GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 63-45

GLACIAL FANS IN TILL FROM THE KIRKLAND LAKE FAULT: A METHOD OF GOLD EXPLORATION

(Report, 13 figures, 3 plates, 4 tables)

Hulbert A. Lee

Price 75 cents

1963

CANADA

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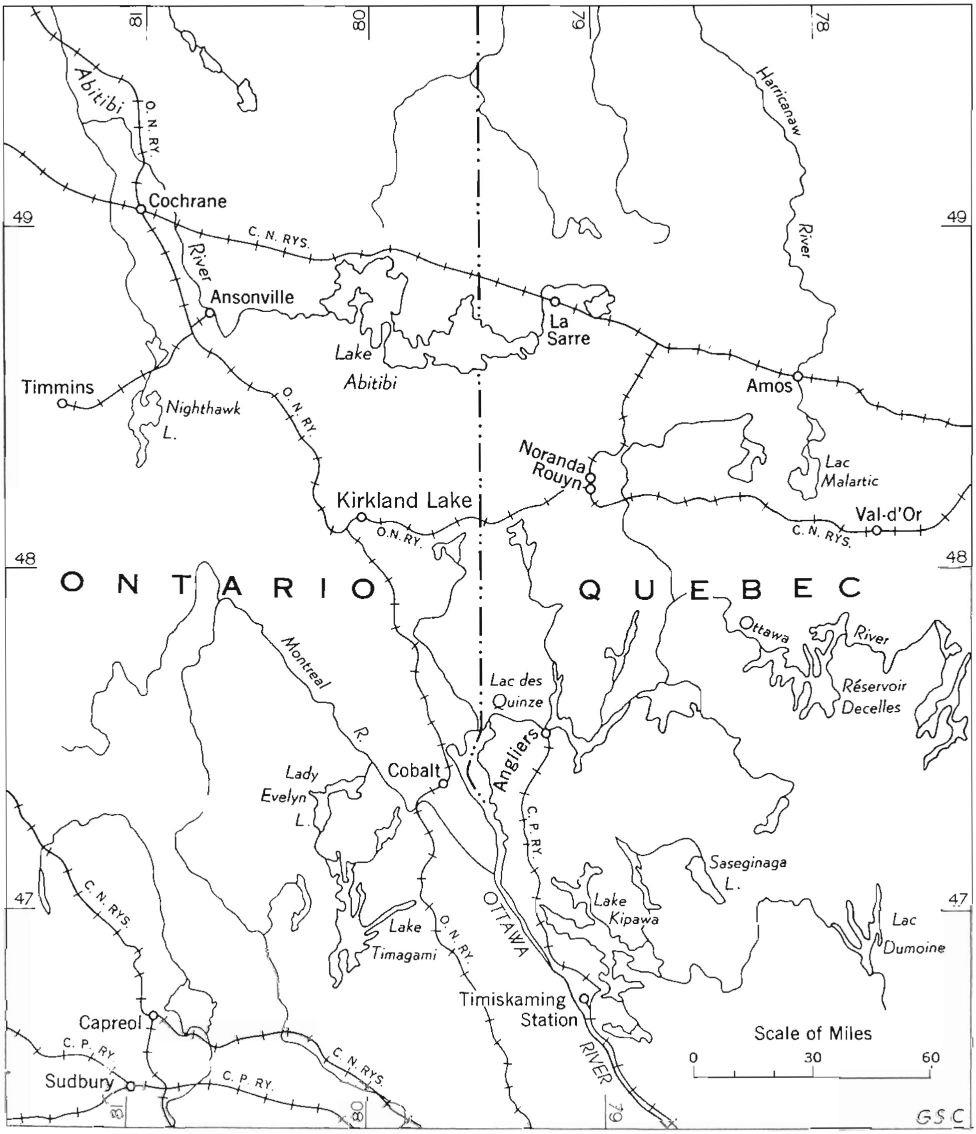


Figure 1. Index map

GLACIAL FANS IN TILL FROM THE KIRKLAND LAKE FAULT : A METHOD OF GOLD EXPLORATION

INTRODUCTION

Armed with a set of sieves, a sluice-box, a pulverizing mill, and a microscope, the writer and twelve university student assistants experimented during the 1963 field season with ideas and techniques for measuring gold dispersion, other minerals, and elements in the various size fractions of till as dispersed by glacial action from the Kirkland Lake fault. This work was done to aid the mineral exploration and development in the Kirkland Lake region (Fig. 1). It was carried out in conjunction with geochemical and geophysical investigations of the Geological Survey of Canada, bedrock mapping and compilation programs of the Ontario Department of Mines, and in cooperation with the following operating gold mining companies of the region: Macassa, Teck Hughes, Lake Shore, Wright-Hargreaves, and Upper Canada.

The writer's investigation is still in the preliminary stage. Results and tentative interpretations, and a description of techniques are being offered as a service to the mining industry. All results obtained to date are reported, although their full significance is not yet known.

Some of the observations made in 1963 are valuable in recognizing glacial fans in the till. These fans begin over the Kirkland Lake fault and disperse southeastwards. Indicators for these fans are: (1) grains of free gold, (2) silver-bearing magnetite grains, (3) chloritic rock fragments, and (4) dark vein-quartz rock fragments.

QUATERNARY STRATIGRAPHY

Without a proper recognition of the till formation, a sampling for glacial fans will be unsuccessful. Many of the disappointing results in the past stem from failure to differentiate till from float. A knowledge of the Quaternary stratigraphy is useful in telling where to expect the till, and what processes have altered it, hence what the till should look like.

The composite stratigraphy for the Kirkland Lake region shown in Table I is probably valid for the very large area south of Cochrane covered by glacial Lake Barlow-Ojibway (see Hughes, 1956, 1959, 1960) and would include the area in which lies the economically important Cadillac-Larder Lake break.

Two of the units (3 and 6) shown on Table I were not encountered at Kirkland Lake and need no further discussion. Descriptions of the other units follow, in the order in which they are encountered from the surface downwards.

TABLE I

COMPOSITE STRATIGRAPHY

Unit	Description
(7) Organic deposits	- peat, root mat, trees, etc.
(6) Aeolian deposits	- fine sands, in places as dunes
(5) Colluvium and boulder zone	- chiefly boulders, locally as material that resembles till
(4) Lake Barlow-Ojibway deposits	- sand facies; varved clay facies
(3) Glaciofluvial deposits	- clean gravelly sands, as eskers and outwash
(2) Till	- dirty gravelly sands
(1A) Glaciated bedrock surface	
(1) Bedrock basement	

Because the area around Kirkland Lake is heavily wooded, an organic mat (unit 7) covers most of the surface and laps well up onto the areas of bedrock "outcrops". In order to examine and sample material below the organic mat deep pits were made by a method described later in this report. The following descriptions apply to the materials encountered in these pits.

Underlying the organic mat, colluvial and boulder material (unit 5) are widespread, although erratic in their distribution. These were formed most probably by the washing by wave action of coarser material from high altitudes to lower altitudes at a time of lowering of the level of former glacial Lake Barlow-Ojibway. The coarse material came to rest on the earlier deposited fines of the lake, frequently on varved clays. Some of the material in unit 5, however, was formed by masswasting, including the agents of rain, snow, frost, and gravity creep, agents that have been active since the disappearance of glacial Lake Barlow-Ojibway. Although the colluvium and boulder unit may at first glance be occasionally confused with till, its topographic position at the base of slopes provides a clue to its identify and its stratigraphic position above the clays or as coarse zones on top of uniform till, identifies it.

Glacial Lake Barlow-Ojibway clays (unit 4) were encountered in less than one-quarter of the pits opened. Up to a 3-foot thickness of clay was easily penetrated in the pits. Where the clay formation was thicker, a new pit was opened at a few feet higher altitude to reduce the amount of excavating.

In most of the pits the clay unit was not present and the hole passed directly from the organic mat (unit 7) through the colluvium and boulder zone (unit 5) into till (unit 2). This till consists of an upper and a lower part. The upper part is interpreted as reworked till, consisting generally of a brown gravelly sand, with many iron-stained and cemented streaks, some of which form iron-cemented layers. The texture of this part can be seen from the graph in the upper half of Figure 5. This upper part of the till is probably in many cases basal till reworked beyond definite recognition by the wave action of glacial Lake Barlow-Ojibway. Included in it, however, may be some ablation till that was carried to its present location in the englacial or superglacial position of the ice-sheet, and also probably some erratics, which were brought in by icebergs that floated in the glacial lake.

The lower part of the till is greenish grey, in contrast to the brown oxidized material in the upper part. This is the basal till, and consists of silty gravelly sand. This basal till characteristically breaks so that the enclosed pebbles protrude, have no clay coating, and the pebble casts are preserved on the matching piece. The writer has found this to be characteristic not only of the basal till at Kirkland Lake but also of basal tills in New Brunswick.

As seen in those holes that continued to bedrock the basal till rests directly on the glaciated bedrock surface, thereby establishing its stratigraphic position. This lower part, or basal till part of unit 2 was the stratigraphic unit from which samples were obtained for this investigation of a method for gold exploration.

TECHNIQUES AND COST OF STUDY

Introduction

Both detailed work on a glacial fan from the Kirkland Lake fault and reconnaissance searching for other glacial fans outside of the Kirkland Lake area were carried out daily in 1963. One field sample of 1.7 cubic feet, about 80 - 100 pounds, was collected each day from the detailed fan and was completely processed in the field laboratories the following day. On reconnaissance one hole per day was sampled in the till and all boulders were broken open and examined for evidence of mineralization. Some were selected for assay.

Equipment designed and constructed in the spring of 1963 or purchased for the job withstood well the wear of field use.

The glacial fan method as applied to boulders is not new. Sauramo (1924, p. 5) wrote:

> "All new discoveries of ore deposits made in Finland during the last few decades have got their first impulse from the finding of glacial boulders derived from those deposits. This is due to the peculiar geological structure of the country, and certain other conditions. There is at present little chance of finding ore in actually exposed rock, mainly because earlier prospectors who only paid regard to exposed occurrences have searched the country very thoroughly. The greatest part of the bedrock, including its mineral resources, is hidden beneath several kinds of younger deposits, as drift, sand, clay, peat bogs, and also lakes. Thus, the loose drifts and boulders, in many vast areas, are the only witnesses that give any hint of the existence of mineral wealth that lies deep hidden under the soil. In searching for the sources of loose boulders, prospectors lacking geological training will in most cases fail completely, while men employing

scientific methods may be able to solve such problems easily, as is confirmed by experience. Special methods of tracing the boulders to their sources have been developed. For this purpose geological maps must be consulted and use must be made of the data available concerning the directions of the movement of the Quaternary land ice that has carried the boulders."

Grip (1953) gave several examples of boulder trains in Sweden and mentioned how they led to discoveries of new ore deposits. The methods outlined by Grip are still being actively used in Sweden (Gunnar Kautsky, 1963, personal communication).

The finer particle sizes in glacial till have been examined by Kauranne (1958) in prospecting for molybdenum in Finland, and by Dreimanis (1958) in outlining lead, copper, and zinc fans.

Although methods of boulder tracing have been described frequently in the literature, the writer was not able to find any published descriptions of the techniques suitable for this investigation. Because of this, a description is here given of the techniques and equipment used in 1963.

Design Considerations

The primary requirements for the laboratory were that the equipment be simple, mobile, rugged, and adequate to permit the complete analysis of a 1.7 cubic-foot sample per day. The goal was to gain immediate results, preferably daily, so as to guide the progress and direction of the operation. The concentrating unit was designed to give minimum element contamination, except aluminum, and to provide a continuous flow treatment. The grinding unit is made completely of mullite so as to minimize element contamination.

Sample Spacing Considerations

The usual procedure in sampling a glacial fan is to run a series of traverse lines at right angles to the dominant direction of the last striations. A number of samples are taken at intervals along these traverse lines. The spacing of the traverses, and the number of samples to be taken on each traverse, must be decided upon before sampling begins. A useful pattern of holes can be attained for a particular job by a consideration of the following questions:

1. What characters, such as rock, mineral, or element, define the target (source area) and will be used to outline the fan?

2. What is the size of the target and the direction of its orientation?

3. Is the target concentrated in a fault or shear zone?

4. Did the glacier sample a fresh bedrock surface, or a zone of concentration, or a zone of depletion?

5. What is the spread of the fan?

The first two questions on character and size of the target are complementary. A lithologically distinct rock may be easy to recognize when broken into fragments. Thus, even very small quantities would be apparent in the till. Such types of target make ideal boulder fans and some have been traced 25 miles. An example is the Steep Rock boulder train described by Dreimanis (1956). Coarse sulphide minerals in boulders can also give distinct characters for a fan. Such materials have been used successfully in locating ore deposits. The spacing of traverse lines for sampling such easily recognized target material can be fairly wide.

