A STUDY OF THE KIMBERLITE IN

ELLIOIT COUNTY, KENTUCKY

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Geology 570
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[Signature]

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This paper is presented as a fulfillment of the requirement for Geology 570, the Senior Thesis. This investigation was suggested by my thesis advisor, Dr. C. H. Shultz, who made possible the actual field study of the outcrop. The kimberlite outcrop was visited in December, 1967 and subsequent library and laboratory study was conducted during the Winter and Spring quarters 1968. Dr. Shultz also provided thin sections of the rock samples collected at the site, and provided access to photomicrograph equipment. His advice and introduction to references was also greatly appreciated. Dr. Faure supervised the X-ray investigations.
CONTENTS

ABSTRACT ........................................ page 1

INTRODUCTION .................................. 2
  Location and History

GENERAL GEOLOGY ................................. 3
  Introduction
  Stratigraphy
  Structure

PETROGRAPHY .................................... 4
  Outcrop
  Hand Specimen
  Thin Section
  Heavy Mineral Concentrate
  Calculated Chemical Analyses

DISCUSSION ...................................... 12
  Relation to Regional Occurrences of Similar Intrusives
  Comparison with Kimberlites of Siberia and South Africa
  Method of Intrusion
  Garnet and Olivine Evidence for Formation of Kimberlite
    Magma and its Condition Upon Intrusion

CONCLUSIONS .................................. 16

REFERENCES CITED ............................... 17
ILLUSTRATIONS

Figures

Plate 1, Figure 1. Sketch map of Elliott County, Kentucky, showing relative position of kimberlite (modified from Koenig 1956).

Plate 1, Figure 2. Map showing outcrops and pattern of kimberlite in area between Ison Creek and Hamilton Creek.

Plate 2, Figure 1. Fresh surface of kimberlite "hardbank" with limestone and shale inclusions.

Plate 3, Figure 1. Photomicrograph of general section of kimberlite showing large rounded olivine, and small euhedral olivine phenocrysts, opaque ilmenite, magnetite, and perovskite in matrix of serpentine and carbonate.

Plate 3, Figure 2. Photomicrograph of perovskite alteration rim around ilmenite, serpentinization of olivine, and magnetite in groundmass of serpentine and carbonate.

Plate 4, Figure 1. Photomicrograph showing sugary fracture pattern of large ilmenite phenocrysts.

Plate 4, Figure 2. Photomicrograph of kelyphitic reaction rim around garnet, with magnetite in serpentine and carbonate groundmass.

Tables

Table 1. Index of Refraction of Garnet Arranged Into Groups According to Color. page 9

Table 2. Chemical Analyses of Kimberlites. 11
ABSTRACT

The Elliott County diatremes are basaltic kimberlites occurring as radially arranged groups of apophysis type intrusions centering around a large outcrop on Hamilton Creek. An explosive fluidization intrusion of a gas-solid mixture is indicated by the lack of structural deformation and contact metamorphism of the country rock. The outcrops have identical mineralogy but vary in percent composition of minerals and inclusions because of differences in the degree of alteration, intrusive conditions, and stratigraphy of the country rock. Inclusions of probable upper mantle material, Precambrian basement material, and local wall rock occur indicating the probable source of the kimberlite as the upper mantle. The relationship between garnet color and pyrope content is apparently a result of one color being the first melted fraction of the upper mantle while the other is the residual garnet caught up by the magma as it intruded. Olivine phenocrysts are of two ages indicating a pause in the intrusive sequence which could, according to Bardet (1965), account for the absence of diamond. The 269 m.y. age (Zartman, et al. 1957) of this intrusion corresponds to that of the ultrabasic mica-peridotites of the Kentucky-Illinois fluorspar district. Both lie on one of several deep crustal fault zones of the eastern United States craton along which intrusion apparently took place at various times throughout Paleozoic and Mesozoic time.
INTRODUCTION

The kimberlites of Elliott County were the first igneous rocks discovered in Kentucky. A. R. Crandall of the Kentucky Geological Survey found the intrusives in the valley of Ison Creek around 1881. J. S. Diller, also of the Kentucky Geologic Survey, was told of the outcrop and published several reports of his investigations of it before 1900. Later, Crandall (1910) described this intrusive as a "crater-like dike" with arms radiating north, west, and southwest from the main body. Diller referred to the rock as a peridotite until Lewis (1888) coined the term "kimberlite" for the diamantiferous plugs of the Kimberley area of South Africa to which these rocks are nearly identical.

