MACRODIAMONDS AND MICRODIAMONDS FROM MURFREESBORO LAMPROITES, ARKANSAS: MORPHOLOGY, MINERAL INCLUSIONS, AND CARBON ISOTOPE GEOCHEMISTRY

By
McCandless,[1] T.E., Waldman,[2] M.A., and Gurney,[3] J.J.

ABSTRACT

The first report of diamond in igneous rock in the United States originated at Prairie Creek, Arkansas. We have examined the morphological, carbon isotope, and inclusion characteristics of diamonds from Prairie Creek, and from the Twin Knobs #1, #2, Black Lick, and American lamproites. White is the most common macrodiamond color at Prairie Creek (62% of total), with 20% brown and 16% yellow. This contrasts with Australian lamproites where brown predominates, and with other North American localities such as the Sloan, Colorado kimberlites where yellow is rare. Lamination lines indicate ductile deformation at mantle conditions. The macrodiamonds are very resorbed; 82% are equiform or distorted tetrahexahedroida and none are octahedra. Low relief surfaces indicate prolonged and/or intense resorption. Microdiamonds differ dramatically, with octahedra and fragments common and tetrahexahedroida absent. Serrate laminae, knob-like asperities, pointed plates, ribbing, and non-uniform resorption are the most common surface features. Diamonds from the Twin Knobs #1 lamproite are similar to microdiamonds with respect to size and surface features.

Magnetite and olivine (Fo_{93}) are the only primary inclusions found in the diamonds, although inclusions of peridotitic and eclogitic parageneses have been reported in previous studies. Carbon isotope $\delta^{13}C$ values for Prairie Creek macrodiamonds peak at -3.0 to -6.2 ‰ (ave. -4.7 ‰ for 19 stones) and -10.3 to -10.6 ‰ (ave. -10.5 ‰ for 2 stones). The diamonds with magnetite and olivine inclusions have $\delta^{13}C$ values of -5.1 ‰ and -4.0 ‰ respectively. Microdiamonds from Prairie Creek, Twin Knobs #2, American, and Black Lick are similar to Prairie Creek macrodiamonds (-0.5 to -7.8; ave. -4.1 ‰ for 8 stones). A Prairie Creek and a Black Lick microdiamond have $\delta^{13}C$ values of -26.1 and -25.2‰ respectively, and the latter exhibits non-uniform resorption.

Lamination lines on macrodiamonds and xenocrystic surface features on microdiamonds imply that both are xenocrysts in lamproite. Carbon isotopes are characteristic of a peridotitic or primordial carbon reservoir. Two ^{13}C-depleted microdiamonds may be from a subducted carbon source. In comparison to macrodiamond populations from most kimberlites, Prairie Creek macrodiamonds are intensely resorbed, and lamproite may be more corrosive than kimberlite with respect to diamond resorption. Microdiamonds were probably encapsulated in xenolith material and escaped resorption. The differences in size and color of Prairie Creek macrodiamonds relative to Sloan kimberlitic diamonds are genetic, and may be related to their formation in lithosphere of differing age and tectonic history.

INTRODUCTION

The first report of diamond in igneous rock in the United States originated at Prairie Creek, Arkansas (Miser, 1913). Mining operations initiated in 1906 represent the only commercial diamond mining in the United States (Waldman et al., 1987). In spite of their geological significance, detailed research on diamonds from these localities is lacking. This preliminary study characterizes the morphology, inclusions, and carbon isotope geochemistry of diamonds from these lamproites, for comparison to other lamproitic diamonds (Ellendale, Australia) and to diamonds from other North American occurrences (Sloan, Colorado).

Regional Setting and geology

The Murfreesboro lamproites are located in southwestern Arkansas, 4 km southeast of Murfreesboro at the southern base of the Ouachita Mountains, a fold-thrust orogen of late Paleozoic age (Fig. 1a; Thomas, 1985). The Mesozoic strata through which the lamproites were emplaced thicken rapidly to the south, suggesting a continental margin setting (Thomas, 1985). The lamproites are at the edge of

(1) Dept. of Geochemistry, University of Cape Town, Rondebosch, 7700, South Africa
(2) Waldman Consulting, 6900 W. Quincy Ave #5E, Littleton, Colorado, 80123, USA
*Present address: Dept. of Geosciences, University of Arizona, Tucson, Arizona, 85721, USA

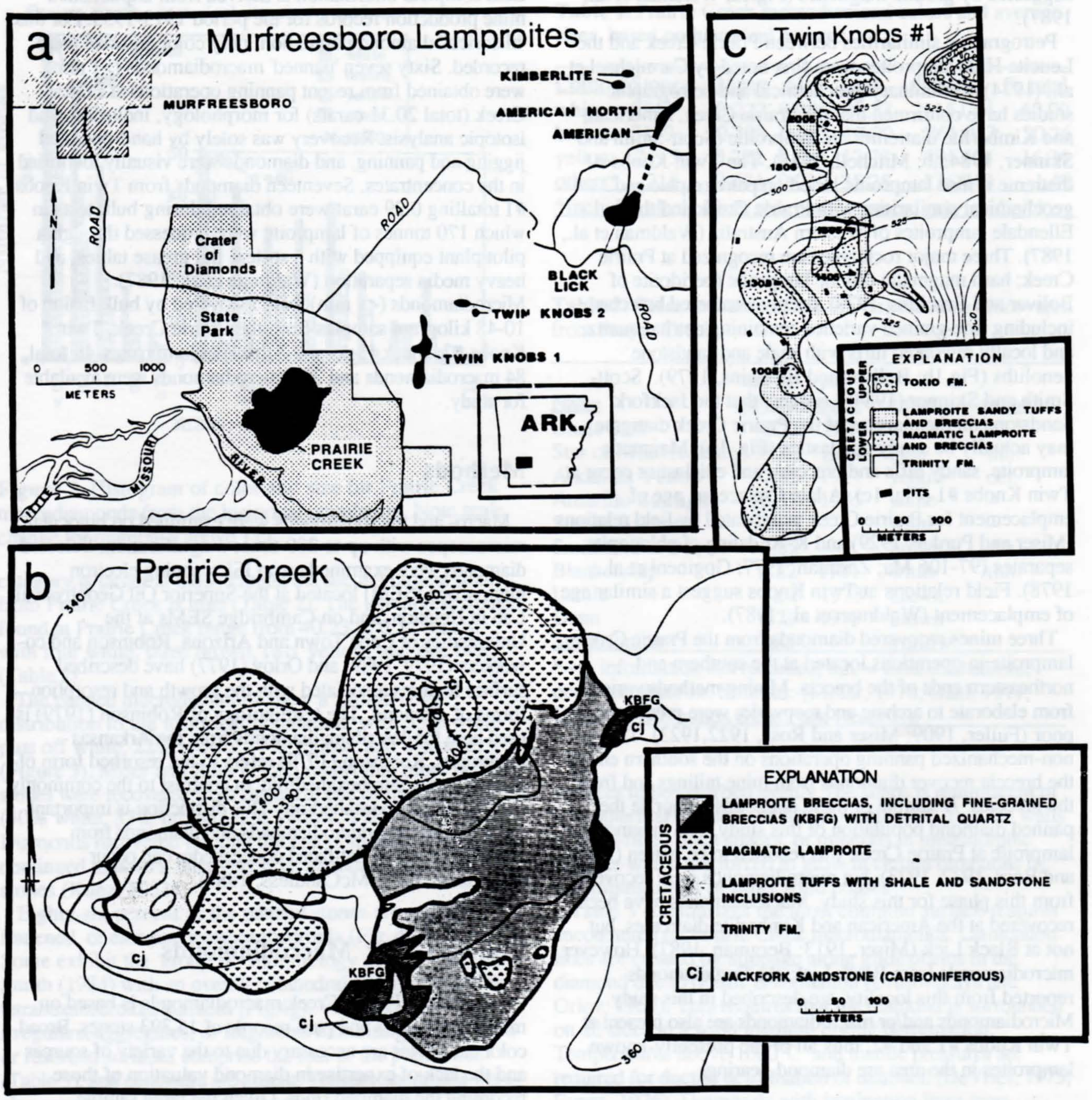

Figure 1. (a) Locality map of the Murfreesboro lamproites and Crater of Diamonds State Park. The extension of lamproite between the American and Black Lick lamproites is inferred by ground magnetics (from Waldman et al., 1987). (b) Geology of the Prairie Creek lamproite (simplified after Bolivar and Brookins, 1979). (c) Geology of the Twin Knobs #1 lamproite (from Waldman et al., 1987).

or slightly off-craton, with nearest exposed basement 200 km to the northwest and dated at 1340-1400 Ma (Bickford et al., 1986).

The Prairie Creek diatreme was first identified as peridotite in 1889 (Branner and Brackett, 1889). In 1906 diamonds were discovered at Prairie Creek, and the Black Lick, American, and Kimberlite diatremes were found shortly thereafter (Miser, 1913). Twin Knobs #1 and #2 were rediscovered in 1981 using combined geophysical and geochemical techniques (Waldman et al., 1987). Waterlain tuffs described by Miser (1912) in a well in this vicinity may have been the tuffs uncovered on the southern part of the Twin Knobs #1 pipe (Fig. 1c). The Black Lick and American occurrences may be a single dike system, as suggested by ground magnetics (Fig.1a; Waldman et al., 1987).

Petrographic similarities between Prairie Creek and the Leucite Hills lamproites were first noted by Carmichael et al., (1974). Preliminary geochemical and petrographic studies have confirmed that the Prairie Creek, American, and Kimberlite diatremes are lamproitic (Scott-Smith and Skinner, 1984a,b; Mitchell, 1985). The Twin Knobs #1 diatreme is also lamproitic based on petrographic and geochemical similarities with Prairie Creek and the Ellendale lamproites of Western Australia (Waldman et al., 1987). Three major rock types are recognized at Prairie Creek; hard magmatic olivine lamproite (peridotite of Bolivar and Brookins, 1979), deeply weathered breccias, including fine-grained varieties containing detrital quartz, and locally reworked tuffs with shale and sandstone xenoliths (Fig.1b; Bolivar and Brookins, 1979). Scott-Smith and Skinner (1984b) suggest that the Jackfork Sandstone on the margins of the Prairie Creek diatreme may actually be sandy epiclastics (Fig. 1b). Magmatic lamproite, sandy tuffs and breccias, and epiclastics occur at Twin Knobs #1 (Fig. 1c). A late Cretaceous age of emplacement for Prairie Creek is indicated by field relations (Miser and Purdue, 1929) and K-Ar dating of phlogopite separates (97-106 Ma; Zartman, 1977; Gogineni et al., 1978). Field relations at Twin Knobs suggest a similar age of emplacement (Waldman et al., 1987).

Three mines recovered diamonds from the Prairie Creek lamproite in operations located at the southern and northeastern ends of the breccia. Mining methods varied from elaborate to archaic and recoveries were predictably poor (Fuller, 1909; Miser and Ross, 1922,1923). Today, non-mechanized panning operations on the southern end of the breccia recover diamonds from mine tailings and from the breccias. A sample of these diamonds comprise the panned diamond population of this study. The magmatic lamproite at Prairie Creek was reported to be barren (Miser and Ross, 1922, 1923), but microdiamonds were recovered from this phase for this study. Macrodiamonds have been recovered at the American and Kimberlite diatremes, but not at Black Lick (Miser, 1913; Bergman, 1987). However, microdiamonds from Black Lick, the first diamonds reported from this locality, are described in this study. Microdiamonds and/or macrodiamonds are also present at Twin Knobs #1 and #2, thus all of the presently-known lamproites in the area are diamond-bearing.

