

Institute on Lake Superior Geology



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Michigan Technological University
Houghton, Michigan

Volume 40

Part 4—Michigan kimberlites and diamond exploration techniques

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INTRODUCTION

During the past 150 years, at least 17 purported diamond discoveries were made in Wisconsin, with additional finds in the Lower Peninsula of Michigan and other midwestern states. The accidental discovery of a kimberlite pipe in Iron county, Michigan in 1971 suggested the possibility that these diamonds might have been derived from source bodies closer than northern Ontario, and several diamond exploration companies initiated sampling programs to assess the diamond potential of the Upper Peninsula of Michigan, as well as adjacent Great Lake States.

To date, more than 20 kimberlites have been discovered in Michigan. These post-Ordovician intrusions range between 1 and 20 acres, and follow a crude northwest trend through Iron, Dickinson and Menominee counties from Crystal Falls to Hermansville. Age dates have been obtained for several of these kimberlites, placing the intrusions between approximately 186 and 209 million years before present, the youngest in the state (Jarvis, 1993). While none of the bodies discovered so far have been proven to be economic, there is abundant evidence to suggest that many undiscovered kimberlites exist in the Great Lakes region. Some of these bodies may be the source of the large historical diamonds found in glacial and alluvial sediments throughout the midwestern United States.

In November 1991, Dia Met Minerals Ltd. announced the discovery of 81 diamonds in 59 kilograms of drill core from a kimberlite in the Lac de Gras region of Canada's Northwest Territories. This release set off the largest claim-staking frenzy in the history of North America, and diamonds are currently the most exciting exploration commodity in Canada. Diamond exploration is also progressing in the United States, with ongoing economic evaluations of several bodies in Arkansas, Colorado and Montana, in addition to continuing efforts in the Lake Superior region.

This field trip is designed as a professional prospecting course, and will familiarize participants with the science of diamond exploration, including the dynamics of kimberlite emplacement, relative importance of glaciation, and sample collection and processing techniques. While most emphasis has been placed on the Michigan kimberlites and exploration in the midwest, kimberlite and lamproite rock samples from many worldwide localities will be presented for examination, and a brief update of current diamond exploration activities throughout North America will be given.