A kimberlite, as defined by Lewis, is a porphyritic peridotite composed essentially of olivine and its alteration products. In addition, phlogopite, ilmenite, pyrope, diamond, perovskite, and other minerals are present in varying amounts. Chemically, kimberlites are characterized by low SiO₂ and Al₂O₃ content, high MgO, fairly high TiO₂ and CO₂, presence of P₂O₅, and Al₂O₃ greater than K₂O and Na₂O combined. Kimberlite therefore is a notably magnesium-rich ultrabasic rock.

The outcrop being studied is located in northeastern Kentucky in Elliott County. More precisely, it occupies the southwest corner of the southwest 1/9 of the Willard geologic quadrangle, 83°00' west longitude-38°07' north latitude (Plate 1, Fig. 1). Exposures sporadically dot the ridge between Ison Creek and Hamilton (Hambleton) Creek for about a mile east of the Ison-Johnson School (Plate 1, Fig. 2).

Within the last few years drilling has been done at the largest outcrop, labeled "mine" (Plate 1, Fig. 2), to determine possible economic value of the rock, but although there is a continuing attempt to promote a mining operation, nothing of outstanding economic importance seems to have been found. Recently a magnetic survey was conducted in an attempt to establish the actual extent and form of the intrusions. This paper is a petrographic study of this group of intrusives to gain additional information concerning the origin and manner of implantation of this kimberlite in particular and of all kimberlites in general.
Figure 1 Sketch map of Elliott County, Kentucky, showing relative position of kimberlite (modified from Koenig 1956).

Figure 2 Map showing outcrops and pattern of kimberlite in area between Ison Creek and Hamilton Creek.
GENERAL GEOLOGY

Introduction

Elliott County is characterized by steep hills forming even-crested ridges which are separated by narrow alluviated stream valleys. The topography is mature with average elevation between 700 and 1100 feet. Limited farming and grazing is done in the larger valleys, while the streams cutting the ridges are narrow and deep.

Stratigraphy

The region is underlain by a sequence of nearly flat lying Middle Pennsylvanian beds of the upper half of the Breathitt Formation. This consists of a typical coal measure sequence predominantly of sandstones, with interbedded siltstones, shales, thin coal beds with underclay and limestones. Sandstone members of this formation cap the hills accounting for the even-crested ridges of the area. The region is a part of the Allegheny Plateau physiographic province.

Structure

Elliott County is located on the west flank of the Parkersburg Synclinorium. Regional dip is to the south and southeast at a very small angle. The dip is reversed locally by faults, small domes and basins associated with the regional structure. The intrusives are on the upthrown side of the Little Sandy Fault, a high angle normal fault extending east-west for about 12 miles, located one mile south of the outcrop area. This fault is part of the more extensive Rough Creek-Kentucky River fault zone which connects the Elliott County diatremes with the mica-peridotites of the western Kentucky-southern Illinois fluor spar district. K-Ar and Rb-Sr dating (Zartman, et al. 1967) shows these two intrusive complexes to be of similar age, around 269 m.y., Late Pennsylvanian-Early Permian. The Elliott County diatremes show no obvious relation to the faults in the area except possibly as pre-existing subsurface zones of weakness along which intrusion took place. Evidence of minor doming or fracturing in the immediate vicinity of the intrusions is very slight or entirely lacking.
PETROGRAPHY

Outcrop

The kimberlite bodies are best exposed in and on the banks of steep stream valleys. The most obvious exposure is 0.25 mile south of the Ison-Johnson School. This is a rough ridge of "hardbank" on the west facing bank of the stream. On the opposite bank, erosion is less rapid and the outcrop consists of "yellow-ground" with residual grains of garnet and ilmenite scattered through the soil. Additional outcrops were difficult to locate due to their small size, apparently radial distribution, and residual soil cover. Although the rock appears in hand sample to be relatively resistant, it actually weathers at about the same rate as the country rock. This inhibits recognition of additional exposures or tracing existing ones topographically. The local extent, identical mineralogy, and roughly radial outcrop pattern of these small isolated outcrops indicate that they may be part of the same intrusion at depth.

