GEOLOGICAL SURVEY CIRCULAR 842

# The Potential for Diamond-Bearing Kimberlite in Northern Michigan and Wisconsin

*Prepared in cooperation with the Geological Survey Division, Michigan Department of Natural Resources*

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*Description of a kimberlite pipe and possible cryptovolcanic structures and a discussion of the possibility that kimberlites in Wisconsin and Michigan might be the source for drift diamonds in Wisconsin*

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# The Potential for Diamond-Bearing Kimberlite in Northern Michigan and Wisconsin

By W. F. Cannon and M. G. Mudrey, Jr.[1]

**ABSTRACT**

Between 1876 and 1913, diamonds were found in at least seven localities in southern and central Wisconsin. All were found in Pleistocene glacial deposits or Holocene river gravel. The bedrock kimberlite source for the diamonds is unknown but has been presumed to be in northern Canada, the only area north of Wisconsin previously known to contain kimberlites. Recently, a kimberlite pipe, here named the Lake Ellen kimberlite, has been found in Iron County, Michigan. That find suggests the possibility that drift diamonds in Wisconsin have come from a more local source—kimberlites in northern Michigan and Wisconsin.

The Lake Ellen kimberlite is very poorly exposed, but a strong positive magnetic anomaly indicates that it is roughly circular in plan and about 200 m in diameter. Although the kimberlite is entirely surrounded by Precambrian rocks, it contains abundant inclusions of fossiliferous dolomite, probably from the Ordovician Black River Group that overlay the area when the kimberlite was intruded. The post-Ordovician age of the kimberlite leads us to suspect that other possible cryptovolcanic structures in Paleozoic rocks in the region were formed over kimberlite pipes that are not yet exposed by erosion. Such structures include Limestone Mountain and Sherman Hill, in Houghton and Baraga Counties, Michigan; Glover Bluff, in Marquette County, Wisconsin; and possibly an area along the Brule River south of Iron River, Michigan.

No diamonds are known in the Lake Ellen kimberlite, but it has not been adequately sampled. The cryptovolcanic structures could not be the source of the drift diamonds in Wisconsin because even if the structures are caused by kimberlites, those kimberlites have not yet been exposed by erosion.

Elsewhere in the world, kimberlite is seldom found as a single isolated body; clusters of bodies are more common, and the presence of one kimberlite implies that others may exist nearby.

The discovery of additional kimberlites may be very difficult because of the extensive cover of glacial drift and the typical small size of kimberlite bodies. If all are magnetic, they might be found by detailed aeromagnetic surveys. However, the magnetism of the Lake Ellen kimberlite appears to be caused by secondary magnetite formed during serpentinization of olivine, so an unserpentinized kimberlite may not be strongly magnetic.

We suggest that one or more diamond-bearing kimberlites may exist in northern Michigan or Wisconsin, but the discovery of such bodies is unlikely unless a very thorough search is undertaken.

[1] Wisconsin Geological and Natural History Survey.

## INTRODUCTION

At least seven diamond discoveries were made in Wisconsin between 1876 and 1913. All diamonds were found in Pleistocene glacial deposits or Holocene river gravel. The diamonds must have been eroded from one or more kimberlite bodies because kimberlite is the only primary bedrock source of diamonds. It has generally been presumed that drift diamonds in Wisconsin were carried to their discovery sites by glaciers that eroded them from the nearest known kimberlites in northern Ontario, 800 km (kilometers) (500 miles) or more away.

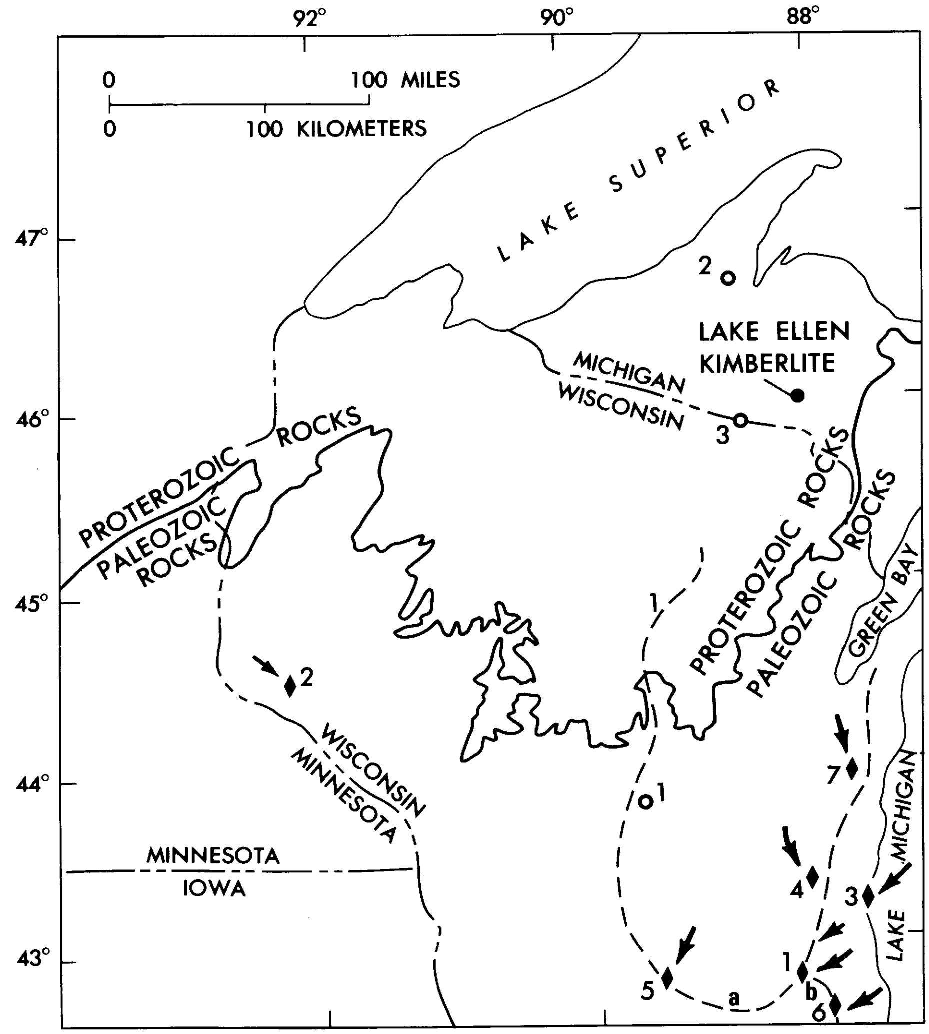
In this paper, we describe a newly discovered kimberlite in northern Michigan and suggest several other areas where kimberlites may exist in the subsurface. We discuss the possibility that drift diamonds in Wisconsin were eroded from kimberlites in Wisconsin or Michigan.

## DIAMOND DISCOVERIES IN WISCONSIN

Verified discoveries of diamonds have been made at seven localities in Wisconsin (figs. 1, 2). Other diamonds have been reported, but they were probably not from Wisconsin and are only briefly discussed in the following sections.

### EAGLE, WAUKESHA COUNTY

The first documented diamond discovery in Wisconsin was made during the digging of a well in 1876 by Charles Wood, who was a tenant on the farm of Tom Devereaux near Eagle in southwestern Waukesha County (Hobbs, 1899; Vierthaler, 1958; Olson, 1953; Alden, 1918). This first important Wisconsin diamond discovery is recorded in the files of the Milwaukee County Circuit Court and the Wisconsin Supreme Court. The digging passed through 10–15 m (meters) (33–44




EXPLANATION

o POSSIBLE CRYPTOVOLCANIC STRUCTURES

1. GLOVER BLUFF
2. STRUCTURES NEAR PELKIE (INCLUDES LIMESTONE MTN AND SHERMAN HILL)
3. BRULE RIVER OUTLIER

DIRECTION OF ICE MOVEMENT NEAR DIAMOND LOCALITIES

♦ DRIFT DIAMOND LOCALITIES

1. EAGLE, WAUKESHA COUNTY
2. PLUM CREEK, PIERCE COUNTY
3. SAUKVILLE, OZAUKEE COUNTY
4. KOHLSVILLE, WASHINGTON COUNTY
5. OREGON, DANE COUNTY
6. BURLINGTON, RACINE COUNTY
7. COLLINS, MANITOWOC COUNTY

— — — EXTENT OF ICE LOBES

a. GREEN BAY LOBE
b. LAKE MICHIGAN LOBE

FIGURE 1.—Map showing the location of diamond discovery sites, marginal moraines of major ice lobes and direction of ice movement, possible cryptovolcanic structures, and the Lake Ellen kimberlite.