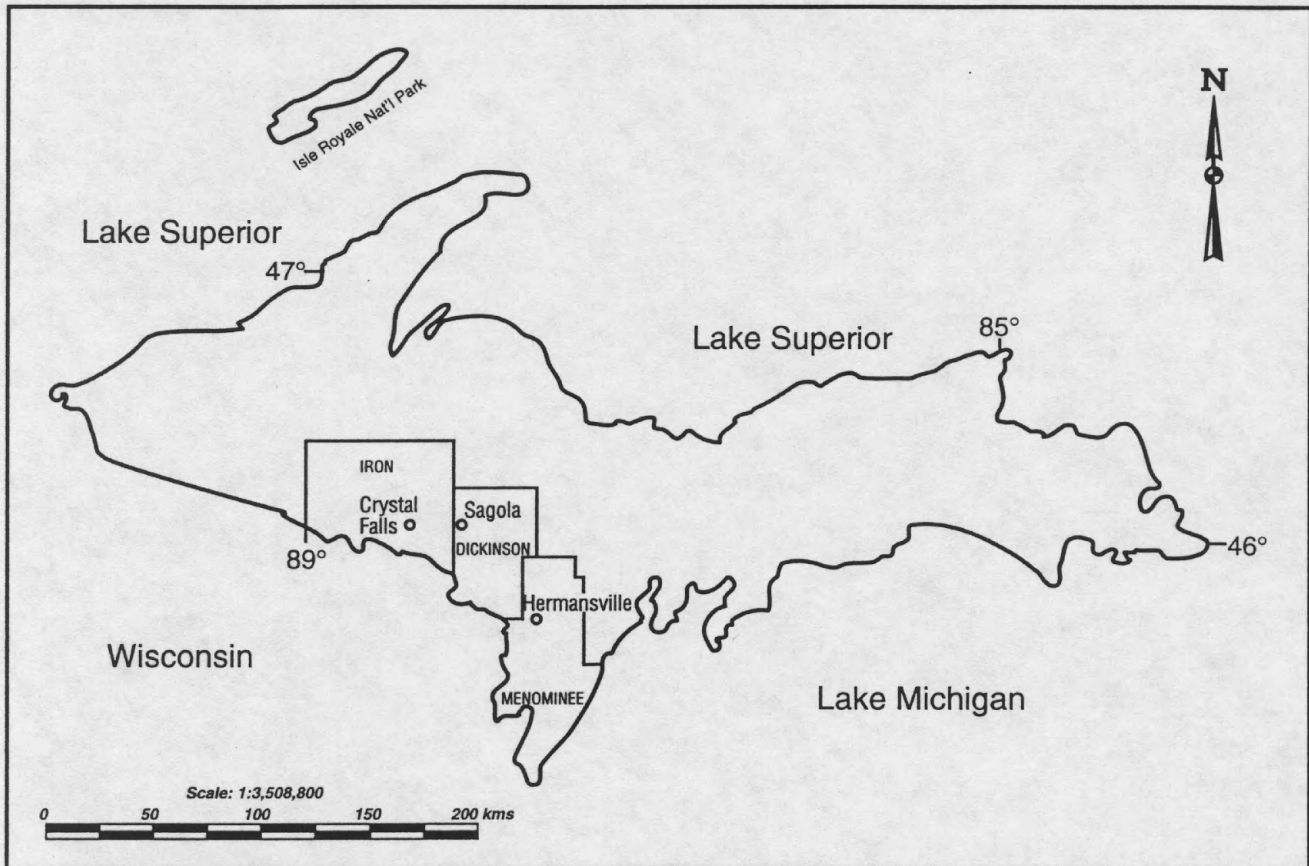


FIGURE 1: Diagram of the Upper Peninsula of Michigan, showing relevant counties and small towns.

ROAD LOG

This road log begins in the parking lot of Williams Mini Mall in Crystal Falls. Crystal Exploration maintains a processing laboratory and office here, in conjunction with Dow Chemical Company and Ashton Mining. These facilities will be toured as the last stop of this field trip. Parking should not be a problem at any of the stops, and vehicles with 4WD or high clearance are not required. The total driving distance is approximately 40 miles.

Mileage

- 0.0** Begin at parking lot of Williams Mini Mall. Turn right onto highway US-2, and proceed east through town.
- 1.0** Turn left at four-way stop, and proceed east on M-69.
- 10.2** Junction of Way Dam Road and M-69. Turn left on Way Dam Road and proceed north.
- 10.7** A large outcrop should be barely visible above tree level to the west. This exposure of Hemlock metavolcanics shows excellent east-west glacial striations, and can serve as an additional field trip stop, time and interest permitting.
- 16.3** Turn left onto Phelan Road, also known as the access road to the Lake Ellen Baptist Camp and Public Recreation Area #14. Proceed north.
- 17.1** Turn left onto Phelan Road, and proceed west.
- 17.3** Turn right onto Phelan's landing strip. Parking is best near the yellow gate at the northern end of the strip, at mileage 17.4. The walk to the Lake Ellen kimberlite takes approximately five minutes. Note the granular kimberlite that has been used as road gravel throughout this area.

Stop 1: The Lake Ellen Kimberlite.

The Lake Ellen kimberlite was discovered in 1971 by Klaus Schultz and William Spence. The pipe is located in eastern Iron county, approximately 2 miles north of Kiernan and 5 miles west and north of Channing. Several exploration companies have evaluated the economic potential of Lake Ellen, and the property is currently leased by Crystal Exploration.

The Lake Ellen kimberlite has been described by Cannon and Mudrey (1981) and by McGee and Hearn (1983). Readers are referred to these publications for detailed mineralogical, petrographic and historical descriptions. Lake Ellen is a diatreme-facies kimberlite of approximately 20 acres, and is roughly ellipsoidal in shape. Small diamonds are present in the kimberlite, but have not been detected in economic quantities. No precise age date has yet been obtained for Lake Ellen, but the body is known to be post-Ordovician by cross-cutting and xenolithic relationships.

Due to a logging road excavation in 1992, Lake Ellen is currently one of the best-exposed kimberlites in the United States. The 20 x 12 x 5 meter pit shows a number of subtle structural features, and atypically large kimberlite specimens may be collected from the pit floor. Crustal xenoliths and rare eclogite nodules may also be collected, along with a variety of minerals including garnet, ilmenite, olivine, serpentine, clinopyroxene, calcite and phlogopite. Some of the pyrope and ilmenite megacrysts from this locality may exceed 4 centimeters.

Processing equipment has been set up at stop 1 to allow participants to collect heavy mineral concentrates. The plastic tubs and small jig screens (saruca) are similar to equipment used at the Crater of Diamonds State Park in Arkansas to process small diamonds from olivine lamproite. Granular Lake Ellen kimberlite can be placed into these conical screens and shaken underwater; heavy minerals settle to the bottom in a distinct "eye", which can be removed after the screen contents are inverted onto a flat table. Good concentrates containing ilmenite, garnet and chrome diopside can easily be obtained in this manner, with a minimum of effort.