DIAMOND MORPHOLOGY

Sources

Color and size information for Prairie Creek diamonds has been tabulated from the Crater of Diamonds State Park records and early mining and historical records. The greatest amount of data are from park records that include finds from 1972 to 1990, and from 1950 to 1970 when Prairie Creek was operated as a private tourist attraction (Millar, 1976). Less complete information is derived from unpublished mine production records for the period 1913-1933. For this 'historical' diamond population, only color and size were recorded. Sixty seven 'panned' macrodiamonds (>1 mm) were obtained from recent panning operations at Prairie Creek (total 20.31 carats) for morphology, inclusion, and isotopic analysis. Recovery was solely by hand-operated jigging and panning, and diamonds were visually identified in the concentrates. Seventeen diamonds from Twin Knobs #1 totalling 0.29 carat were obtained during bulk tests in which 170 tonnes of lamproite were processed through a pilot plant equipped with a sortex, jig, grease tables, and heavy media separation (Waldman et al., 1987). Microdiamonds (<1 mm) were recovered by bulk fusion of 10-48 kilogram samples from the Prairie Creek, Twin Knobs #2, Black Lick, and American lamproites. In total, 84 macrodiamonds and 282 microdiamonds were available for study.

Methods

Macro- and microdiamonds were examined on binocular microscopes with up to 200 times magnification. Selected diamonds were examined on an ISI scanning electron microscope (SEM) located at the Superior Oil Geophysical Lab in Houston, and on Cambridge SEMs at the Universities of Cape Town and Arizona. Robinson and co-workers (1979, 1989) and Orlov (1977) have described surface features associated with the growth and resorption forms of diamond. The terminology of Robinson (1979) is used here for describing diamonds from the Arkansas lamproites. Robinson (1979) refers to the resorbed form of diamond as a 'tetrahexahedroid' in contrast to the commonly used 'rounded dodecahedron'. This distinction is important when considering microdiamonds and diamonds from xenoliths in which flat-faced dodecahedra can occur (Robinson, 1979; McCandless, 1989).

Prairie Creek Macrodiamonds

Color of the Prairie Creek macrodiamonds is based on mining references and park records of 15,393 stones. Broad color categories are necessary due to the variety of sources and the lack of expertise in diamond valuation of those recording the diamond finds. Given the large sample population, however, some general color groupings can be determined for diamonds produced from Prairie Creek. White is the most common color (62% of total) followed by brown (20%) and yellow (16%; Fig 2, Table 1). This is in marked contrast to Australian lamproite diamonds where brown and yellow are predominant (Hall and Smith, 1984). White stones greatly dominate over other colors in the <0.1 to 1.0 carat size range and are less prevalent for stones over 1.0 carat (Fig. 2). Brown and white diamonds are of similar average sizes, 0.222 and 0.308 carats respectively (Table 1). The average size of diamonds in the 'other' color

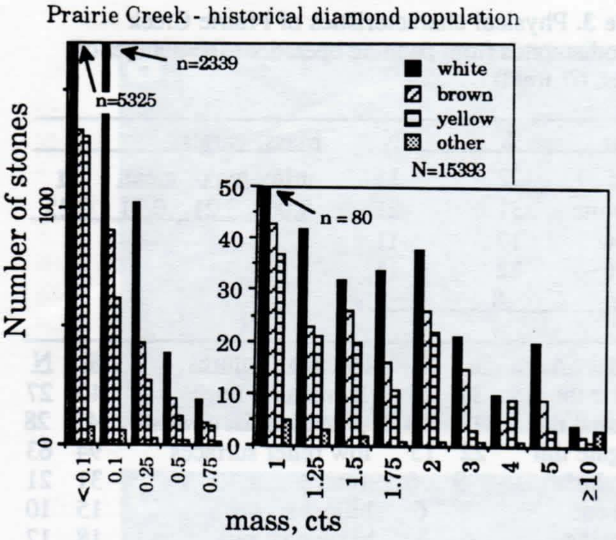

Figure 2. Histogram of color and size for Prairie Creek macrodiamonds from the historical population. Note scale change for diamonds above 1 ct.

category is larger at 0.634 carats; the second largest stone from Prairie Creek is blue (Table 2). The ten largest stones found at Prairie Creek range from 40.23 to 6.54 carats, with four white, three brown, two yellow, and one blue (Table 2).

The panned macrodiamonds show a similar color distribution to the historical population, with 53% white plus off white, 22% brown, 17% yellow, and 8% other (Figure 3). Miser and Ross (1922) report that more brown stones were recovered from the north end of the breccias (40% white, 37% brown, 22% yellow, 1% other; Fig. 3). Diamonds recovered through the end of mining operations continued to have a relatively high abundance of white stones (Kunz, 1931).

Eighty-six percent of the panned stones are regular, flattened, or elongate tetrahexahedroida (Fig. 4a-h; Table 3). Some exhibit the 'group A' morphology of Hall and Smith (1984) with an overall octahedral shape bounded by tetrahexahedroidal surfaces (Fig.4g). Very resorbed irregulars, aggregates, or fragments exhibiting only broken or resorbed surfaces comprise the rest of the population (Table 3), and octahedra are absent. Tetrahexahedroida were also common in diamonds recovered from Prairie Creek mining operations (Kunz and Washington, 1909). The dominance of tetrahexahedroida suggests that resorption was prolonged and intense at Prairie Creek. Resorbed shapes also dominate at the Ellendale 4 and 9 lamproites in Western Australia (Hall and Smith, 1984; Jaques et al., 1986, 1989). Some elongate tetrahexahedroida have a curious bullet-like shape, with the blunt end of the crystal truncated by a flat surface (Fig. 4e). The flat surface is as intensely resorbed as the rest of the diamond. The shape suggests that the diamond nucleated with its blunt end on a solid surface, but was allowed or forced to grow freely outward from this solid surface. Liberation of the diamond from its host rock during resorption allowed all the crystal

Table 1. Prairie Creek macrodiamond colors and average sizes, based on historical sources.

Color	#Stones	Mean	Min	Max	#Carats	% total
white	9543	0.222	0.004	40.23	2115.044	62.00
brown	3119	0.308	0.003	17.00	961.083	20.26
yellow	2515	0.272	0.004	17.78	684.594	16.34
others*	216	0.634	0.010	35.25	136.840	1.40

*Includes black, blue, red, orange, green, gray, and pink.

Table 2. Color and size of the ten largest stones recovered from Prairie Creek.

Name	mass, carats	year found	color	shape*
Uncle Sam	40.23	1924	white	
Star of Murfreesboro	35.25	1964	blue	thh.
Arkansas Yellow	17.85	1917	yellow	oct.
Amarillo Starlight	16.37	1975	white	–
Star of Arkansas	15.33	--	white	–
Smithsonian Brown	12.82	--	brown	thh.
Blankenship	8.82	1981	white	thh.
Lamle	8.61	1978	brown	–
Dunn	6.75	1975	brown	–
Smithsonian	6.54	--	yellow	--

*-- = information not recorded; thh. = tetrahexahedroid; oct. = octahedron. Sources: (Millar, 1976; Gaal, 1977; Crater of Diamonds State Park Records).

surfaces to be resorbed evenly. The shape is reminiscent of hydrothermal minerals which grow outward from the walls of fluid-filled open spaces, or minerals in metamorphic regimes which are forced to grow in certain directions by the impingement of other solid phases

Table 3 summarizes the most common surface features encountered on Prairie Creek macrodiamonds. Lamination lines are created by slippage along glide planes in the diamond due to plastic deformation (Urusovskaya and Orlov, 1964). This requires that the diamond is surrounded on all sides in a solid medium during deformation. Temperatures above 1000°C and mantle pressures are required for ductile deformation of diamond (DeVries, 1975; Evans, 1976). Diamonds with lamination lines were probably enclosed in mantle peridotite or eclogite which experienced deformation prior to entrainment into the ascending magma (Orlov, 1977; Robinson, 1979). Lamination lines are present on 40% of the macrodiamonds from Prairie Creek (Table 3). Graphitization along the glide planes in diamond may account for the correlation between lamination lines and brown color for diamonds from kimberlites (Robinson et al., 1989). At Prairie Creek, however, more non-brown diamonds show lamination lines than brown diamonds (70% vs 30%), contrary to observations for most kimberlitic diamonds (Robinson et al., 1989). Graphitization may be caused by heating associated with stress at the time of conduit formation for

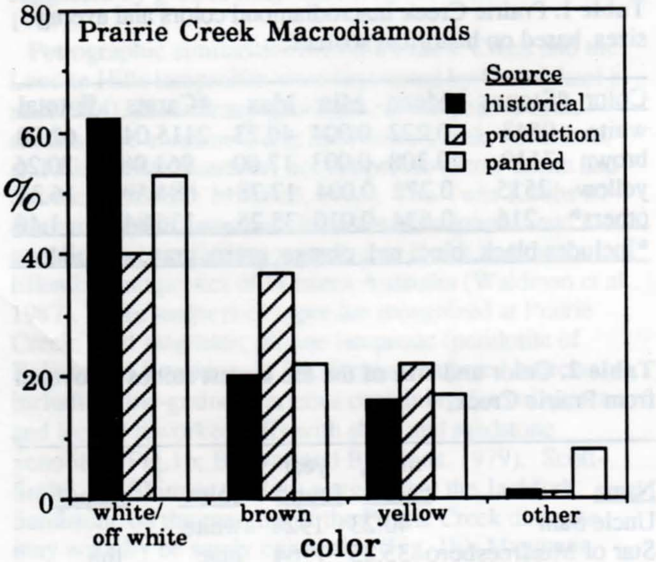

Figure 3. Comparison of colors reported for Prairie Creek macrodiamonds from the historical population, mine production, and panned population. Production data from Miser and Ross, 1922.

Table 3. Physical characteristics of Prairie Creek macrodiamonds from panning operations (N=number of stones, 67 total).

Color	%	N
white	22	15
off white	31	21
yellow	17	11
brown	22	15
other	8	5

Mass, carats			
min	max	mean	σ
0.06	3.21	0.31	0.25

Crystal Shape	%	N
regular thh	37	25
flattened thh	15	10
elongate thh	22	15
irregular*	9	6
fragment	9	6
thh twins	6	4
aggregate	2	1

Surface Features	%	N
lamination lines	40	27
pitted hemis. cavities	42	28
low relief surfaces	94	63
ruts	31	21
hillocks	15	10
hexagonal pits	18	12
positive trigonal pits	4	3
tetragonal pits	2	1
etched broken surfaces	22	15
unetched broken surfaces	2	1

*crystal with resorbed surfaces forming re-entrant angles suggesting an aggregate or cubic shape, but too insufficient for classification

the ascending magma (Robinson, 1979; Robinson et al., 1989). The abundance of non-brown stones with lamination lines at Prairie Creek suggests that some deformation must have taken place prior to this event. The presence of lamination lines indicates that the diamonds are xenocrysts in the lamproite.

Pitted cavities are hemispherical to rectangular depressions which are finely pitted with hexagonal or tetragonal pits (Fig.4). The exact cause for development of pitted cavities is not known. Hexagonal pitting in the cavities may form at 950-1000°C under oxidizing conditions (O_2), whereas tetragonal pitting forms above 950°C from H_2O and/or CO_2 (Robinson, 1979; Phaal, 1965). Hexagonal-pitted cavities are positioned in areas of former octahedral surfaces (Fig. 4a,b,g). At Prairie Creek some cavities contain altered material which may have been inclusions exposed late in the resorption history of the diamond. The shallow pitted cavity in Figure 4a,b has hexagonal pits focused around cylindrical holes which may have contained inclusions. The deeply pitted cavity in Figure 4c,d has tetragonal pits with included material which may have been primary. These cavities are strikingly similar to cavities reported by Giardini and Melton (1975a) and Melton and Giardini (1975, 1980) to have been occupied by fluid inclusions. One irregular diamond which exhibits a few rectangular cavities may have been a cube or cubo-octahedron prior to resorption (Fig.4f). The unstratified growth structure of cubes and the ease with

Figure 4. Common forms and surface features of Prairie Creek macrodiamonds. Scale bars are millimeters (MM), or microns (UM). Carbon isotopes listed for a,c,e,f in Table 9. (a) PC29. Flattened tetrahexahedroid with lamination lines, low relief surfaces and deep, pitted cavities on the lower and right edges. A shallow pitted cavity comprised of hexagonal pits is on the upper surface. (b) Close-up of hexagonal pits shows cylindrical holes which may have contained inclusions and influenced positioning of hexagonal pits. (c) PC54b. Elongate tetrahexahedroid with low relief surfaces and deep pitted cavities. Silver conductive paint is on the lower portion of the stone. (d) Close-up of pitting in cavity shows tetragonal pits indicative of cubic surfaces. Material in pits may be altered primary minerals, or secondary material from the lamproite. (e) PC27a. Bullet-shaped diamond with low-relief surfaces, tetragonal pitting in the lower left, and deep linear pitted cavities cutting across the length of the crytal. Note that the right surface is marked by low-relief features and shallow hexagonal pitting. (f) PC54a. Irregular diamond which may be cubic, with shallow tetragonal pits on the lower left and upper surfaces. (g) PC21. Tetrahexahedroid with Group A morphology of Hall and Smith (1984), having an overall octahedral shape but with tetrahexahedroidal surfaces. Deep pitted cavities occur at the six-fold intersections of the tetrahexahedroidal surfaces. Hexagonal pitting in the cavities (not clear in the photograph) indicates an octahedral primary growth form. (h)PC21. Close-up of the low-relief surfaces typical of the Prairie Creek macrodiamonds, consisting of shallow hillocks.