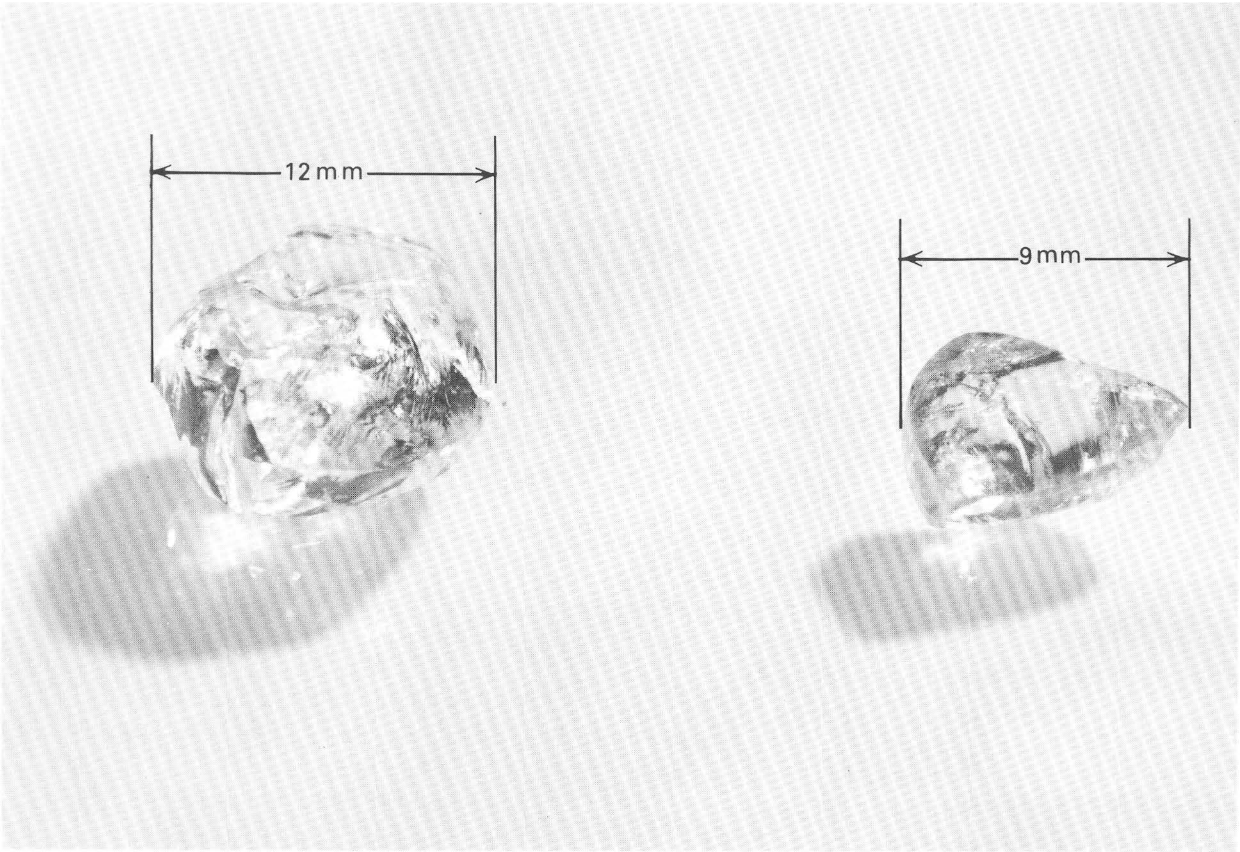



FIGURE 2.—The Saukville diamond (left) and Burlington diamond (right).

ft) of clay and then through loose gravel of approximately 5 m (16 ft), when a 2-m (7-ft) layer of a hard yellow material was penetrated. A hard stone of unknown identity was recovered. Clarissa Wood took this peculiar pebble to Col. Samuel B. Boynton, a jeweler in Milwaukee. Boynton identified the stone as "topaz" and purchased it for $1.00. Once the true identity of the diamond was disclosed, Clarissa offered to buy the diamond back, first for $1.10 and later for $1.50. Boynton refused, and Mrs. Wood sued. The Supreme Court ruled that the stone was Boynton's because he had believed it was topaz when he bought it. He later sold the stone to Tiffany & Company of New York for $850. He had offered the stone to the State of Wisconsin for $1,000, but his offer was declined. The crystal, originally known as the Waukesha diamond and later as the Eagle diamond, is a warm yellow color and weighs 16.25 carats.

Boynton formed a diamond-mining company and later, in 1883, claimed to have discovered more diamonds, along with other precious and semiprecious stones, according to Silvers (1978) writing in a recent issue of The Milwaukee Journal. A mining boom resulted. G. F. Kunz, a noted gemnologist, visited the area and noted that the newly found stones differed in size, color, and number of crystal faces from the original find. He identified the new stones to be of African origin, and the bottom fell out of the great Eagle diamond rush.

J. P. Morgan, the late 19th century financier, purchased the Eagle diamond from Tiffany's and ultimately donated the gem to the American Museum of Natural History in New York City. The stone was on public display at the Museum until the evening of October 29, 1964, when the Museum was broken into and the Eagle diamond and other gems stolen. On February 8, 1965, Jack Roland Murphy, a Florida beach boy, also known as "Murph the Surf," and two colleagues, admitted the theft, but the stone was not recovered.

## PLUM CREEK, PIERCE COUNTY

In the period 1880–1887, G. H. Nichols and two colleagues prospected for gold along Plum Creek in Pierce County. While sluicing for gold, one of the workmen detected a bright stone, which proved to be a diamond. Over several years, this group found about 10 small diamonds there (Kunz, 1892, p. 337).

In 1906, another discovery of diamonds was reportedly made downstream from the earlier find. A company was immediately organized and stock advertised extensively in Chicago. Samuel Weidman of the Wisconsin Geological and Natural History Survey contended that this was a bogus find and had been staged (letter to G. F. Kunz on December 15, 1907).

### SAUKVILLE, OZAUKEE COUNTY

Near the Milwaukee River, about 4 km (2.5 mi) north of Saukville, a diamond was discovered by Conrad Schaefer in 1881. It was not identified as a diamond until 1896 (Alden, 1904). This diamond is 6.57 carats and about 12 mm (0.5 in.) in diameter. The last known owner is Bunde and Upmeyer Co., in Milwaukee (Vierthaler, 1958).

### KOHLSVILLE, WASHINGTON COUNTY (THERESA DIAMOND)

The Theresa diamond created the greatest interest in the possibility of diamonds in Wisconsin. It was discovered in 1888 by Louis Endlick of Kohlsville on or near the Green Lake moraine. The stone weighed 21.5 carats; it is the largest diamond on record ever recovered in the State and the fifth largest in the United States (Alden, 1918; Sinkankas, 1959).

This diamond was of further interest because of its uncommon color. One side of the crystal was colorless, whereas the other side was cream yellow. These two parts were separated by a flaw or distinct cleavage plane. The crystal was almost spherical.

Shortly after the Theresa diamond was discovered, the Endlick family moved away from Kohlsville, taking the diamond with them. Later inquiries regarding the whereabouts of the diamond were fruitless until an article on the subject was published in a newspaper and read by a son of Mr. Endlick (Olson, 1953). He explained that the family had moved to Kewaskum, Wis. In 1918, the Theresa diamond had been cut into 10 stones at a cost of $400. Total weight of the 10 stones was 9.27 carats, divided as follows: 1.48 carats, 1.09 carats, 0.97 carats, 0.96 carats, 0.95 carats, 0.85 carats, 0.84 carats, 0.83 carats, and two stones weighing 0.65 carats each.

### OREGON, DANE COUNTY

In 1893, a 4.0 carat diamond was discovered on the Charles Devine farm near Oregon on the Johnstown moraine in Dane County (Alden, 1918). It was later sold to Tiffany's for $50. Its present owner is not known.

### SURLINGTON, RACINE COUNTY

In 1903, G. Pufahl recovered a diamond weighing 2.11 carats near Burlington, in Racine County (Alden, 1918). The last known owner is the Bunde and Upmeyer Co., in Milwaukee (Vierthaler, 1958).