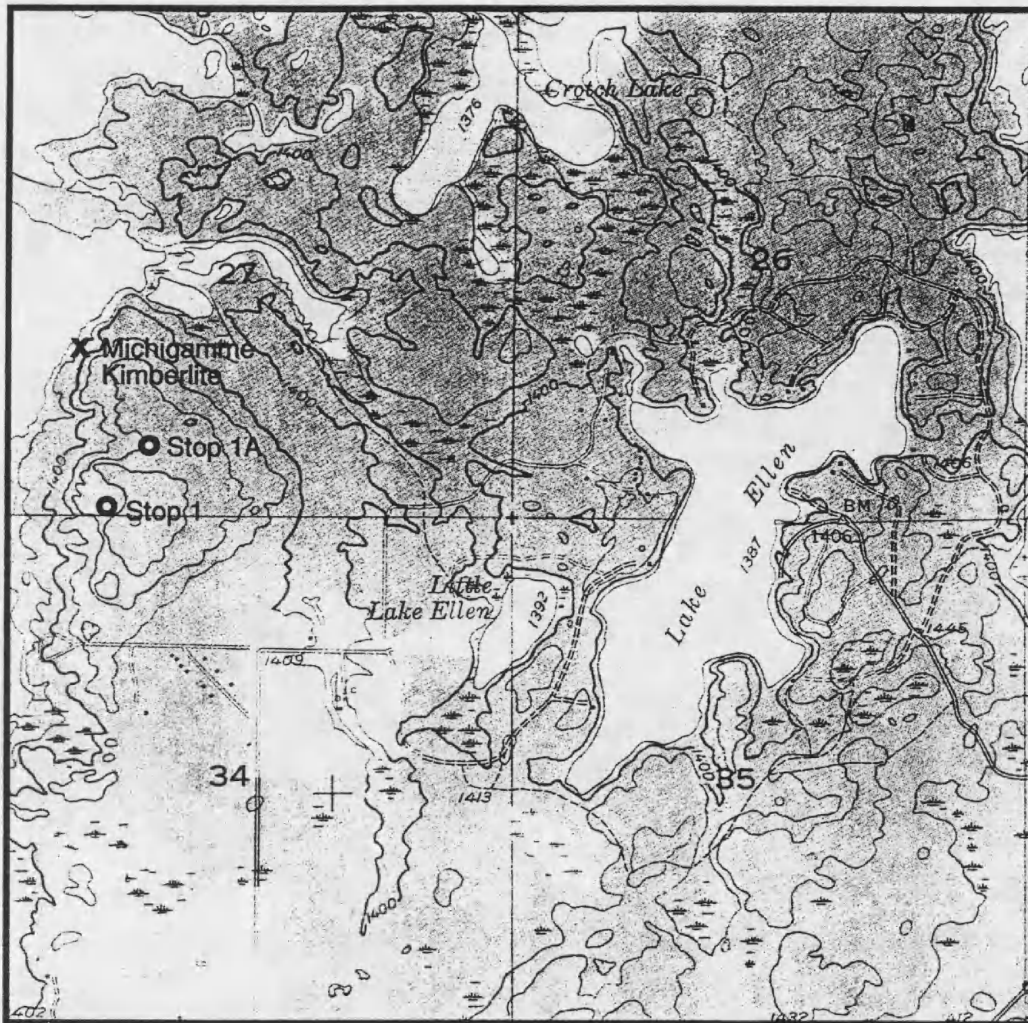


FIGURE 2: Portion of the Kiernan 7½' USGS topographic map, showing the locations of field trip stops 1 and 1A (Lake Ellen kimberlite) and the Michigamme kimberlite.

Stop 1A: North Side of the Lake Ellen Kimberlite

The brief walk to stop 1A will allow participants to examine several rubbly outcrops and filled-in test pits, as well as gain a sense of the general topography of the Lake Ellen kimberlite. The topography in this area is more typical of other Michigan kimberlites; most do not have distinct surficial expressions, and good outcrops are rare. Stop 1A also provides an opportunity to discuss the nearby Michigamme pipe, a kimberlite located in the SE¼ of the NW¼ of the SW¼ of section 27. This body was discovered in the mid-1980's, and an extensive collection of drill core has been donated to the DNR core library at Marquette by Kenecott Exploration Company, and is available for public use.

The Lake Ellen kimberlite has a high relative eclogitic garnet population when compared to other well-known North American kimberlites, with eclogite comprising approximately 6% of the "reconstituted mantle" (Schulze, 1993). While no detailed studies are yet available, it is interesting to note that the Michigamme pipe apparently has a much greater eclogitic garnet population than Lake Ellen. Core samples from the Michigamme pipe will be presented at stop 1A; all cores must be returned to the core library, but samples for both non-destructive and destructive analysis may be obtained by contacting the DNR offices at Marquette, and following core library guidelines.