Hand Specimen

Fresh samples of the kimberlite are dark olive green to nearly black, while weathered surfaces are yellow brown. Yellow phenocrysts of olivine show up prominently on specimens of intermediate degrees of decomposition. It is a holocrystalline, porphyritic rock with phenocrysts of olivine, partially serpentinitized olivine, pyropic garnet, ilmenite, enstatite, chrome-diopside, and phlogopite in a serpentine and carbonate groundmass (Plate 2, Fig. 1). The size of the phenocrysts varies from one exposure to another generally ranging from 2 to 15 mm, but some reach 25 mm across. Anhedral deep-green or yellow olivines are most common, while rounded jet-black ilmenite and deep-red, nearly spherical garnets are more easily seen. Enstatite occurs as large anhedral crystals only at the "mine" area. Phlogopite occurs sparingly in all outcrops as subhedral crystals, and is particularly well developed at the "mine" outcrop. Chrome-diopside rarely exceeds 3 mm. It is not common, but stands out because of its vivid green color. Combined, the phenocrysts may compose as much as 60 percent of a sample.
Figure 1 Fresh surface of kimberlite "hardbank" with limestone and shale inclusions.
Inclusions are common, composing 80 percent of one outcrop. The majority are shales of local origin, but limestones and feldspathic nodules are also present. The shale-kimberlite boundary shows large blocks of shale which have been separated from the bedrock by thin outlines of kimberlite. The shale is not strongly metamorphosed as might be expected, being slightly baked at most. Limestone inclusions are more rounded, having traveled further, and show some effects of metasomatism. Inclusions of the entire Paleozoic section could probably be recognized by careful analysis and comparison. Rounded syenite inclusions, possibly from the Precambrian of the upper crust, show rounding effects from transport in a more or less solid magma but no evidence of being altered by it.

Thin Section

Thin sections were examined from several outcrops. The mineralogy of these, excluding inclusions, is identical. Variations in the percent of each mineral from section to section mostly reflect differences in the amount of alteration. The most obvious feature of the rock is its high olivine content, originally as high as 80 percent in some sections before serpentinization. Thus the rock is a basaltic kimberlite, since it contains over 50 percent olivine. Lamprophyric or micaceous kimberlite contains more than 50 percent phlogopite. The minerals identified include olivine, serpentine (antigorite variety), a carbonate (mostly calcite), magnetite, ilmenite, perovskite, chlorite, garnet, orthopyroxene, kelyphite, and leucoxene. Although some chrome-diopside, enstatite, and phlogopite phenocrysts were identified in hand specimens, none could be found in thin section. Some inclusions were found in these sections.

The minerals can be divided into two large groups. One of primary minerals including phenocrysts of olivine, ilmenite, and garnet with some orthopyroxene, magnetite, and perovskite. The second group are the alteration products and include carbonate, serpentine, chlorite, kelyphite, leucoxene, and some perovskite and magnetite. The rock is essentially fine-grained carbonate and serpentine enclosing altered olivine phenocrysts (Plate 3, Fig. 1).
Figure 1  Photomicrograph of general section of kimberlite showing large rounded olivine and small euhedral olivine phenocrysts, opaque ilmenite, magnetite, and perovskite in matrix of serpentine and carbonate.

Figure 2  Photomicrograph of perovskite alteration rim around ilmenite, serpenitinization of olivine, and magnetite in a groundmass of serpentine and carbonate.
The olivine is apparently of two generations. The older is larger, 5-12 mm, generally anhedral, and greatly fractured. Some grains of this group show undulatory extinction indicating deformation while still under considerable pressure. Most are highly serpenitized, more so than crystals of the other group. The smaller olivines, 0.5-3 mm, are euhedral and show little evidence of having been strained or altered. No difference was found in the optical properties of the two types. Both have 2V of approximately 90° indicating a composition of forsterite90-fayalite10.