### COLLINS, MANITOWOC COUNTY

The Milwaukee Sentinel carried a short article on January 19, 1913, about Peter Zagloba of Collins, in Manitowoc County. Zagloba had passed away several days earlier. While examining his property, local farmers found several uncut diamonds in an old coffee pot. Zagloba was a hermit and spent his time digging into hillsides. This suggested that the diamonds might have come from gravel deposits in the Collins area.

## WHY NO FINDS SINCE 1913?

The seven localities in Wisconsin yielded a total of 16 diamonds. All diamonds were found in Pleistocene glacial deposits or Holocene river gravel. Although none of the discoveries was made by geologists and no further documented discoveries have been made since 1913, the Wisconsin diamond discoveries, in conjunction with discoveries in other Midwest States, argue that the diamonds did in fact come from the Midwest and do in fact provide evidence for kimberlite in the Midwest.

A possibility exists that the finds may have been bogus. The diamonds could have been found elsewhere and subsequently brought to Wisconsin. Examples of such fraudulent discoveries include the second Eagle discovery and the second Plum Creek discovery just discussed. In both cases, almost immediately after discovery of the diamonds, shares of stock were offered for sale. Kunz and Weidman were able to demonstrate that these two finds were not in situ but rather were salted.

Similarly, the lack of strong field control at the seven discovery localities in Wisconsin leaves open the possibility that factors other than geologic processes were agents in their discovery. Gunn

(1968) summarized the known diamond discoveries in the Midwest. In order of number of diamonds found, Indiana lists 34; Illinois, 25; Wisconsin, 16; Michigan, 3; and Ohio, 3. This tends to suggest that diamonds are geologically distributed throughout the Midwest. The paucity of discoveries in Ohio and Michigan suggests sources west of Lake Michigan.

In Wisconsin at least, none of the diamond discoveries was adequately documented at the time of discovery. The geologic details of the occurrences are not known and can only be inferred from the geology in the area of the discoveries. Most were found at shallow depths and presumably in the youngest glacial material. Similar relations are known for the discovery of drift copper nuggets in southeastern Wisconsin (Clayton, oral commun., 1980). The drift copper has a source in the upper peninsula of Michigan and is spatially close to the Lake Ellen locality discussed later.

No effort was made at the time of the original diamond discoveries to exploit them, suggesting accidental finds offering little possible financial return. The Kohlsville diamond may be a typical example, in that the stone was cut and mounted for members of a family, rather than sold.

Why then have so few diamonds been found in the last 80 years? Brummer (1978) reported that most of the diamonds found in the upper midwest were located by prospectors panning or sluicing river gravels for gold, especially in Indiana. The Wisconsin diamonds were found by a prospector sluicing at Plum Creek and by enterprising farmers at the other localities.

Since the last Wisconsin discovery in 1913, excavations in Pleistocene materials have continued. In recent years, nearly 30 million tons of Pleistocene sand and gravel have been produced annually for industrial use, and numerous excavations for buildings, utilities, and roadways have been constructed. Although machinery is commonly used, a significant percentage of hand labor is also used, and thus the chance of finding additional diamonds should be quite high compared with the era of the diamond discoveries.

Why then, have no additional discoveries been made?

The diamonds were found during the era of "gold" rushes. Although modern society remembers the rushes, few rushes have attracted the excitement of those in the 19th century. Since that time, rock hounds and mineral collectors have prowled pits, quarries, and streams for colorful stones, but no diamonds have been reported. Part of the answer may lie in the story of the Eagle diamond, which sat unreported on a shelf for some 20 years. Stones may well have been found in the past 80 years, but their significance is poorly understood by the finder, and the stone rests on a shelf or in a box awaiting rediscovery.

## THE LAKE ELLEN KIMBERLITE

A kimberlite pipe, here named the Lake Ellen kimberlite, has recently been discovered about 15 km (10 mi) northeast of Crystal Falls, Mich., and about 1.5 km (1 mi) west of Lake Ellen, from which it derives its name. The kimberlite was apparently first recognized by William H. Spence and Klaus J. Schulz about 10 years ago during a mining company exploration project, but its existence and location have not been widely known, and it has not been described previously.

The only two known exposures of the kimberlite are in the SW¼ sec. 27, T. 44 N., R. 31 W. (fig. 3). They consist of low exposures of rubbly reddish-brown, highly weathered kimberlite along the roadbed of an abandoned logging road. The two exposures are about 120 m (390 ft) apart and provide a limit for the minimum dimension of the body. The exposed kimberlite is strongly magnetic. A magnetic survey of the area (Gair and Wier, 1956) defined an elliptically shaped positive magnetic anomaly about 180 m (590 ft) long in an east-west direction and 120 m (390 ft) wide (fig. 2). Gair and Wier did not know of the existence of the kimberlite (the logging road had not yet been constructed) and believed the magnetic readings were spurious, caused by magnetic boulders in glacial drift. However, the close spatial correspondence of the anomaly to exposures of magnetic kimberlite lead us to conclude that the anomaly is caused by the kimberlite and roughly defines the size and shape of the body.

The kimberlite is intruded into volcanic rocks of the Hemlock Formation, a part of the Proterozoic X Marquette Range Supergroup. The weathered exposures of the kimberlite are heavily iron-stained rubble consisting of fragments about 1 cm (0.4 in.) in diameter. The material is soft enough to be dug with a shovel to a depth of about 0.5 m (1.5 ft) below the surface, at which depth it becomes harder, although still largely rubbly and disaggregated, and in places somewhat gray, in contrast to the browner colors nearer the surface. The rubble fragments are a mixture of fine- to medium-grained kimberlite and inclusions of a variety of other rocks. The kimberlite is composed of olivine

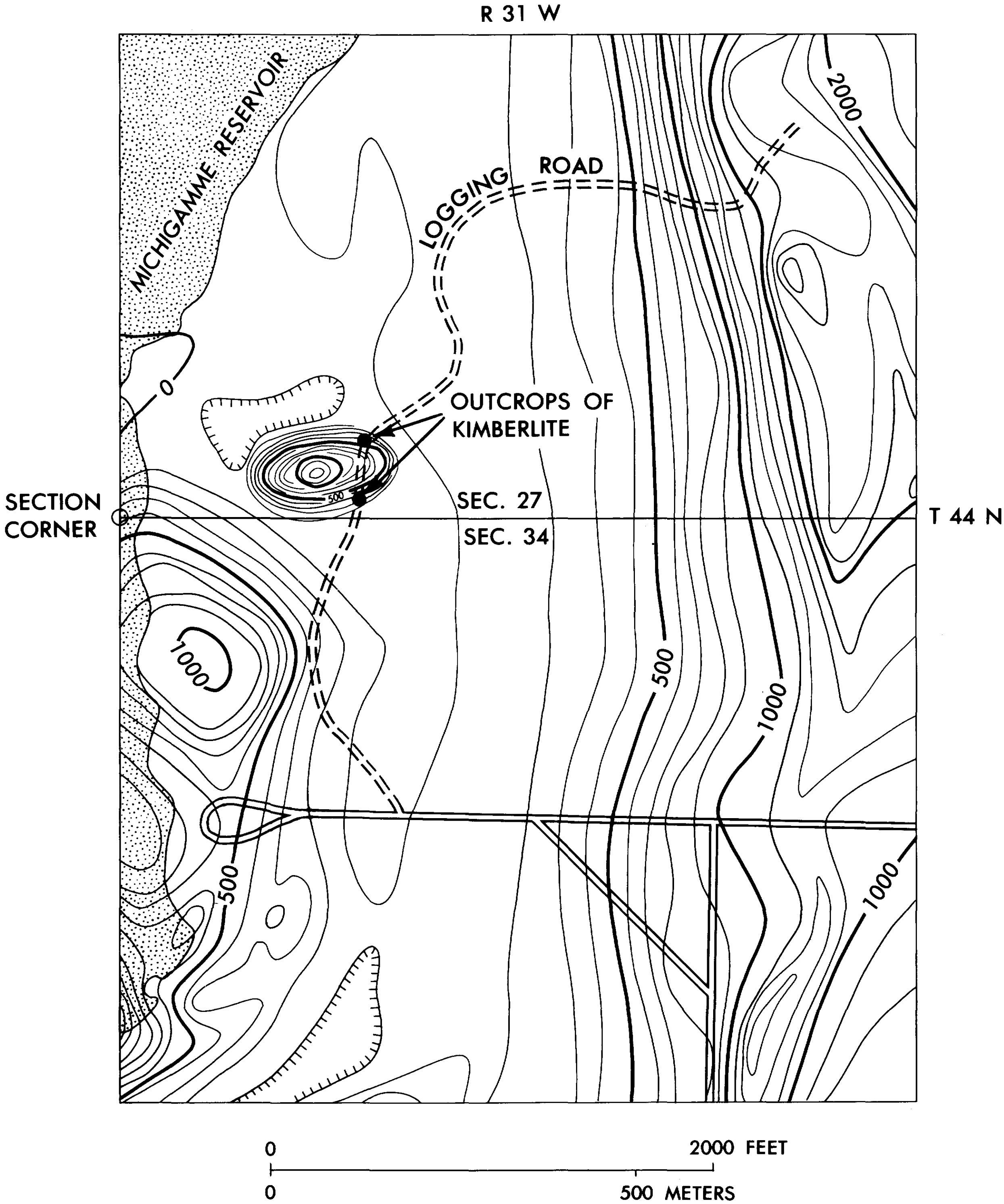



FIGURE 3.—Map showing the location of the Lake Ellen kimberlite and its magnetic expression. The magnetic data are from Gair and Wier (1956). Magnetic contours in the immediate area of the Lake Ellen kimberlite were drawn by W. F. Cannon in 1979 from the original data. Contours in gammas.