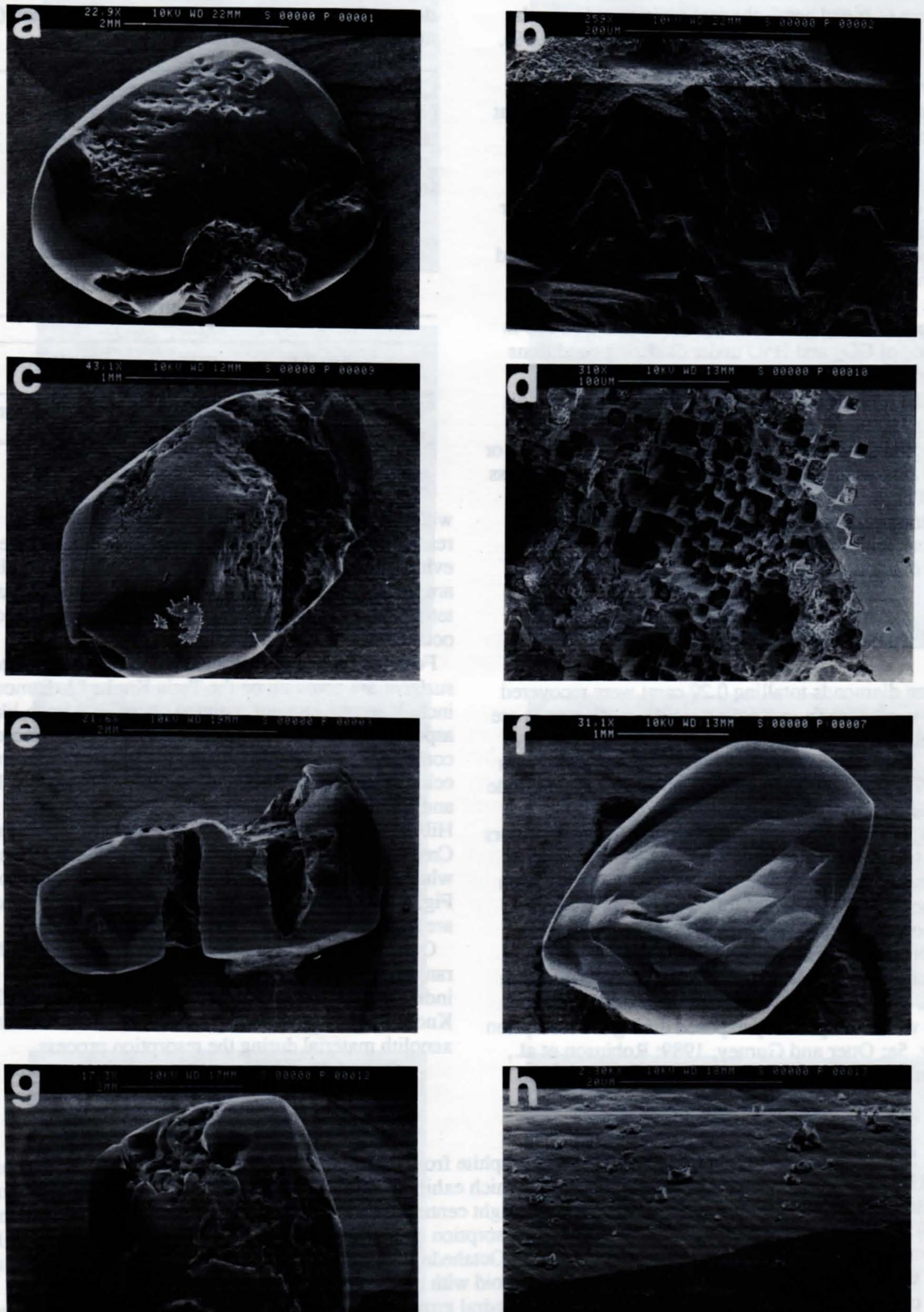
a
22.9X 10KU WD 22MM S 00000 P 00001
2MM
b
c
43.1X 10KU WD 12MM S 00000 P 00003
1MM
d
310X 10KU WD 13MM S 00000 P 00010
100UM
e
f
31.1X 10KU WD 13MM S 00000 P 00007
1MM
g
h

Figure 4

which cubic surfaces are resorbed may lead to the development of pitted hemispherical cavities and irregular shapes in advanced stages of resorption (Robinson, 1979). Forty-two percent of Prairie Creek stones have pitted hemispherical cavities, and many are distorted or irregular with tetragonal pits (Table 3; Fig. 4c-f). It is possible that some of these diamonds were initially cubes or cubo-octahedra.

Low-relief surfaces include the shagreen texture of Robinson (1979) and are represented by abundant small or low hillocks which give the diamond a translucent to glassy appearance (Fig. 4g,h). They represent the advanced stages of resorption, and are found on 94% of the diamonds. Low-relief surfaces and pitted cavities indicate that resorption took place at temperatures above 950°C in the presence of CO_2 and H_2O under oxidizing conditions (Robinson, 1979).

Twenty-four percent of the Prairie Creek stones exhibit breakage, but 90% of these surfaces are frosted or etched. On the micron scale the frosting consists of fine trigonal or hexagonal pits which develop late in the resorption process (Robinson et al., 1989). The frosting suggests that most breakage took place prior to the end of resorption, within the diatreme, and is not due to mechanical processes utilized in diamond recovery.

Twin Knobs #1 Macrodiamonds

Seventeen diamonds totalling 0.29 carat were recovered from bulk testing of Twin Knobs #1. Fifteen diamonds are from the olivine lamproite breccias and 2 are from sandy tuffs (Fig. 1c; Waldman et al., 1987). They range in mass from 0.007-0.021 ct. which is nearly an order of magnitude smaller than macrodiamonds from Prairie Creek (compare Tables 3,4). Light brown and white are the dominant colors and there are no yellow stones.

In contrast to Prairie Creek, 53% of the diamonds from Twin Knobs #1 are octahedra, followed by tetrahexahedroida (23%), irregulars (12%) and fragments (12%; Table 4). Three of the 9 octahedra are multicrystalline aggregates, and one exhibits non-uniform resorption. This feature is characteristic of diamonds in xenoliths which are partially exposed during the resorption event (Fig. 5a; Otter and Gurney, 1989; Robinson et al., 1989). Similar features are seen on a tetrahexahedroid

Table 4. Physical features of Twin Knobs #1 macrodiamonds, in percentages of the total population (N= number of stones, 17 total).

Crystal Shape*	%	N	Surface Features	%	N
octahedron	53	9	serrate laminae	29	5
tetrahexahedroid	23	4	knob-like asperities	29	5
irregular	12	2	pointed plates	47	8
fragments	12	2	shield laminae	35	6
			(-) trigonal pits	47	8
			terraces	6	1
			coarse hillocks	59	10
			hexagonal pits	12	2
			tetragonal pits	6	1

Mass, carats			
min	max	mean	s
0.007	0.021	0.013	0.005

*3 octahedra are aggregates, one has uneven resorption. One tetrahexahedroid shows uneven resorption.

which is a macle twin in which one of the crystals is more resorbed than the other (Fig. 5b). These features are evidence that at least some of the Twin Knobs #1 diamonds are xenocrystic in origin. One irregular diamond has tetragonal pitted surfaces suggesting a cubic or cubo-octahedral primary morphology.

Features typical of restricted resorption of octahedral surfaces are common on the Twin Knobs #1 diamonds, and include serrate laminae, pointed plates, and knob-like asperities (Table 4; Fig.5c). These features are more commonly seen on microdiamonds and diamonds from eclogite xenoliths (McCandless, 1989; Robinson, 1979), and are described in detail in the following section. Hillocks on tetrahexahedroida are coarser than on the Prairie Creek diamonds, and one tetrahexahedroid has terraces which indicate an octahedral growth form (Robinson, 1979; Fig. 4d). Pitted cavities similar to Prairie Creek diamonds are also present on this stone.

Octahedra present at Twin Knobs #1 are within the size range of microdiamonds, and have surface features indicating a xenocryst origin. The octahedra from Twin Knobs #1 may have been protected in small remnants of xenolith material during the resorption process.

Figure 5. Macrodiamonds from Twin Knobs #1, and graphite from Prairie Creek macrodiamond PC37. Scale bars are in microns (UM or U). (a) TK13-1. Octahedral aggregate which exhibits non-uniform resorption. Surfaces of the diamond on the upper left are resorbed to hillocks, lower central and right central diamonds exhibit only serrate laminae and tetragonal pitting. (b) TK10-1. Tetrahexahedroid macle with only resorption surfaces on the right, and preservation of shield laminae and flat-bottomed trigons on the left crystal. (c) TK20-2. Octahedron with shield laminae and knob-like asperities at the corners of the octahedral faces. (d) TK10-2. Tetrahexahedroid with broad hillocks on resorbed surfaces, and terraces preserved on the front and upper faces indicating an octahedral growth form. Shallow pitted cavities and ruts are also present. (e) Graphite mass from PC37, showing porous nature. Flat areas are tweezer marks. (f) Close up showing aggregate of subhedral to anhedral graphite crystals which comprise the aggregate in (e). (g) Graphite along a plane of diamond PC37. Note the difference in scale compared to (e). (h) Close-up of the graphite in (g) showing platy habit, in contrast to the book-like to spherical masses of (f).

