass and xenocrystic olivine also can be important constituents in lamproites. Olivine lamproites begin to resemble kimberlites when they contain two generations of olivine.

The minerals which are unique to each of these rock types, when most kimberlites and lamproites are compared, are indicated in Table 1. Some of the other minerals listed in Table 1, which are common to both rock types, have different characteristics that can also be used to distinguish kimberlites and lamproites. Firstly, these minerals may have different petrographic characteristics. For example, phlogopite phenocrysts in lamproites typically display polysynthetic twinning, whereas those in kimberlites do not. Secondly, the compositions of these minerals may be distinctive. For example, phlogopite in most lamproites can be distinguished from that in kimberlites on the basis of its TiO_2 and Al_2O_3 contents (Scott Smith and Skinner, 1984a; Mitchell, 1986; Mitchell and Bergman, 1991). The bulk rock chemistry of these rocks can also be used as a guide (Mitchell and Bergman, 1991).

The recognition of these rock types is most successfully applied to more slowly cooled magmatic rocks where characteristic groundmass minerals have been able to crystallize. There is a paucity of such minerals in the rapidly cooled crater-facies volcaniclastics and diatreme-facies tuffisitic kimberlite breccias. For such rock types, there are, however, still some features which can be used to distinguish these rock types. For example, true glass, glass shards and scoriaceous lapilli have not been observed in kimberlites.

Recognition of Other Rock Types

Prospecting for diamonds can result in a variety of rock types being encountered. So far, rock types other than kimberlites and lamproites have not produced significant quantities of diamond. The early identification of any newly discovered body found during prospecting has the potential of preventing costly follow-up work being undertaken on pipes which have a low potential to carry diamonds.

It is, therefore, important to be able to distinguish kimberlites and lamproites from other petrographically similar rocks, such as minettes, melilitites, alnoites, other ultramafic lamprophyres, katungites, kamafugites, leucitites and even carbonatites. These other rock types, which can carry mantle-derived xenocrysts or "kimberlite indicator minerals", can be distinguished from kimberlites and lamproites using petrography. The presence of primary minerals such as plagioclase, nepheline, andraditic garnet, kalsilite, abundant melilite, Na-leucite and nepheline-bearing pseudoleucite can be used to discriminate these rock types. Mineral compositions can also be helpful. For example, the more evolved sanidine phlogopite lamproites begin to resemble minettes, but the compositions of phlogopite can be used to distinguish them (e.g. Figs. 6.34 and 6.32 in Mitchell and Bergman, 1991, respectively). The terminology of these other rock types is confusing and difficult to apply meaningfully. Discussion of this problem is not within the scope of this paper, but it should be noted that the different types of lamprophyres discussed by Rock (1989, 1991) clearly do not form a petrogenetic suite of rocks, so the approach to lamprophyres proposed by Mitchell (1991b) is preferable.

An example in Canada of the application of this aspect of petrography to diamond exploration may be the case study presented by Janse et al. (1989). It should be noted that the following comments are easily made in hindsight. Approximately 45 intrusions were discovered using geophysics by Selco Mining Corporation and Esso Minerals Canada under 50 meters of glacial cover in the Hudson Bay Lowlands. All the bodies were drilled and proved to be barren. They were classified as alnoites, carbonatites and tuff breccias. It is an igneous province which may compare to the Oka-Ile Bizard part of the Monteregian Province. If the alnoitic affinity of these bodies had been recognized early on during exploration, it may have been possible to avoid much of the follow up work. Another similar example might be the picritic monchiquites at Wandagee in Western Australia (Jaques et al., 1989a). This approach, however, raises the question as to whether other mantle-derived rocks have the potential to carry economic quantities of diamond (for example see discussion in section 1.4.2 of Atkinson, 1989; Janse, 1991b).

Table 1. A comparison of the mineralogy of lamproites and kimberlites

Kimberlite	Lamproite
Olivine†	Phlogopite
MONTICELLITE	LEUCITE
Phlogopite	(GLASS)
CARBONATE*	Clinopyroxene
SERPENTINE*	AMPHIBOLE
Clinopyroxene	Olivine
Apatite	SANIDINE
Spinel	Perovskite
Perovskite	PRIDERITE
Ilmenite	Apatite
	Spinel
	WADEITE

Minerals given in upper case are unique to each rock type when most kimberlites and lamproites are compared.