Mineral and mineral associations have been effectively used to define a target zone for glacial fans. As an example, different types of garnet have been used by Dreimanis (1960). Another example is the tracing of gold grains visible to the unaided eye from riffle concentrates of till, which is the technique used in the present study. For the effective tracing of minerals it is preferable to have a single source for the mineral in one region, or at least a dominant source in one region. If there are many local sources it becomes necessary to space the traverse lines closer together.

Trace elements have been used by Kauranne (1958) for molybdenum fans in Finland; by Hyvärinen (1958) for a lead fan at Korsnäs, Finland; and by Dreimanis (1958) for a zinc fan at MacDonald orebody, Quebec, and for a copper-zinc fan at Noranda, Quebec.

The material used in these studies was from the very fine size fraction of the basal till. All minerals were analyzed together. Best results in those studies were attained when traverse lines were spaced close to the source, or target area. Another method of trace-element analysis has been used in alluvial and bedrock studies. This is to analyze individual minerals separately. The method was applied to till in the present study using magnetite, and it seems to have permitted a wider spacing of traverse lines than in the case where all minerals were analyzed together.

Question number 3 (on page 4) is whether or not the target is in a fault or shear zone. If it is desirable to separate the results in the till from different major faults (such as the Kirkland Lake, the North Harvey, the South Harvey, and the Murdock Creek faults), then it is necessary to space traverse lines so that they lie between the faults; hence a closely spaced grid may be required. This has the advantage of obtaining a strong representative sample from each fault.

The amount of alteration in the target zone before the glacier sampled it is a problem that is probably not of great importance in northern Ontario, for the till in this region was probably derived from relatively fresh bedrock.

The spread of a glacial fan is measured by the magnitude of the angle between the boundary lines of the fan. Its size has been determined by local shifts that took place in ice flow and these can be evaluated from a plot of striations and till fabrics for the particular region. In general, when the angle of dispersion is narrow, a close spacing of samples is needed along traverse lines.

The Kirkland Lake Sampling Pattern

Striations and the directions of elongated stones in the till of the Kirkland Lake region are oriented at about 155° azimuth

(S25° E). Traverses were made at right angles to this bearing. The Kirkland Lake fault was taken as the zero position, and the first traverse was 2,000 feet south, the next 4,000 feet south, and the third 10,000 feet south. A traverse line was placed about 1,000 feet north of the Kirkland Lake fault so as to record the types and relative amounts of material that entered the fan and became mixed with it.

Spacing of sample points along the traverses were set at 2,000 feet for the first two traverses and at 4,000 feet for the third traverse. The intercepts along the northern traverse were set at 2,000 feet.

The above spacing proved practical for the Kirkland Lake fan, and only a few additional holes had to be made for the collection of samples at positions other than those originally planned.

Obtaining the Sample

The sample desired is basal till. From observations in major excavations at the Adams mine in Boston township, the writer gained the impression that the best place in the Kirkland Lake region to look for till was on the stoss side of outcrops where the glacier had placed the till in depressions between bedrock 'highs' and around the nose of these 'highs'. This impression was partly confirmed during the 1963 season, although till samples were occasionally collected from other positions.

As the unreworked (basal) till is nowhere exposed at the surface, pits had to be opened up. Experiments in methods of excavation resulted in the use of dynamite for this job, because of its easy transport in a packsack through the woods where there are no trails. This gives immense versatility over use of a backhoe or a bulldozer.

The following items were used for blasting:

No. 6 short period caps

1 in. x 8 in. 40% forcite

200 feet of double line blasting cord

6 volt dry-cell battery

steel scaling bar about 4 feet long, and pointed at one end.

The best pattern of holes found through experimenting was to place them at the corners of a square 2 1/2 feet on a side and with a fifth hole at the centre of the square. The holes were made by gyrating a steel mine scaling bar. The powder factor of 2 sticks of 1 in. x 8 in. 40% forcite was used in each hole with one instantaneous cap. It was found that by using the above pattern with a minimum of 30-inch depth for holes and top of explosive 12 inches below collar of holes, excessive movement of earth was attained and a larger hole was made in which to work. Occasionally an extra stick of dynamite and cap were placed to move a big boulder or a tree. The usual hole obtained by this method was 24 inches deep and 5 to 6 feet in diameter The first blast efficiently removed the mat of tangled roots, and loosened and exposed the material below so that it could be cleaned with a shovel. If the bottom of the hole from the first blast ended in clay then the scaling bar was worked down another 30 inches into the clay. If the lower point of the bar encountered gritty material then another dynamite pattern was laid and blasted to expose the till. If, however, the bar did not penetrate below the clay, a new site was located at 5 to 10 feet higher altitude and there clay was generally not encountered. Most of the pits contained no clay and the hole passed directly from the organic mat through colluvium and boulder zone into reworked till and then the lower part of the till. After the hole was cleaned out with a shovel, a sample was taken from the lower part of the till. All iron-stained or cemented zones were avoided, including the cemented zone that was frequently found at the till-bedrock contact. Such zones caused difficulty in later treatment. The sample was placed in a paraffin-coated canvas bag in sufficient amount to fill the bag to a marked volume of 1.7 cubic feet. It was then carried on a packboard to a road, from where it was taken by truck to the field laboratory.

Treatment of the Sample

The Concentrating Unit

The concentrating unit consisted of a set of sieves and a sluice box shown in Plate I. The stacking sieves are made of stainless steel wire mesh cloth held in aluminum frames. The sizes of openings are: 16 mm, 8 mm, 3.35 mm (6 mesh), 1.23 mm (15 mesh) and 0.50 mm (35 mesh). The sieves stack on an aluminum feeder box into which there was a continuous spray of water from several rows of holes. A second stream of water was played on top of the sieves and was used for washing down the sample. Care was taken at this time to clean all stones with a nylon brush to release any attached gold grains. The sluice box is made of aluminum and the floor is covered with a rubber matting that is designed for use with heavy minerals.

The sluice box was set at a slope of 2 to 4 degrees and a flow of water over it was maintained so that there was just enough to cover the ribs on the mat and to cause some turbulence. This process along with the wet sieving should wet the heavy minerals and prevent them from floating. The gold was concentrated on the riffle mat along with other heavy minerals. Because of its high specific gravity (as shown in Table II) it usually comes to rest within a few feet of the beginning of the riffle mat.

TABLE II

SPECIFIC GRAVITY OF HEAVY MINERALS

Mineral	Specific Gravity
Garnet	3.15 - 4.3
Epidote	3.25 - 3.5
Diamond	3.5 - 4.1
Barite	4.3 - 4.6
Pyrite	4.95 - 5.10
Magnetite	5.17 - 5.18
Scheelite	5.8 - 6.1
Galena	7.4 - 7.6
Gold	15.6 - 19.3

Time needed to wash a sample thoroughly was about 4 hours. After the sieving was finished a little time was allowed with

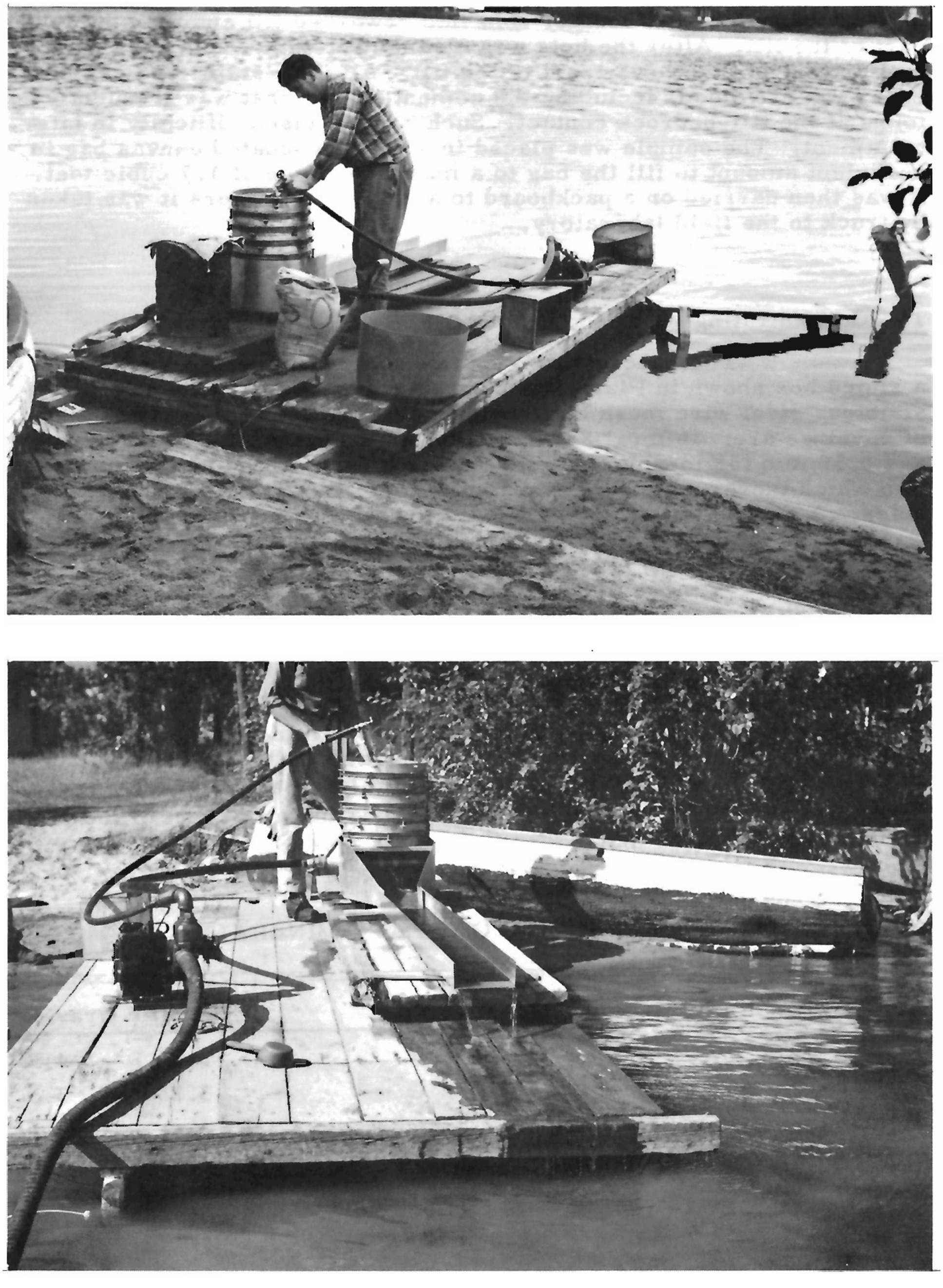


Plate I. Concentrating unit.

Plate II. Size fractions of the till analyzed in the field laboratories.

Plate III. Equipment used in the ore dressing unit.

a flow of water for the last light minerals to clear the deck. Then the number of gold grains visible to the unaided eye on the riffle mat were counted. The total riffle concentrate was then washed into a large fibreglass tub. After excess water was poured off, the sieve and riffle fractions were placed in aluminum basins (as shown on Plate II) and were then ready for further treatment in the ore dressing unit.

Ore Dressing Unit

The purpose of the ore dressing unit is to prepare the sieve fractions from the till for further analysis. The operation involves drying, fine sieving, separation of the magnetite, and grinding. The flow sheet for the ore dressing unit is given on Figure 2.

A drying room, 4 feet x 4 feet x 6 feet high, was constructed from plywood. The sides were raised 1 inch off the floor, and the roof was lifted 1 inch above the walls to permit ventilation. Four electric hot plates were placed on the floor of the oven. A shelf was constructed of chicken wire mesh and rested on a frame.

All material except the two coarest sizes, were spread on separate sheets of brown paper and placed on the shelf. These dried within several hours.

Grinding was done in six small ball mills, which were turned end over end by a paint-shaking machine. Each ball mill consists of a cylinder and 2 end caps all made of mullite (see Plate III). Three mullite balls were used as grinding media in each mill. Each ball mill was assembled with a sample and all were rotated at one time in a rack held by the paint-shaking machine. Length of time for grinding was one hour.

Visual Counts

Visual measurements were made on the two coarser size fractions and the total number of rock fragments was counted. These ranged from 50 to 399 for the coarser fraction and from 101 to 2,342 for the other. Rock fragments containing vein quartz were separated and their percentage was computed. The vein quartz was saved for later reference. Mineralized rock fragments were separated. Counts were made on fragments showing veined pyrite. Fragments with chlorite were counted, separated, and saved. Strongly magnetic fragments were counted and saved. Various other distinctive mineralized and fossilized rock fragments were also saved. All fragments that were saved were re-examined in a block inspection so as to minimize possibility of error during classification.