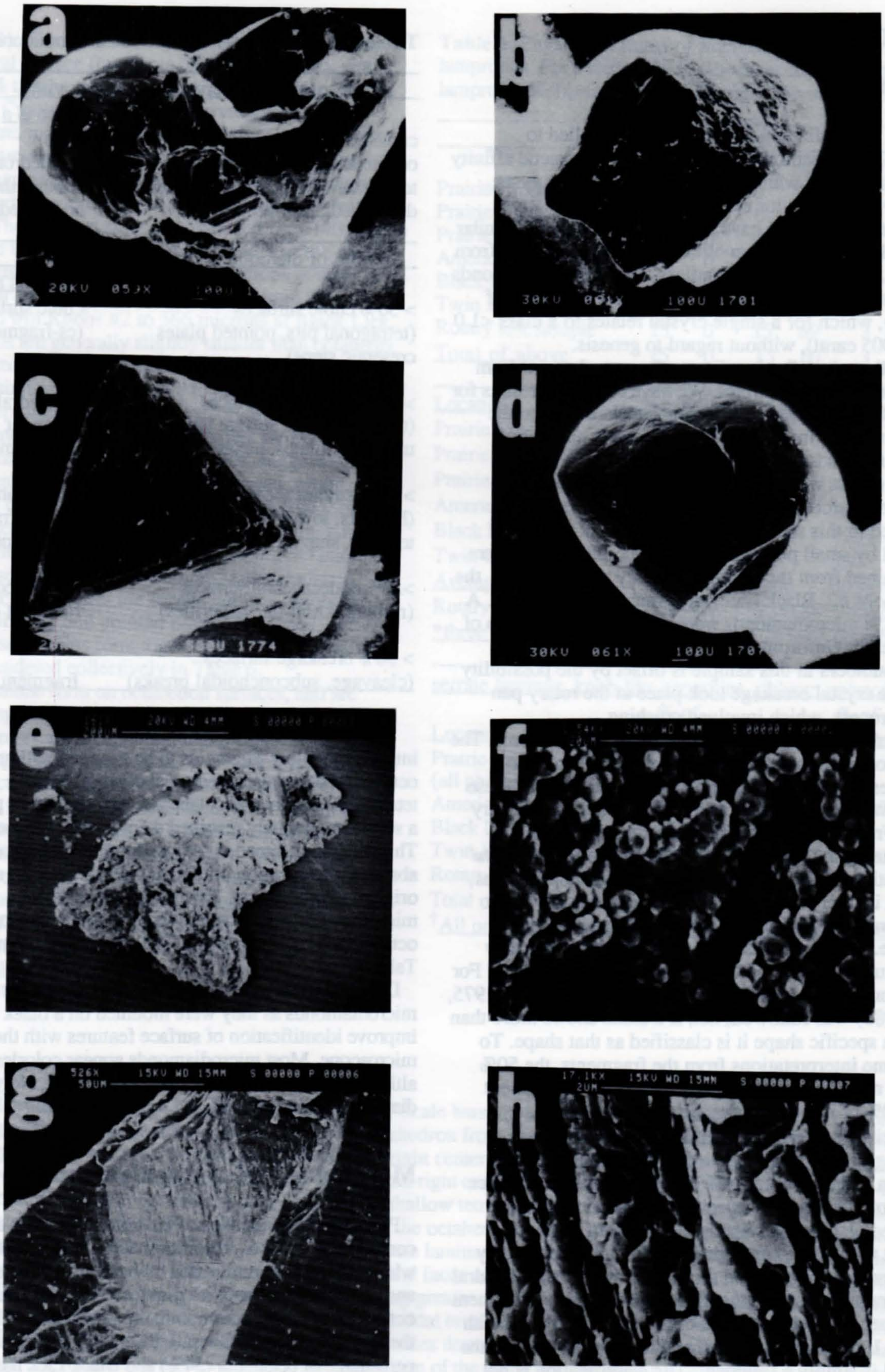
a
b
30KV 061X 100U 1701
c
d
30KV 061X 100U 1707
e
f
g
526X 15KV WD 15MM S 00000 P 00006
50UM
h
17.1KX 15KV WD 15MM S 00000 P 00007
2UM

Figure 5

MICRODIAMONDS

Definitions

The term 'microdiamonds' is commonly implied to represent small diamonds which may have a genetic affinity for the magmas in which they occur (i.e., phenocrysts; Haggerty, 1986; Taylor et al., 1990). However, some microdiamonds clearly have physical characteristics similar to microdiamonds from xenoliths, and may be derived from them (i.e., xenocrysts; McCandless, 1989). Microdiamonds are defined in this study to have maximum diameters of <1.0 mm, which for a single crystal relates to a mass <1.0 mg (<0.005 carat), without regard to genesis.

Typically only 1-7 microdiamonds were obtained from individual 10-48 kg samples. We have combined results for samples from each phase at Prairie Creek, and from the other lamproites in the district. The largest number of microdiamonds for a given lamproite is 15 for Prairie Creek; 6 or less were recovered from each of the other lamproites. Percentages of the total number present are again used in this section but significance of data is tempered by small population sizes. Microdiamonds were also obtained from the tailings of rotary pan testing of the Twin Knobs #2, Black Lick, and American lamproites. A total of 254 microdiamonds were recovered from fusion of this material. Unfortunately, the statistical validity of greater numbers in this sample is offset by the possibility that some crystal breakage took place in the rotary pan testing process, which involved crushing.

Many of the microdiamonds recovered are fragments. The bulk fusion technique for recovery of microdiamonds minimizes crushing and milling, which for most of these samples was not necessary as the rocks were already very friable. Fragmental microdiamonds are common in kimberlites (McCandless, 1989) and can be found *in situ* in xenoliths (Robinson, 1979; McCandless and Collins, 1989). It is likely that many of the fragments are due to natural breakage during or after emplacement of the lamproite. We cannot discount that some breakage may have occurred during the bulk fusion process, however. For nearly complete stones the 50% rule of Harris et al., (1975, 1979, 1983) was followed, i.e., if a stone shows more than 50% of a specific shape it is classified as that shape. To make some interpretations from the fragments, the 50% rule was modified in the following manner. A fragment with >50% of its non-breakage surfaces exhibiting characteristics specific to a certain form is classified accordingly. This scheme relies on the observations of Robinson and co-workers (1979; 1989) that some surface features of diamonds are specific to cubic, octahedral, dodecahedral, or tetrahexahedroidal surfaces. Hence, a fragment with >50% octahedral surfaces characterized by features such as trigons and serrate laminae is an octahedral surface fragment (os-fragment); a tetrahexahedroid fragment (ts-fragment) may have >50% of its surfaces covered with hillocks. If no surfaces other than breakage are present the diamond is simply a fragment. The classification is not intended to allow fragments to be grouped with unbroken octahedral or tetrahexahedroidal crystals; both tetrahexahedroidal and octahedral surfaces can be present on a single, moderately resorbed diamond (Robinson, 1979). This scheme is intended to document the presence or absence of resorption on the diamond fragment, not its original crystal shape. This is significant for microdiamonds, as most are thought to be unresorbed octahedra (Haggerty, 1986). The scheme is summarized in Table 5.

Table 5. Classification scheme for microdiamonds.

>50% of diamond crystal is present with	Shape is a
cubic surface features	cube
octahedral surface features	octahedron
tetrahexahedroidal surface features	tetrahexahedroid
dodecahedral surface features	dodecahedron
<50% of diamond crystal is present with	**Shape is a**
> 50% cubic surfaces (tetragonal pits, pointed plates cresentic steps)	cubic surface fragment (cs-fragment)
>50% octahedral surfaces (trigons, shield, serrate laminae, triangular plates, hexagonal pits	octahedral surface fragment (os-fragment)
>50% tetrahexahedroidal surfaces (hillocks, low-relief surfaces, terraces, shagreen, corrosion sculpture)	tetrahexahedroidal surface fragment (ts-fragment)
>50% dodecahedral surfaces (ribbing, knob-like asperities)	dodecahedral surface fragment (ds-fragment)
> 50% breakage surfaces (cleavage, subconchoidal breaks)	fragment

Detailed color information is not available for the microdiamonds as they were mounted on a black base to improve identification of surface features with the binocular microscope. Most microdiamonds appear colorless, although some brown diamonds are present. No yellow diamonds were observed.

Morphology of microdiamonds

Physical characteristics of the microdiamonds are compiled in Table 6. Tetrahexahedroida are absent, and whole crystals are dominated by octahedra, including twin and aggregate forms. With respect to Prairie Creek, octahedra are most common in the breccias, and absent in the magmatic phase. Overall, Prairie Creek has the highest percentage of octahedra (54%) and Black Lick has the lowest (33%). The remainder of the samples are dominated by octahedral surface fragments (67% of the total), with less than 3% tetrahexahedroidal surface fragments present. The Prairie Creek magmatic phase contains all os-fragments and more than half of the diamonds in the other lamproites are also os-fragments. The rotary test sample has 15% fragments, 69% os-fragments, and 13% octahedra.

The microdiamonds range in size from 167-566 microns (Table 6). The smallest size is constrained by a 140 micron cutoff in the bulk fusion process. Octahedra in the Prairie Creek breccias average just over 300 microns in size. Octahedra in the other lamproites average from 250 microns at Twin Knobs #2 to 566 microns at Black Lick. Os-fragments are generally slightly smaller than octahedra from the same sample. Octahedra from the rotary test sample are similar in average size to octahedra from the specific lamproites (average 377 vs 356 microns). Os-fragments and fragments in the rotary test sample are also similar in size to the specific lamproites, suggesting that minimal breakage occurred during rotary pan testing.

Nearly all of the microdiamonds are unresorbed; only 1% exhibit tetrahexahedroidal surfaces. There are, however, surface features indicative of early stages of resorption, or restricted resorption, on octahedral and cubic surfaces. These distinctive features are serrate laminae, knob-like asperities, ribbing, and pointed plates (Robinson, 1979). Because these features form together in close association, they are considered collectively in Table 6.

Serrate laminae form on octahedral surfaces, and are stacked triangular features of diminishing areal extent (Fig. 6a). The features are the remnant highs adjacent to flat-bottomed negative trigons which have coalesced at the corners of octahedra, and are a product of resorption (Robinson, 1979). Pointed plates form on cubic surfaces, commonly in conjunction with serrate laminae on octahedral surfaces. When isolated, they resemble tiny protruding octahedra, *en masse*. They are the high points of closely-spaced negative tetragonal pits, resulting from resorption of cubic surfaces (Fig.6b,c). Ribbing represents a dodecahedral surface developed from restricted resorption of octahedral growth plate edges (Fig. 6a). Knob-like

Table 6. Physical features of microdiamonds from Arkansas lamproites. For Prairie Creek, Kb=breccias, Km=magmatic lamproite, Kbfg=fine-grained breccias. (N=number of stones).

	Shape, % of N					N
	octa	thh	frag	os-frag	ts-frag	
Prairie Creek Kb	80	0	0	20	0	5
Prairie Creek Km	0	0	0	100	0	3
Prairie Creek Kbfg	57	0	0	43	0	7
American	60	0	0	40	0	5
Black Lick	33	0	17	50	0	6
Twin Knobs #2	50	0	0	50	0	2
Rotary test sample	13	0	15	69	3	254
Total of above	15	0	15	67	3	282

Average size in microns				
Location	octahedra	frag	os-frag	N
Prairie Creek Kb	313±95	0	325	5
Prairie Creek Km	0	0	193±12	3
Prairie Creek Kbfg	318±191	0	193±12	7
American	250±212	0	167±76	5
Black Lick	566±378	300	475±132	6
Twin Knobs #2	300	0	300	2
Average of above	377±233	300	303±140	28
Rotary test sample*	356±94	288±88	285±63	254

*three ts-fragments with average size 285+63 present

Surface features: serrate laminae, knob-like asperities, ribbing, pointed plates†				
Location	% of octahedra	N	% of os-fragments	N
Prairie Creek (all phases)	88	8	71	7
American	67	3	100	2
Black Lick	100	2	33	3
Twin Knobs #2	100	1	100	1
Rotary test sample	100	34	65	169
Total of above	98	48	66	182

†All or some combination of these features are present

Figure 6. Microdiamonds from Murfreesboro lamproites. Scale bars are in microns (UM). See Table 10 for carbon isotope compositions of these diamonds. (a) MF55-1. Octahedron from Prairie Creek with serrate laminae on the lower center and upper right surfaces, pointed plates on left and right center of photograph, and ribbing on upper portion of crystal. A few knob-like asperities are evident on the left and right central corners of the octahedral faces. (b) Clôse-up of the left cornerof diamond in (a) shows pointed plates and shallow tetragonal pits indicating minor resorption of a cubic surface. Point-bottomed trigonal pits are faintly visible on the octahedral surface in the upper left of the photograph. (c) MF55-2. Octahedron from Prairie Creek, with ribbing, serrate laminae, and abundant pointed plates along crystal edges and corners, respectively. Knob-like asperities occur on edges and faces of the diamond. (Amorphous material is conductive paint.) (d) MF58-1. Octahedron from Prairie Creek, showing greater resorption compared to (a,c). Knob-like asperities dominate the faces and edges of this diamond. A sub-conchoidal break is present in the upper left. (e) MF37-1. Octahedron from Twin Knobs #2 with grossly irregular knob-like asperities dominating the surfaces. (f) Close-up of the left face of the diamond in (e). Resorption has revealed the microstructure of the diamond. Shield laminae are present on the tops of the asperities. (g)MF38-1. Aggregate from Black Lick, positioned to show non-uniform resorption, with hillocks on tetrahexahedroidal surfaces in the lower center and upper left. Serrate laminae and trigons (not seen in the photograph) cover the rest of the diamond. (h)MF56-1. Macle from Prairie Creek with serrate laminae and knob-like asperities at the corners and on the diamond faces.