The olivine alters to antigorite and fine magnetite dust which retain the outline of the former crystal. Chlorite was found in small quantities within the serpentine in some sections. Serpentine also exists as a part of the groundmass being derived from the pre-existing matrix which is now totally altered. A little serpentine was found in limestone inclusions from metasomatic replacement of mineral grains within the limestone.

The inclusions are not greatly metamorphosed, but due to the high pressure and volatile content of the original gas-solid magma, most show some evidence of metasomatic replacement. The boundaries of the limestone inclusions are sharp and show only minor signs of reaction with the groundmass. No shale inclusions were found in the sections. A few masses of serpentine and orthopyroxene were observed, which may represent altered remnants of upper mantle inclusions. The boundary was very obscure and none of the other typical Kimberlite minerals were found inside these masses. Orthopyroxene, near enstatite in composition, also was seen in several sections as fine needles scattered throughout the matrix.

The carbonate, like the olivine, is apparently of two types. One is the result of late forming carbonate rich solutions and occurs as large single anhedral crystals several mm across. The other type is more intimately associated with the serpentine of the groundmass. It occurs as fine grained masses, which enclose the other minerals of the matrix.
Where this carbonate comes into contact with ilmenite, it produces a reaction rim of fine grained perovskite (Plate 3, Fig. 2). Perovskite also occurs as square brown euhedral crystals up to 0.01 mm across existing alone in the matrix unassociated with ilmenite. Crystals of this nature are considered primary, or at least formed very early.

Ilmenite and magnetite make up the opaque minerals. Some ilmenite is in large phenocrysts showing perovskite alteration rims and a sugary texture (Plate 4, Fig. 1). Others occur with magnetite in the matrix as 0.01 mm across anhedral grains occasionally altering to leucoxene. Magnetite in the matrix is usually euhedral, but is otherwise nearly impossible to distinguish from ilmenite.

Garnets range in size from 0.5-15 mm across. They are nearly spherical and are always surrounded by a kelyphitic reaction rim. Kelyphite (Smirnov, 1959) is composed of a fibrous inner layer of biotite and amphibole oriented normal to the surface of the garnet with an outer layer of magnetite, chlorite and some carbonate (Plate 4, Fig. 2). This complex mineral assemblage results from the reaction of garnet and the kimberlite magma.

On the average, olivine composes about 30 percent of each section, serpentine about 35 percent, carbonate about 25 percent, perovskite 3 percent, magnetite and ilmenite combined about 5 percent, and less than one percent of each of the other minerals.

Heavy Mineral Concentrate

A sample of detrital material was collected from a gully containing small placer-like concentrations of kimberlitic minerals immediately below the "hardbank" outcrop 0.25 mile south of the Ison-Johnson School. The heavy minerals were concentrated in Bromoform and then screened into different size fractions. No diamonds were found either in this concentrate or in thin section.

Ilmenite was the most abundant mineral in the concentrate. These grains were jet black phenocryst fragments with conchoidal fracture and no apparent cleavage. Many larger grains had a sugary texture as shown in Plate 4, Figure 1.
Figure 1  Photomicrograph showing sugary fracture pattern on large ilmenite phenocryst.

Figure 2  Photomicrograph of kelyphitic reaction rim around garnet, with magnetite in serpentine and carbonate groundmass.
Rounded surfaces of the original phenocrysts are pitted and discolored when present. The pitted surface is a result of alteration to leucocxene or perovskite and remnants of these minerals cause the "white" discoloration. A few crystals were coated with hematite resulting from the oxidation of magnetite lamellae within the ilmenite.

X-ray diffraction of the ilmenite confirmed the presence of small quantities of both hematite and magnetite. It was impossible to determine the MgO content since geikielite, MgO.TiO₂, and ilmenite have nearly identical diffraction patterns and occur in solid-solution with one another. An X-ray fluorescence scan revealed the presence of several trace elements common to kimberlites throughout the world. These included chromium, manganese, nickel, copper, zinc, niobium, zirconium, and rare earths of the Lanthanum Series.