(in part serpentinized), pyroxene, mica, garnet, and ilmenite, and fine-grained serpentine (?) matrix.

Preliminary petrographic and analytical studies have been done by B. Carter Hearn, Jr., and Elaine S. McGee of the U.S. Geological Survey (written commun., 1980), and the following is their description of the kimberlite:

> Electron microprobe analysis of grains picked from a panned concentrate and from fragments of weathered kimberlite show the presence of typical kimberlite indicator minerals: chromian pyrope garnet, magnesian ilmenite, chromian diopside, and forsteritic olivine.
>
> Garnets of 1–5 mm size were sorted into 6 color groups (purple, pink, red, red-orange, orange, light orange) from which 3 to 6 grains of each color group were analysed. Sixteen garnets classified as purple, red, and pink are pyrope-rich and chromium-rich. These 16 garnets form a tight cluster on a Ca-Mg-Fe plot with a range of 67 to 75 percent Mg molecule and 12 to 20 percent Ca molecule and have the following ranges of weight percent $Cr_2O_3$: 4.64–9.29 for purple garnets, 3.18–6.17 for red garnets, and 1.72–3.43 for pink garnets. The ranges of $MgO$ and $Cr_2O_3$ content are similar to those of garnet in garnet peridotite zenoliths and garnet xenocrysts, which occur in kimberlites in North America (Mitchell, 1979; Hearn and Boyd, 1975; McCallum and others, 1975) and in Africa (Dawson and Stephens, 1975; Reid and Hanor, 1970). Ten red-orange, orange and light orange garnets are more iron-rich and more widely scattered on a Ca-Mg-Fe plot, and contain less than 0.79 weight percent $Cr_2O_3$. One red-orange and one orange garnet plot in the Mg-rich cluster of purple, red and pink garnets, but contain only 1.80 and 0.82 weight percent $Cr_2O_3$. The compositions of most red-orange, orange and light orange garnets fall into a compositional field which includes garnets from eclogites and granulites.
>
> Ilmenite grains are either single crystals or granular multicrystal aggregates up to 6 mm in size. Five single crystals and two aggregates form a tight cluster near 50 percent geikielite molecule ($MgTiO_3$) on a geikielite-ilmenite-hematite plot ($MgTiO_3$–$FeTiO_3$–$Fe_2O_3$). Weight percent of $MgO$ ranges from 12.85 to 14.96 and is typical of ilmenites in North American and African kimberlites (Mitchell, 1973, 1977; Haggerty, 1975).
>
> Six analysed diopside grains 1 to 3 mm size are green to bright green, and contain 0.11 to 0.95 weight percent $Cr_2O_3$ and 0.87 to 1.31 weight percent $Na_2O$. These ranges are typical of diopside xenocrysts, diopside in garnet lherzolite xenoliths (Stephens and Dawson, 1977), and diopside from spinel lherzolite xenoliths in kimberlite (McCallum and others, 1975). $Al_2O_3$ and $Na_2O$ are too low for typical eclogitic pyroxenes. $CaO$ content of pyroxenes indicates relatively low temperatures of equilibration, 900 to 1,000°C according to the Davis and Boyd (1966) solvus.
>
> Olivine grains of 1–3 mm size contain 91 to 92 percent forsterite molecule, typical of kimberlitic olivines.

A common type of inclusion in the kimberlite is buff, gray, and black dolomite. Fragments are as much as about 10 cm (4 in.) in diameter and generally angular to subrounded. The dolomite is fossiliferous and may be derived from the Ordovician Black River Group that apparently overlay the area when the kimberlite was intruded, although other stratigraphically higher Paleozoic carbonate units could also have provided the fragments. At present, we do not have an adequate fossil collection to determine the precise age of the fragments, but their Paleozoic age seems certain. Paleozoic strata have since been eroded away, except for scattered outliers of basal Paleozoic sandstone (Gair and Wier, 1956). The nearest exposures of the Black River Group are now about 60 km (36 mi) to the east, but the Black River Group could have been as little as 200 m (660 ft) stratigraphically above the present surface when the kimberlite was intruded.

## POSSIBLE CRYPTOVOLCANIC STRUCTURES

Several small areas of disturbed Paleozoic rocks have been known in Wisconsin and northern Michigan for many years (fig. 1), but the cause of the disturbance is not known. Until the recognition of the Ordovician or younger age for the Lake Ellen kimberlite, no intrusive or major structural events of Ordovician or younger age were known in the region. We now suspect that these disturbed areas may be collapse features formed over buried kimberlite bodies. No intrusive rocks have been found at the surface in any of the disturbed areas. We know of no drill holes in the disturbed areas.

### GLOVER BLUFF STRUCTURE

The Glover Bluff structure is an area of disturbed Cambrian and Ordovician strata in Marquette County, Wis. (fig. 1). The structure was mapped and described by Ekern and Thwaites (1930). The authors stated that the disturbed strata are exposed on three adjacent hills in the SW¼ sec. 3, T. 17 W., R. 8 E. (fig. 4). The area of the disturbance appears to be roughly circular and about 500 m (1,600 ft) in diameter. Because exposures are discontinuous, the complete structural pattern has not been determined, but Ekern and Thwaites showed the structure to be folded and complicated by several faults. The exposed disturbed strata range in age from the Cambrian Galesville Sandstone to the Ordovician Oneota Dolomite. The structure is complex but generally synclinal. Beds dipping as steeply as 30° are common, and locally bedding is vertical. The strata within the structure have been dropped at least 60 m (200 ft) relative to their altitude in the surrounding undisturbed area, where they dip less than 1° to the southeast. Outside of the structure Proterozoic rocks are at a depth of about 200 m (650 ft) below the surface.