17.4 Leave gate, and proceed south to access road.

17.5 Turn left on Phelan Road, and proceed east.

17.7 Turn right on Phelan Road, and proceed south.

18.4 Turn right on Channing (Way Dam) Road.

24.6 Junction of Way Dam Road and M-69. Turn left on M-69, and proceed east. Extensive fields in this area are based on outwash sediments related to the Green Bay lobe.

25.6 Turn right on Camp 5 road, and proceed south.

26.6 Camp 5 gravel pit.

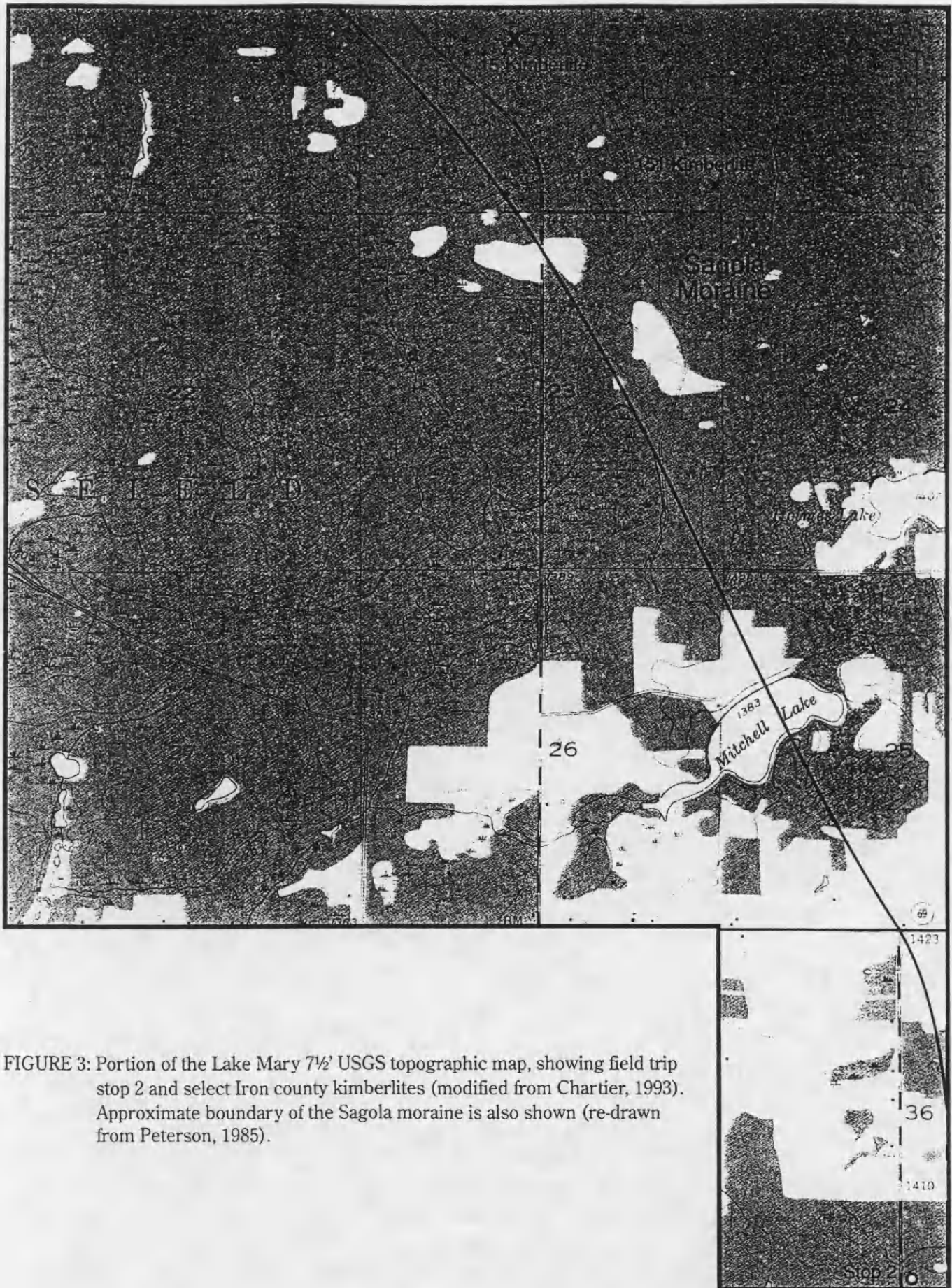


FIGURE 3: Portion of the Lake Mary 7½' USGS topographic map, showing field trip stop 2 and select Iron county kimberlites (modified from Chartier, 1993). Approximate boundary of the Sagola moraine is also shown (re-drawn from Peterson, 1985).