Binocular Microscope Counts

Material in the 1.23 to 3.35 mm and the 3.35 to 8 mm size ranges consisted chiefly of rock fragments. The material was examined both visually and with the aid of a binocular microscope. A flow sheet outlining the measurements made is given on Figure 3. A further check count was made at the end of the season.

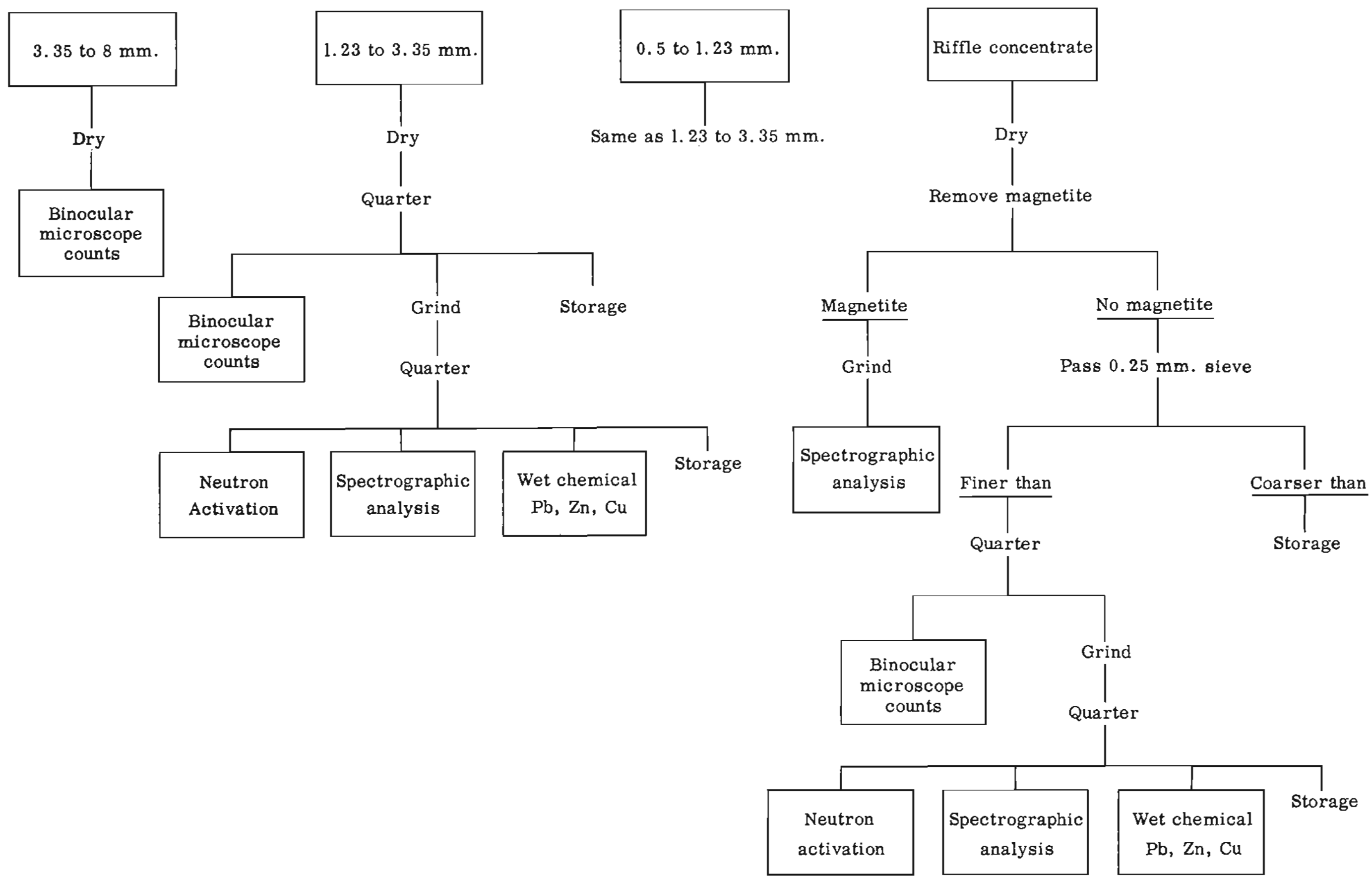
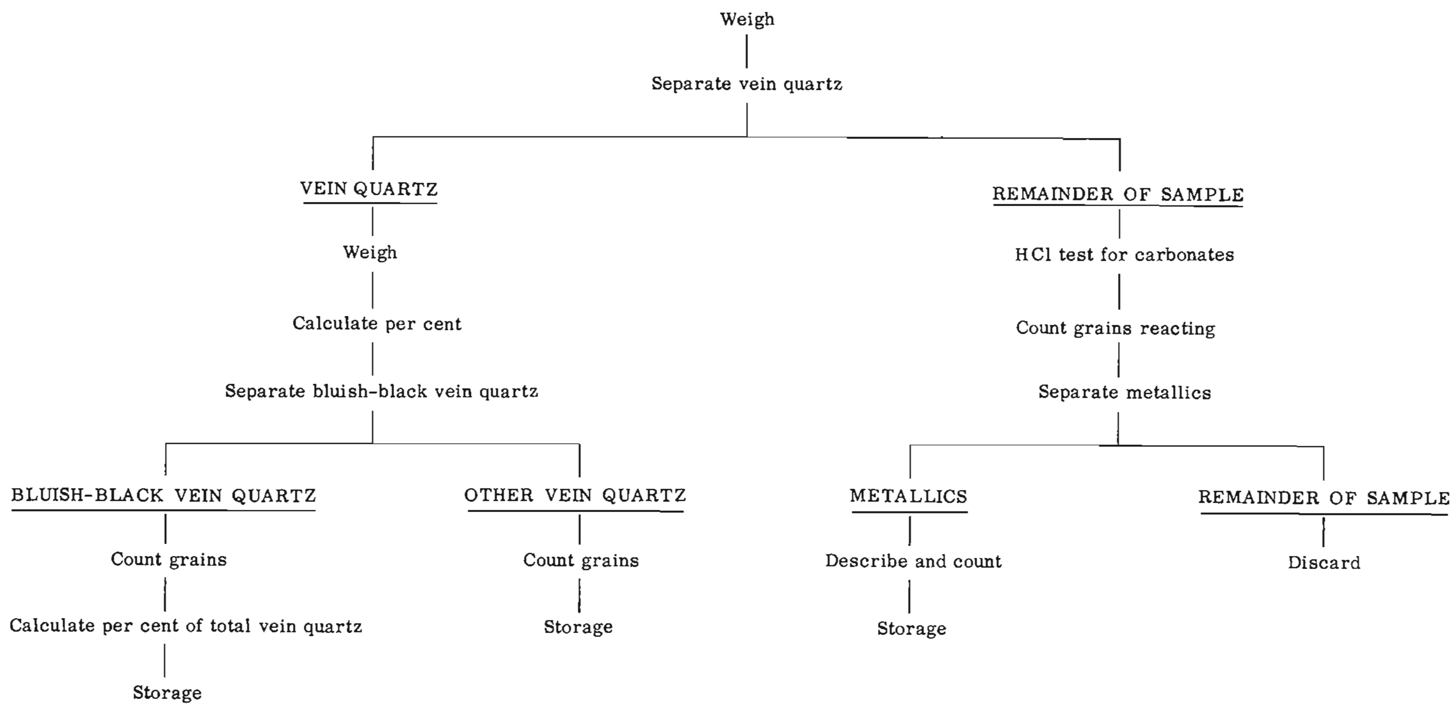


Figure 2. Flow sheet for ore dressing unit

GSC



GSC

Figure 3. Flow sheet for measurements made on size ranges 1.23 to 3.35 mm. and 3.35 to 8 mm.

Material from the riffle concentrate and from the 0.5 to 1.23 mm size range consisted chiefly of mineral grains. A heavy liquid separation was made of the material using tetrabromoform. Microscope slides were made using the heavy mineral fraction and the light mineral fraction. Expoxy cement was used to mount the grains. It has the advantage of not completely covering a grain and of permitting the use of different index oils consecutively. A flow sheet for measurements made on material from these size ranges is shown on Figure 4.

Spectrographic Analyses

Spectroscopic analyses were made in a Geological Survey field laboratory under the direction of R.H.C. Holman. A 1.5 metre Wadsworth mounted grating-type emission spectrograph was used. Analyses were made on finely pulverized material from two size fractions of the till (1.23 to 3.35 mm sizes and 0.5 to 1.23 mm sizes) and on a riffle concentrate after magnetite was removed. Separate spectrographic analyses were made on magnetite from the riffle concentrate.

Spectrographic analyses were done for the following purposes:

(1) To indicate anomalous abundance of a metal which could then be checked for in mineral combination by use of the binocular microscope. This was an attempt to bypass a tedious identification of all heavy minerals.

(2) To assist in evaluating post-depositional alteration of elements and minerals in the till.

(3) To make comparisons between the trace elements in various sizes of the till and different bedrock lithologies in the region.

Neutron Activation Analysis for Gold

A total of 180 gold analyses were carried out by neutron activation over a period of 3 months. Samples were irradiated and counted in the Chalk River laboratories of Atomic Energy of Canada Limited. The techniques and equipment used will be described elsewhere by R.A. Washington. The fractions of the till that were analyzed included ground portions of the riffle concentrate after magnetite was removed, and also ground portions of the two finest sieve sizes.

The neutron activation method for gold analysis was used because of its low limit of detection of about 0.001 ppm (0.00003 oz./ton). This compares to fire assay that measures to about 0.17 ppm (0.005 oz./ton) and can be estimated to about 0.03 ppm (0.001 oz./ton). However, fire assay was used on boulders.

Gold analyses were made for the following purposes: (1) to determine in what amounts gold was present in the till, (2) whether one size fraction of the till contained more gold than another, and (3) whether gold in the till would outline a glacial fan from the Kirkland Lake fault.

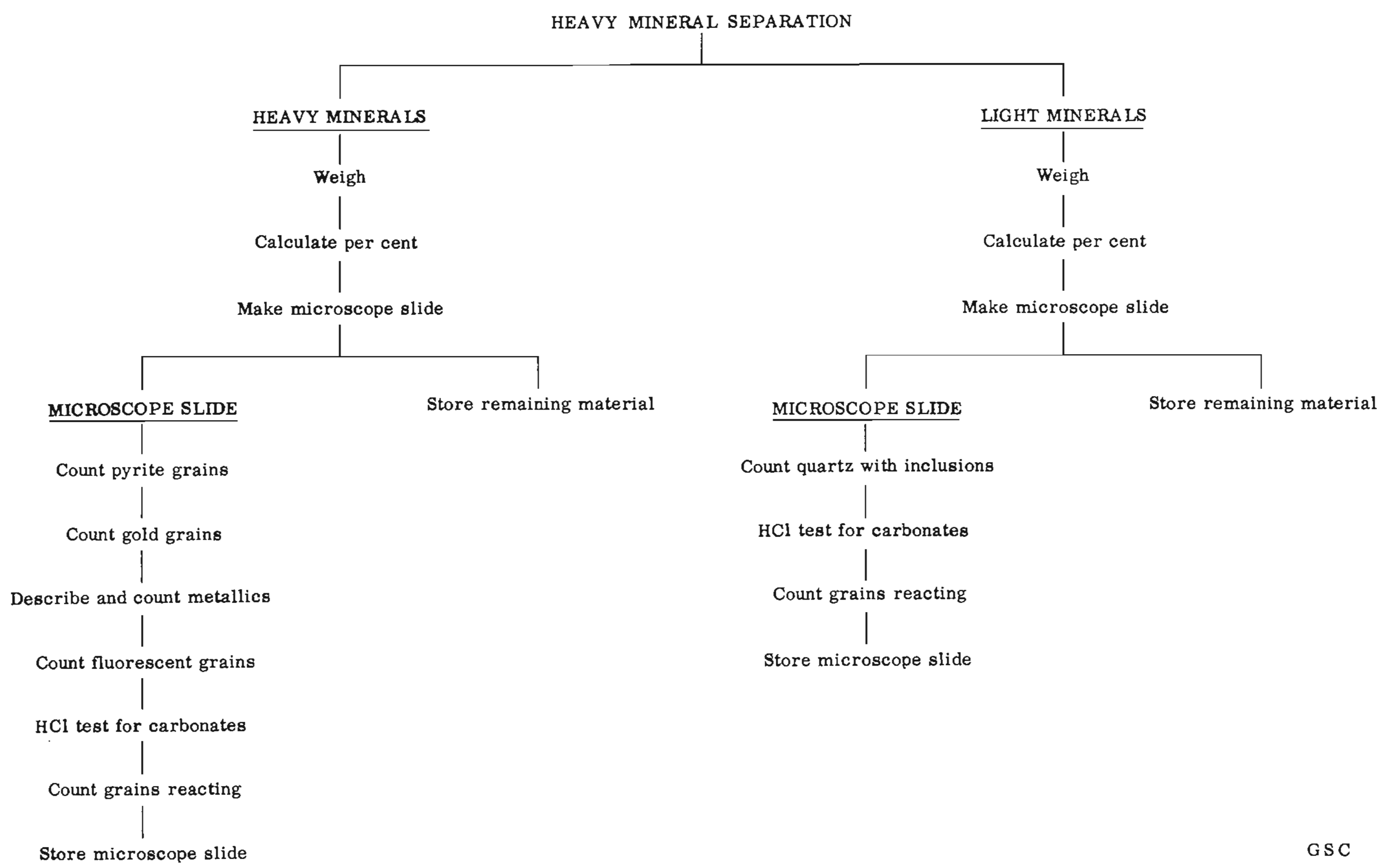


Figure 4. Flow sheet for binocular microscope counts on material from riffle concentrate and sizes 0.5 to 1.23 mm.