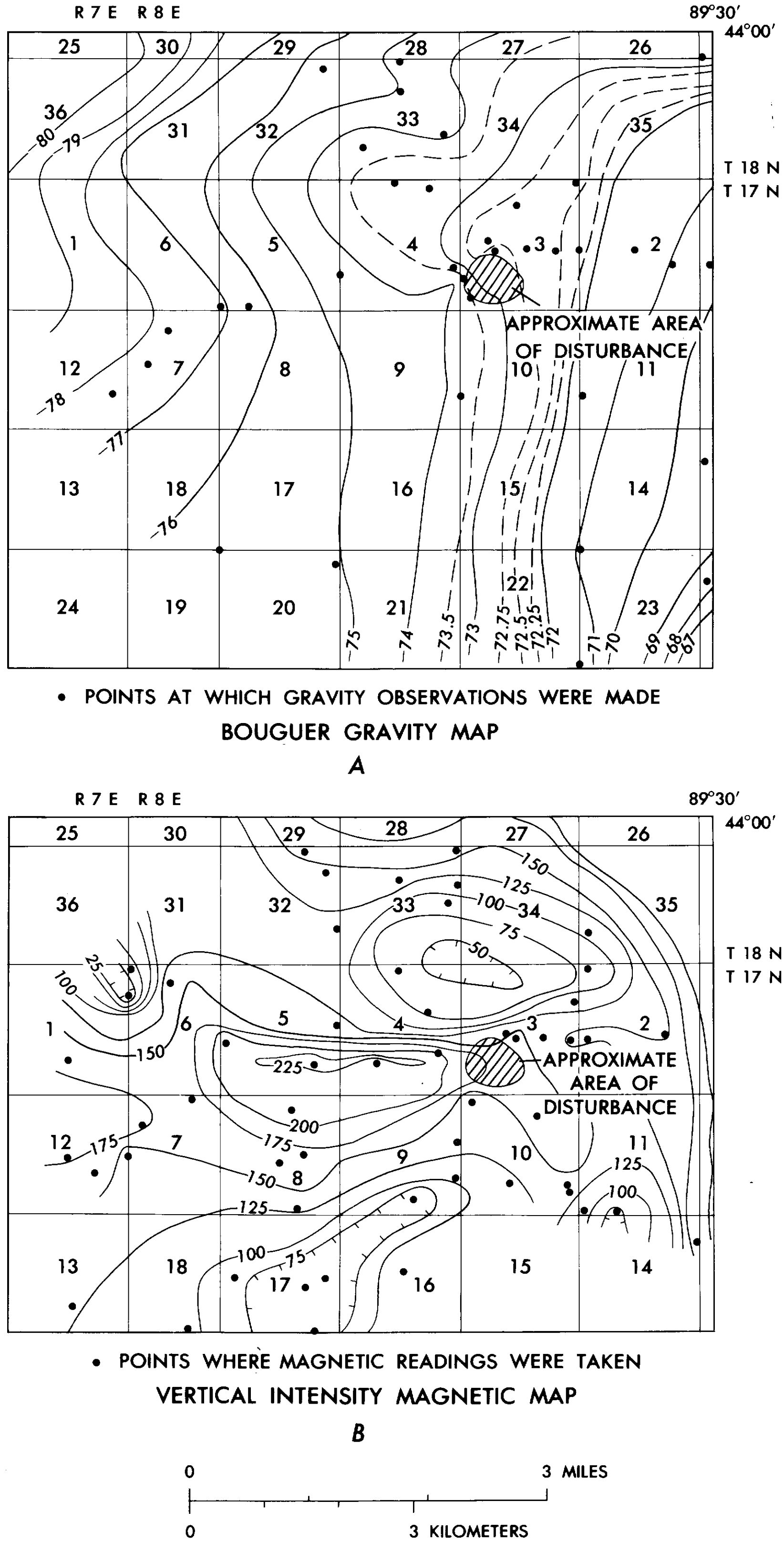



FIGURE 4.—*A*, Bouguer gravity map showing the location of the Glover Bluff disturbed area (gravity data from Koenen, 1956). Contours in milligals. *B*, Ground magnetic map showing the location of the Glover Bluff disturbed area (magnetic data from Koenen, 1956). Contours in gammas.

A gravity and magnetic survey of the area was made by Koenen (1956). Part of his maps are reproduced in figure 4. The Glover Bluff structure is near the east end of a prominent west-trending positive magnetic anomaly and also is within the area of a positive Bouguer gravity anomaly. Koenen has calculated that both anomalies could be caused by a mafic plug at a depth of about 2 km (1.2 mi) below the surface. He proposed that the Glover Bluff structure could be caused by faulting and collapse during intrusion of the plug.

### STRUCTURES NEAR PELKIE, MICHIGAN

Several anomalous disturbances of Proterozoic and Paleozoic strata are in Houghton and Baraga Counties near the town of Pelkie, Mich. (fig. 5). These may be cryptovolcanic features.

### LIMESTONE MOUNTAIN

Limestone Mountain, in secs. 13, 14, 23, 24, T. 51 N., R. 35 W., is an outlier of Paleozoic strata overlying the Proterozoic Jacobsville Sandstone. The Paleozoic rocks at Limestone Mountain, mostly dolomite and dolomitic limestone, form a prominent bluff that rises about 100 m (330 ft) above the surrounding gently rolling topography. The outlier is about 1.5 km (1 mi) long in a north-south direction and about 1 km (0.6 mi) wide. The Paleozoic strata generally dip gently to steeply centripetally inward; therefore, the gross structure is a doubly plunging syncline.

The earliest detailed description of the area was by Case and Robinson (1914), who mapped the mountain and studied the paleontology to determine the age of the strata. They identified forma-

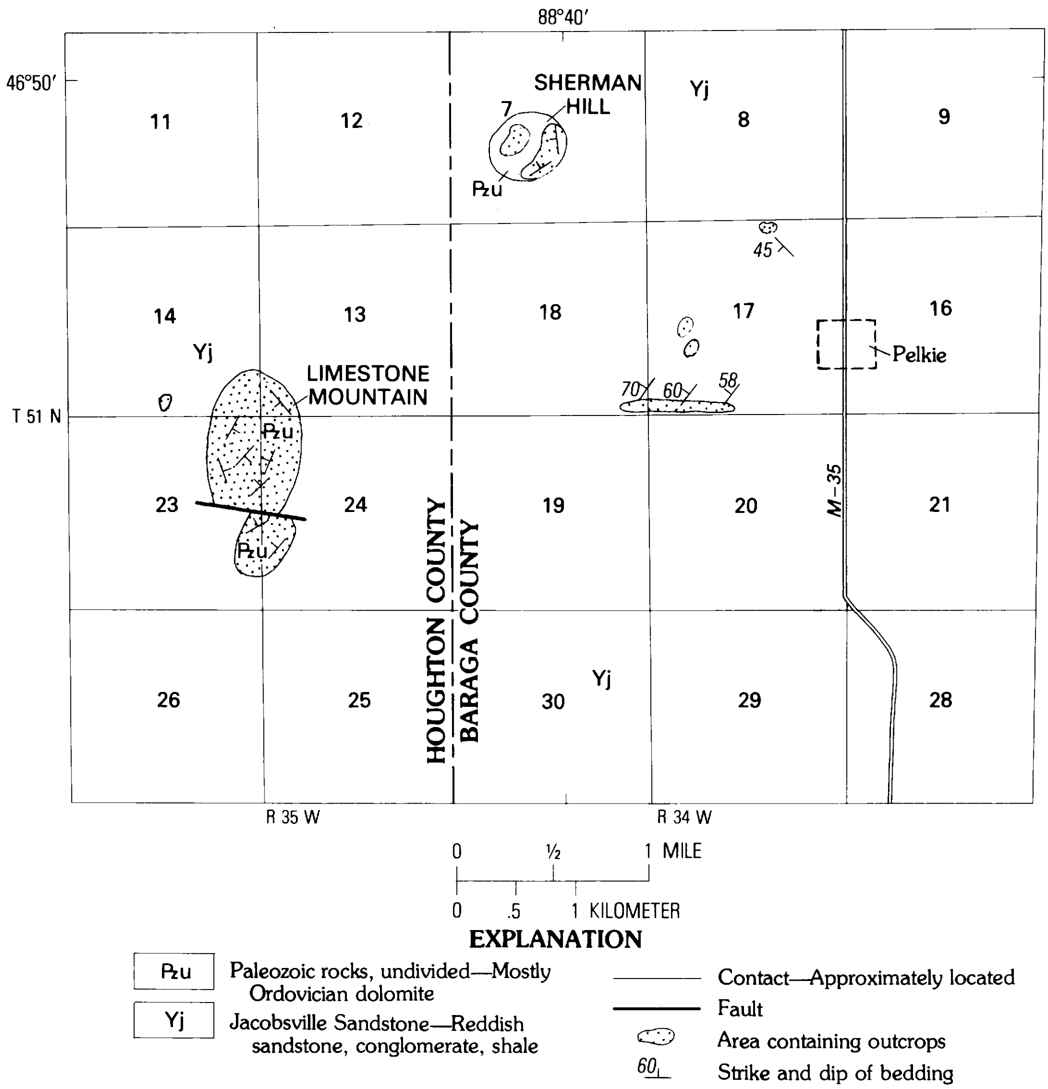



FIGURE 5.—Map showing the general geology of an area near Pelkie, Mich., including Limestone Mountain, Sherman Hill, and areas of disturbed Jacobsville Sandstone. Geologic data modified from Case and Robinson (1914) and Roberts (1940).

tions ranging in age from Proterozoic to Late Ordovician in outcrops and also found talus fragments of rocks as young as Early Devonian that could not be found in outcrops. The area was remapped by Roberts (1940), whose detailed work confirmed the structures identified earlier by Case and Robinson.