Stop 2: Camp 5 Gravel Pit.

The Camp 5 gravel pit is a large exposure of coarse glaciofluvial sediments at the western margin of the Sagola moraine. Most rock types present as clasts can be correlated to known or inferred occurrences in Dickinson county, and were deposited by a series of east-to-west advances of the Green Bay lobe during late Wisconsinan time. The Crystal Falls, Sagola, and Sagola-II moraines were all created by the Green Bay lobe, and several outcrops in the Mansfield area show prominent striations or grooves oriented almost due east-west.

Kimberlite clasts were first discovered in the Camp 5 gravel pit in 1991. Several hundred clasts ranging from small pebbles to small boulders in size have since been removed from the pit for analysis. At least eleven different hand-sample variations of kimberlite have been recognized at the pit. These somewhat subjective categories are based on a combination of macroscopic characteristics, including color, type and abundance of crustal xenoliths, the presence or absence of typical indicator minerals, and general textural relationships.

As seen in thin section, these inequigranular rocks are composed primarily of olivine, serpentine, calcite and spinel, with accessory ilmenite, diopside, garnet, phlogopite and apatite. Olivine ranges from dominantly euhedral in some samples to completely anhedral in others, and most olivine is at least partly replaced by serpentine, calcite, and fine-grained opaques. Pelletal lapilli and well-defined autoliths are notably absent, and most of these rocks are best classified as diatreme-facies kimberlite breccias or hypabyssal kimberlites. The hypabyssal clasts seem to have been most susceptible to alteration, and many of the different hand-sample "varieties" are nearly identical in thin section, except for varying degrees of post-glacial oxidation and calcite leaching.

Indicator mineral populations are extremely variable in the kimberlite from Camp 5. While results are preliminary at this stage, it appears that ilmenite is by far the most common indicator, followed by chromite, chrome diopside, and garnet. While many of the hypabyssal clasts are quite rich in some of these minerals, most of the diatreme-facies breccias do not contain indicator minerals in the 0.4 to 0.8 millimeter range. These samples do have extremely small indicators that can be seen in thin section, and it is expected that digestion of a sufficiently large sample would produce at least a few larger grains.

	Ilmenite	Chromite	Chrome Diopside	Garnet, Undifferentiated
Camp 5 Variation 1	24	Ø	Ø	Ø
Camp 5 Variation 2	57	1	1	1
Camp 5 Variation 3	Ø	Ø	Ø	Ø
Lake Ellen	42	Ø	Ø	30

FIGURE 4: Typical indicator mineral counts per gram of various disaggregated kimberlite samples. Indicator minerals reported are within the 0.4 to 0.8 millimeter range. Camp 5 variations 1 and 2 represent hypabyssal clasts. Results for Lake Ellen may vary depending on portion of pipe sampled.

A set of ilmenites from Camp 5 variations 1 and 2 and from Lake Ellen was sent to a commercial laboratory for microprobe analysis. An average MgO value of 14.4% was obtained for ilmenite from variation 1, and 14.1% for variation 2. These values indicate good diamond preservation potential, and are slightly higher than the average MgO content of ilmenites from Lake Ellen, both as analyzed in this study (13.7%) and as compared to the MgO/Cr₂O₃ plot of McGee and Hearn (1983). Unfortunately, minerals that are useful in estimating diamond grade are not very abundant in most Camp 5 clasts, and no statistically significant approximations have yet been obtained. One small anhedral chromite which was accidentally included with the variation 1 ilmenites for analysis did not plot within accepted major-element diamond inclusion parameters.

Although there are several kimberlites and kimberlite clusters east and southeast of the Camp 5 gravel pit, these bodies are either too distant or too oblique to the accepted direction of glacial advance in this area to account for the abundance of kimberlite clasts in the Camp 5 sediments. Most kimberlite fragments in the Camp 5 pit are probably derived from undiscovered kimberlites in eastern Iron or western Dickinson counties. These bodies are probably small diatremes with associated dikes or sills.

Approximately twenty kimberlite clasts have been located throughout the pit, and are marked with wooden stakes and flagging tape. A few samples of greenstone and amygdaloidal Keweenaw basalt have also been flagged, as both of these rock types can resemble kimberlite at first glance. Field trip participants are encouraged to examine all of these clasts *in situ*, and evaluate for themselves how effective ground searching can be as a supplemental exploration technique. Participants may collect and keep any of the kimberlite clasts they wish; additional samples will be provided if attendance is larger than expected.