Equipment and Costs

The total budget expended on the 1963 operation excluding the writer's salary and the costs of spectrographic analyses was $14,970.00. This figure includes $1,180 for fire assay analyses and $450 for irradiation time for neutron activation analyses. A list of equipment is given below.

Sampling unit - 3 men on detail, 2 on reconnaissance

6 volt dry-cell battery
4-foot steel scaling bar, pointed at one end
No. 6 electric blasting caps
1 in. x 8 in. 40% forcite
1 roll - 20 gauge blasting wire
3 packboards, 3 safety helmets
3 sets of safety goggles
shovel, prospector's mattock
2 prospector's hammers, 2 pound rock hammer
100 pound capacity paraffin-coated canvas bags
pace-meter, 2 hand lenses, compass

Concentrating unit - 2 men

5 sets of aluminum screen rings
stainless-steel wire cloth for sieves
aluminum feeder and sluice box
rubber matting designed for heavy minerals
water pump and connections
2 automagnets
2 nylon scrub brushes, 2 fibreglass tubes
12 aluminum wash basins

Ore dressing unit - 1 man

6 ball mills, mullite
paint shaker, reinforced
holder for ball mills, wooden
mortar and pestle
2 automagnets
plastic vials, plastic bags

Binocular microscope units - 2 men

Wilde binocular microscope and lamp
microscope slides, storage boxes
scraping pin, plastic mineral grain vials
ultraviolet lamp
direct-reading balance
heavy-mineral separatory funnel
stand, clamps, filter paper, funnel
tetrabromoform, acetone

PARTICLE SIZE DISTRIBUTION IN TILL

A plot of the size distribution of the till gives a characteristic frequency curve (see Fig. 5). This chiefly trimodal distribution is characteristic of glacial tills near Kirkland Lake (5 samples). Similar distributions have been observed in basal tills from New Brunswick (19 samples; Lee, 1953), as well as basal tills analyzed from other parts of Canada.

One explanation for these modes is the crushing process that took place between the bottom load of the ice-sheet and the bedrock surface. Gaudin (1926) has experimentally produced similar results using a ball mill and with feed coarser than the balls. He noted that angles of the coarse feed were chipped off at an early stage, making grains of all sizes from feed-size down. The coarse grains presented fewer and fewer sharp edges that could be conveniently chipped and these edges became smaller until they were so small that comminution became "wear" instead of "fracture". At the same time Gaudin found that balls unable to break the larger grains crushed the next finer, and so on, and the remaining grains became increasingly difficult to reach because of cushioning effects. The result noted by Gaudin was a certain preponderant size range.

In addition to this dominant grinding process, the size distribution of the till is affected by local loading. The abundant sheared fragments in the till immediately south of the Kirkland Lake fault is a good example. Reworking of the upper parts of the till by glacial Lake Barlow-Ojibway has changed the initial size distribution. Post-depositional alteration of the till through breakdown in pyrite, and the mobility of some elements have also been factors.

Because the polymodal character of the till relates a story, it seemed important to introduce sieves that would sample each mode separately. Other factors that affected the selection of sieve sizes had to be considered. These were: (1) the lower size limit of a rock fragment that could be identified; this was taken to be 8 mm and a sieve of that opening was introduced; (2) a suitable size range for binocular microscope study of the heavy minerals, which was taken as 0.5 mm to 1.23 mm; and (3) the lower limit for practical wet sieving of bulk sample, which was 0.5 mm. A screen with 0.5 mm opening also effectively sampled the major mode in the fine sizes.

Size fractions of the till on which laboratory analyses were done are shown on Figure 5. The riffle concentrate has proved to be an important measure, and it is seen to represent a concentrate from a large proportion of the total till sample.

POST-DEPOSITIONAL ALTERATION OF TILL

Changes have taken place in the till since it was deposited by the ice-sheet. First, there is a change in texture, which was seen in most of the holes excavated, from a gravelly sand in the strong zone of reworking (see upper half of Fig. 5) where some fines were removed, to a silty gravelly sand at depth (see lower half of Fig. 5).

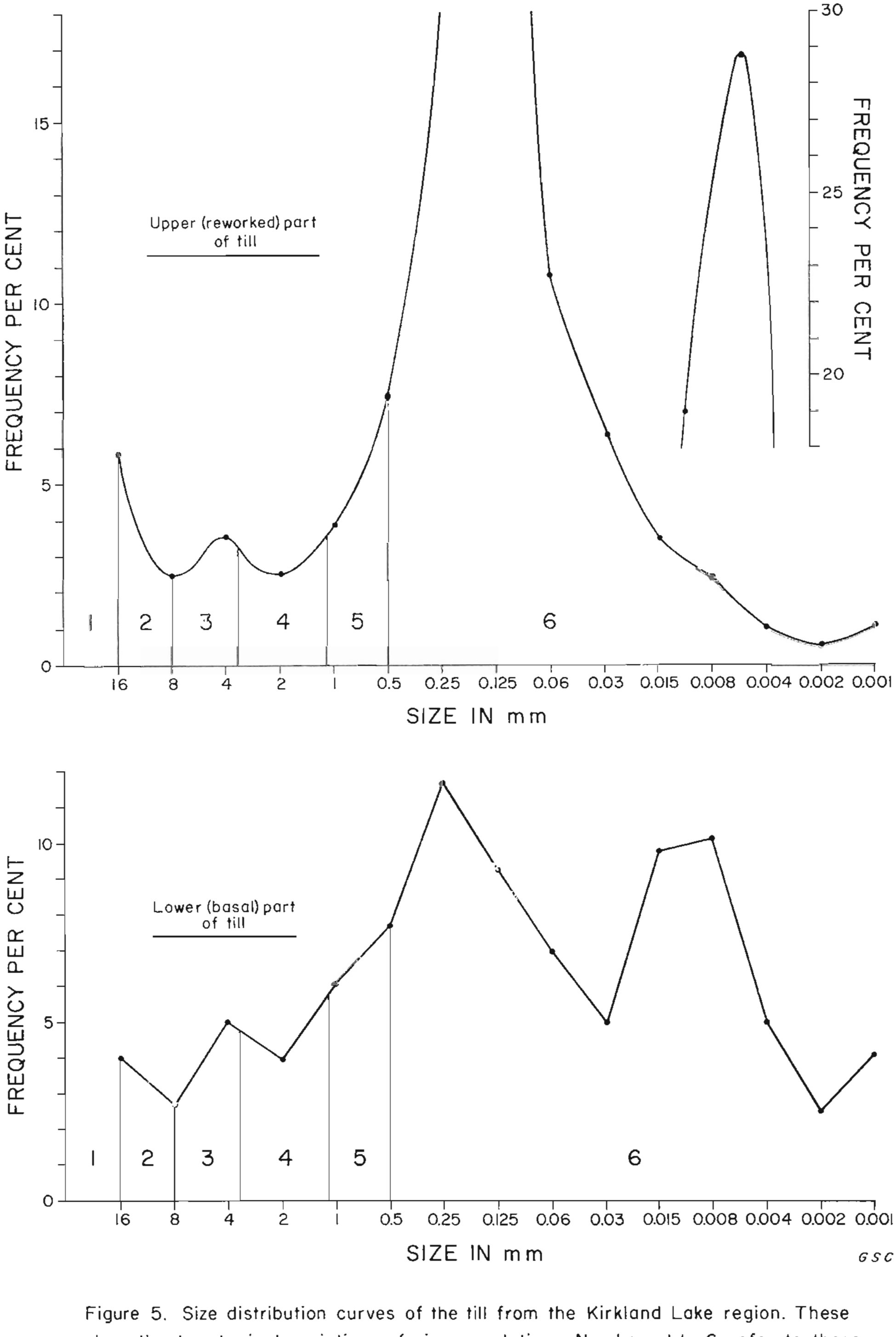


Figure 5. Size distribution curves of the till from the Kirkland Lake region. These show the two typical variations of size populations. Numbers 1 to 6 refer to these size fractions examined in the field laboratories. Heavy minerals from number 6 give the riffle concentrate.