### SHERMAN HILL

Sherman Hill is in sec. 7, T. 51 N., R. 34 W., about 2 km (1.2 mi) northeast of Limestone Mountain (fig. 5). The area was included in the studies of Limestone Mountain by Case and Robinson (1914) and Roberts (1940). Like Limestone Mountain, it is an outlier of deformed Paleozoic rocks surrounded by Jacobsville Sandstone. Strata dip from about 5° to as much as 30° inward along a semicircular ridge, suggesting that a roughly conical depression about 0.5 km (0.3 mi) in diameter exists in the area, although its topographic expression is not as complete. The area was included in the studies of Case and Robinson (1914) and Roberts (1940).

### AREAS OF DISTURBED JACOBSVILLE SANDSTONE

Several areas where the Jacobsville Sandstone has been disturbed and dips steeply were identified by Roberts (1940). Along the north, west, and south sides of sec. 17, T. 51 N., R. 34 W. (fig. 4), scattered small exposures of Jacobsville, consisting of reddish-brown sandstone and conglomerate, have dips ranging from 45° to 70°. In the rest of the region, the Jacobsville is generally nearly horizontal or locally has dips as steep as 20°, apparently as initial dips on large-scale crossbedding.

Exposures of the Jacobsville are widely separated, and there is no obvious topographic expression of structure, so the size and shape of the disturbed area is not known.

## BRULE RIVER OUTLIER

An outlier of limestone about 10 m (33 ft) in diameter is exposed in the bed and banks of the Brule River on the Michigan-Wisconsin border, in sec. 27, T. 42 N., R. 35 W., about 8 km south of Iron River, Mich. (fig. 1). The limestone was first described by Allen (1910), who dated it paleontologically as Ordovician. It apparently lies on and is surrounded by Proterozoic X metavolcanic rocks. James and others (1968) described the limestone as "* * * light gray to tan, flaggy and irregularly bedded. The general attitude of bedding is probably horizontal, although, in the stream bank, possibly because of slumping, some strata dip as much as 15° E." In July 1979, the outcrop could not be located, perhaps because of high water in the Brule River or slumping of the river bank. About 2 km (1.2 mi) northwest of the limestone exposure, basal sandstone (Cambrian?) of the Paleozoic section is exposed on hills about 50 m (160 ft) higher than the limestone, suggesting that the limestone has been dropped down on the order of 100 m (330 ft) relative to surrounding Paleozoic outliers.

We suggest that this could be a cryptovolcanic structure. Although the downdropping of the limestone could have been caused by faulting, faults having post-Ordovician throws of 100 m (330 ft) are not known in this region. The 15° dip reported by James and others (1968) might be a true dip into a cryptovolcanic depression rather than a slump feature.

## POSSIBLE RELATIONSHIP BETWEEN CRYPTOVOLCANIC STRUCTURES AND KIMBERLITE

The four areas of deformed Paleozoic rocks described have several features in common:

1. All disturbances occurred in Ordovician or later time. At Limestone Mountain, the disturbance was apparently of Devonian or younger age.
2. All disturbed areas are relatively small, at most about 1.5 km (1 mi) in diameter and are surrounded by apparently undisturbed rocks. At least three of the areas are roughly circular. The fourth, the Brule River outlier, is not adequately exposed to determine the shape or size of the disturbed zone.
3. The three well-exposed areas are synclinal or basinal structures characterized in general by moderate to steep inward dips and local complications caused by faulting and small-scale folding.
4. Strata in all structures have dropped at least 50 m (160 ft) below their normal altitudes in surrounding undisturbed areas.

The area of disturbed Jacobsville Sandstone near Pelkie is also similar in that generally flat-lying sedimentary rocks are locally highly deformed. Lack of outcrops, topographic expression of structure, and marker beds do not permit the determination of the size and shape of the disturbed area or the amount of downdropping that might have occurred. The close proximity to Limestone Mountain and Sherman Hill, however, suggest a common origin for all three structures in Devonian or later time.

We suggest that all five disturbed areas could be cryptovolcanic structures formed over kimberlite pipes. Although this is certainly not proved with available data, we offer the suggestion as a starting point in the search for kimberlites.

Alternatively, the disturbed areas might be explained as (1) solution collapse features or (2) grabens related to faults in the Proterozoic basement. Alternative 1 seems unlikely because, for most features, no soluble rock is known stratigraphically beneath the disturbed strata. Alternative 2 is possible, but we know of no faults in the region having well-documented post-Ordovician throws of 100 m (330 ft) or more. Also, the circular, rather than linear, nature of the downthrown areas make this alternative seem unlikely.

We feel that a more likely explanation is that the disturbed areas are collapse features formed over kimberlite pipes. Figure 6 shows an idealized cross section of a kimberlite pipe in which massive kimberlite at depth grades upward into a breccia with kimberlite matrix and, still higher, grades into a zone of downfaulted and downfolded sedimentary rocks. Various levels of erosion of such structure could account for the Lake Ellen kimberlite and all the other areas of disturbed strata described. The Lake Ellen kimberlite would represent the deepest level of erosion, at which the kimberlite containing downdropped xenoliths of Paleozoic rocks is exposed. Limestone Mountain, Sherman Hill, and the Brule River outlier would represent higher levels of erosion, which have exposed subsided Paleozoic strata above the main kimberlite intrusion. Glover Bluff would be a still higher level of erosion, at which Paleozoic strata are downdropped and deformed but erosion was not deep enough to expose Proterozoic rocks or an underlying intrusion.

## DO WISCONSIN DRIFT DIAMONDS HAVE A LOCAL SOURCE?

In the early 1900's, shortly after the discovery of diamonds in glacial deposits of Wisconsin, it was generally assumed that the bedrock source for the diamonds was far from Wisconsin, probably in northern Ontario. Six of the seven diamond occurrences in Wisconsin are in the marginal moraines of the Green Bay and Lake Michigan ice lobes (fig. 1). Hobbs (1899) concluded on the basis of the shape and character of the diamonds, and known glacial transport directions, that the ultimate source of the diamonds was probably in the James

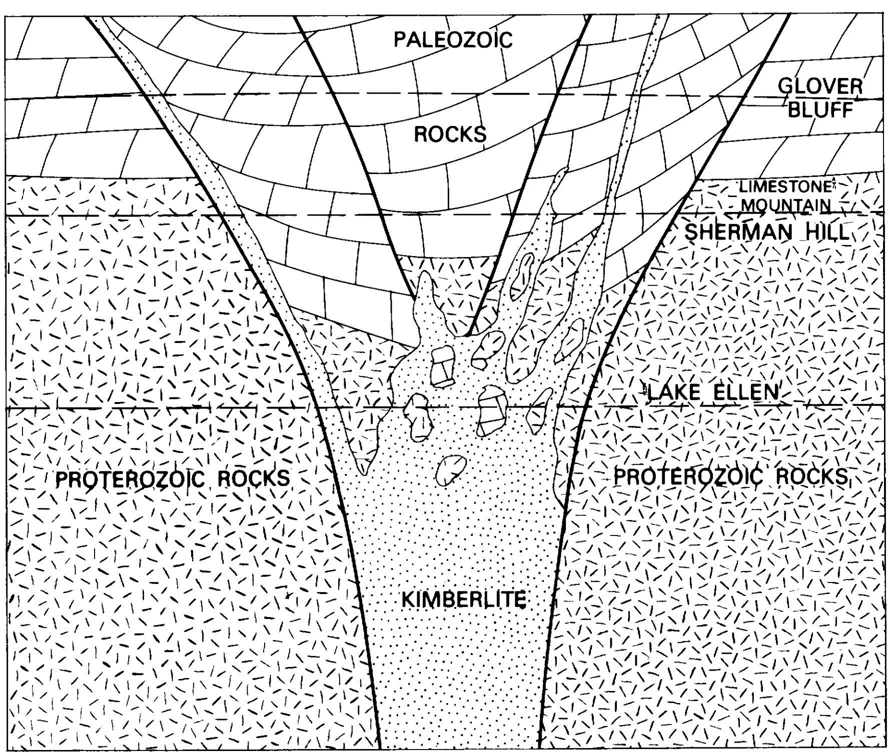



FIGURE 6.—Idealized cross section of a kimberlite pipe and overlying disturbed strata. Dashed lines suggest the stages of erosion of various features mentioned in the text.