† essential

* as primary groundmass minerals (not secondary)

Correctly classifying rocks found during prospecting, particularly when altered, both deuterically and as a result of weathering, is often not straightforward. Such altered rocks are best identified petrographically, with varying degrees of confidence. The identification of rapidly chilled glassy rocks can also be problematic. The whole rock geochemistry of these rock types, in particular kimberlites, is complex and can only be used as a guide. No worker has yet satisfactorily unravelled these complexities.

Mineralogical Classification

Mineralogical classifications are best applied to hypabyssal or magmatic rocks. They are useful in comparing kimberlites and lamproites within, and between, provinces. The application of such a classification lead to the recognition of two varieties of kimberlite in South Africa. The two types, termed Group 1 and 2, can be distinguished on the basis of their petrography, isotopic character, distribution, whole rock geochemistry and the nature of the mantle-derived xenocrysts and xenoliths (Smith, 1983; Skinner, 1989). Group 1 kimberlites are very similar worldwide, possibly reflecting a uniform (asthenospheric?) source. These kimberlites include many mines (e.g. Kimberley, Siberia). They can carry a full suite of mantle-derived constituents (i.e. olivine, ilmenite, garnet, chromite, clinopyroxene, orthopyroxene, zircon). Group 2 kimberlites are so far confined to one age group among the kimberlites of South Africa. They are probably a reflection of a unique aspect of the evolution of the Kaapvaal craton, maybe a particular metasomatic event(s) in the lithosphere, which has not been duplicated elsewhere in the world. Different, but equivalent, groups of kimberlites may be expected to occur on different cratons that have each evolved differently. An example of this may be the kimberlites and related rocks of the Sao Francisco craton in Brazil with their distinct isotopic signature (Bizzi et al., 1991). Group 2 kimberlites do not appear to contain any mantle-derived ilmenite, zircon or megacrysts, effectively reducing the potential number of "kimberlite indicator minerals" which could be located during prospecting.

The indicator minerals which occur in both kimberlites and lamproites appear to be similar, suggesting similar mantle sources (e.g. Hall and Smith, 1984; Lucas et al., 1989). Indicator minerals seem to be less abundant in most lamproites than in many kimberlites (Atkinson, 1989; GSC Open File Report, 1989; Fipke and Nassichuk, 1991). For example, only rare garnets are found at Argyle and most of these are crustal almandines (Jaques et al., 1989b). The discovery of such lamproites is therefore more difficult (Muggeridge, 1991). It is also noted that the assessment of the diamond potential of lamproites using the indicator mineral approach, which is based on the identification of the distinctive compositions of mainly garnets and chromites derived from the same areas of the mantle as diamond (see Gurney and Moore, 1991), does not appear to be reliable for lamproites (GSC Open File Report, 1989). For example, none of the garnet compositions reported from Argyle have compositions similar to sub-calcic peridotitic garnet inclusions from diamond (Jaques et al., 1989b; GSC Open File Report, 1989). Also only 10% mildly sub-calcic garnets occur in the Prairie Creek lamproite (Griffin et al., 1991). In contrast, a typical kimberlite mine may contain more than 60% sub-calcic garnets (e.g. New Elands in South Africa, Fig. 24a in GSC Open File Report, 1989). Hence, it is important to identify the nature of the host rock before applying these criteria. Caution must be used, however, in comparing different sets of garnet data depending on whether the garnet population are representative or have undergone preferential visual selection. The absence of picroilmenite from lamproites (Atkinson, 1989) indicates a similarity with Group 2 kimberlites. Group 2 kimberlites have other mineralogical affinities to lamproites (e.g. abundant mica, microphenocrystal diopside). In addition, some rocks which form an extension to the suite of Group 2 kimberlites are petrographically very similar to lamproites, although they should not be classified as such (Tainton and Browning, 1991).

The mineralogical classification of lamproites shows that they comprise a wide range of model types. The abundances of diamond and other mantle-derived minerals varies between different mineralogical types (Atkinson, 1989). Among them two main varieties have been recognized: leucite lamproite and olivine lamproite (*sensu lato*). Previous classifications of lamproites using locality based terminology are illustrated by Figure 1 of Mitchell (1985). The absence of olivine in this figure shows that olivine was not previously considered to be an important or significant mineral in lamproites. Olivine lamproites, therefore, form an extension to the previously (pre-1984) recognized lamproite clan. As a result all known diamondiferous lamproites were first termed kimberlites. In addition to those in Western Australia, they include Prairie Creek in Arkansas, Kapamba in Zambia, Majhgawan in India and possibly Seguela in the Ivory Coast (Scott Smith and Skinner, 1984a; Scott Smith et al., 1989; Scott Smith, 1989; Mitchell, 1985). Economic quantities of diamond have been found so far only in olivine lamproites.