Garnets were isolated by magnetic separation and then divided visually into seven groups based on color. The index of refraction of about 40 grains in each group were measured and plotted (Table 1). The color range from light brown through red-brown to deep purple was found to closely parallel a rise in n values. This reflects an increase in the almandine content of the garnets. At n=1.74 the composition is pyrope₈₀-almandine₂₀ and at n=1.75 it is pyrope₇₀-almandine₃₀. This variation will be discussed later with regard to the initial magma formation. The range of measured indices compares favorably with index data on Siberian kimberlites (Smirnov, 1959) and the James Bay Lowlands kimberlites of Canada (Skimming, 1960) whose dominant ranges are 1.744-1.759 and 1.74-1.76 respectively. The index of refraction of the garnets was measured within an accuracy of ±0.003. Garnets of color groups #3, #4, and #6 make up about 80 percent of the total. Since garnet color can be determined by factors other than almandine content, CaO or Cr₂O₃ content for instance, the results of Table 1 should be considered only as an approximation. This is, in fact, probably the reason for the anomalous values of sample #3.
Table 1  Index of Refraction of Garnet Arranged into Groups According to Color.

<table>
<thead>
<tr>
<th>Garnet Color Group</th>
<th>Index of Refraction</th>
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<tbody>
<tr>
<td>#1 Very light brown</td>
<td>1.76</td>
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<tr>
<td>#2 Light brown, insufficient quantity, not plotted</td>
<td>1.75</td>
</tr>
<tr>
<td>#3 Brown</td>
<td>1.74</td>
</tr>
<tr>
<td>#4 Red-brown</td>
<td>1.73</td>
</tr>
<tr>
<td>#5 Red-purple</td>
<td>1.72</td>
</tr>
<tr>
<td>#6 Purple</td>
<td>1.71</td>
</tr>
<tr>
<td>#7 Deep-purple, nearly opaque</td>
<td>1.70</td>
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</table>

Enstatite, chrome-diopside, olivine, and some extraneous sedimentary debris, in decreasing order of abundance, make up the remainder of the heavy mineral concentrate. Enstatite is a translucent olive green color, which becomes darker and more cloudy with increased alteration. It was most easily separated from chrome-diopside by color since the optical properties of both were nearly the same. Chrome-diopside is a lighter transparent vivid green color, which loses some of its luster with alteration. Olivines were simply the cores of serpentinized phenocrysts that had weathered out.
Calculated Chemical Analyses

Chemical analyses of the various outcrops were computed by substituting known or supposed mineral compositions into thin section modal analyses. The results were compared with actual chemical analyses of various kimberlites (Table 2). Modal analyses of 1000-2000 counts were made on each of six sections.

Certain assumptions had to be made concerning the chemical formulas of the minerals involved. For olivine, forsterite$_{90}$-fayalite$_{10}$ was used based on the optical property, $2V$ approximately 90°. For garnet, pyrope$_{78}$-almandine$_{22}$ was used based on the index of refraction. The carbonate was assumed to be all calcite since nothing was known about the dolomite content, if any. Ilmenite from kimberlite is typically rich in MgO, which could not be determined. It was therefore assumed to be ilmenite $(\text{FeTiO}_3)_{70}$-geillekite $(\text{MgTiO}_3)_{30}$, about the same as that of the Siberian kimberlites. Ideal compositions were used for serpentine, magnetite, and perovskite. Orthopyroxene and kelyphite were neglected since neither exceeded one percent in any mode, and their composition was uncertain.

The only major discrepancy between the computed and the actual chemical analyses is the amount of $\text{Al}_2\text{O}_3$ which is much lower in the computed analyses, essentially absent. Garnet is the only modal mineral containing $\text{Al}_2\text{O}_3$ and large garnet phenocrysts were avoided while making the modes. To count one of the big garnets would have produced equally erroneous high values for $\text{Al}_2\text{O}_3$ since they occur so sparingly. $\text{H}_2\text{O}$ values are low since serpentine is its only modal source, while chemical analyses also count unattached water in the rock. Trace elements are naturally absent in the modal analyses since they are not a part of the formulas of minerals counted in the mode.

