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HEAVY MINERALS IN THE GLACIAL DRIFT OF WESTERN NEW YORK

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INTRODUCTION

The purpose of this study is to determine the heavy mineral assemblages present in the glacial drift of western New York.

Heavy minerals can be used to indicate the provenance (the source and its environment) of the sediments in which they occur. From the provenance of the heavy minerals in the glacial drift, the source of the ice that deposited the drift may be inferred.

Using the character of the heavy mineral assemblages present and the provenance inferred from these assemblages, some of the various drift deposits present in western New York are differentiated by means of statistical analysis.

Stability relationships between heavy minerals having the same provenance, but occurring in deposits of different ages, are determined.

Pettijohn (1957, pp. 514–520) in a survey of the literature on heavy minerals, observed that the frequency with which heavy minerals occur is inversely proportional to the age of the deposit. He attributed this increasing complexity of younger assemblages to intrastratal solution, which removes or alters the less stable minerals with time.

In the literature reviewed by Pettijohn however, a second factor is noted: increasing age corresponds to increasing depth of burial. Provenance and distance of transport are also definitive factors for any given heavy mineral assemblage.

To date, it has not been possible to determine which factors are operative. Surficial Pleistocene glacial deposits do not involve depth of burial as a factor, so that if the inferred provenance is a constant, transportation distance can be determined and the time factor will be the only variable. Thus, any change observed in the heavy minerals of this study, which is based on a time-sequence of deposits, will indicate instability due only to increasing age.

GEOLOGIC SETTING

PLEISTOCENE CHRONOLOGY

During the Pleistocene epoch of the Quaternary period, much of the territory in the northern latitudes of the world was subjected to glaciation. Four separate glaciations were represented during this epoch. Each glaciation was followed by an interglacial climate, warmer than that of today. The four glaciations have been designated, from oldest to youngest, as Nebraskan, Kansan, Illinoian, and Wisconsin.

The Wisconsin glaciation has been further subdivided into stadia. Between these were intrastadia; during their existence the individual ice lobe fronts of each stadium retreated and the climate warmed enough to support a limited flora (Leighton, 1958). The stadia of the Wisconsin have been designated as Farmdale (oldest), Iowan, Tazewell, Cary, Mankato, and Valders (youngest). For an excellent discussion of the evolution of the classification of glaciations and stadia, see Leighton (1958).

The evidence for postulating the former presence of a glacier may be conveniently broken down into two categories: evidence of glacial erosion, and evidence of glacial deposition. The sedimentary deposits are formed from the material that the glacier eroded and transported.

GLACIAL DEPOSITS OF WESTERN NEW YORK

Evidence of glacial erosion in western New York is limited to fragments of local bedrock incorporated in glacial deposits, and to striations on the bedrock (Flint, 1959). As most of the striations have been buried by subsequent glacial deposits, interpretation of glacial activity in western New York must rest almost entirely on depositional evidence.

The two types of deposits of an advancing glacier that are most easily recognized and interpreted are drumlins and terminal moraines, both composed of unsorted and unstratified sediment called till. Till has its origin in the material that a glacier erodes and pushes along in front of (or under) it. A terminal moraine is composed of the till that has been left at the point of maximum extension of the glacier. Drumlins are formed when a glacier overides the till which it has been pushing, and may be used to infer the direction in which the glacier flowed.

The most common depositional features of a receding glacier are kames, kame terraces, eskers, and outwash plains. These are found either in belts called recessional moraines, or in places, as isolated deposits. The deposits formed during the recession of a glacier are composed of water-borne sediment and are termed stratified drift. Here it will suffice to describe kames, eskers, and kame terraces as deposits of coarse, stratified sediment from superglacial, subglacial, and ice marginal streams, respectively. These deposits are formed in contact with the ice margin. An outwash plain is a deposit of finer sediment that has been transported and deposited farther from the margin of the glacier. For a complete description of glacial deposits, see Flint (1945, pp. 102–160).