Other Comments

Some of the differences between kimberlites and lamproites and their significance to diamond exploration have been discussed above. Other differences are important but will not be discussed in detail here. For example, geophysical responses can vary with the two rock types having different mineralogies. Also geochemical exploration surveys would require different criteria to be used with the two rock types having different bulk rock compositions. Lamproites and kimberlites also have different tectonic settings. Economic kimberlites have long been considered to be confined to Archaean cratons (Clifford, 1966) while diamondiferous lamproites occur both within and outside Archaean cratons (e.g. Majhgawan and Argyle, respectively: Mitchell, 1991a; Janse, 1991a). This effectively increases the potential areas for diamond exploration off the Archaean cratons to include certain Proterozoic and maybe younger terranes. Large areas in Canada can be considered prospective for primary diamond sources.

It is interesting also to note that the Argyle lamproite pipe which is the richest known primary source of diamond with grades ranging over 500 carats/100 tonnes (Boxer et al., 1989) is now, in terms of number of carats, the world's top single producer, currently at approximately 33 million carats per annum (Metals and Minerals Annual Review, 1991). Argyle is, however, unique among the known lamproites where reported grades elsewhere are less than 30 carats/100 tonnes. The only other operating lamproite mine is Majhgawan in India which has a grade in the order of 10 carats/100 tonnes (currently producing only approximately 20 000 carats per annum). Significantly, more than 50% of the world's current diamond production, which is the order of 100 million carats per annum, derives from numerous kimberlites. Far fewer lamproites are known worldwide and it is interesting to postulate whether this is a result of them being truly less common than kimberlites or whether they are more difficult to locate using existing prospecting techniques.

New Occurrences in Canada

Although no lamproites are known in Canada, information is being released for newly discovered kimberlites which are reported to contain more significant quantities of diamonds than previously known in Canada. It remains to be seen whether any prove to be economic. Their occurrence, however, does change the overall kimberlite picture in Canada. As these bodies have not yet been well documented (see this volume, not available to the author prior to publication) they were not included in this review. The first detailed public communication by K. Lehnert-Thiel (CIM meeting, Saskatoon, September 1991; Lehnert-Theil et al., 1991) reported that a province of kimberlites was discovered in 1988/89 under 100 m of glacial overburden in central Saskatchewan (Fig. 1) using geophysics. This province may comprise over 70 bodies up to 80 hectares in size. Lehnert-Thiel noted that the kimberlites were "pancake" shaped and at least in part comprise bedded volcaniclastic material and may deviate from the kimberlite model (Fig. 2). Another recent and rare mention of crater-facies kimberlites in North America was at Kelsey Lake in Colorado (Coopersmith, 1991). The discovery of another diamondiferous kimberlite in the Northwest Territories has been recently reported (e.g. Mining Journal, November 15, 1991, Vol. 317, No., 8148; Northern Miner, December 9, 1991) but no further information is available.

Conclusions

During the last two decades lamproites have joined kimberlites as the only known primary sources of economic quantities of diamonds. Differences in the petrography, mineralogy, petrology and geology show that lamproites and kimberlites are petrogenetically distinct rock types. Although these magmas act only as the transporting medium to surface for the upper mantle-derived xenocrystic diamond, they must be considered separately for exploration purposes. Differences in tectonic setting, mantle sources, composition, near surface emplacement processes and both primary and xenocrystic mineralogy result in the need for, and application of, different exploration philosophies and techniques.

Acknowledgments

I would like to acknowledge the many co-workers and exploration companies who have all contributed significantly to my knowledge of these rocks and without whom this paper would not have been possible. An earlier version of this paper was produced as notes to accompany a talk given at the International Seminar Kimberlite in Beijing, China, in August 1987. These notes were never published in English.

References

APTER, D.B., HARPER, F.J., WYATT, B.A. and SCOTT SMITH, B.H., 1984, The geology of the Mayeng kimberlite sill complex, South Africa. *In* Kimberlites I: Kimberlites and Related Rocks. *Edited by* J. Kornprobst. Elsevier Press, New York, p. 43-57.

ATKINSON, W.J., 1989. Diamond exploration philosophy, practice, and promises: a review. Geological Society of Australia Special Publication 14, 2, p. 1075-1107.