The overall similarity of the analyses would seem to credit the assumptions concerning mineral composition. It was also noted that in spite of differences from section to section in degree of alteration and percent of individual minerals, the analyses were nearly alike, showing the overall compositional equivalence of separate outcrops. Also, the sections were biased, cut to show specific features rather than representing the general rock. Inclusions were avoided while making the modes.
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<td>99.52</td>
<td>100.86</td>
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1. Average chemical composition of basaltic kimberlite, 10 analyses (Nockolds, 1954).
2. Kimberlite, Kao pipe, Basutoland (Dawson, 1962, p. 551); M. H. Kerr, analyst.
3. Elliott County, Kentucky, kimberlite (Koenig, 1956, p. 49); M. E. Coller, analyst.
4. Elliott County, Kentucky, kimberlite (Diller, 1887, p. 25); T. M. Chatard, analyst. Includes 0.43 Cr₂O₃, 0.05 Ni, and 0.28 SO₃ in total but not in the table.
5. Average of six analyses based on modal analyses of thin sections. Elliott County, Kentucky.
6. Calculated analysis from modal analysis of thin section # P67KY6A. Elliott County, Kentucky.
DISCUSSION

Kimberlites are usually found around the margins of stable continental cratons. The cratons are not entirely static, however, particularly near the margins where they may contain large scale crustal deformation structures. The Elliott County kimberlite lies along one such feature, the Rough Creek-Kentucky River fault zone, which extends westward into Missouri. The mica-peridotites of the western Kentucky-southern Illinois fluorspar district are also located along this feature. Crustal deformation apparently created this zone of weakness along which these ultrabasics were then intruded. Zartman, et al. (1967) have determined the K-Ar and Rb-Sr ages of both intrusives from phlogopite phenocrysts. The results of both types of age determination were overlapping and averaged 269 m.y., Early Permian, for both areas. This indicates that both ultrabasic complexes are related to the time of formation of the major zone of weakness. The composition difference between the two areas is probably a factor of the depth of formation of the original magma and the intrusive history of each.

Many other alkaline intrusive complexes occur along the eastern craton of North America. Each seems to be related to a similar structural feature, but the structural features are apparently not related to one another. Intrusions occurred sporadically throughout most of Paleozoic and Mesozoic time reflecting a history of repeated stress, of unknown cause, against the stable craton.

This relationship is also true of other continents, and it is interesting to note that the igneous rock produced is nearly identical. Compared with the Elliott County exposure nearly identical descriptions were given for Siberian and South African kimberlites. The minerals present, their relative proportions and the chemical compositions are very close (Table 2). Inclusions are also characteristic. However, in other kimberlites eclogite inclusions of supposed upper mantle origin seem to be more common.
A characteristic of many kimberlites not observed in the Elliott County outcrop is the presence of inclusions from higher stratigraphic levels. Hearn (1968) describes identifiable kimberlite inclusions that represent formations more than 4000 feet stratigraphically higher than the unit adjacent to the kimberlite intrusive at the present erosion surface.

The presence of magnesium minerals like perovskite and magnesium-rich ilmenite are characteristic of kimberlites everywhere, and along with low silica content, distinguishes kimberlites from most other igneous rocks. The carbonate is part of the original magma. It has been suggested that the carbonate could be derived from assimilation of carbonate inclusions, but kimberlites of shield areas such as those in Canada have not penetrated carbonate formations and yet contain the normal amount of carbonate in the matrix.

The kimberlites of Siberia, South Africa and elsewhere occur as pipe-like intrusions similar to the Elliott County exposure. They may be larger, as in South Africa, but they still show the same relationships to the enclosing country rock. Metamorphism is very slight if recognizable at all. The type of intrusion seems to be nearly the same in all localities. Judging from their worldwide similarities of mineralogy, texture and structure, it seems likely that they all were produced from a homogeneous source. This, in addition to the presence of occasional eclogite inclusions and other typically high pressure mineral phases like pyropic garnet and diamond indicate that their source is somewhere within the upper mantle.