26.6 Leave Camp 5 gravel pit, and proceed north to M-69.

27.6 Junction of Camp 5 road and M-69. Turn left and proceed west toward Crystal Falls.

38.0 Turn right at four-way stop.

39.0 Return to parking lot at Williams Mini Mall.

Stop 3: Crystal Exploration

The Sample Preparation Facility (SPF) of Crystal Exploration Inc. was established in 1984 to process one-ton kimberlite bulk samples from various Upper Peninsula projects in preparation for diamond analyses. The facility was later expanded to handle the processing of field samples.

The SPF is partitioned into two sections. The kimberlite evaluation plant consists of two ball mills, a small Wilfley Table, a trommell, an auger, a Denver Jig, and vibrating screens. The sample processing plant includes a sample mixer, a large Wilfley Table, a drying oven, a magnetic separator, and a small heavy liquid concentrating lab. The SPF is run by two technicians operating the physical plant and one person conducting the heavy liquid concentrating procedures in the lab. Under normal operating conditions, a one-ton bulk sample can be processed in about two to three weeks. Approximately ten 50-kilogram field samples can be reduced to the desired concentrate ready for heavy liquid separation in one day.

Figures 5 and 6 contain flow charts with descriptive notes outlining the various stages for both the bulk and field sample processing. The final concentrates are either sent to outside facilities for microscopic examination or passed on to Crystal Exploration's own experienced, in-house team for indicator mineral observation. Mineral grains requiring further probe analyses are shipped to various commercial facilities.

KIMBERLITE BULK SAMPLES

Stage 1 -- 1 Ton Bulk Sample

1 ton bulk sample of kimberlite from an evaluation drill hole/trench/pit.

Stage 2 -- Trommel (Cleans & Screens)

Bulk sample goes into trommel for cleaning and screening. After passing through the trommel, there are three (3) size fractions.

- (1) +6mm 50 kilogram sample is shipped to a lab for diamond and indicator analysis.
- (2) 2-6mm material is placed in ball mill for reduction to -2mm fraction.
- (3) -2mm material continues for further size divisions (Stage 3).

Stage 3 -- Vibrating Screen

Vibrating screen divides the -2mm material into three size fractions.

- (1) 1-2mm sample passes into a double hatched Denver Jig.
- (2) ¼-1mm sample passes onto the Wilfley Table.
- (3) -¼mm is considered slimes and passes out of the plant.

Stage 4 -- Denver Jig

The 1-2mm fraction is then concentrated by a Denver Jig. The concentrate is magnetically separated with the non-magnetic fraction being shipped to a laboratory for digestion in hydrofluoric acid and diamond analysis. The tails from the Denver Jig are reduced in the ball mill to a size fraction that is less than 1mm and then passed over the vibrating screen.

Stage 5 -- Wilfley Table

The ¼-1mm fraction is concentrated by the Wilfley Table. The concentrate is treated by the same methods as the Denver Jig concentrate. The Wilfley Table tails are returned to the ball mill for a specified period of time and then passed over the vibrating screen.

****The remilling procedure of the tails insures that a diamond(s) is not missed in the concentrating procedures. When the ball milling is complete, a 2,000 pound sample is reduced to a weight of around 100 pounds (plus the concentrates).**

FIELD SAMPLES

Stage 1 -- Field Sample

Samples consist of approximately 50 kilograms of glacial till (soil sample).

Stage 2 -- Cleaning & Screening

Till is placed in a small cement mixer to disaggregate the sand grains from the clay/silt matrix. The resultant slurry is then passed through a screen to get two (2) size fractions.

- (1) +1.2mm (oversized) - stored for possible later identification of kimberlite clasts. Once there is no use for the sample, it is discarded.
- (2) -1.2mm - fraction is passed over the Wilfley Table.

Stage 3 -- Wilfley Table Concentration

The Wilfley Table uses a shaking motion combined with a water flow to separate the higher specific gravity (S.G.) grains (heavies) from the lower S.G. grains (lights). This heavy mineral concentrate is then screened into two (2) size fractions.

- (1) +0.5mm is the fraction of most interest. In this size range, kimberlite mineral identification is much easier than in the -0.5mm fraction. This fraction is dried in an oven and then passed over a magnetic separator (Stage 4).
- (2) -0.5mm fraction is stored as a back-up for indicator confirmation of a sample or in determining the number of indicator grains found in the entire sample.