It becomes obvious that no matter how pronounced a record of drumlins and moraines a glacier may leave, subsequent glaciation will tend to obliterate the traces of the older one. In western New York the terminal moraines of four individual ice sheets lie, preserved, beyond the terminus of the last glacier to cover this area. Even though no remnants of Nebraskan or Kansan glaciation have been recognized in this area, the display of Illinoian and Wisconsin deposits make New York an excellent locality for the study of glacial stratigraphy.

During the glaciation of western New York much of the melt water from the ice was ponded in front of the glacier, due to the relative increase in elevation of the land from north to south. These glacial lakes, formed only in New York and Ohio, led to the building of large moraines, for much of the sediment that poured from the glacier was deposited under water. This also led to the semistratification of even the terminal moraines.

Although this paper is not directly concerned with glacial lakes, the writer would like to note here the excellent work of Dr. Herman L. Fairchild, on the correlation of the succession of glacial lakes in New York State (Fairchild, 1932a).

GLACIAL STRATIGRAPHY

The problems of correlation, and dating off glacial deposits are those common to any terrestrial deposits. Due to the topographic expression of the environment of deposition, the drift may be irregularly distributed and in places missing from the higher elevations. Also the deposits have been subjected to subsequent erosion. Thus, the only methods by which the principal of superposition may be determined are: recognizing non-glacial deposits between drift sheets and studying zones of decomposition, indicative of a soil profile between two tills.

In areas where older drift has been almost completely destroyed by younger glaciation, more indirect methods for correlation must be used. One that has been frequently used is drift lithology, which is determined from the type of rock fragments incorporated in the drift. This procedure however, can only be used to differentiate tills within a limited area, for the provenance of the rock fragments is generally quite close to the site of deposition. The reason is because rock fragments, in contrast to individual grains, are unstable and tend to break down rapidly during transportation. Thus, deposits found in the same locality will have a similar lithology, regardless of their relative ages.

Another method commonly used, for sediments younger than 40,000 years, is radio-carbon dating. The scarcity of fossil wood fragments, the material from which the dates are obtained, limits the usefulness of this method in New York State.

Other methods that have been used involve varve chronology, correlation by means of fossil spores and pollens, examination of the depth to which leaching has occurred in drift sheets, and heavy minerals. All the aforementioned factors are limited in their use because they investigate only one or two aspects, such as glacial flow direction. Therefore they must be used in relation with one another in order to obtain an accurate stratigraphic representation of any given area. Holmes (1952) has determined flow direction by means of drift lithology, MacClintock (1954) determined relative age from the depths to which deposits have been leached, and Ernest Muller (personal communication) is preparing a revised map of the drift of New York State. This paper therefore, adds to the knowledge of glacial stratigraphy in western New York by presenting analyses of the heavy mineral assemblages present in the drift.

HEAVY MINERALS

Heavy mineral assemblages are a useful tool in the study of glacial stratigraphy. As heavy minerals are found in the sand-size fraction of a sediment, they survive long distances of transportation with much less loss than rock fragments (Plumley, 1948, pp. 570–576). Thus their provenance can be used to infer a relatively distant source for the glacial ice that formed a given deposit. Another advantage to studying heavy minerals is that they generally comprise less than 15 percent by weight of the sand fraction of a sediment and therefore representative samples are easy to store and work with in the laboratory.

Dreimanis, Reavely, Cook, Knox, and Moretti (1957) have examined the heavy minerals in tills of Ontario and adjacent areas in Canada. The results of their studies indicate that heavy minerals give excellent evidence of the source of the glaciers depositing these tills, and may be used to differentiate one till sheet from another. With this work, and more recent work of Dreimanis (personal communication), as a basis, the writer has undertaken a heavy mineral study of the glacial drift of western New York State. Before the writer's field work and results are discussed the character and location of the New York State deposits will be reviewed.