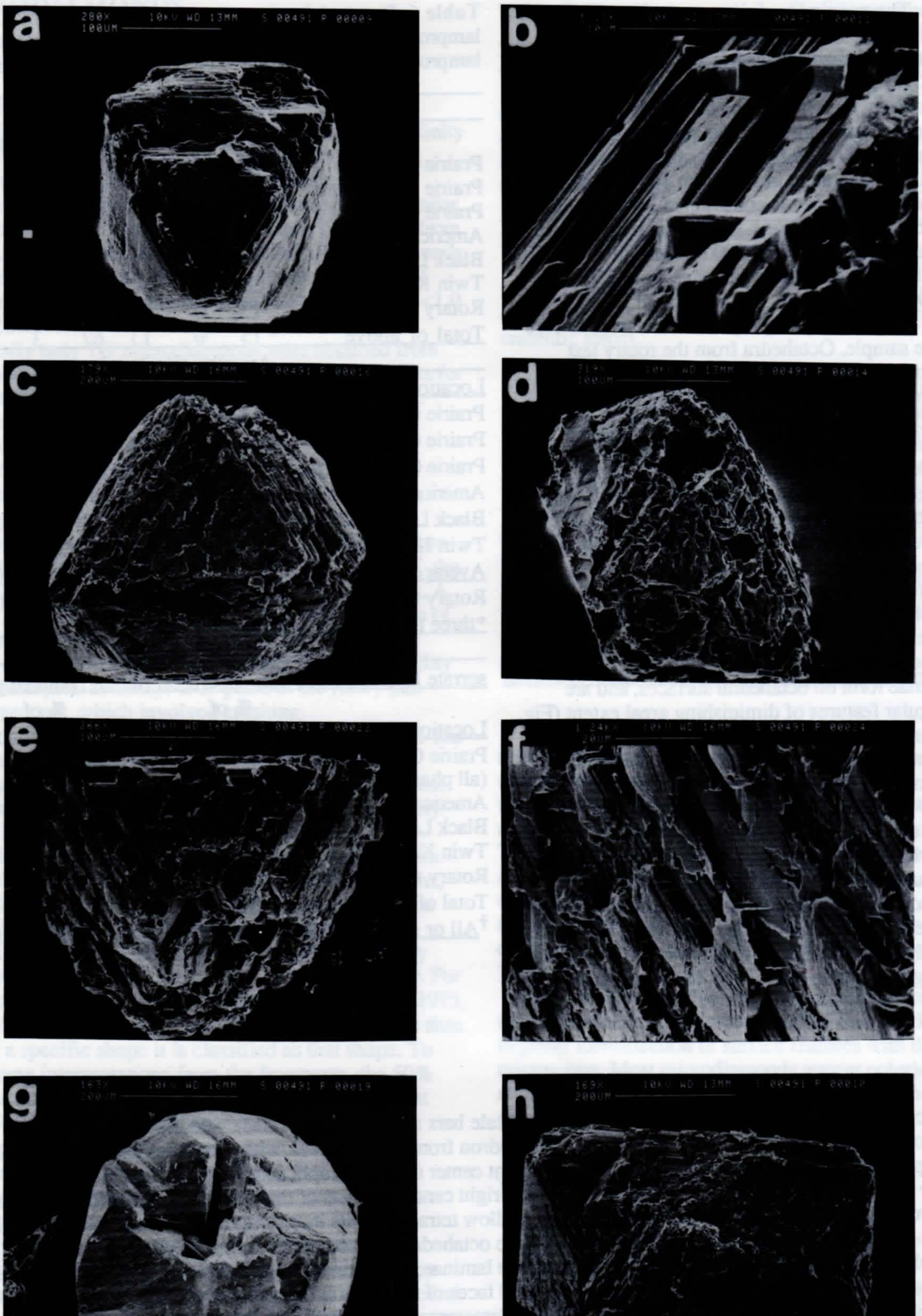

Figure 6

asperities develop on ribbing and on octahedral surfaces. They are usually triangular on octahedral surfaces, but can also be grossly irregular (Robinson, 1979). For microdiamond populations, the latter case predominates (Fig.6c-f). All of these features are products of resorption, and varying degrees of their development are reflected on octahedral microdiamonds. Initial stages of development of these features are shown in Figure 6a-c, whereas in Figures 6d-f they are the most prevalent features. In Figure 6d and e, large knob-like asperities dominate all of the surfaces, and the diamond microstructure is revealed in their edges(Fig. 6f).

These features dominate in all of the lamproite microdiamond samples. Ninety-eight percent of the octahedra and 66% of the os-fragments exhibit one or several of these features (Table 6). The remaining one-third of the os-fragments exhibit triangular plate edges, an octahedral growth feature.

Robinson (1979) noted that these surface features are rare, and are present mainly on diamonds from eclogite xenoliths. Non-uniform resorption, also a feature of xenocrystic diamonds is present on an octahedron and an octahedral aggregate from the rotary test sample (Fig. 6g). The strong similarity of these diamonds to diamonds from xenoliths suggests a xenocryst origin for the Arkansas lamproite microdiamonds. Based on similar forms and surface features, the octahedra from Twin Knobs #1 are also considered to be from xenoliths.

INCLUSIONS IN PRAIRIE CREEK MACRODIAMONDS

Previous studies of inclusions in 13 Prairie Creek diamonds are summarized in Table 7. Most of the inclusions represent peridotitic P-type (enstatite, olivine, Cr-pyrope, chrome diopside, chromite) and eclogitic E-type (pyrope-almandine garnet) parageneses (Newton et al., 1977; Pantaleo et al., 1979). Sulfides and magnesite were believed to be present based on Ni-Fe and MgO + magnetite residues which remained after burning the diamonds to retrieve the inclusions (Newton et al., 1977; Pantaleo et al., 1979). Also reported are magnetite, amorphous C-Fe-Ni-S, diamond, and an Fe-Ti-Zn-K-bearing aluminosilicate (Pantaleo et al., 1979). At the time of their discovery, these inclusions were unique but have since been confirmed with the discovery of magnetite, ferro-periclase, and dolomite in diamonds elsewhere (Meyer, 1986; Gurney, 1989; Otter, 1989; Moore and Gurney, 1989; Hill, 1989). Entrapped gases were reported in eight diamonds (Melton and Giardini, 1975; Giardini and Melton, 1975a,b), and an estimated age of 3.1 Ga was established for a 6.3 ct. diamond based on argon isotopes (Melton and Giardini, 1980; Table 7). The presence of gas (i.e., fluid) inclusions in diamond remain in question (Roedder, 1984; Harris and Gurney, 1979; Navon et al., 1986). Giardini and Melton (1975a) reported that gases in the 2.06 and 1.53 ct. diamonds were contained in etched cavities, some of which

Table 7. Physical features of Prairie Creek diamonds and their inclusions from this study and from Melton and Giardini (1975), Giardini and Melton (1975a,b, 1980), Newton et al., (1977, and Pantaleo et al., (1979).

Carats	Shape	Color	Inclusions[1]
minerals confirmed by XRD or microanalysis			
0.36	irregular	tan	cd+en+olv[3]
0.43	hexoctahedron[2]	pale yellow	en+olv+S
0.45	elongate	colorless	pa-gt
0.50	tetrahexahedroid	colorless	en+pyr+olv+S
0.62	tetrahexahedroid	colorless	di+en+mgt[4]
this study			
0.15	irregular	white	psb(?)
0.15	tetrahexahedroid	white	mgt
0.51	tetrahexahedroid	off white	olv
major gases determined by mass spectrometry			
0.37	--	brown	$H_2O>H_2>CO_2$
0.43	--	colorless	$H_2O>H_2>CO_2$
0.54	--	pale yellow	$H_2O>CO_2>H_2$
0.76	--	colorless	$H_2>H_2O>CO_2$
0.89	fragment	colorless	$H_2O>N_2>CO_2>H_2$[5]
1.53	rounded[2]	colorless	$N_2>CO_2>H_2O>H_2$
2.06	rounded[2]	pale yellow	$CO_2>H_2O>H_2>N_2$
6.30	hexoctahedron[2]	light tan	H_2,H_2O,CO_2,N_2,Ar[6]

[1] en = enstatite, olv = olivine, S = sulfides, pa-gt = pyrope-almandine garnet, pyr = pyrope, di = diamond, mgt = magnetite, psb = pseudobrookite, il = ilmenite, cd = chrome diopside; inclusions without identification are listed by elements present; [2]morphology used in original studies; not conformable to Robinson (1979). [3]a Ti-Fe-Zn-K bearing aluminosilicate also reported. [4]enstatite+magnetite are in a fluffy mass in this diamond. [5]a C-Fe-Ni-S mass also reported in this diamond. [6]estimated age at 3.1 Ga using argon isotopes

are identical to the pitted hemispherical cavities described in this study and shown in Figure 4. These features on Prairie Creek diamonds may therefore result from exposure and removal of contained fluids during resorption, although inclusions of this type were never observed.

In this study, mineral inclusions were visually located and extracted by cracking the diamond. These diamonds were well below the size range of previous inclusion studies of Arkansas diamonds (0.06-3.21 cts., ave. 0.31 ct.; Table 7). Small size and translucent low-relief surfaces created by resorption made locating and identifying clear inclusions extremely difficult. Twenty-three inclusions from 10 diamonds were extracted; most are graphite along planes or in masses as described by Pantaleo and others (1979). Two opaque inclusions exhibiting crystal faces are identified as magnetite and pseudobrookite (Table 7,8). Magnetite has been reported in diamonds from kimberlites worldwide but is extremely rare (Meyer, 1986; Gurney, 1989). Meyer and McCallum (1986) and Otter (1989) consider titano-magnetites from Sloan diamonds to be epigenetic. Nearly pure magnetite found by Otter (1989) in a Sloan diamond is possibly syngenetic, although magnetite was also present on the diamond surface. The magnetite from Prairie Creek is nearly identical to the syngenetic magnetite reported by Otter (Table 8). There were no cracks or other minerals on the surface of the Prairie Creek diamond and the magnetite is considered syngenetic. Magnetite has an unknown paragenesis (Gurney, 1989), and occurs with native iron and sulfides in diamond from the Mir kimberlite (Sobolev et al., 1981). The pseudobrookite is nearer to an Fe-rich kennedyite in composition, with 61.0 wt.% TiO_2 (von Knorring and Cox, 1961; Table 8). It is higher in TiO_2 than ilmenite inclusions reported from diamonds elsewhere (Table 8). The Fe-rich kennedyite inclusion is from the badly etched diamond of Figure 4c, and is not considered primary. One P-type olivine inclusion was partially liberated from a gem quality white stone (Table 8). It is forsterite (Fo_{93}), similar to olivine previously reported in Prairie Creek diamonds (Fo_{92}; Newton et al., 1977; Pantaleo et al., 1979).

Several opaque inclusions from diamonds PC37 and PC39 disintegrated when placed in the epoxy mounting medium. Wavelength dispersive microprobe scans of the material revealed no major element peaks but carbon. One inclusion roughly 200 microns in size was examined by SEM and found to consist of numerous subhedral to anhedral crystals of hexagonal habit averaging 5-10 microns in diameter which are believed to be graphite (Fig. 5e,f). Graphite on glide planes in Prairie Creek diamonds is commonly platy in habit, and is much smaller than the graphite aggregates (Fig. 5g,h). Robinson (1979) noted graphite aggregates coating the surface of diamond in an eclogite xenolith, which are similar in size and appearance to the inclusions noted here, and he considered them to be the product of graphitization of diamond. The aggregates in Prairie Creek diamonds did not appear to be connected to the surface by cracks, and could represent entrapment of metastable graphite during crystallization of the diamond near the graphite/diamond stability region.

CARBON ISOTOPES

Macrodiamonds

Twenty-one macrodiamonds from Prairie Creek were analyzed for carbon isotopes. The diamonds were broken, and fragments 0.05-0.75 mg in mass were combusted to

Table 8. Microprobe analyses of magnetite, pseudobrookite(?) and olivine from Prairie Creek macrodiamonds, compared to inclusions from Sloan, Argyle, and other Prairie Creek diamonds.