Stage 4 -- Magnetic Separator

The magnetic separator uses a rare earth (steep gradient) magnet as a head pulley for a short conveyor. As concentrate is conveyed over the magnet, the highly magnetic (left hand - LH) and the partially magnetic (center - C) grains adhere to the belt while the non-magnetic (right hand - RH) grains fall freely off the end of the conveyor. Since the kimberlitic indicator minerals are magnetic in nature, they will fall in the LH and C compartments while the majority of the sample (including any diamonds) will be in the RH compartment which is either inventoried or discarded.

Stage 5 -- Heavy Liquid Separation & Concentration

The concentrate is further reduced by passing the grains through a heavy liquid separation process using Methylene Iodide, Sodium Polytungstate, Lithium Metatungstate, or other heavy liquid depending on the S.G. needed to recover the specific indicator minerals desired.

Stage 6 -- Microscopic Observation

After the heavy liquid separation, the total weight of the sample to be observed will be between 20-50 grams. This sample is then observed in detail by trained "pickers" who examine the sample under magnification for the desired indicator minerals.

One-Ton Kimberlite Processing Procedure

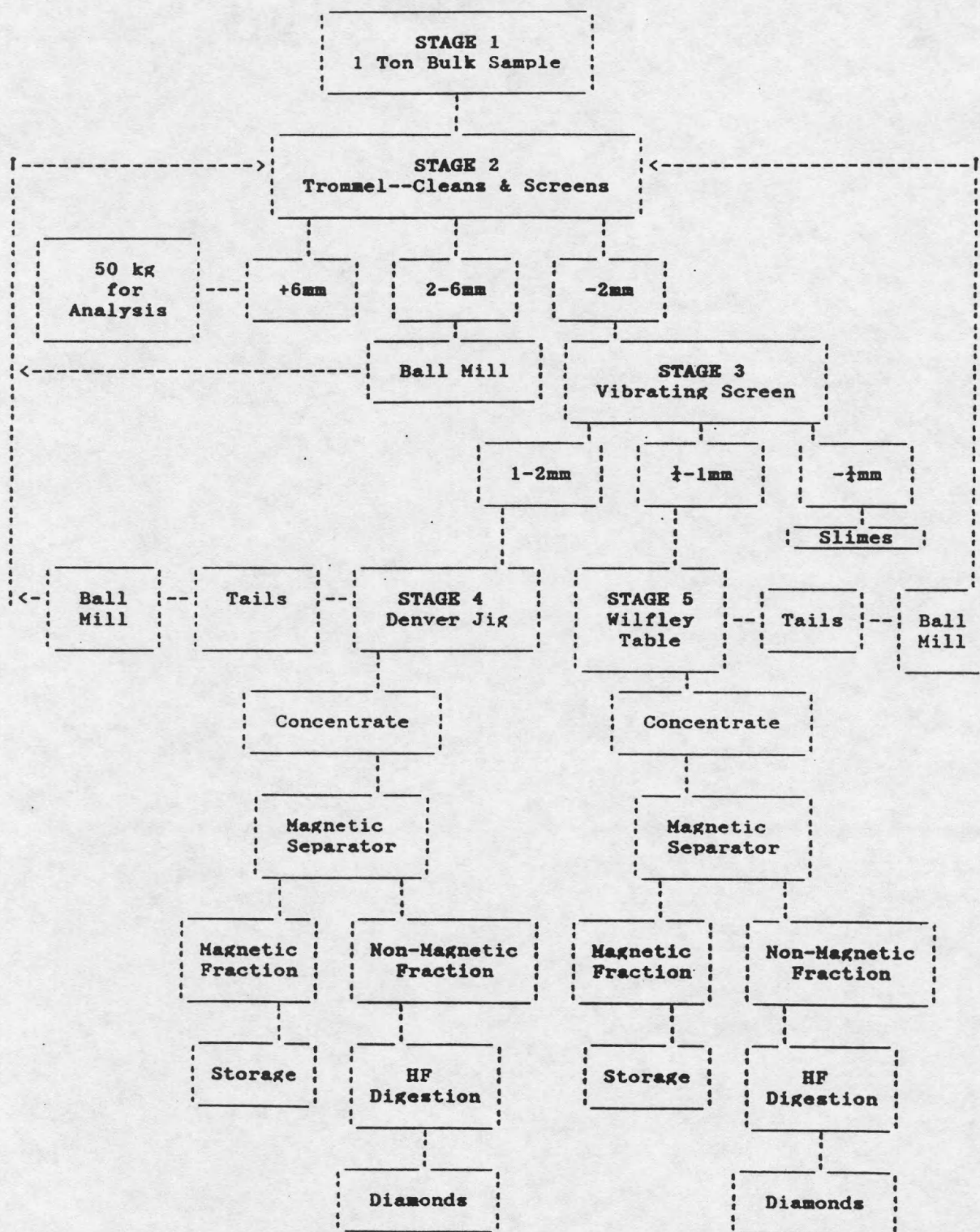


FIGURE 5

Exploration Field Sample Procedure in the S.P.F.