Kimberlite intrusion apparently results from crustal movement producing zones of structural weakness in the lower crust and plastic deformation of the upper mantle. Any rock will flow if subject to enough pressure. Because of the tremendous pressure at that depth, the upper mantle becomes mobile without necessarily melting. The high density "magma" intrudes the crust along the zone of weakness with a relatively high velocity, working its way upward toward the surface. At the lower confining pressures of the upper crust the gaseous components expand fluidizing the magmatic mass, which breaks its way
by stoping through overlying rocks while producing only minor structural deformation in the immediate vicinity. At the surface, local joint systems, fault zones or lithologic units will control the actual outcrop pattern. The percent of inclusions would depend upon the gaseous content of the particular "magma", the lithology intruded, the geometric relationship of the particular pipe to the main body and on how well the gas pressure was maintained throughout intrusion.

As this gas-solid "magma" rises it picks up pieces of country rock from all depths. These inclusions are rounded by abrasion, the degree of rounding being a function of their resistance to abrasion as well as the distances traveled from their sources. The high pressure and gas content cause significant metasomatic replacement within some inclusions. Metamorphism, however, is nil since the "magma" is intruded relatively cold, less than 500°C. No flow structure or preferred orientation of crystals is present. According to Mikheyenko and Nenashev (1962) kimberlite begins to melt at 1230° and melts completely at 1500°. If kimberlites were ever molten, much greater contact metamorphism would be expected. Because of this, all phenocrysts must have formed very early, being preserved by maintaining a relatively high pressure until shortly before movement ceased. Any pause in the intrusion cycle would allow pressure to escape and the less stable high pressure minerals would begin to break down. According to Bardet (1965) this could account for the lack of diamonds in the Elliott County kimberlites. The presence of two generations of olivine would further indicate a break in the intrusive cycle at some level.

The existence of a range in composition in garnet indicates differentiation or partial melting at some point in the kimberlite history. Since it is evident that the kimberlite was intruded as a solid, differentiation by partial melting would have to have been from a previous heating event. Another possibility would be ion diffusion within the mantle creating a compositional gradation with depth. In this case the color and composition series would indicate a certain depth of formation of the kimberlite "magma".
However formed, the garnets were rounded by abrasion and developed their kelyphitic rim due to reaction with the gaseous "magma" during the final stage of intrusion as movement ceased. Serpentinization would begin as soon as the relatively cold "magma" got below 400-500°C near the surface. Carbonitization is a late stage effect of the gaseous fraction. Carbonate, from ground water, is also present as crack and fracture fillings in the kimberlite.
CONCLUSIONS

1. The Elliott County, Kentucky, diatremes are basaltic kimberlites strongly resembling kimberlites of Siberia, South Africa and elsewhere in mineralogy, chemical composition, high magnesium content, and texture.

2. It is an apophysis type intrusion surrounding a single pipe at depth. The mineralogy of each branch pipe is identical while varying in amount of alteration and inclusion content.

3. The source of the kimberlite is the upper mantle and therefore kimberlite intrusions potentially could contain inclusions of all intermediate formations. Garnets form a parallel color and composition series that either represents partial melting of one type of garnet and the inclusion of the other as residual matter, or indicate the depth within the upper mantle from which the kimberlite "magma" was derived because of a compositional gradient due to ion diffusion.

4. The kimberlite was intruded as a relatively cold gas-solid crystal mush by fluidization. The maximum age of the intrusion is around 269 m.y., Early Permian. A two stage intrusion or major pressure loss at some point is indicated by the two generations of olivine phenocrysts and the absence of diamond.

5. The Elliott County kimberlite is related to the regional structure, as are the other alkalic intrusives of eastern North America. However, the elements of the regional structure, namely the various fault zones, along which the intrusions occur, are not related in time. Intrusions occurred sporadically throughout much of Paleozoic and Mesozoic time along the eastern edge of the North American craton.
REFERENCES CITED


2. Crandall, A. R., 1910, Coals of the Licking Valley Region and some contiguous territory, including also an account of Elliott County and its dikes: Kentucky Geol. Survey Bull. 10, p. 70-90.