ATKINSON, W.J., HUGHES, F.E. and SMITH, C.B., 1984. A review of the kimberlitic rocks of Western Australia. *In* Kimberlites I: Kimberlites and Related Rocks. *Edited by* J. Kornprobst. Elsevier Press, New York, p. 195-224.

BIZZI, L.A., SMITH, C.B., MEYER, H.O.A., ARMSTRONG, R., and De WIT, M.J., 1991. Mesozoic kimberlite and related alkalic rocks in south-western Sao Francisco craton, Brazil: a case for local mantle reservoirs and their interaction. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 17-19.

BOLIVAR, S.L. and BROOKINS, D.G., 1979. Geophysical and Rb-Sr study of the Prairie Creek, AR kimberlite. *In* Proceedings of the Second International Kimberlite Conference, 1, Kimberlites, diatremes and diamonds: their geology, petrology and geochemistry. *Edited by* F.R. Boyd and H.O.A. Meyer. Am. Geophys. Union, Washington, D.C., p. 289-299.

BOXER, G.L., LORENZ, V. and SMITH, C.B., 1989. The geology and volcanology of the Argyle (AK1) lamproite diatreme, Western Australia. Geological Society of Australia Special Publication 14, 1, p. 140-152.

CHAPMAN, L., 1980. Diamonds in Australia. The Fields and Prospectus. Bay Books, Sydney and London.

CLEMENT, C.R., 1982. A comparative geological study of some major kimberlite pipes in the northern Cape and Orange Free State. Unpublished Ph.D. thesis, University of Cape Town, South Africa.

CLEMENT, C.R. and REID, A.M., 1989. The origin of kimberlite pipes: an interpretation based on a synthesis of geological features displayed by southern African occurrences. Geological Society of Australia Special Publication 14, 1, p. 632-646.

CLEMENT, C.R. and SKINNER, E.M.W., 1985. A textural-genetic classification of kimberlites. Transactions of Geological Society of South Africa 88, p. 403-409.

CLEMENT, C.R., SKINNER, E.M.W. and SCOTT SMITH, B.H., 1977. Kimberlite redefined. Extended Abstract for the Second International Kimberlite Conference (unpaginated).

CLEMENT, C.R., SKINNER, E.M.W. and SCOTT SMITH, B.H., 1984. Kimberlite redefined. Journal of Geology 32, p. 223-228.

CLIFFORD, T.N., 1966. Tectono-metallogenic units and metallogenic provinces of Africa. Earth and Planetary Science Letters 1, p. 421-434.

COOPERSMITH, H.G., 1991. Geology and exploration of the Kelsey Lake diamondiferous kimberlites, Colorado, U.S.A. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 52-57.

DEMAIFFE, D., FIEREMANS, M. and FIEREMANS, C., 1991. The kimberlites of central Africa: A review. *In* Magmatism in extensional structural settings. The Phanerozoic Plate. *Edited by* A.B. Kampunzu and R.T. Lubala. Springer Verlag, p. 537-559.

FIPKE, C.E. and NASSICHUK, W.W., 1991. Heavy mineral geochemical exploration for lamproite. Abstract for 93rd AGM of CIM, Vancouver, 1991, p. 81.

FISHER, R.V. and SCHMINKE, H.-U., 1984. Pyroclastic Rocks. Springer Verlag, 472 p.

GEOLOGICAL SURVEY OF CANADA Open File Report, 1989. The development of advanced technology to distinguish between diamondiferous and barren diatremes. Three parts (coordinated by C.F. Fipke; report preparation and interpretation by R.O. Moore and J.J. Gurney).

GRIFFIN, W.L., O'REILLY, S.Y., RYAN, C.G. and WALDMAN, M.A., 1991. Indicator minerals from Prairie Creek and Twin Knobs lamproites: relation to diamond grade. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 139-141.

GURNEY, J.J.,1989. Diamonds. Geological Society of Australia Special Publication 14, 2, p. 935-965.

GURNEY, J.J. and MOORE, R.O., 1991. Geochemical correlations between kimberlitic indicator minerals and diamonds as applied to exploration. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 125-126.

HALDER, D. and GHOSH, D.B., 1974. Tectonics of the kimberlites around Majhgawan, Madhya-Pradesh, India. *In* International Seminar on tectonics and metallogeny of Southeast Asia and Far East. *Edited by* M.V.N. Murty, Geol. Sur. India, p. 47-48.

HALL, A.E. and SMITH, C.B., 1985. Lamproite diamonds: are they different? *In* Kimberlite occurrence and origin; a basis for conceptual models in exploration. *Edited by* J.E. Glover and P.G. Harris. Geology Department and University Extension, University of Western Australia Publication 8, p. 167- 212.