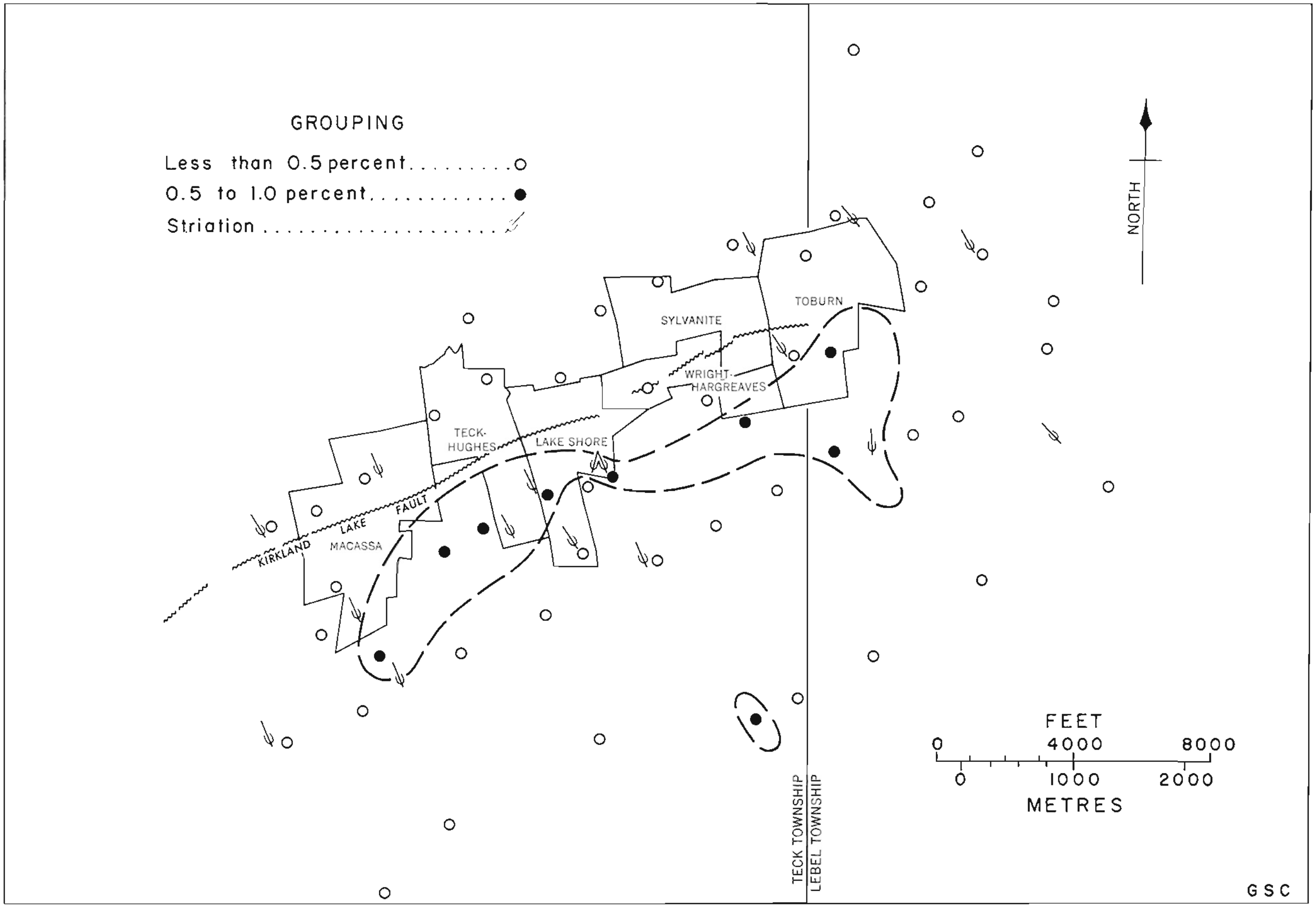


Figure 6. Chlorite fragments in till by number percent, 8 to 16 mm sizes

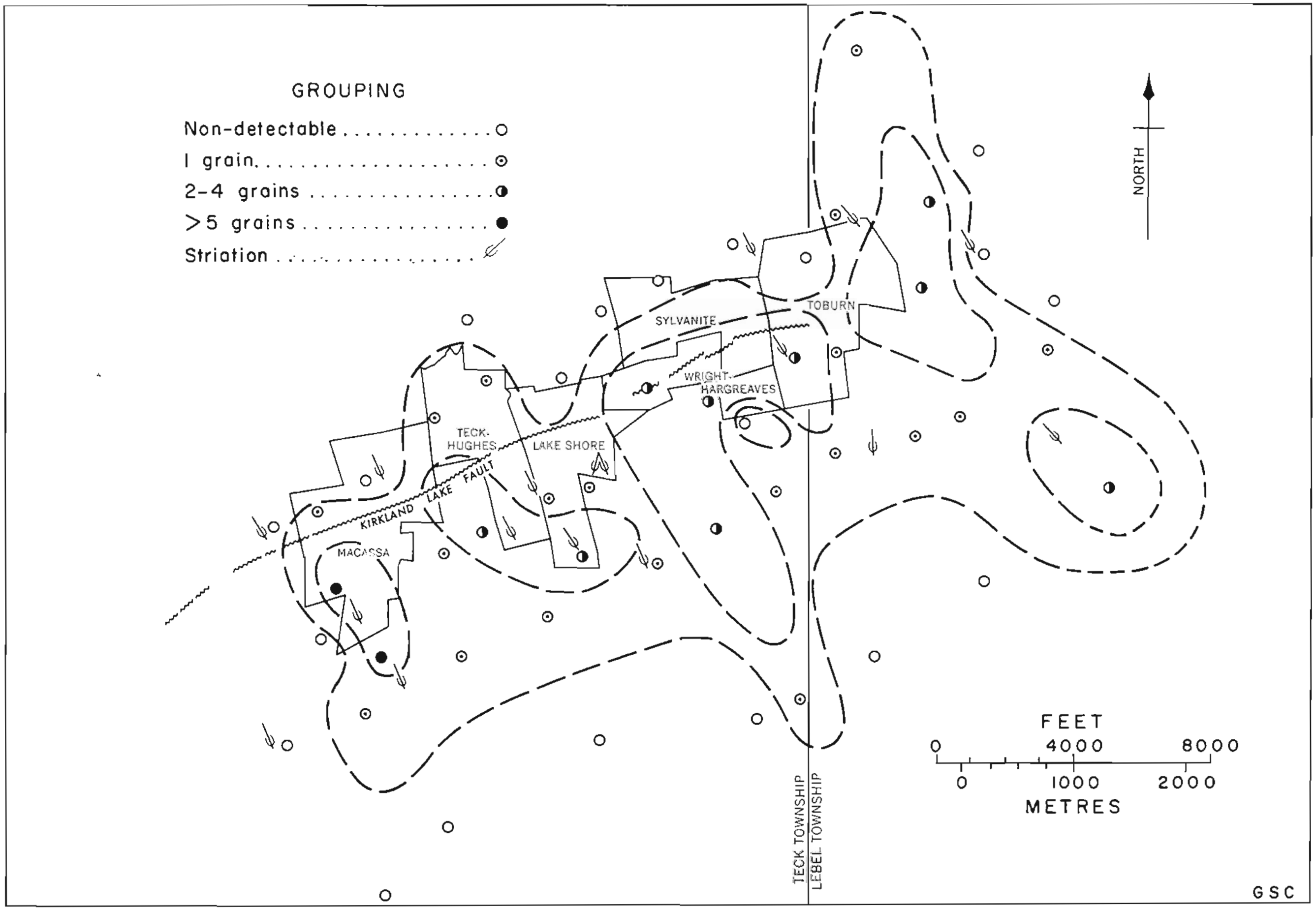


Figure 7 Gold grains visible to unaided eye in riffle concentrate from till

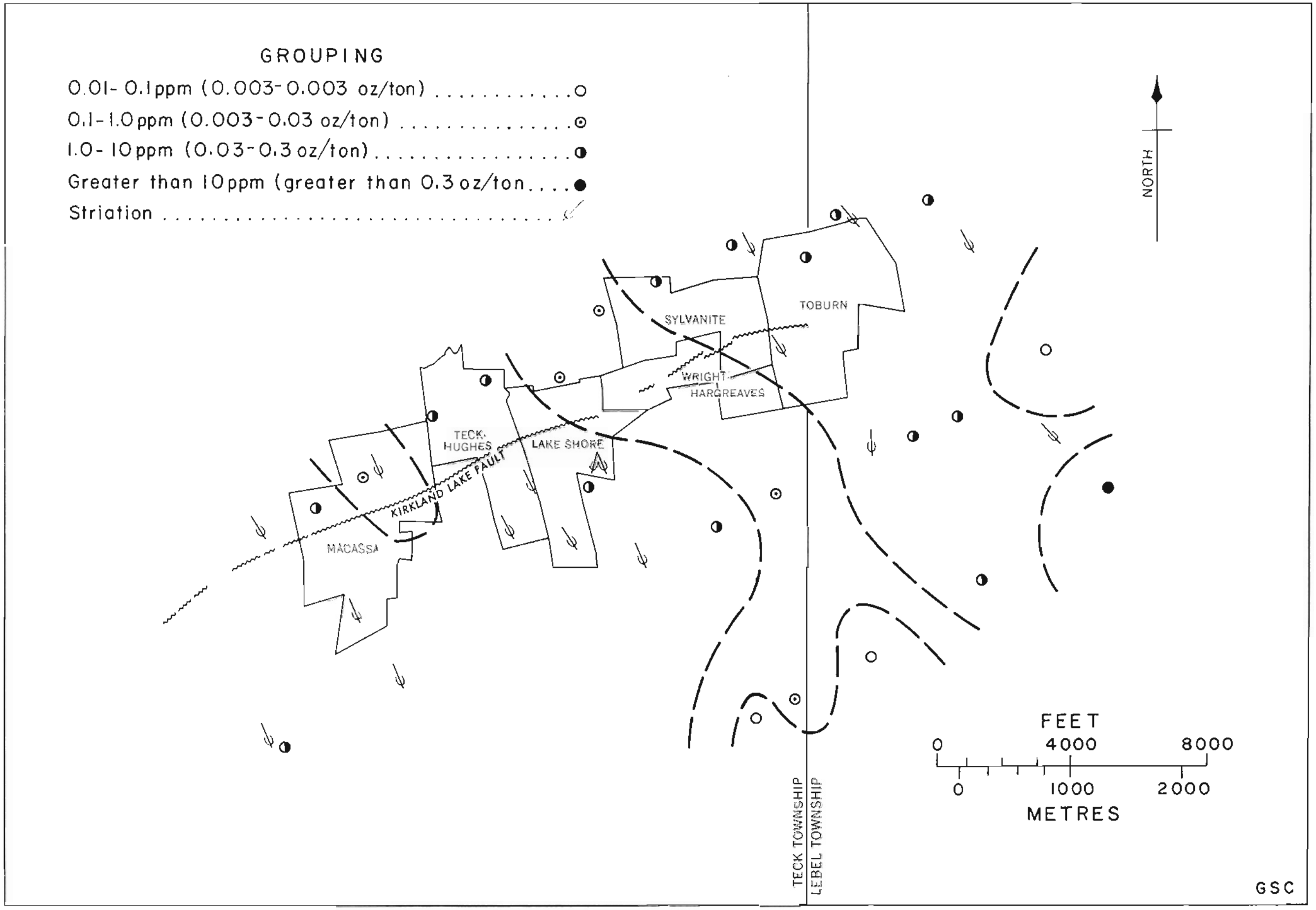


Figure 8. Total gold in riffle concentrate by neutron activation

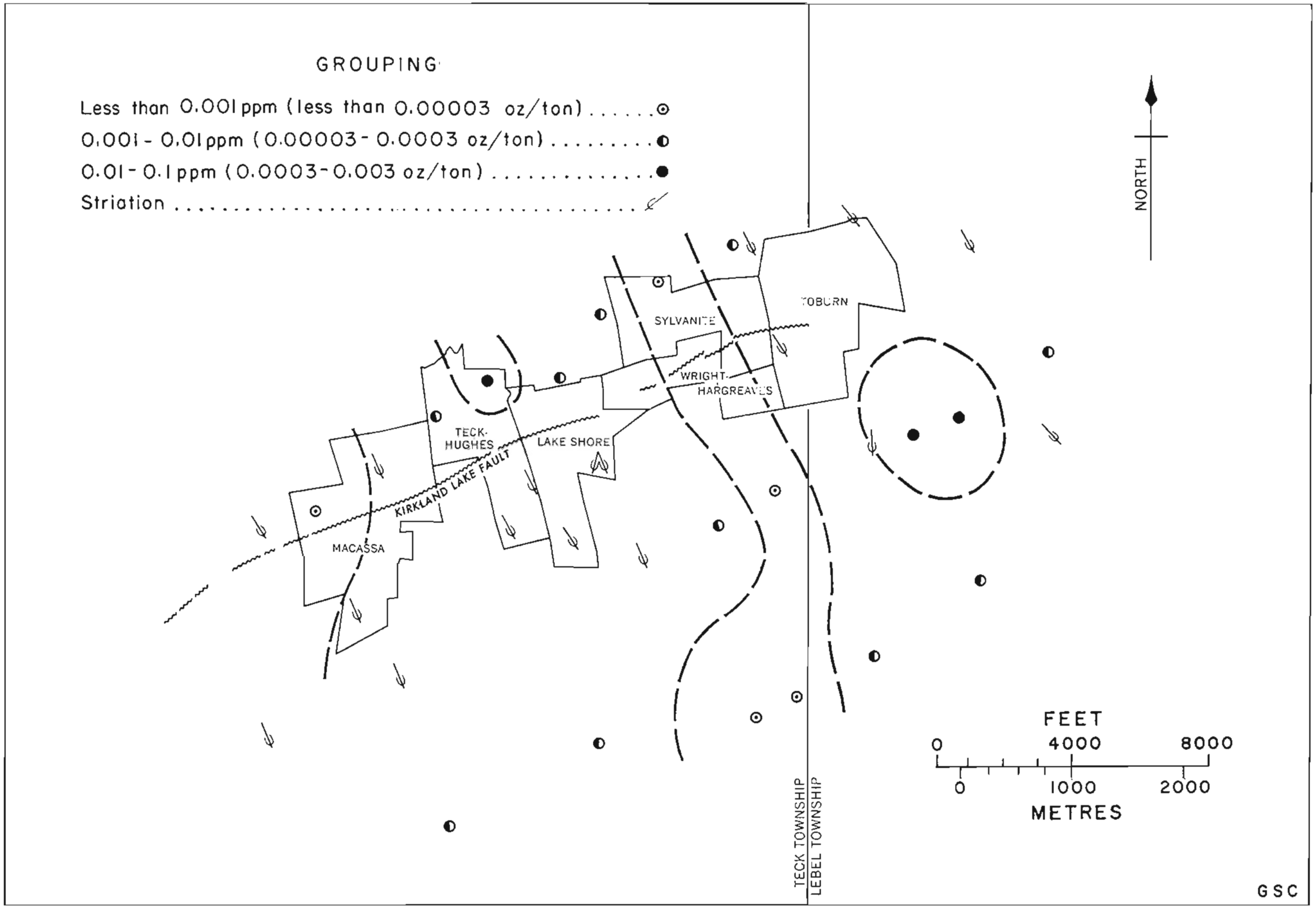


Figure 9. Total gold in till, size range: 1.23mm to 3.35mm, by neutron activation