	Prairie Creek magnetite PC13-1	Sloan magnetite[1] syngenetic? SL 45-6	Sloan magnetite[1] epigenetic SL 2
SiO_2	--	–	0.05
TiO_2	0.11	–	20.8
Al_2O_3	0.13	–	8.14
Cr_2O_3	--	–	0.61
FeO*	95.8	93.2	51.0
MnO	0.26	0.18	0.69
MgO	--	–	15.9
CaO	--	--	--
TOTAL	96.3	93.5	97.2
	Prairie Creek pseudobrookite PC54b-2	kennedyite[2] A81	Argyle†[3] ilmenite A163
SiO_2	0.23	–	0.03
TiO_2	61.0	60.3	51.8
Al_2O_3	0.54	2.15	–
Cr_2O_3	0.12	0.37	–
FeO*	33.1	27.9	46.6
MnO	1.41	0.07	0.68
MgO	0.80	6.45	0.47
CaO	--	--	0.04
TOTAL	97.2	97.2	99.7
	This study olivine PC40-1	Pantaleo et al., 1979 olivine 0.50 ct.	Pantaleo et al., 1979 olivine 0.43 ct.
SiO_2	36.7	40.1	40.3
TiO_2	–	–	–
Al_2O_3	–	–	–
Cr_2O_3	–	–	–
FeO*	7.42	8.3	7.8
MnO	0.19	–	–
MgO	54.3	51.1	51.3
CaO	--	--	--
TOTAL	98.6	99.5	99.4

-- not detected; *all Fe as FeO; †0.05 % ZrO_2, also present. [1] Otter, 1989; [2]Jaques et al., 1989; [3]von Knorring and Cox, 1961).

CO_2 in purified oxygen by resistance heating in a platinum crucible after the method described by Deines et al, (1984). Measured yields were generally within 2% of calculated yields. The CO_2 gas was analyzed on a VG Micromass 602E mass spectrometer. Results are reported as $\delta^{13}C$ in per mil (‰) relative to PDB. Standards for the combustion line and mass spectrometer show combined reproducibility within 0.3 ‰ (2σ). Macrodiamonds from Twin Knobs #1

Table 9. Carbon isotope data for Prairie Creek macrodiamonds. Diamonds with two values are for interior and rim, respectively.

Sample	$\delta^{13}C$	Crystal shape	Color	Carats
PC13	-4.4	elongate thh	white	0.15
PC17	-5.7,-5.6	elongate thh	yellow	0.15
PC20	-4.2	thh	brown	0.75
PC23	-10.6	macle thh	off white	0.36
PC25	-4.7,-4.6	broken thh	brown	0.57
PC26	-5.2	thh	off white	0.57
PC27a*	-3.8	broken thh	off white	0.21
PC27b	-6.1	broken thh	white	0.18
PC29*	-5.5	flattened thh	brown	0.30
PC35	-4.7,-5.2	distorted thh	off white	0.21
PC36	-4.2	flattened thh	off white	0.18
PC37	-3.9	elongate thh	yellow	0.15
PC38	-5.3	irregular	yellow	0.24
PC39	-5.1,-5.2	thh	white	0.09
PC40	-3.9	flattened thh	off white	0.51
PC48	-6.2	elongate thh	white	0.29
PC50a	-3.8	thh fragment	white	0.33
PC50b	-4.6,-3.7	broken thh	white	0.24
PC53b	-10.3,-10.6	broken thh	brown	0.09
PC54a*	-3.0,-3.2	irregular (cube?)	off white	0.15
PC54b*	-4.9,-4.5	thh	white	0.06

*See Figure 4.

were not available for carbon isotope analysis. Results are compiled in Table 9.

Nineteen diamonds range from -3.00 to -6.2 ‰ (ave. -4.7 ‰) and two yield values of -10.26 and -10.60 ‰ (ave. -10.5 ‰; Table 9). These values are consistent with primordial mantle carbon (-1 to -10‰, ave. -6 ‰), and are similar to values for diamonds with peridotitic mineral inclusions (Deines, 1980; Kirkley et al., 1991). This suggests that the Prairie Creek macrodiamonds may have a P-type origin, which is further supported by a peridotitic olivine inclusion (Fo_{93}) in one diamond with $\delta^{13}C$=-3.9 ‰. A negative distribution from the mean is similar to that predicted for diamond formation by Rayleigh fractionation from CH_4 (Fig. 7; Deines, 1980; Kirkley et al., 1991). This suggests that the Prairie Creek diamonds could have been produced from primordial mantle carbon through fractionation. However, recent carbon isotope analyses of diamonds in eclogite xenoliths have similar $\delta^{13}C$ values. Only 5 of the 45 diamonds from eclogite xenoliths analyzed by Deines et al., (1991) have $\delta^{13}C$ values outside the primordial carbon range. In the absence of diagnostic inclusion data, an E-type source for some of the diamonds cannot be discounted. No correlation between isotopic character and color or morphology was noted.

Eight stones had internal and external portions analyzed, and within-diamond variations are from 0.07-0.54 ‰. Most heterogeneity falls within experimental reproducibility except for four diamonds. PC50b and PC54b have similar

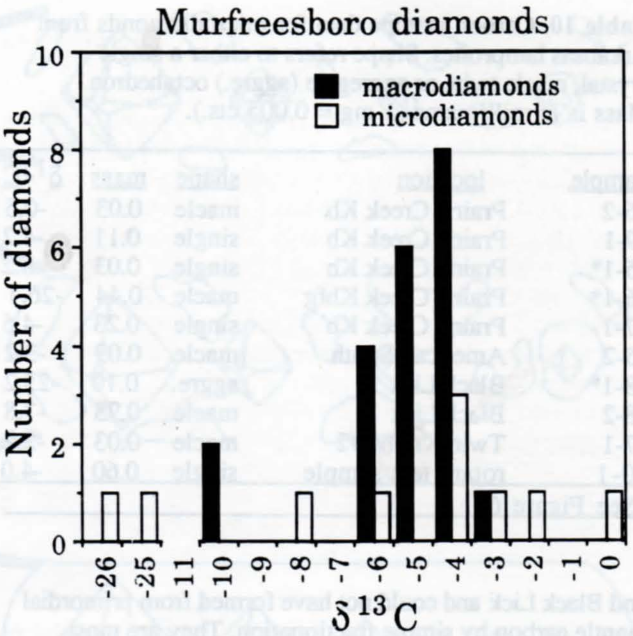

Figure 7. Carbon isotope compositions of Prairie Creek macrodiamonds and microdiamonds from Murfreesboro lamproites.

internal values of -4.6 and -4.9, but externally are ^{13}C-enriched by 0.4 and 0.9 ‰, respectively. PC35 and PC53b with $\delta^{13}C$ values of -4.66 and -10.3 have only slightly lighter external values of -5.2 and -10.6 ‰ respectively. Externally ^{13}C-enriched and depleted diamonds have also been found at other localities (Otter, 1989), and within single diamonds (Wilding, 1990). The diamonds with magnetite and pseudobrookite inclusions have $\delta^{13}C$ values of -5.1 and -4.7 ‰, respectively.

Microdiamonds

Ten microdiamonds were analyzed for carbon isotopes, five from Prairie Creek, one each from Twin Knobs #2 and American, two from Black Lick, and one from the rotary test sample (Table 10). Three Prairie Creek microdiamonds are similar to Prairie Creek macrodiamonds (-4.2, -4.5, -6.2 ‰) and imply a similar paragenesis (Fig. 7). One Prairie Creek microdiamond is heavier at -0.46 ‰. The American and Twin Knobs #2 microdiamonds are also similar to Prairie Creek (-3.18, -2.20 ‰), as are two Black Lick microdiamonds (-4.0,-7.8 ‰). This suggests that the microdiamonds and macrodiamonds formed from a similar carbon reservoir. An eclogitic origin is probable for two microdiamonds with $\delta^{13}C$ values of -25.2 and -26.1 ‰, one of which exhibits non-uniform resorption (Fig. 6g,h). These ^{13}C-depleted microdiamonds are from Prairie Creek

Table 10. Carbon isotope data for microdiamonds from Arkansas lamproites. Shape refers to either a single crystal, macle twin, or aggregate (aggre.) octahedron. Mass is in milligrams (1 mg = 0.005 cts.).

Sample	location	shape	mass	$\delta^{13}C$
46-2	Prairie Creek Kb	macle	0.03	-0.5
49-1	Prairie Creek Kb	single	0.11	-4.2
55-1*	Prairie Creek Kb	single	0.03	-6.2
56-1*	Prairie Creek Kbfg	macle	0.44	-26.1
57-1	Prairie Creek Kb	single	0.23	-4.5
35-2	American South	macle	0.09	-3.2
38-1*	Black Lick	aggre.	0.10	-25.2
38-2	Black Lick	macle	0.95	-7.8
37-1	Twin Knobs #2	macle	0.03	-2.2
40-1	rotary test sample	single	0.60	-4.0

*See Figure 6.

and Black Lick and could not have formed from primordial mantle carbon by simple fractionation. They are most similar to diamonds from eclogitic sources (Kirkley et al., 1991).

DISCUSSION - DIAMOND SOURCE, GENESIS, AND RESORPTION HISTORY

Regional variations in primary diamond color are noted for kimberlite provinces in southern Africa (Robinson et al., 1989), and may apply to North America as well. Yellow diamonds comprise 16-22% of the population at Prairie Creek, in contrast to Sloan, Colorado diamonds where <1% are yellow (Otter, 1989). Brown color in diamonds is attributed to graphitization coupled with deformation, possibly during conduit formation for lamproitic or kimberlitic magma (Robinson et al., 1989). Brown diamonds dominate in the Ellendale and Argyle lamproites (Hall and Smith, 1984), but make up less than half the colors observed at Prairie Creek. Lamproitic magmas therefore do not have a greater tendency to produce brown diamonds. More white than brown diamonds exhibit lamination lines at Prairie Creek, which indicates that some deformation took place without graphitization, presumably before generation of the lamproite magma. Diamonds with lamination lines had to be enclosed in a solid medium during deformation, and are probably from mantle peridotite or eclogite which experienced deformation prior to entrainment into the ascending magma (Orlov, 1977; Robinson, 1979).

Both octahedra and cubes were present as growth forms in the mantle. With respect to resorbed forms, tetrahexahedroida completely dominate over octahedra at Prairie Creek. The same is true for diamonds from the Ellendale 4 and 9 lamproites (Hall and Smith, 1984; Jaques et al., 1986), and the similarities may be more than coincidental. To answer the question posed by Hall and Smith (1984); with respect to intensity and/or duration of resorption, lamproitic diamonds are different. Diamond populations comprised almost entirely of tetrahexahedroida with low relief surfaces may be unique to some lamproites such as Prairie Creek and Ellendale 4 and 9. Low relief surfaces form on diamond at T> 950°C by CO_2 in the presence of water (Robinson, 1979). Higher H_2O/CO_2 ratios, coupled with higher temperatures for lamproitic magmas (Bergman, 1987), may account for the extreme resorption observed on Prairie Creek and Ellendale diamonds.

At Prairie Creek only six diamonds with diagnostic inclusions have been documented; five contain P-type and one contains E-type inclusions. This number is insufficient to state which paragenesis is more common. Oxidizing conditions were present during formation of some diamonds as indicated by the presence of magnetite in one diamond. The carbon isotope values for Prairie Creek diamonds are consistent with derivation from primordial mantle carbon. Diamonds with peridotitic mineral inclusions show a similar distribution, and a P-type olivine inclusion (Fo_{93}) in one diamond with $\delta^{13}C$=-3.90 ‰ indicates a peridotitic source. A negative distribution from the mean is similar to that predicted for diamond formation by Rayleigh fractionation from CH_4 (Deines, 1980; Kirkley et al., 1991), although recent carbon isotope analyses of diamonds in eclogite xenoliths have revealed similar $\delta^{13}C$ values (Deines et al., 1991). In the absence of confirmatory inclusion data, either a P-type or E-type paragenesis is possible.