Bay lowland of northern Ontario, at least 800 km (500 mi) distant. The existence of kimberlite in the James Bay lowland lends support to this idea. Hobbs' conclusions seem to have persisted over the years (see, for instance, Gunn, 1968), and the possibility of a kimberlite source in Wisconsin or northern Michigan has been given little consideration. However, we feel now, that in view of the occurrence of one kimberlite in Michigan and the suspicion that several other disturbed areas may be related to kimberlites, diamond-bearing kimberlites could exist in Wisconsin and Michigan.

The fact that diamonds have been found at seven or more localities in Wisconsin, all by accidental discoveries, suggests that diamonds may be a widespread, although certainly very rare, constituent of drift in Wisconsin. To our knowledge, no concerted effort to find diamonds in drift has been made, and we suspect that such a search could yield substantially more diamonds. That is, the diamonds already found are almost surely only a very small sampling of a much larger number that may be scattered widely through the drift.

Although glacial ice is known to transport material for hundreds of kilometers and could have carried the drift diamonds in Wisconsin from Canada, several factors suggest that a more local source is likely.

Glacial drift commonly is composed largely of material eroded from nearby bedrock that has been transported only a few kilometers or less and material from very distant sources forms a minor part of the drift. This is clearly demonstrated in many areas of Wisconsin and Michigan. Although it has recently been shown (Gwyn and Dreimanis, 1979) that heavy mineral assemblages may reflect bedrock sources 50–150 km (30–100 mi) away, we question whether a kimberlite source at least 800 km (500 mi) from Wisconsin is adequate to explain the number of diamonds that probably exist in drift in Wisconsin.

As glaciers transport material from its source, the material tends to become progressively diluted as it becomes mixed with rocks from other areas. Diamonds, which would be a very small fraction of the drift, even at their bedrock source, may become so diluted through 800 km (500 mi) or more of transport that we question whether a source as remote as northern Ontario is adequate to account for the large number of diamonds that probably exist in the drift in Wisconsin.

In the James Bay lowland, the predominant rock type is Paleozoic carbonate rock. Paleozoic rock fragments are very rare in the drift on Proterozoic terranes in northern Michigan and Wisconsin. It seems, therefore, that the principal bedrock type from the James Bay lowland makes very little contribution to drift in the study area. We feel that the rare kimberlites in the lowland are very unlikely to contribute diamonds to the study area.

We feel that the discovery of the Lake Ellen kimberlite places a new perspective on a possible source for drift diamonds in Wisconsin. Throughout the world, kimberlites are found in clusters rather than as a single body. Well-explored kimberlite fields, as in southern Africa and Siberia, contain tens or even hundreds of individual bodies in regions that commonly have dimensions of a few tens to a few hundreds of kilometers. The discovery of one kimberlite is a strong, but not necessarily conclusive, indication that others exist nearby. On the basis of the existence of the Lake Ellen kimberlite and five possible kimberlite-related structures, we suggest that one or more kimberlite fields exist in Wisconsin or northern Michigan. The fact that many of the diamond finds are in the area of the Green Bay lobe further suggests that sources are concentrated in northeastern Wisconsin or northern Michigan.

Brummer (1978) stated that, on a world-wide basis, about 1 kimberlite in 10 contains diamonds and about 1 in 100 contains diamonds in commercially recoverable quantities.

If we are correct in our suggestion that the five areas of disturbed strata described are underlain by kimberlite, then at least six kimberlites are in the region. However, those proposed to exist beneath the disturbed areas are not exposed at the surface and could not be the source of drift diamonds in Wisconsin. No diamonds have been found in the Lake Ellen kimberlite, but it has not been adequately sampled to our knowledge. Diamond is a very minor constituent in kimberlite, even at economic grades, and many tons of rock might have to be processed to determine if diamonds are present.

Because most of Wisconsin and northern Michigan is covered by glacial drift, much less than 1 percent of the bedrock is exposed at the surface. Kimberlite pipes, which typically are nonresistant to erosion and at best would be small bodies, probably no more than 500 m (1,600 ft) in diameter, are unlikely to be exposed.

The discovery of one kimberlite, the tendency for kimberlites to occur in clusters, the very limited amount of exposed bedrock, and the presence of diamonds in the glacial drift suggest that more kimberlite bodies, some of which are diamond bearing, may exist in the area.

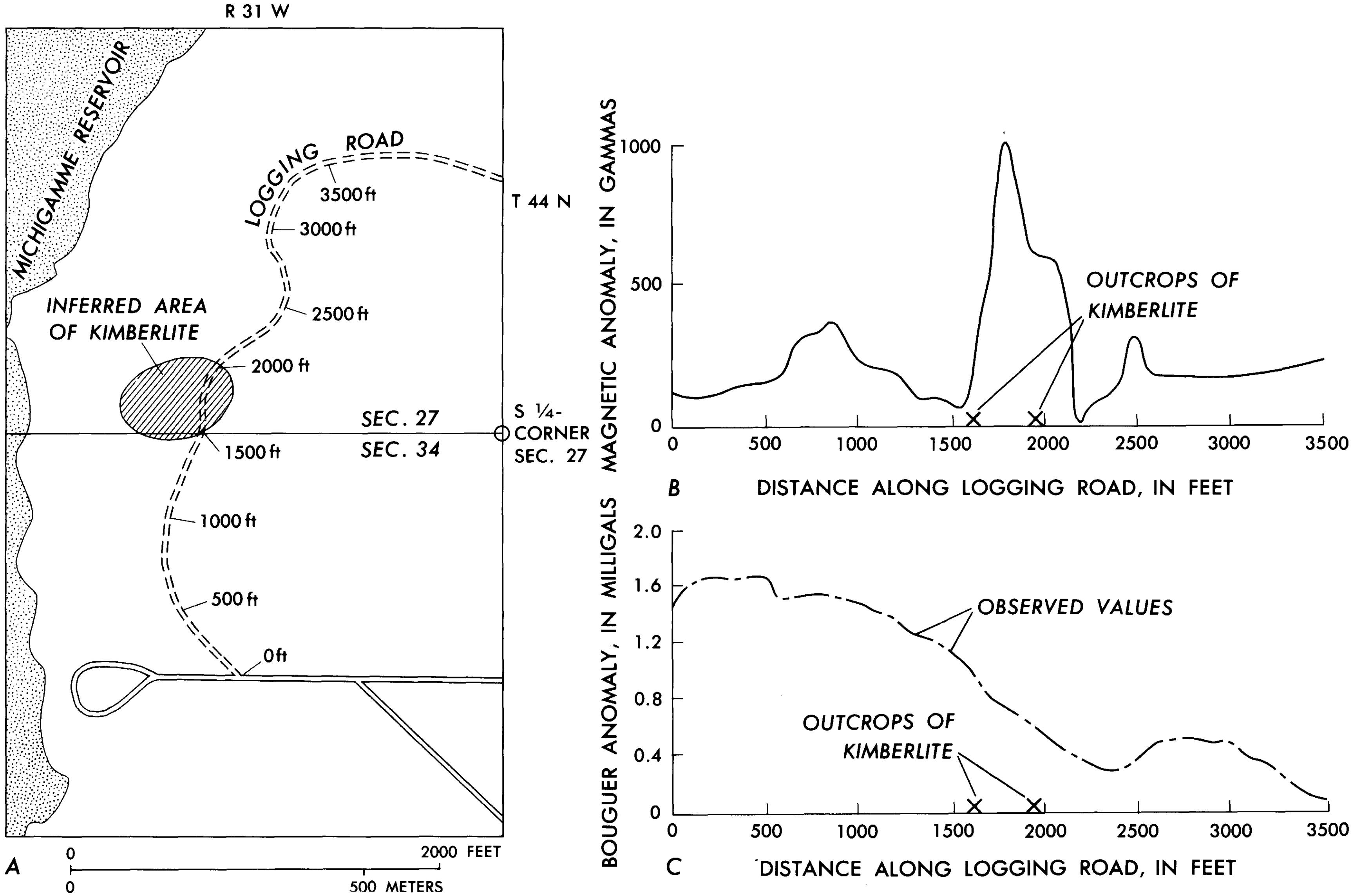



FIGURE 7.—*A*, Map of area around Lake Ellen kimberlite. *B*, Total intensity magnetic profile across the Lake Ellen kimberlite. *C*, Bouguer gravity profile across the Lake Ellen kimberlite.

## EXPLORATION FOR KIMBERLITE

The general scarcity of bedrock exposures in northern Michigan and Wisconsin and the relatively complete geologic mapping in northern Michigan during which most exposures have been examined suggest that few, if any, kimberlite bodies remain to be found in outcrop. If additional kimberlites are discovered they will probably be identified first by geophysical techniques that will recognize a diagnostic signature of kimberlite beneath glacial deposits.