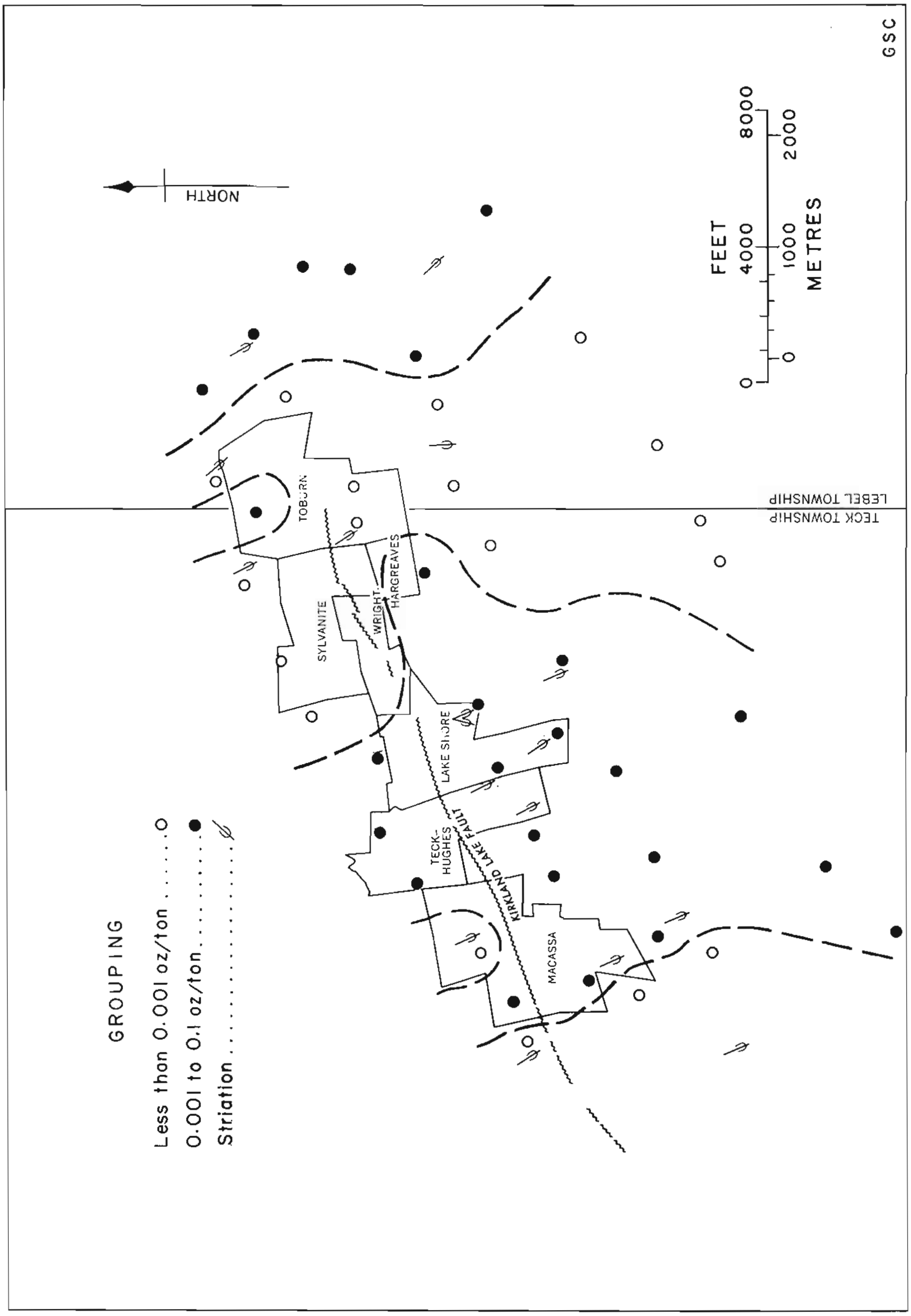


Figure 10. Gold content determined by fire assay on boulders from the till

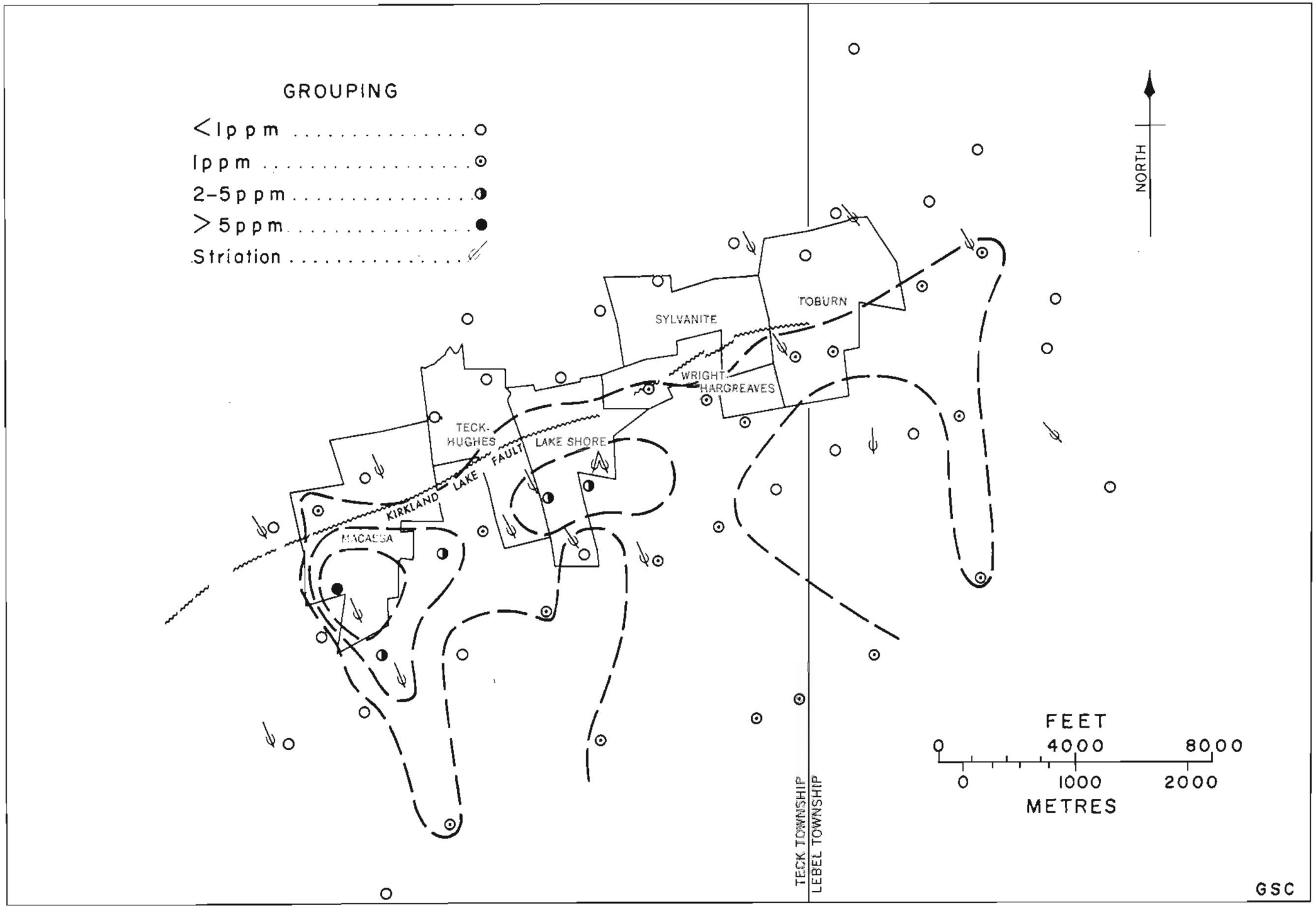


Figure II. AG Content in magnetite taken from a riffle concentrate of till and determined spectrographically

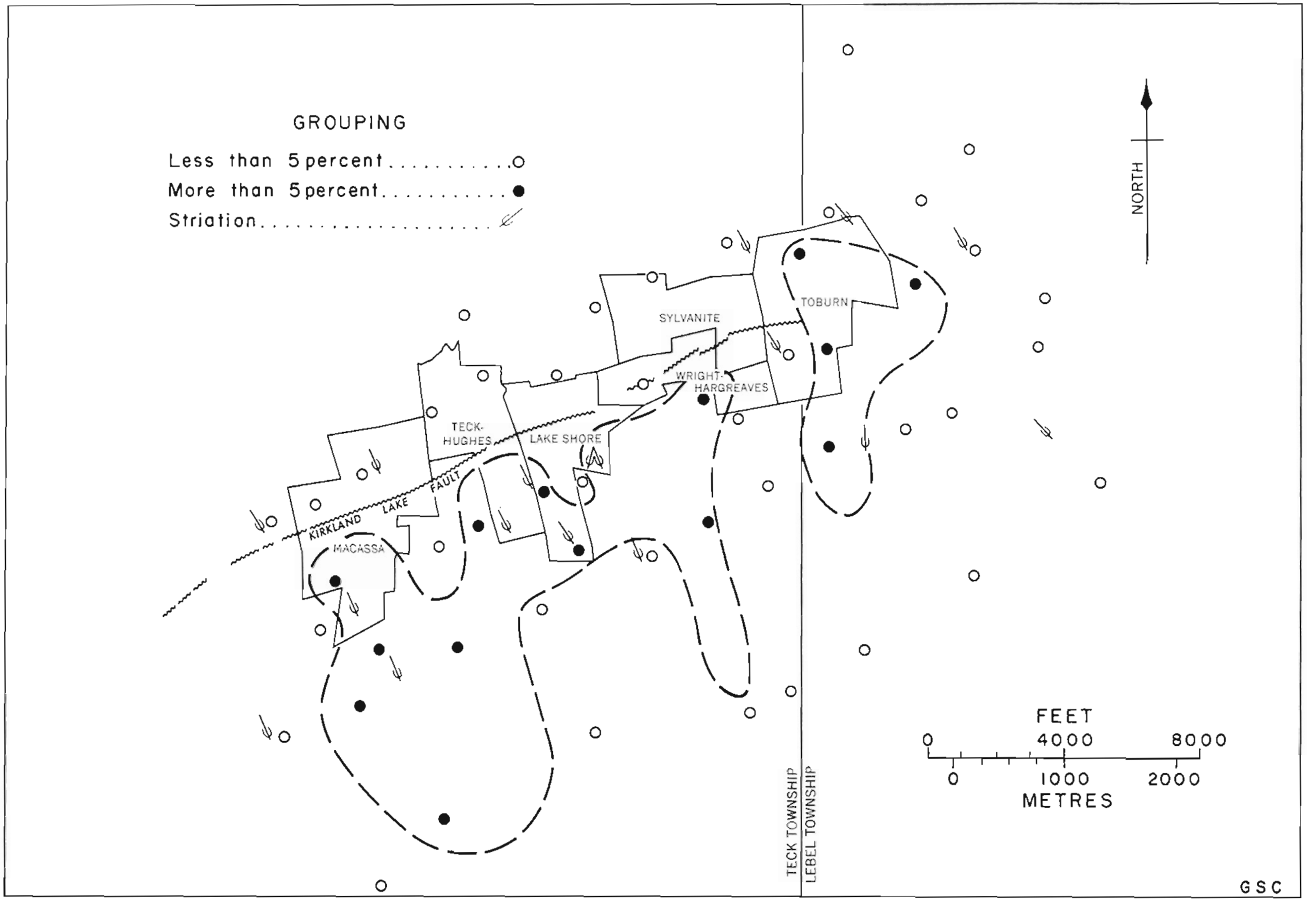


Figure 12. Bluish-black vein quartz in till, size 3.4 mm to 8 mm. (percent by weight of the bluish-black vein quartz to the weight of total vein quartz in this size range)

Secondly there has been some mineral change. The pyrite has almost disappeared in the reworked till, but is more abundant in the basal till especially in the deeper excavations, where it is less oxidized. Extensive oxidation in the reworked till can be explained by the former presence of glacial Lake Barlow-Ojibway, which brought the till of the region into the zone of effective wave action near its shorelines. This was an oxidizing environment. A fluctuating modern water-table has also been a factor. The iron-cemented zones seen in the reworked till resulted from both these processes.

The alteration of pyrite has been noted because attempts were made in this study to use it as an indicator in the till. It is not yet known, however, how many more minerals have been altered both mechanically and chemically in the upper part of the till and may have filtered down into the top of the sampling unit. Table III shows the concentrations of trace elements in two sand-size fractions of the lower part of the till. The finer material has a consistently lower concentration of trace elements than the coarser, except for barium and strontium, which may be considered constant. Further studies are needed to ascertain if the variation pattern shown on Table III was caused by vertical infiltration into the lower part of the till from material of the reworked zone, which has been modified both mechanically and chemically, or if it was caused by preferred groundwater leaching on the finer sizes.

TABLE III

TRACE ELEMENTS IN THE TILL
(Arithmetic averages of 52 samples analyzed spectrographically)

Elements	Concentration in ppm	
	1.23 to 3.35 mm size	0.50 to 1.23 mm size
Ti	2742	1779
Ba	295	329
Sr	197	232
Mn	747	527
V	179	98
Cu	35	22
Cr	172	101
Zr	74	60
Ni	80	47
Co	27	15

CHARACTER OF THE KIRKLAND LAKE FAULT AS EXPRESSED IN THE TILL

Fault Gouge

The mines of the Kirkland Lake camp are in fault zones, and the importance of these faults to gold deposition has been described by Hopkins (1949).