Gas (i.e.. fluid) inclusions in diamonds reported in previous studies were not confirmed in the present study and remain enigmatic. The cavities reported by Giardini and Melton (1975a) to contain gases are identical to the pitted cavities observed in this study. These features are unique to Prairie Creek (Robinson, 1979), and are present on 42% of the diamonds. The possibility that these cavities once contained fluids which were removed during resorption cannot be discounted.

The overwhelming majority of microdiamonds from the Murfreesboro lamproites are octahedra or fragments with octahedral surfaces. Serrate laminae, pointed plates, knob-like asperities, and ribbing dominate and are xenocrystic surface features. Non-uniform resorption is also present on a single octahedron and an octahedral aggregate microdiamond. These xenocrystic features stongly support a xenolith origin for the microdiamonds. The dichotomy of macro- and microdiamond forms is not unique to Prairie Creek; microdiamond octahedra are also common at Ellendale, Argyle (Jaques et al., 1986; 1991), Sloan (McCandless, 1989), and Premier (Tolansky, 1973).

Carbon isotope values for most microdiamonds are similar to the Prairie Creek macrodiamonds and imply a similar paragenesis. An eclogitic origin is indicated for one Prairie Creek macle with $\delta^{13}C$=-25.19 and an octahedral aggregate from Black Lick with $\delta^{13}C$=-26.06

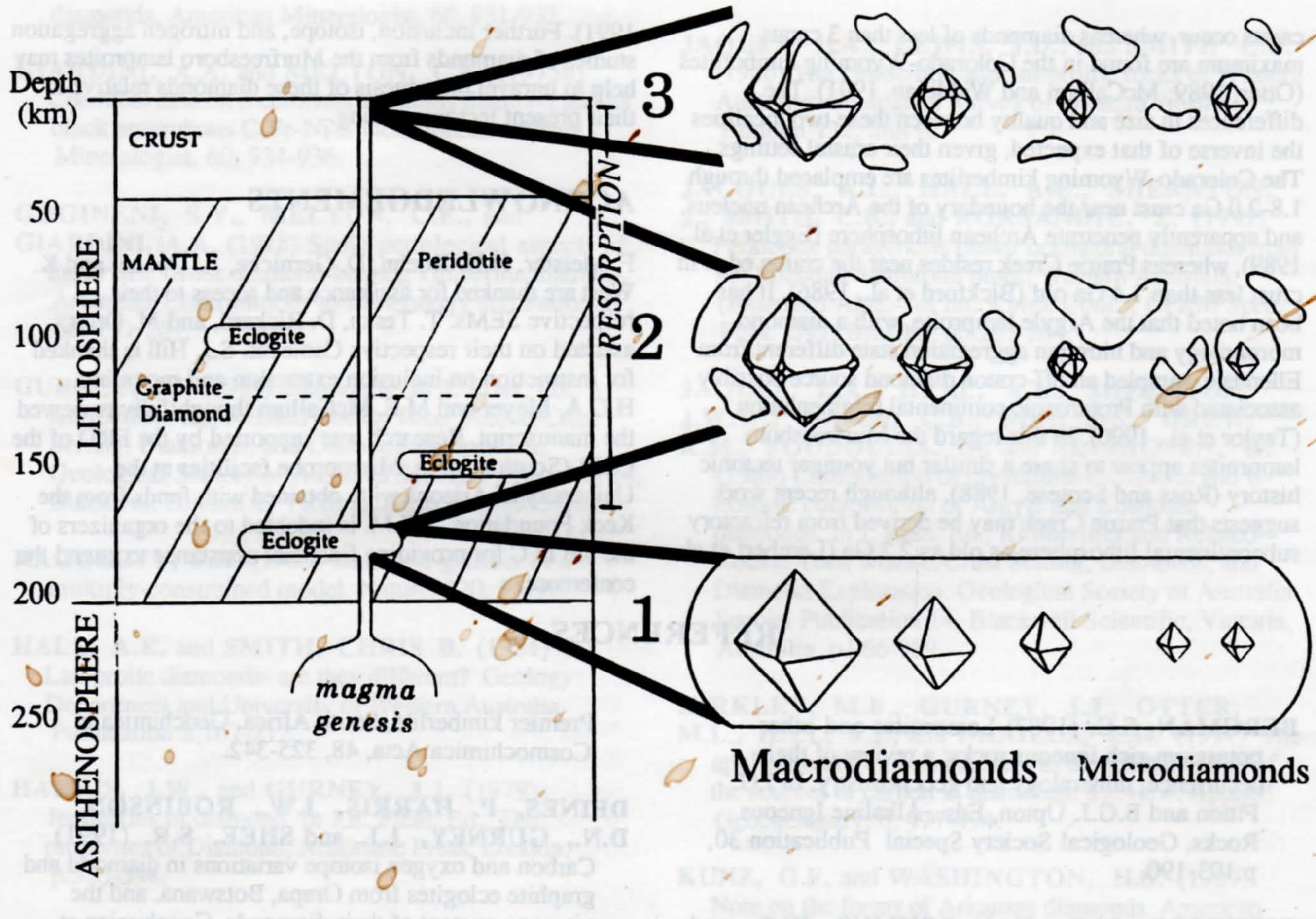

Figure 8. A model to explain the preservation of xenocryst microdiamonds in a resorbing magma. An idealized cross-section to the asthenosphere is shown, with regions of diamond-bearing eclogite below ~120 km. On the right is a representative block of diamond eclogite, containing sharp-edged octahedra. This block is tracked in its ascent to the surface at times 1,2, and 3. See text for discussion.

‰, the latter exhibiting non-uniform resorption (Fig. 6g,h). These ^{13}C-depleted microdiamonds could not have formed from primordial mantle carbon by simple fractionation, and are most similar to diamonds from eclogitic sources.

The 17 diamonds from Twin Knobs #1 recovered during bulk testing are within the size range of microdiamonds; total weight of all the stones is less than an average Prairie Creek macrodiamond. Serrate laminae, pointed plates and knob-like asperities are common surface features on the octahedra, which suggests that they are derived from xenoliths. Non-unform resorption is also present and requires a xenolith origin for some of the diamonds. Some of the Twin Knobs #1 diamonds were small enough to be shielded from resorption in the lamproitic magma by residing in xenolith fragments during the resorption process (McCandless, 1989).

A model to explain the morphological differences between macro- and microdiamonds is presented in Figure 8. The model uses diamond-bearing eclogite, but the process applies to either peridotite or eclogite. At time 1, the diamond-bearing elcogite is sampled by the ascending magma, and at time 2 the eclogite reacts and begins to disaggregate. Only small degrees of disaggregation expose the macrodiamonds, and the smaller macrodiamonds are resorbed more rapidly due to greater surface area/volume ratios. Microdiamonds, with much higher surface area/volume ratios, are completely eliminated upon exposure. As disaggregation and resorption proceed, remnants of the eclogite become increasingly smaller. Only the microdiamonds which remain encapsulated in these xenolith remnants are unaffected. At time 3 resorption has ended and the diamonds represent what is sampled at the surface of the earth; macrodiamonds showing greater abundance of resorbed forms with decreasing size, and unresorbed microdiamonds (McCandless, 1989).

Size and color are economically important genetic features. The common observation is that worldwide, the best diamonds are found well within stable Archean cratons (Gurney, 1989). At Prairie Creek, diamonds of up to 40 carats occur, whereas diamonds of less than 3 carats maximum are found in the Colorado-Wyoming kimberlites (Otter, 1989; McCallum and Waldman, 1991). The differences in size and quality between these two localities the inverse of that expected, given their crustal settings. The Colorado-Wyoming kimberlites are emplaced through 1.8-2.0 Ga crust near the boundary of the Archean nucleus, and apparently penetrate Archean lithosphere (Eggler et al., 1989), whereas Prairie Creek resides near the craton edge in crust less than 1.4 Ga old (Bickford et al., 1986). It has been noted that the Argyle lamproite, with a diamond morphology and nitrogen aggregation state different from Ellendale, sampled an off-craton diamond source possibly associated with Proterozoic continental fragmentation (Taylor et al., 1990). In this regard the Murfreesboro lamproites appear to share a similar but younger tectonic history (Ross and Scotese, 1988), although recent work suggests that Prairie Creek may be derived from refractory subcontinental lithosphere as old as 2.2 Ga (Lambert et al., 1991). Further inclusion, isotope, and nitrogen aggregation studies of diamonds from the Murfreesboro lamproites may help to unravel the genesis of these diamonds relative to their present tectonic setting.

ACKNOWLEDGEMENTS

F. Meister, H.H. Koehn, D. Gernicke, A. Cohen, and K. West are thanked for assistance and access to their respective SEMs. T. Teska, D. Rickard, and M. Otter assisted on their respective Camecas. S.J. Hill is thanked for instruction on inclusion extraction and mounting. H.O.A. Meyer and M.E. McCallum thoughtfully reviewed the manuscript. Research was supported by the FRD of the CSIR (South Africa). Microprobe facilities at the University of Arizona were obtained with funds from the Keck Foundation. T.E.M. is indebted to the organizers of the 5th IKC for providing financial assistance to attend the conference.

REFERENCES

BERGMAN, S.C. (1987) Lamproites and other potassium-rich igneous rocks: a review of their occurrence, mineralogy and geochemistry. In J.G. Fitton and B.G.J. Upton, Eds., Alkaline Igneous Rocks, Geological Society Special Publication 30, p.103-190.

BICKFORD, M.E., VAN SCHMUS, W.R., and **ZIETZ, I.** (1986) Proterozoic history of the midcontinent region of North America. Geology, 14, 492-496.

BOLIVAR, S.L. and **BROOKINS, D.G.** (1979) Geophysical and Rb-Sr study of the Prairie Creek, Arkansas kimberlite. In H.O. A. Meyer and F.R. Boyd, Eds., Kimberlites, Diatremes, and Diamonds: Their Geology, Petrology, and Geochemistry. American Geophysical Union, p. 289-299.

BRANNER, J.C. and **BRACKETT, R.N.** (1889) The peridotite of Pike County, Arkansas. American Journal of Science, 3rd Series, 38, 50-59.

CARMICHAEL, I.S.E., TURNER, F.S. and **VERHOOGEN J.** (1974) Igneous Petrology, McGraw Hill, New York.

DEINES, P. (1980) The carbon isotopic composition of diamonds: relationship to diamond shape, color, occurrence and vapor composition. Geochimica et Cosmochimica Acta, 44, 943-961.

DEINES, P., GURNEY, J.J., and **HARRIS, J.W.** (1984) Associated chemical and carbon isotopic compositon variations in diamonds from Finsch and Premier kimberlite, South Africa. Geochimica et Cosmochimica Acta, 48, 325-342.

DEINES, P. HARRIS, J.W., ROBINSON, D.N., GURNEY, J.J., and **SHEE, S.R.** (1991) Carbon and oxygen isotope variations in diamond and graphite eclogites from Orapa, Botswana, and the nitrogen content of their diamonds. Geochimica et Cosmochimica Acta, 55, 515-524.

DE VRIES, R.C. (1975) Plastic deformation and 'work-hardening' of diamond. Materials Research Bulletin, 10, 1193-1200.

EGGLER, D.H., MEEN, J.K. WELT, F., DUDAS, F.O., FURLONG, K.P., MCCALLUM, M.E., and **CARLSON, R.W.** (1989) Tectonomagmatism of the Wyoming Province. In J.Drexler and E.E. Larson, Eds., Colorado Volcanism, Colorado School of Mines Quarterly, 3, p.

EVANS, T. (1976) Diamonds. Contemporary Physics, 17, 45-70.

FULLER, J.T. (1909) Diamond mine in Pike County, Arkansas. The Engineering and Mining Journal, January 16th, 152-155.

GAAL, R.A.P. (1977) The Diamond Dictionary. Gemmological Institute of America, Santa Monica, California. 342 p.

GIARDINI, A.A. and **MELTON, C.E.** (1975a) The nature of cloud-like inclusions in two Arkansas diamonds. American Mineralogist, 60, 931-933.

GIARDINI, A.A. and MELTON, C.E. (1975b) Chemical data on a colorless Arkansas diamond and its black amorphous C-Fe-Ni-S inclusion. American Mineralogist, 60, 934-936.