HAWTHORNE, J.B., 1975. Model of a kimberlite pipe. Physics and Chemistry of the Earth 9, p. 1-15.

HENDRIX, B.L.. 1989. Crater of Diamonds: Jewel of Arkansas.

JAGO, B.C. and MITCHELL, R.H., 1985. Mineralogy and petrology of the Ham kimberlite, Somerset Island, Northwest Territories. Canadian Mineralogist 23, p. 619-634.

JANSE, A.J.A., 1991a. Is Clifford's rule still valid? Affirmative examples from around the world. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 196-198.

JANSE, A.J.A., 1991b. Non-kimberlitic diamond source rocks. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 199-210.

JANSE, A.J.A., DOWNIE, I.F., REED, L.E. and SINCLAIR, I.G.L., 1989. Alkaline intrusions in the Hudson Bay Lowlands, Canada: exploration methods, petrology and geochemistry. Geological Society of Australia Special Publication 14, 2, p. 1192-1203.

JAQUES, A.L., LEWIS, J.L., GREGORY, G.P., FERGUSON, J., SMITH, C.B., CHAPPELL, B.W. and McCULLOCH, M.T., 1984. The diamond-bearing ultrapotassic (lamproitic) rocks of the West Kimberley region, Western Australia. *In* Kimberlites I: Kimberlites and Related Rocks. *Edited by* J. Kronprobst. Elsevier Press, New York, p. 225-254.

JAQUES, A.L., LEWIS, J.D. and SMITH, C.B., 1986. The kimberlites and lamproites of Western Australia. Geological Survey of Western Australia Bulletin 132, 268 p.

JAQUES, A.L., KERR, I.D., LUCAS, H., SUN S-S. and CHAPPELL, B.W., 1989a. Mineralogy and petrology of picritic monchiquites from Wandagee, Carnarvon Basin, Western Australia. Geological Society of Australia Special Publication 14, 1, p. 120-139.

JAQUES, A.L., HAGGERTY, S.E., LUCAS, H. and BOXER, G.L., 1989b. Mineralogy and petrology of the Argyle (AK1) lamproite pipe, Western Australia. Geological Society of Australia Special Publication 14, 1, p. 151-169.

JENNINGS, C.M.H., 1989. Exploration for diamondiferous kimberlites and lamproites. *In* Modern Exploration Techniques, Saskatchewan Geological Society, Special Publication 10, p. 139-148.

LEHNERT-THIEL, K., LOEWER, R., ORR, R. and ROBERTSHAW, P., 1991. Diamond-bearing kimberlites in Saskatchewan, Canada: the Forte à la Corne case history. Abstract for the 1st Annual Field Conference of the Geological Society of CIM, Saskatoon, September 1991, p. 29-30.

LEWIS, H.C., 1887. On diamondiferous peridotite and the genesis of diamond. Geological Magazine 4, p. 22-24.

LEWIS, H.C., 1888. The matrix of diamond. Geological Magazine 5, p. 129-131.

LUCAS, H., RAMSAY, R.R., HALL, A.E., SMITH, C.B. and SOBOLEV, N.V., 1989. Garnet from Western Australia kimberlites and related rocks. Geological Society of Australia Special Publication 14, 2, p. 809-819.

MADIGAN, R., 1983. Diamond exploration in Australia. Indiaqua 35, p. 27-38.

MANNARD, G.W., 1962. The Singida kimberlite pipes, Tanganyika, Ph.D. thesis, McGill University, Montreal.

McCALLUM, M.E., 1991a. The Sloan 1 and 2 kimberlite complex near the southern boundary of the State Line district of the Colorado-Wyoming kimberlite province. Wyoming Geological Association Guidebook for 42nd Field Conference, p. 229-250.

McCALLUM, M.E., 1991b. Lamproitic(?) diatremes in the Golden Area of the Rocky Mountain Fold and Thrust Belt, British Columbia, Canada. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 257-260.

McCALLUM, M.E. and WALDMAN, M.A., 1991. The diamond resources of the Colorado-Wyoming State line district: kimberlite indicator mineral chemistry as a guide to economic potential. Wyoming Geological Association Guidebook, 42nd Field Conference, p. 77-90.

MEEKS, D.P., 1979. Geology and petrology of the Cross kimberlite, Crossing Creek area, British Columbia, B.A.Sc. thesis, The University of British Columbia.