The writer has found that by observing fragments of the fault material in the till some characteristics of the fault zone become apparent, which were not obvious before. This is possible because faults have produced zones of physically shattered rock. Such material was easily picked up by the ice-sheet and it is now found in great abundance in the till immediately south of the faults. This local loading of fault material into the till is doubly important when the gold target is also in the fault.

The fault material shows in the till as schistose platy fragments. It is most abundant in the size range 8 to 16 mm, or about the size of a Canadian five-cent piece. Chlorite fragments of that size were found to be an indicator in the till. The rock fragments in the till were classified as chlorite only if they were good plates of schistose chlorite. Excluded were fragments of rock with only chlorite veneers. Chlorite gouge collected underground from the "main break" of the Kirkland Lake fault at the Teck Hughes mine was used as a reference for classification.

A plot of the geographic distribution of chlorite fragments in the till is given on Figure 6. It outlines a glacial fan with a source over the Kirkland Lake fault. The correlation is good.

South of the other faults in the region—the two Harvey faults and the Murdock Creek fault—a large amount of sheared rock fragments were seen in the till. Chlorite fragments were absent. Only veneers of chlorite were seen on sheared rock fragments. The Kirkland Lake fault is then distinct in the sense that it contains abundant chlorite as gouge, and this separates it from two of the non-producing faults in the immediate area. Only a spatial relationship is indicated between the chlorite coming from the Kirkland Lake fault and the fault itself. No time relationship relative to gold deposition is implied.

Visible Gold in Riffle Concentrate

Visible gold was found and measured in the till at Kirkland Lake, where it was observed in the riffle concentrate. A geographic plot of the visible gold (Fig. 7) shows a glacial fan stretching from Macassa mine on the west to Toburn on the east, with its source over the Kirkland Lake fault. The number of visible gold grains per sample in the fan decreases generally southwards from 1 grain to 10 grains in the first grid line 2,000 feet south of the fault, to 1 grain to 3 grains on the 4,000-foot line south of the fault, and is generally absent 10,000 feet south of the fault. This glacial fan shows a fairly good correlation with the mines along the Kirkland Lake fault.

The original grid selected for this study did not include the Macassa mine. Gold for that property is only known at depth.

However, the fan does include the property (as shown on Fig. 7) and the grid had to be extended before the results began to drop off to the west. One prong of the fan near the Toburn property juts northwards along a series of closely spaced north-south faults (not shown on Fig. 7).

Certain geological conditions have combined to make possible the recognition of this gold anomaly. First, we have shear zones in which the visible gold is associated and which provided a major selective load to the ice-sheet, from which was deposited the till. The chlorite fan of Figure 6 emphasizes this point. The other geologic factors of importance are the wave action of former glacial Lake Barlow-Ojibway and shifting water-tables, which altered the till and hastened the disintegration of pyrite, thus allowing the gold to be freed. The pyrite in the Kirkland Lake mining camp is auriferous. The free gold from the disintegrated pyrite went into the fines, where it was picked up in the riffle concentrate. This explains the abnormally low gold values in the sand size of the till of about 0.001 ppm (0.00003 oz./ton) by neutron activation, compared to as much as 20 ppm (0.6 oz./ton) in the riffle concentrate.

The riffle-concentrate technique for gold exploration was tested outside of the Kirkland Lake area. Localities were tested southeast of two gold mines where results should have been positive. One grain appeared in the riffle concentrate from south of the Queenston mine in Gauthier township, and two grains were found south of the Omega mine in McVittie township. These results were as expected.

Localities were tested next in areas of no known gold deposits. One locality in Catherine township showed no gold grains in a riffle concentrate. This was as expected. Another such locality was at the Adams iron-ore mine in Boston township, where there were extensive excavations. Again no gold showed in the riffle concentrate. This result was as expected, but is inconclusive because pyrite in the very deep till sample was not disintegrated.

The finding of a new gold fan was attempted at a locality in McGarry township where reconnaissance showed a number of boulders containing low gold values. Two grains of visible gold showed in the riffle concentrate.

This preliminary testing of the riffle-concentrate method for gold exploration indicates that it should work along the western part of the entire Cadillac-Larder Lake break.

Total Gold in the Till

The neutron activation method of analyses used in 1963 measured "total" gold in the sample. Residues from sample attack indicated that better than 99 per cent of the gold was removed in the initial aqua regia treatment of the sample (R.A. Washington, oral communication). This includes gold present in other minerals—as intergrowths, as ion substitution, as wedging in distorted lattices—as well as in mineral combination such as tellurides, and as free gold. This differs from the "recoverable" gold that would be available in normal mining practice.

Geographic plots of total gold in the riffle concentrates of till are shown on Figure 8, and in the size range 1.23 to 3.35 mm on

Figure 9. Results on the first 18 samples are omitted because the field technique differed for these. Plans are to re-analyze these under the revised technique.

These early results shown on Figure 8 indicate that total gold in the riffle concentrate does not outline a glacial fan from the Kirkland Lake fault. Why this is the case, when visible gold outlined a fan as shown on Figure 7 may lie in the following hypothesis. The gold in the Kirkland Lake fault is present in a recoverable state, much of it as fine free gold. In comparison, the gold outside of the fault may be highly dispersed and is not readily recoverable with standard mining practice.

Gold in Boulders of the Till

The technique of boulder tracing was applied to see whether there was a glacial fan of auriferous boulders emanating from the Kirkland Lake fault.

Because the gold can almost never be seen in the boulders certain criteria had to be established for selecting for fire assay a number of auriferous boulders from a population of several hundreds at each sample locality. To do this, a mine reference collection was made and the following criteria were drawn up:

(1) Dark-coloured vein quartz - All the gold mines sampled contained this dark-coloured quartz, hence it was considered a good parameter. From boulder counts in the field it was found that vein quartz was not overly abundant. All boulders containing it were checked by fire assay. Some gave low values, but most, even though they looked the same gave non-detectable results. The number of fragments of dark-coloured quartz were too few in the boulder sizes to warrant any conclusions being drawn.

(2) Cherty quartz - A useful parameter comes from the Upper Canada mine about 10 miles east of Kirkland Lake. Ore deposition in this mine generally took place in silicified zones, and gold is generally associated in these zones with brecciated and mineralized veinlets of pale to dark bluish cherty quartz (Tully, 1963). Contacts are generally indistinct. Some boulders from the till sampled in the Kirkland Lake area showed the pale cherty quartz in veinlets and these commonly gave low assay values (0.001 to 0.01 oz./ton). They were, however, equally abundant north of the Kirkland Lake fault as they were south of it.

(3) Abundant disseminated pyrite and pyrite in veinlets - Boulders containing veinlets of pyrite commonly gave low gold values. However, pyrite occurred only in larger boulders that were not too weathered in the interior. The auriferous and pyritic boulders were equally abundant north of the Kirkland Lake fault as they were south of it.

(4) Bleached, carbonatized, and otherwise altered boulders - showing this type of alteration were analyzed for gold, but the results generally were disappointing.

A geographic plot of the gold content of boulders in the till (Fig. 10) shows that the auriferous boulders continue across the

Kirkland Lake fault without a noticeable change in concentration. Hence the boulder tracing technique as applied in 1963 was unsuccessful in producing a concentrate pattern, probably caused mainly by imperfections of sampling—having to select the 10 or so auriferous boulders from a count of about 800—when the gold could not be seen in the boulders.

Magnetite

Work elsewhere has shown that magnetite may contain trace elements of metals indicating the origin of the magnetite (Hegemann, 1958; Landergren, 1958; Mackenzie, 1963; Putman and Burnham, 1963; Theobald and Havens, 1960; and Theobald and Thompson, 1962).

In this study the riffle concentrate was found to give an excellent magnetite product. The magnetite grains were easily picked out with a hand operated auto-magnet, they were then crushed, and picked over once more. The product was pure magnetite, except for a few magnetic grains of a mineral identified by x-ray diffraction as lepidocrocite, an altered form of goethite. Mineral identification was made by R.N. Delabio of the Geological Survey of Canada. The combined product of lepidocrocite-magnetite was analyzed spectrographically.

A geographic plot showing a distribution of silver in the magnetite (Fig. 11) outlines a glacial fan with its source at the Kirkland Lake fault. This fan compares with that for gold (Fig. 7) by its continuation westward to include the Macassa mine property. The concentration of silver in the magnetite is near its detection limit, hence quantitative work is needed to definitely confirm the existence of this fan.

An explanation is needed as to why there should be an argentiferous magnetite fan commencing at the Kirkland Lake fault. Argentiferous magnetite has not yet been identified from within the fault. Silver is known to be present in petzite ($(AgAu)_2Te$) in the silver-gold ratio of 3 to 1 (Hawley, 1950). Petzite has been reported by Todd (1928) in ores from the Wright-Hargreaves, Sylvanite, and Toburn mines. Some silver is also alloyed with the gold (Hawley, 1950).

The writer tentatively suggests that argentiferous magnetite is present within the fault. This argentiferous magnetite may be (1) very fine grained, (2) a product of late alteration of other minerals, and (3) have a distorted lattice capable of jamming in the relatively large silver ions. These ideas have not been tested for the Kirkland Lake fault.

The use of argentiferous magnetite as an indicator for gold requires that there be a weak silver anomaly, and that this anomaly is present because of its relationship to gold. The method will probably not work where the background trace-element content of silver is very high.

Bluish Black Vein Quartz

The mines located in the Kirkland Lake fault are known to contain varying amounts of bluish black vein quartz. This seemed to be a worth while parameter and it was tested to see whether it could be used as an indicator for a gold-bearing glacial fan.

In the till, the only size range that carried sufficient fragments of bluish black vein quartz for counting was 3.4 to 8 mm. A geographic plot showing distribution of this dark-coloured vein quartz in this size range of the till (Fig. 12) shows a glacial fan with a dominant source along the Kirkland Lake fault. The correlation is fair. This vein quartz fan resembles the visible gold fan (Fig. 7) and the argentiferous magnetite fan (Fig. 11) in that it had to be extended westward to include the Macassa mine property.

Although the fan indicates a dominant source of the bluish black vein quartz from the Kirkland Lake fault, there is evidence of some material brought in from north of the fault, as shown on Figure 12, and there are also some additions to the fan from veins of bluish black vein quartz south of the fault.

Other Parameters

Molybdenum in Magnetite

The mineral molybdenite makes up only a fraction of 1 per cent of the average ore, but it is widespread in the mines located on the Kirkland Lake fault (Hawley, 1950). Hence the molybdenum in magnetite was considered a possible indicator. Samples of magnetite from the riffle concentrate were analyzed spectrographically for this element. A geographic plot of molybdenum in magnetite (not included in this report) gave the following results: of 15 samples analyzed from north of the fault, only 1 contained more than 2 ppm molybdenum; of 36 samples analyzed from south of the fault, 10 contained 2 ppm or over of molybdenum. Although these results are suggestive no significance should yet be attached to them.

Trace Elements in the Sand Sizes of the Till

Spectrographic analyses were done on two sand sizes of the till as well as on the riffle concentrate. Geographic plots of these results have not yet provided indicators for outlining glacial fans from the Kirkland Lake fault. Averages of the analyses for the two sand sizes are given in Table III. They still need more study for an adequate interpretation.

Fluorescent Zircon

A mineral fluorescing pale green in the riffle concentrate of many samples was identified, by A. Sabina of the Geological Survey of Canada, as zircon by x-ray diffraction. The grains of fluorescent zircon were found to be equally abundant in samples from north of the Kirkland Lake fault as south of it.