GOGINENI, S.V., MELTON, C.E., and GIARDINI, A.A. (1978) Some petrological aspects of the Prairie Creek diamond-bearing kimberlite diatreme, Arkansas. Contributions to Mineralogy and Petrology, 66, 251-261.

GURNEY, J.J. (1989) Diamonds. In J. Ross, Ed., Kimberlites and Related Rocks: Their Mantle/Crust Setting, Diamonds, and Diamond Exploration. Geological Society of Australia Special Publication 14, Blackwell Scientific, Victoria, Australia, p.935-965.

HAGGERTY, S.H. (1986) Diamond genesis in a multiply-constrained model. Nature, 320, 34-37.

HALL, A.E. and SMITH, CHRIS B. (1984) Lamproite diamonds- are they different? Geology Department and University of Western Australia Publication 8,167-212.

HARRIS, J.W., and GURNEY, J.J. (1979) Inclusions in diamond. In J.E. Field, Ed., The properties of Diamond, Academic Press, London, p.555-594.

HARRIS, J.W., HAWTHORNE, J.B., OOSTERVELD, M.M., and WEHMEYER, E. (1975) A classification scheme for diamond and a comparative study of South Africa diamond characteristics. Physics and Chemistry of the Earth, 9, 477-506.

HARRIS, J.W., HARTHORNE, J.B., and OOSTERVELD, M.M. (1979) Regional and local variations in the characteristics of diamonds from some southern Africa kimberlites. In F.R. Boyd and H.O.A. Meyer Eds., The Mantle Sample: Inclusions in Kimberlites and other Volcanics, American Geophysical Union, Washington, D.C., p.27-41.

HARRIS, J.W., HAWTHORNE, J.B., and OOSTERVELD, M.M. (1983) A comparison of diamond characteristics from the De Beers pool mines, Kimberley, South Africa. In J. Kornprobst, Kimberlites II: The Mantle and Crust-Mantle Relationships, Elsevier, Amsterdam, p.1-13.

HILL, S.J. (1989) A study of the diamonds and xenoliths from the Star kimberlite, Orange Free State, South Africa. M.Sc. Thesis, 184 p. University of Cape Town, South Africa.

JAQUES, L.A., LEWIS, J.D., and SMITH C.B. (1986) The kimberlitic and lamproitic rocks of Western Australia. Geological Survey of Western Australia Bulletin 132, 268 p.

JACQUES, A.L., HALL, A.E., SHERATON, J., SMITH, C.B., and ROKSANDIC, Z. (1991) Peridotitic paragenesis planar octahedral diamonds from the Ellendale lamproite pipes, Western Australia. (Extended Abst.-5th Int. Kimb. Conf.), CPRM Spec. Publ. 2/91, Brasília, pp.202-204.

JAQUES, L.A., HALL, A.E., SHERATON, J.W.W., SMITH, C.B., SUN, S-S., DREW, R.M., FOUDOULIS, C., and ELLINGSEN, K. (1989) Composition of crystalline inclusions and C-isotopic composition of Argyle and Ellendale diamonds. In J. Ross, Ed., Kimberlites and Related Rocks: Their Mantle/Crust Setting, Diamonds, and Diamond Exploration. Geological Society of Australia Special Publication 14, Blackwell Scientific, Victoria, Australia, p.966-989.

KIRKLEY, M.B., GURNEY, J.J., OTTER, M.L., HILL, S.J., and DANIELS, L.R. (1991) The application of carbon isotopes to the identification of the sources of carbon in diamonds: a review. Applied Geochemistry, 6, 477-494.

KUNZ, G.F. and WASHINGTON, H.S. (1907) Note on the forms of Arkansas diamonds. American Journal of Science, 4th Series, 24, 275-276.

KUNZ, G.F. (1931) Diamonds in Arkansas. The mineral industry during 1930, United States Mineral Commodity Report, 39, 522.

LAMBERT, D.D., SHIREY, S.B., CARLSON, R.W., WEAVER, B.L., GILBERT, M.C., BERGMAN,S.C., and DENISON, R.E. (1991) Re-Os and Sm-Nd isotopic systematics of lamproites and basalts from the southern U.S. midcontinent: implications for the evolution of Proterozoic sub-continental lithospheric mantle (abstract). EOS, 72, 543.

MCCALLUM, M.E., and WALDMAN, M.A. (1991) The diamond resources of the Colorado-Wyoming State Line District: kimberlite indicator chemistry as a guide to economic potential. Wyoming Geological Association Guidebook, Forty Second Field Conference, Mineral Resources of Wyoming (in press).

MCCANDLESS, T.E. (1989) Microdiamonds from the Sloan 1 and 2 kimberlites,Colorado, USA. 28th International Geological Congress, Extended Abstracts, Workshop on Diamonds, 44-46.

MCCANDLESS, T.E. and **COLLINS, D.S.** (1989) A diamond-graphite eclogite from the Sloan 2 kimberlite, Colorado, U.S.A. In J. Ross, Ed., Kimberlites and Related Rocks: Their Mantle/Crust Setting, Diamonds, and Diamond Exploration. Geological Society of Australia Special Publication 14, Blackwell Scientific, Victoria, Australia, p. 1063-1069.

MELTON, C.E. and **GIARDINI, A.A.** (1975) Experimental results and a theoretical interpretation of gaseous inclusions found in Arkansas natural diamonds. American Mineralogist, 58, 775-782.

MELTON, C.E. and **GIARDINI, A.A.** (1980) The isotopic composition of argon included in an Arkansas diamond and its significance. Geophysical Research Letters, 7, 461-464.

MEYER, H.O.A. (1987) Inclusions in diamond. In P.H. Nixon, Ed., Mantle Xenoliths, John Wiley and Sons, Chichester, England, p.501-522.

MEYER, H.O.A. and **MCCALLUM, M.E.** (1986) Mineral inclusions in diamonds from the Sloan kimberlites, Colorado. Journal of Geology, 94, 600-612.

MILLAR, A.H. (1976) It Was Finders-Keepers at Americas Only Diamond Mine. Carleton Press, New York. 175p.

MISER, H.D. (1913) New areas of diamond-bearing peridotite in Arkansas. U.S. Geological Survey Bulletin 540, Contributions to Economic Geology, 1912, part. 1, 534-546.

MISER, H.D. and **ROSS, C.S.** (1922) Diamond-bearing peridotite in Pike County, Arkansas. Economic Geology, 17, 662-674.

MISER, H.D. and **ROSS, C.S.** (1923) Diamond-bearing peridotite in Pike County, Arkansas. U.S. Geological Survey Bulletin 735I, 279-322.

MISER, H.D. and **PURDUE, A.H.** (1929) Geology of the DeQueen and Caddo Gap quadrangles, Arkansas. U.S. Geological Survey Bulletin 808, 191p.

MITCHELL, R.H. (1985) A review of the mineralogy of lamproites. Transactions of the Geological Society of South Africa, 88, 411-438.

MOORE, R.O. and **GURNEY, J.J.** (1989) Mineral inclusions in diamonds from the Monastery kimberlite, South Africa. In J. Ross, Ed., Kimberlites and Related Rocks: Their Mantle/Crust Setting, Diamonds, and Diamond Exploration. Geological Society of Australia Special Publication 14, Blackwell Scientific, Victoria, Australia, p.1029-1041.

NAVON, O., HUTCHEON, I.D., ROSSMAN, G.R., and **WASSERBURG, G.J.** (1986) Mantle-derived fluids in diamond micro-inclusions. Nature, 335, p.784-789.

NEWTON, M.G., MELTON, C.E., and **GIARDINI, A.A.** (1977) Mineral inclusions in an Arkansas diamond. American Mineralogist, 62, 583-586.

ORLOV, Yu. L. (1977) The Mineralogy of the Diamond. Wiley, New York, 235p.

OTTER, M.L. (1989) Diamonds and their mineral inclusions from the Sloan diatremes of the Colorado-Wyoming State Line kimberlite district, North America. Ph.D., 171 p., University of Cape Town, South Africa.

OTTER, M.L., and **GURNEY, J.J.** (1989) Mineral inclusions in diamonds from the Sloan diatremes, Colorado-Wyoming State Line kimberlite district, North America. In J. Ross, Ed., Kimberlites and Related Rocks: Their Mantle/Crust Setting, Diamonds, and Diamond Exploration. Geological Society of Australia Special Publication 14, Blackwell Scientific, Victoria, Australia, p.1042-1053.

PANTALEO, N.S., NEWTON, M.G., GOGINENI, S.V., MELTON, C.E., and **GIARDINI, A.A.** (1979) Mineral inclusions in four Arkansas diamonds: their nature and significance. American Mineralogist, 64, 1059-1062.

PHAAL, C. (1965) Surface studies of diamond. Industrial Diamond Review, 25, 486-489, 591-595.

ROBINSON, D.N. (1979) Surface textures and other features of diamonds. Ph.D. thesis, 282 p., University of Cape Town, South Africa.

ROBINSON, D.N., SCOTT, J.N., VAN NIEKERK, A., and **ANDERSON, V.G.** (1989) The sequence of events reflected in the diamonds of some southern African kimberlites. In J. Ross, Ed., Kimberlites and Related Rocks: Their Mantle/Crust Setting, Diamonds, and Diamond Exploration. Geological Society of Australia Special Publication 14, Blackwell Scientific, Victoria, Australia, 990-999.

ROEDDER, E. (1984) Fluid inclusions. Reviews in Mineralogy, 12, 644p. Mineralogical Society of America, Washington, D.C.

ROSS, M.I., and **SCOTESE, C.R.** (1988) A hierarchical tectonic model of the Gulf of Mexico and Caribbean, Tectonophysics, 71, 27-36.

SCOTT-SMITH, B. and **SKINNER, E.M.W.** (1984a) A new look at Prairie Creek, Arkansas. In J. Kornprobst, Ed., Kimberlites I: Kimberlites and Related Rocks: Proceedings of the Fourth International Kimberlite Conference, 1982, p.255-284. Elsevier, Amsterdam.

SCOTT-SMITH, B., and **SKINNER, E.M.W.** (1984b) Kimberlite and American Mines, near Prairie Creek Arkansas. In J. Kornprobst, Ed., Kimberlites III: Documents Annales Scientifique Universitie de Clermont-Ferrand, 74, 27-36.

SOBOLEV, N.V., YEFIMOVA, E.S., and **POSPELOVA, L.N.** (1981) Native iron in Yakutian diamonds, and its paragenesis. Geology and Geophysics, Akademii Nauk SSSR, 12, 25-29 (in Russian).

TAYLOR, W.R., JAQUES, A.L., and **RIDD, M.** (1990) Nitrogen-defect aggregation characteristics of some Australasian diamonds: time-temperature constraints on the source regions of pipe and alluvial diamonds. American Mineralogist, 75, 1290-1310.

THOMAS, W.A. (1985) The Appalachian-Ouachita connection: Paleozoic orogenic belt at the southern margin of North America. Annual Review of Earth and Planetary Sciences, 13, 175-199.

TOLANSKY, S. (1973) Distribution of Type I and Type 2 in South African diamonds. Industrial Diamond Review, 28-31.

UROSOVSKAYA, A.A. and **ORLOV, Yu. L.** (1964) Nature of plastic deformation of diamond crystals. Doklady Akademii Nauk SSSR, 154, 112-115.

VON KNORRING, O., and **COX, K.G.** (1961) Kennedyite, a new mineral of the pseudobrookite series. Mineralogical Magazine, 32, 676-682.

WALDMAN, M.A., MCCANDLESS, T.E., and **DUMMETT, H.T.** (1987) Geology and petrography of the Twin Knobs #1 lamproite, Pike County, Arkansas. Geological Society of America Special Paper 215, 205-216.

WILDING, M.C. (1990) A study of diamonds with syngenetic inclusions. Ph.D. thesis, University of Edinburgh, Scotland.

ZARTMAN, R.E. (1977) Geochronology of some alkalic rock provinces in eastern and central United States. Annual Reviews of Earth and Planetary Sciences, 5, 257-286.