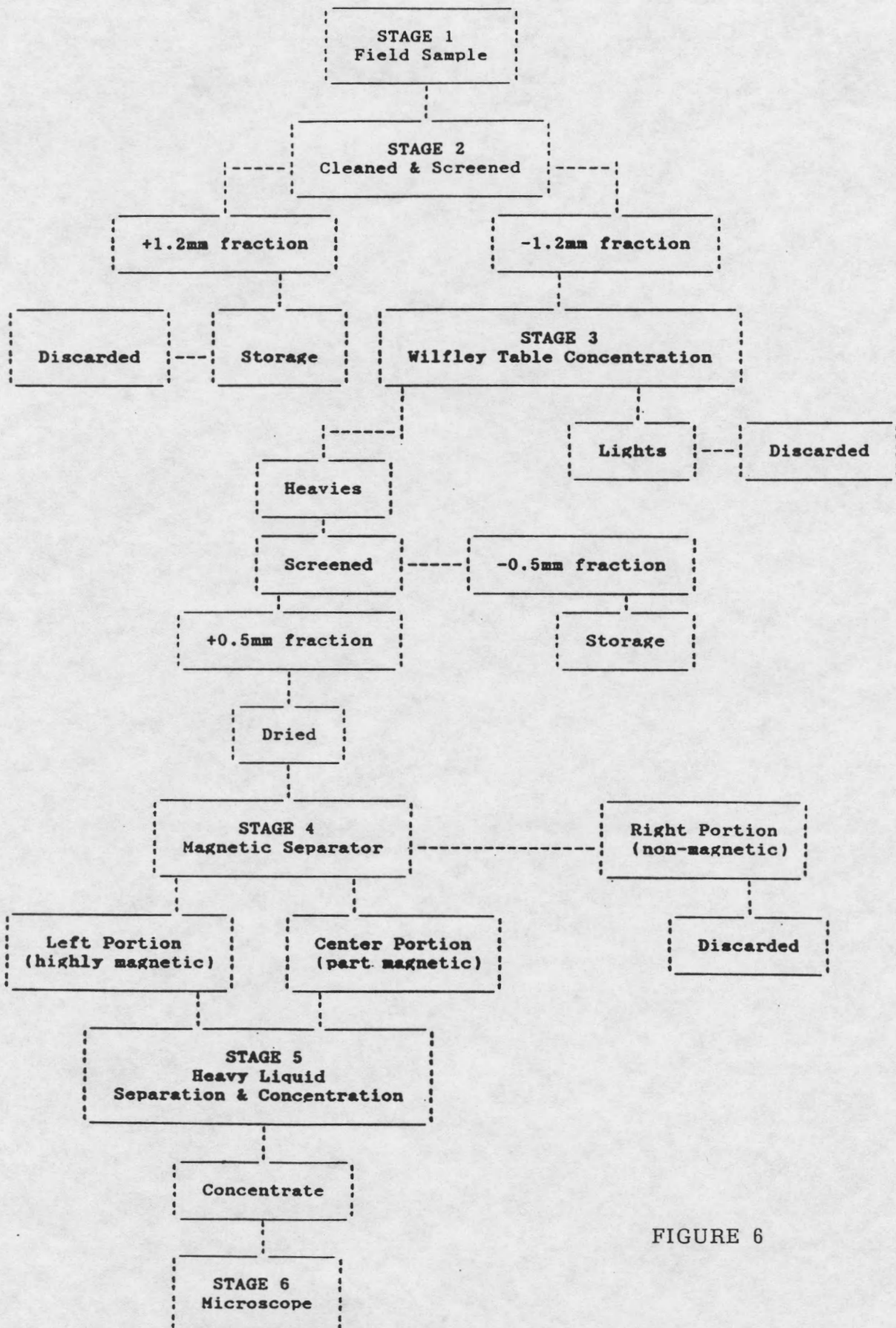


FIGURE 6

Acknowledgments

Credit is due to Dr. Theodore J. Bornhorst of Michigan Technological University for originally suggesting this field trip, and to Glen Adams and Crystal Exploration for allowing visits to the Lake Ellen kimberlite and the Sample Processing Facility. Gene Mottes and Schinella-Mottes Construction also deserve credit for graciously allowing a brief visit to the Camp 5 gravel pit. Bob Regis is thanked for permission to use his "Sagola-II" terminology in this study, and Milt Gere of the Michigan DNR is thanked for general information and support.

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