MEYER de STADHELHOFEN, C., 1963. Les Breches kimberlitiques du Terratoire de Bakwanga (Congo). Archives des Science 16, fasc. 1, p. 87-144.

MITCHELL, R.H., 1985. A review of the mineralogy of lamproites. Transactions of the Geological Society of South Africa 88, p. 411-437.

MITCHELL, R.H., 1986. Kimberlites: mineralogy, geochemistry and geology. Plenum Press, New York.

MITCHELL, R.H., 1989. Aspects of the petrology of kimberlites and lamproites: some definitions and distinctions. Geological Society of Australia Special Publication 14, 1, p. 7-45.

MITCHELL, R.H., 1991a. Kimberlites and lamproites: Primary sources of diamond. Geoscience Canada, 18, p. 1-16.

MITCHELL, R.H., 1991b. What's in a name? Suggestions for revisions to the terminology of kimberlites and lamprophyres from a genetic point of view. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 295-297.

MITCHELL, R.H. and BERGMAN, S.C., 1991. Petrology of Lamproites. Plenum Press, New York.

MUGGERIDGE, M.T., 1991. Distribution of lamproite pathfinders in surface soils. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 301-303.

NIGGLI, P., 1923. Gesteins- und Mineralprovinzen. Verlag Gebruder Borntraeger, Berlin. 586 p.

ROCK, N.M.S., 1989. Kimberlite as varieties of lamprophyres: implications for geological mapping, petrological research and mineral exploration. Geological Society of Australia Special Publication 14, 1, p. 46-59.

ROCK, N.M.S., 1991. Lamprophyres. Blackie, Van Nostrand Reinhold. 285 p.

SCOTT SMITH, B.H. and SKINNER, E.M.W., 1984a. A new look at Prairie Creek, Arkansas. *In* Kimberlites I: Kimberlites and related rocks. *Edited by* J. Kornprobst. Elsevier Press, New York, p. 255-283.

SCOTT SMITH, B.H. and SKINNER, E.M.W., 1984b. Diamondiferous lamproites. Journal of Geology 92, p. 433-438.

SCOTT SMITH, B.H., 1989. Lamproites and kimberlites in India. Neues Jahrbuch Mineral. Abh. 161, p. 193-225.

SCOTT SMITH, B.H., SKINNER, E.M.W. and LONEY, P.E., 1989. The Kapamba lamproites of the Luangwa Valley, Eastern Zambia. Geological Society of Australia Special Publication 14, 1, p. 189-205.

SHAVER, K.C., 1988. Exploration of the Sloan Ranch complex: a diamondiferous kimberlite prospect in northern Colorado. Mining Engineering, January 1988, p. 45-48.

SINKANKAS, J., 1959. Gemstones of North America, Van Nostrand Reinhold, New York, 1.

SKINNER, E.M.W., 1989. Contrasting Group I and Group II kimberlite petrology: towards a genetic model for kimberlites. Geological Society Australia Special Publication 14, 1, p. 528- 544.

SKINNER, E.M.W. and CLEMENT, C.R., 1979. Mineralogical classification of southern African kimberlites. *In* Kimberlites, diatremes and diamonds: their geology, petrology and geochemistry. *Edited by* F.R. Boyd and H.O.A. Meyer. Amer. Geophys. Union, Washington, D.C., p. 129-139.

SMITH, C.B., 1983. Pb, Sr and Nd isotopic evidence for sources of African Cretaceous kimberlite. Nature, 304, p. 51-54.

SMITH, C.B. and LORENZ, V., 1989. Volcanology of the Ellendale lamproite pipes, Western Australia. Geological Society of Australia Special Publication 14, 1, p. 505-519.

SMITHSON, S.B., 1959. Geology of the south eastern Leucite Hills, Sweetwater County, Wyoming. M.A. thesis, University of Wyoming.

TAINTON, K.M. and BROWNING, P., 1991. The Group 2 Kimberlite — lamproite connection: some constraints from the Barkly West District, Northern Cape Province, South Africa. International Kimberlite Conference, 5, Araxa, 1991. Extended Abstracts, p. 405-407.

TROGER, W.E., 1935. Spezialle petrographie der eruptivgesteine, ein nomenklatur kompendium. Verlag de Deutschen Mineralogischan Gesellschaft, Berlin.

WADE, R.T. and PRIDER, R.T., 1940. The leucite-bearing rocks of the West Kimberley area, Western Australia. Quarterly Journal Geological Society London 96, p. 39-98.

WAGNER, P.A., 1914. The Diamond Fields of South Africa. Transvaal Leader, Johannesburg.