Macnae (1979) has reviewed the state-of-the-art of geophysical exploration for kimberlite. Electrical and magnetic surveys, and in some cases gravity surveys, have been successful in finding buried kimberlite.

Electrical methods depend on the existence of conductive residual clay overlying the kimberlite. Such clay cappings are common on kimberlite in unglaciated regions but are unlikely to be preserved in Wisconsin or Michigan because glaciation has probably eroded them. No residual clay is known on the Lake Ellen kimberlite.

Magnetic surveys have also been successful. Most fresh (unweathered) kimberlite is magnetic. Figure 7*A* shows the location of a ground magnetic profile over the Lake Ellen kimberlite. A prominent positive anomaly of about 1,000 gamma amplitude, shown in figure 7*B*, clearly marks the kimberlite. The magnetism is apparently caused by fine-grained magnetite produced during serpentinization of olivine. Ilmenite, a somewhat abundant primary mineral, is apparently not magnetic. The amplitude of the magnetic anomaly may depend, therefore, on the degree of serpentinization of the olivine and could vary substantially from one body to another.

The use of magnetic surveys to find kimberlite in Wisconsin and Michigan is hindered by two factors:

1. The relatively small size of kimberlite bodies requires close flight-line spacing of aeromagnetic surveys to locate bodies. Aeromagnetic surveys have been done for much of the region of interest at a line spacing of one-half mile, but at that spacing, even a relatively large body (500 m (1,600 ft) in diameter for instance) might not be intersected by a flight line. Hence, to be effective, magnetic surveys that have a closer flight-line spacing would be needed.
2. Many of the Proterozoic rocks in the region have strong magnetic expression and commonly cause anomalies as strong as or stronger than would be expected from kimberlite. An anomaly caused by a kimberlite would be difficult to recognize in such magnetically "noisy" regions.

Gravity surveys have had limited success in finding kimberlite (Macnae, 1979) but will probably not be very useful in Wisconsin and Michigan. Figure 7*C* shows a gravity profile across the Lake Ellen kimberlite. Even in this rather precise survey in which station elevations were surveyed to a precision of less than 0.1 ft, no anomaly was detected over the kimberlite. The density of the kimberlite is apparently very nearly the same as that of surrounding rocks.

Apparently, then, magnetic surveys offer the best hope for finding buried kimberlite, but new surveys that have closely spaced flight lines will be needed. Problems of recognition of kimberlite-related anomalies from abundant anomalies from other sources must be solved. Magnetic surveys could be done more efficiently if relatively small areas of high potential could be identified. Regional studies of heavy minerals in drift using kimberlite-indicator minerals, such as pyrope garnet, magnesian ilmenite and chrome diopside, might be used to define zones likely to contain buried kimberlite. Such studies have been used with some success in Canada (Brummer, 1978).

We conclude that the discovery of kimberlite bodies will be difficult but that detailed magnetic surveys of areas where kimberlite indicator minerals are in glacial drift holds some promise of success. For each kimberlite found, however, there may be only about one chance in 100 that it will contain economically exploitable concentrations of diamonds.

## REFERENCES CITED

Alden, W. C., 1904, The Delavan lobe of the Lake Michigan glacier of the Wisconsin stage of glaciation and associated phenomena: U.S. Geological Survey Professional Paper 34, 106 p.

———1918, The Quaternary geology of southeastern Wisconsin with a chapter on the older rock formations: U.S. Geological Professional Paper 106, 356 p.

Allen, R. C., 1910, The Iron River iron-bearing district of Michigan: Michigan Geological and Biological Survey Publication 3, 151 p.

Brummer, J. J., 1978, Diamonds in Canada: Canadian Mining and Metallurgical Bulletin, v. 71, no. 798, p. 64–79.

Case, E. C., and Robinson, W. I., 1914, The geology of Limestone Mountain and Sherman Hill in Houghton County, Michigan: Michigan Geological and Biological Survey Publication 18, p. 165–181.

Davis, B. T. C., and Boyd, F. R., 1966, The join $Mg_2Si_2O_6$-$CaMgSi_2O_6$ at 30 kilobars pressure and its applica-

tion to pyroxenes from kimberlites: Journal of Geophysical Research, v. 71, no. 14, p. 3567–3576.
Dawson, J. B., and Stephens, W. E., 1975, Statistical classification of garnets from kimberlite and associated xenoliths: Journal of Geology, v. 83, no. 5, p. 589–607.
Ekern, G. L., and Thwaites, F. T., 1930, The Glover Bluff structure, a disturbed area in the Paleozoics of Wisconsin: Wisconsin Academy of Science, Arts, and Letters Transactions, v. 25, p. 89–97.
Gair, J. E., and Wier, K. L., 1956, Geology of the Kiernan Quadrangle, Iron County, Michigan: U.S. Geological Survey Bulletin 1044, 88 p.
Gunn, C. B., 1968, Relevance of the Great Lakes discoveries to Canadian diamond prospecting: Canadian Mining Journal, v. 89, no. 7, p. 39–42.
Gwyn, Q. H. J., and Dreimanis, A., 1979, Heavy mineral assemblages in tills and their use in distinguishing glacial lobes in the Great Lakes region: Canadian Journal of Earth Sciences, v. 16, no. 12, p. 2219–2235.
Haggerty, S. E., 1975, The chemistry and genesis of opaque minerals in kimberlites: Physics and Chemistry of the Earth, v. 9, p. 295–307.
Hearn, B. C., Jr., and Boyd, F. R., 1975, Garnet peridotite xenoliths in a Montana, U.S.A., kimberlite: Physics and Chemistry of the Earth, v. 9, p. 247–255.
Hobbs, W. H., 1899, The diamond fields of the Great Lakes: Journal of Geology, v. 7, no. 4, p. 375–388.
James, H. L., Dutton, C. E., Pettijohn, F. J., and Wier, K. L., 1968, Geology and ore deposits of the Iron River-Crystal Falls district, Iron County, Michigan: U.S. Geological Survey Professional Paper 570, 134 p.
Koenen, K. H., 1956, Geophysical studies in south central Wisconsin: Madison, University of Wisconsin, unpub. MS thesis, 44 p.
Kunz, G. F., 1892, Gems and precious stones of North America: New York, The Scientific Publishing Co. (reprinted by Dover Publications, New York, 1968), 336 p.
McCallum, M. E., Eggler, D. H., and Burns, L. K., 1975, Kimberlitic diatremes in northern Colorado and southern Wyoming: Physics and Chemistry of the Earth, v. 9, p. 149–161.
Macnae, J. C., 1979, Kimberlites and exploration geophysics: Geophysics, v. 44, no. 8, p. 1395–1416.
Mitchell, R. H., 1973, Magnesian ilmenite and its role in kimberlite petrogenesis: Journal of Geology, v. 81, no. 3, p. 301–311.
———1977, Geochemistry of magnesian ilmenites from kimberlites in South Africa and Lesotho: Lithos, v. 10, no. 1, p. 29–37.
———1979, Mineralogy of the Tunraq kimberlite, Somerset Island, N.W.T., Canada, *in* International Conference on Kimberlites, 2d, Santa Fe, New Mexico, 1977, Proceedings, v. 1: Washington, D.C., American Geophysical Union, p. 161–171.
Olson, E. E., 1953, History of diamonds in Wisconsin: Gems and Gemology, v. 7, no. 9, p. 284–285.
Reid, A. M., and Hanor, J. S., 1970, Pyrope in kimberlite: American Mineralogist, v. 55, nos. 7, 8, p. 1375–1379.
Roberts, E., 1940, Geology of the Alston district, Houghton and Baraga Counties, Michigan: Pasadena, California Institute of Technology, unpub. MS thesis, 48 p.
Silvers, Amy, 1978, When Eagle pinned hope on diamonds: The Milwaukee Journal, November 9, 1978, Accent section, p. 1 and 10.
Sinkankas, John, 1959, Gemstones of North America: Princeton, N.J., Van Nostrand, 675 p.
Stephens, W. E., and Dawson, J. B., 1977, Statistical comparison between pyroxenes from kimberlites and their associated xenoliths: Journal of Geology, v. 85, no. 4, p. 433–449.
Vierthaler, A. A., 1958, Wisconsin diamonds: Wisconsin Academy Review, v. 5, no. 2, p. 53–55.

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