SOME INDICATOR FRAGMENTS FROM NORTHWEST OF THE KIRKLAND LAKE FAULT

Rock fragments in the till not only show local transport but also give valuable information on mineralization in the bedrock to

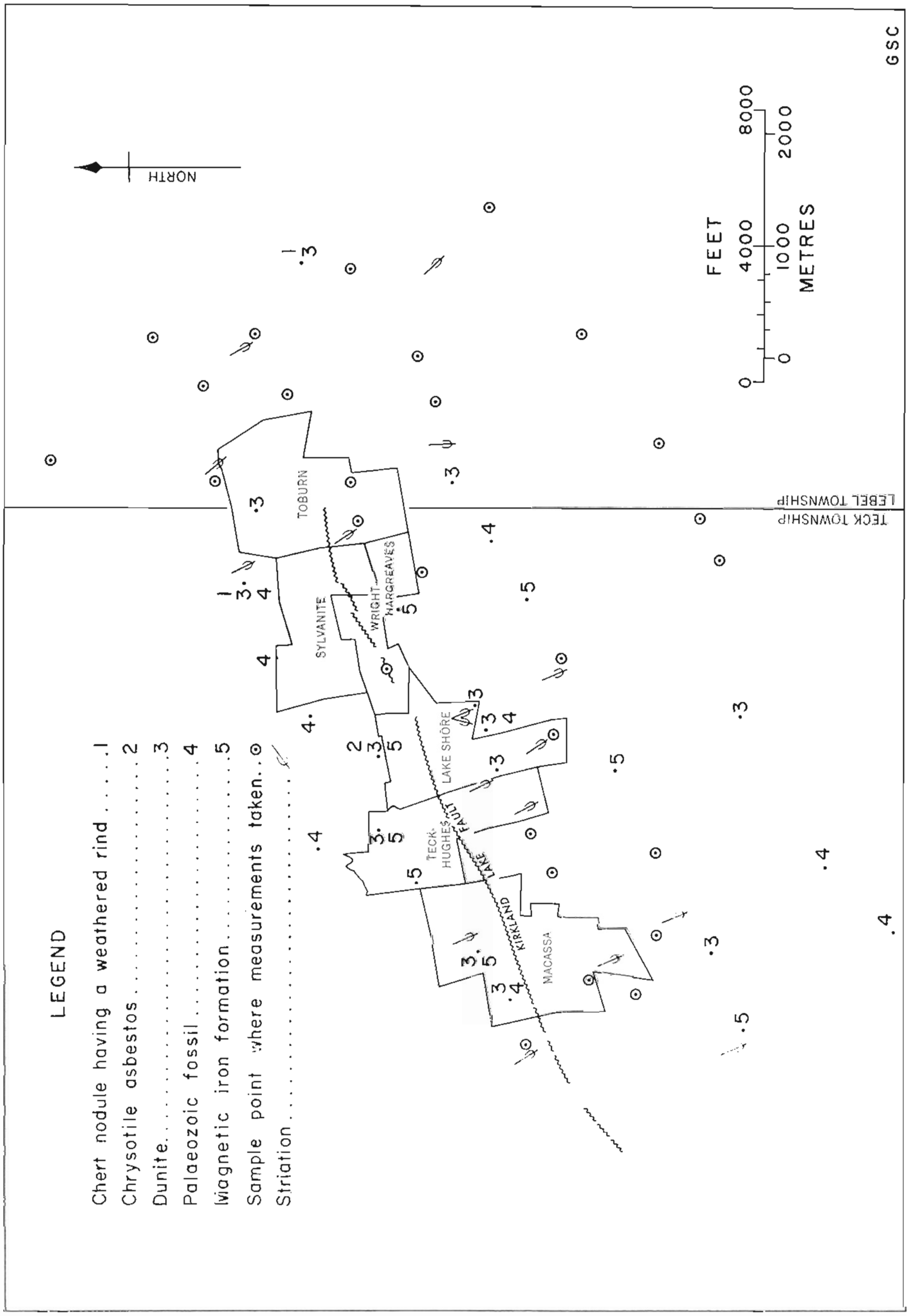


Figure 13. Indicator fragments from north of the Kirkland Lake fault

the northwest. This far-travelled material represents less than one per cent of all fragments in the coarser visible size ranges of the till. Hence, counts of about 1,000 rock fragments are needed in order to consistently observe its presence. Needless to say, this material must be distinct so that it can be recognized.

A geographic plot of this indicator material is shown on Figure 13 and includes the following: (1) iron formation, consisting of magnetite and quartz; (2) dunite; (3) dunite with veinlets of chrysotile asbestos; (4) chert nodules with a distinct weathered rind; and (5) Palaeozoic fossils, including corals and brachiopods. The nearest known probable source for these fossils is about 200 miles to the northwest.

In conclusion, it can be stated generally that the till reflects a dominantly local source, but at the same time gives an important glimpse of the regional pattern.

ANOMALIES

Gold

Ward and Thompson (1950) stated that the first Macassa orebodies were located in 1931 by driving westward along the break (the Kirkland Lake fault) from the 2,475-foot level of the adjoining property on the east. Number 1 shaft was sunk and connected with the workings at this horizon. The earlier development work at shallower depths was unsuccessful.

Knowing this, the writer expected that the glacial fan should lie east of Macassa property, but as reported on a previous page, the measurements for the fan had to be extended westwards. This held true for the visible gold fan shown on Figure 7, and the argentiferous magnetite fan shown on Figure 11. A similar relationship is seen for the bluish black vein quartz on Figure 12. There may still remain an orebody extending to the bedrock surface on Macassa property, which was not encountered in early exploration.

The glacial fan for visible gold (Fig. 7), and the glacial fan for argentiferous magnetite (Fig. 11), both show an anomaly at one locality in the southeastern corner of the sampling area. Coarse fragments in the till at that sample locality show an abundance of sheared and altered fragments, which indicates a fault nearby to the northwest. Two possible interpretations exist for this anomaly. One, it can represent glacial crushing of an ore boulder at this locality. Or secondly, it may indicate a local gold source in the bedrock on or to the northwest of claim 2396 in Lebel township.

One pit opened up in reconnaissance work in claim 31119 of McGarry township had four separate boulders that showed low gold content by fire assay. The riffle concentrate from the till at this locality was examined and 2 grains of visible gold were counted. This result is interpreted as giving one point on a probable gold fan. Further work is needed to first definitely establish the existence of a fan and then trace it back to its source.

Lead-Zinc-Copper

Five localities situated north, east, and southeast of the Toburn mine property gave anomalous results. The anomalies, which are expressed by the following results in Table IV, may in part, or completely, be caused by contamination from blasting caps that were used in opening up pits in the till.

TABLE IV

ANOMALOUS RESULTS

Claim	Spectrographic Analysis		Wet Chemical
See Map No. 53A, Township of Lebel (MacLean, 1956)	Riffle concentrate (excluding magnetite)	Magnetite from riffle concentrate	
1697	300 ppm Pb		
2396			40 ppm Pb in 1.23 to 3.35 mm size
2412		1,500 ppm Cu 70 ppm Pb 1,500 ppm Zn	
2449		700 ppm Zn	
2954	70 ppm Pb		

ACKNOWLEDGMENTS

The writer gratefully acknowledges the continuing assistance given to him by Dr. Geoffrey Charlewood, vice-president of Heath and Sherwood Diamond Drilling Company. Thanks go to Dr. William Savage, resident geologist at Kirkland Lake for the Ontario Department of Mines, for his valuable advice on geology of the region and for his assistance in arranging meetings. Thanks go to the geologists, the mining engineers, and the mine managers of Macassa Mines Ltd., Teck Hughes Mines, Lake Shore Mines, and Wright-Hargreaves Mines, who arranged for surface and underground sampling tours, supplied plans, and gave surface assay values across the Kirkland Lake fault. With Dr. Donald Tully, chief geologist for the nearby Upper Canada Mines, the writer had many stimulating discussions of ideas on gold associations.

The large number of spectrographic analyses on the till were carried out during the field season under the direction of Dr. Ronald Holman of the Geological Survey of Canada. His advice on geochemical matters is appreciated. The gold neutron activation analyses were carried out under the direction of Dr. Robert Washington of the Geological Survey of Canada, and his advice on problems involving nuclear chemistry is appreciated.

Thanks go to the assistants who did the field and field-laboratory work, to James Langille, Guy Yuzicapi, Richard McGregor, Arnold Pedersen, William Blackburn, Richard Carnegie, Donald Strange, Marcel Labonté, Michael Batty, Robert Slater, Rennie Peterson, and Brian Lampi.

Experimentation in using dynamite to open up pits was carried out by Thomas Simms of Teck Northern Roads Ltd., acting under contract to the Geological Survey of Canada. The gold neutron activation analyses were carried out at the Chalk River Laboratories of Atomic Energy of Canada Limited.

With regard to equipment, special thanks go to Dr. Mousseau Tremblay of Hard Metals (Canada) Limited, and to Dr. Christopher Gleeson and Mr. Roy McLeod of the Geological Survey of Canada, who aided in the design of the sieves and sluice box.

REFERENCES

Dreimanis, A.

1956: Steep Rock iron ore boulder train; Proc., Geol. Assoc. Can., vol. 8, pt. 1, pp. 32-68.

1958: Tracing ore boulders as a prospecting method in Canada; Bull. Can. Min. Met., vol. 61, pp. 73-80.

1960: Pre-Classical Wisconsin in the eastern portion of the Great Lakes region, North America; Internat. Geol. Cong., 1960, Rept. of 21st Session Norden, pt. 4, sec. 4, pp. 108-119.

Gaudin, A.M.

1926: An investigation of crushing phenomena; Trans. Am. Inst. Min. Met. Engineers, vol. 73, pp. 253-316.

Grip, E.

1953: Tracing of glacial boulders as an aid to ore prospecting in Sweden; Econ. Geol., vol. 48, pp. 715-725.

Hawley, J.E.

1950: Mineralogy of the Kirkland Lake ores; in Geology of the main ore zone at Kirkland Lake; Ont. Dept. Mines, Ann. Rept. 57, vol. 57, pt. 5, pp. 104-124.

Hegemann, F.

1958: On extensive sedimentary ore deposits of the Eastern Alps; Erzmetall, vol. 11, No. 5, pp. 209-217.

Hopkins, H.

1949: Structure at Kirkland Lake, Ontario, Canada; Bull. Geol. Soc. Amer., vol. 60, No. 5, pp. 909-922.

Hughes, O.L.
1956: Surficial geology of Smooth Rock, Cochrane District, Ontario; Geol. Surv. Can., Paper 55-41.

1959: Surficial geology, Iroquois Falls, Cochrane District, Ontario; Geol. Surv. Can., Map 46-1959.

1960: Surficial geology, Kirkland Lake, Temiskaming and Cochrane Districts, Ontario; Geol. Surv. Can., Map 1-1960.

Hyvärinen, L.
1958: Lyijymalmin Geokemiallisesta Prospektoinnista Korsnäsissa; Summary: On the geochemical prospecting for the lead ore at Korsnäs; Geologinen Tutkimuslaitos. Geoteknillisiä Julkaisuja, No. 61, pp. 7-22.

Kauranne, L.K.
1958: On prospecting for molybdenum on the basis of its dispersion in glacial till; Bull. Comm. Géol. Finl., No. 180, pp. 31-43.

MacLean, A.
1956: Geology of Lebel township; Ont. Dept. Mines, Bull. 150, 63 pp. and map no. 53a.

Landergren, S.
1948: On the geochemistry of Swedish iron ores and associated rocks; Sveriges Geolog. Undersökning, Arsbok 42, No. 5, 182 pp.

Lee, H.A.
1953: Two types of till and other glacial problems in the Edmundston-Grand Falls region, New Brunswick, Quebec, and Maine; unpub. Ph.D. thesis, University of Chicago, Chicago, Illinois, 113 pp.

Mackenzie, G.D.
1962: Minor elements in magnetite from central and northwestern Arizona; unpub. M.Sc. thesis, The Penn. State Univ., The Graduate School, Dept. of Geology, University Park, Pennsylvania.

Putman, G.W., and Burnham, C.W.
1963: Trace elements in igneous rocks, northwestern and central Arizona; Geochim. et Cosmochim. Acta, vol. 27, pp. 53-106.

Sauramo, M.
1924: Tracing of glacial boulders and its application in prospecting; Bull. Comm. Géol. Finl., No. 67, pp. 5-37.

Theobald, P.K. Jr., and Havens, R.G.
1960: Base metals in biotite, magnetite and their alteration products in a hydrothermally altered quartz monzonite porphyry sill; Bull. Geol. Soc. Amer., vol. 71, p. 1991 (abstract).

Theobald, P.K. Jr., and Thompson, C.E.
1962: Zinc in magnetite from alluvium and from igneous rocks associated with ore deposits; in Geol. Sur. Research 1962; U.S. Geol. Surv., Prof. Paper 450C, pp. C72-73.

Thompson, J.E.
1950: Geology of Teck township and the Kenogami Lake area, Kirkland Lake gold belt; Ont. Dept. Mines, 57th Ann. Rept., vol. 57, pt. 5 (1948), pp. 1-53 and map no. 1945-1.

Todd, E.W.
1928: Kirkland Lake gold area; a detailed study of the central ore zone and vicinity; Ont. Dept. Mines, vol. 37, pt. 2, pp. 67-87.

Tully, D.W.
1963: The geology of the Upper Canada mine; Bull. Can. Min. Met., vol. 66, pp. 10-20.

Ward, W., and Thomson, J.E.
1950: Geology of the Macassa mine; in Geology of the main ore zone at Kirkland Lake; Ont. Dept. Mines, Ann. Rept. 57, vol. 57, pt. 5, pp. 125-132.

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