PREVIOUS WORK IN WESTERN NEW YORK

Previous work of Fairchild (1932b) and MacClintock and Apfel (1944) has shown that there are five terminal moraines and at least two recessional moraines represented in New York State (see Plate 1). The southernmost terminal moraine is of Illinoian age, while the more northerly ones are Wisconsin. The Olean drift, Binghamton drift, Valley Heads moraine, and Hamburg-Batavia-Victor moraine all are terminal moraines which represent the Tazewell, Lower Cary, Upper Cary, and Mankato (or Valders) stadia, respectively, of the Wisconsin glaciation. The Waterloo-Auburn and Albion-Rochester are recessional moraines, formed during periods of stagnation while the Mankato glacier was retreating from the terminal position.

"The Terminal Moraine" was the first belt of moraine to be recognized in New York State and was described in papers by Upham (1879), Chamberlin (1883), and Lewis (1884). This moraine was actually the terminus of the Olean drift sheet of MacClintock (1944), along with patches of Illinoian till which project out from beneath it. The two drifts were undifferentiated and given the name of "The Terminal Moraine". No interpretation of the moraine was made until Leverett (1895) attempted to correlate the New York State moraines.

The second moraine to be described was the Albion-Rochester moraine. Fairchild (1895) described the Pinnacle Hills, the Rochester segment of this moraine, as a kame-moraine. Later, he (1932b) included all the morainal material from Albion to Sodus Bay in a single moraine for which he proposed the name Albion-Rochester moraine.

The Waterloo-Auburn moraine of Fairchild (1932b) was first described by Fairchild (1896) as an isolated kame-area south of Irondequoit and Sodus Bays. In the same paper, Fairchild also described the kame deposits which in 1932 he incorporated in the Hamburg-Batavia-Victor moraine.

No accurate map, or description of the Valley Heads moraine was available until Fairchild reported it in his paper in 1932. This moraine was recognized before 1932, however its description by Tarr (1905) was too sketchy for positive identification.

Thus in 1932, Fairchild summarized almost forty years of superb work on the glacial moraines of western New York with his paper: "New York Moraines". The Valley Heads, Hamburg-Batavia-Victor, Waterloo-Auburn, and Albion-Rochester moraines were described and named. Fairchild's work has served as a basis for all work north of the Valley Heads moraine.

The complex problem of "The Terminal Moraine" was resolved by MacClintock and Apfel (1944). Working on the Salamanca Re-entrant, they recognized three distinct deposits: the Binghamton drift, the Olean drift, and deposits of Illinoian till. Although Fairchild (1932b) noted a few isolated kame deposits between the Valley Heads and "Terminal" moraine, which he correctly correlated with the kames of the Susquehanna River valley near Binghamton, it was not until the work on the Salamanca Re-entrant in 1944 that the Binghamton drift was recognized as a distinct terminal moraine.

The work of MacClintock and Apfel (1944) is significant because it was the first time that the moraines of western New York had been proposed as terminal deposits for separate glaciations. The theory of multiple glaciations in New York State was first proposed by Fairchild (1913), but until the work of MacClintock and Apfel, the moraines of northern New York were all thought of as being recessional moraines deposited after "the glacier" receded from the location of "the Terminal Moraine". As a result of their studies, MacClintock and Apfel (1944) proposed three hypotheses for the age of the Wisconsin deposits. They favored the third of these, which dates the Olean drift as Tazewell, the Binghamton drift and Valley Heads moraines as early and late Cary, respectively, and the Hamburg-Batavia-Victor moraine as Mankato. MacClintock (1954) later strengthened this hypothesis by testing the depth to which leaching has occurred in the glacial deposits of New York.

A Canadian source for the glacial ice which overrode New York has been inferred from various lines of evidence (see Flint, 1945 pp. 233–235). The belts of terminal moraine found across the northeastern part of the United States separate the unglaciated area to the south from the northern part of North America, all of which shows evidence of glacial erosion.

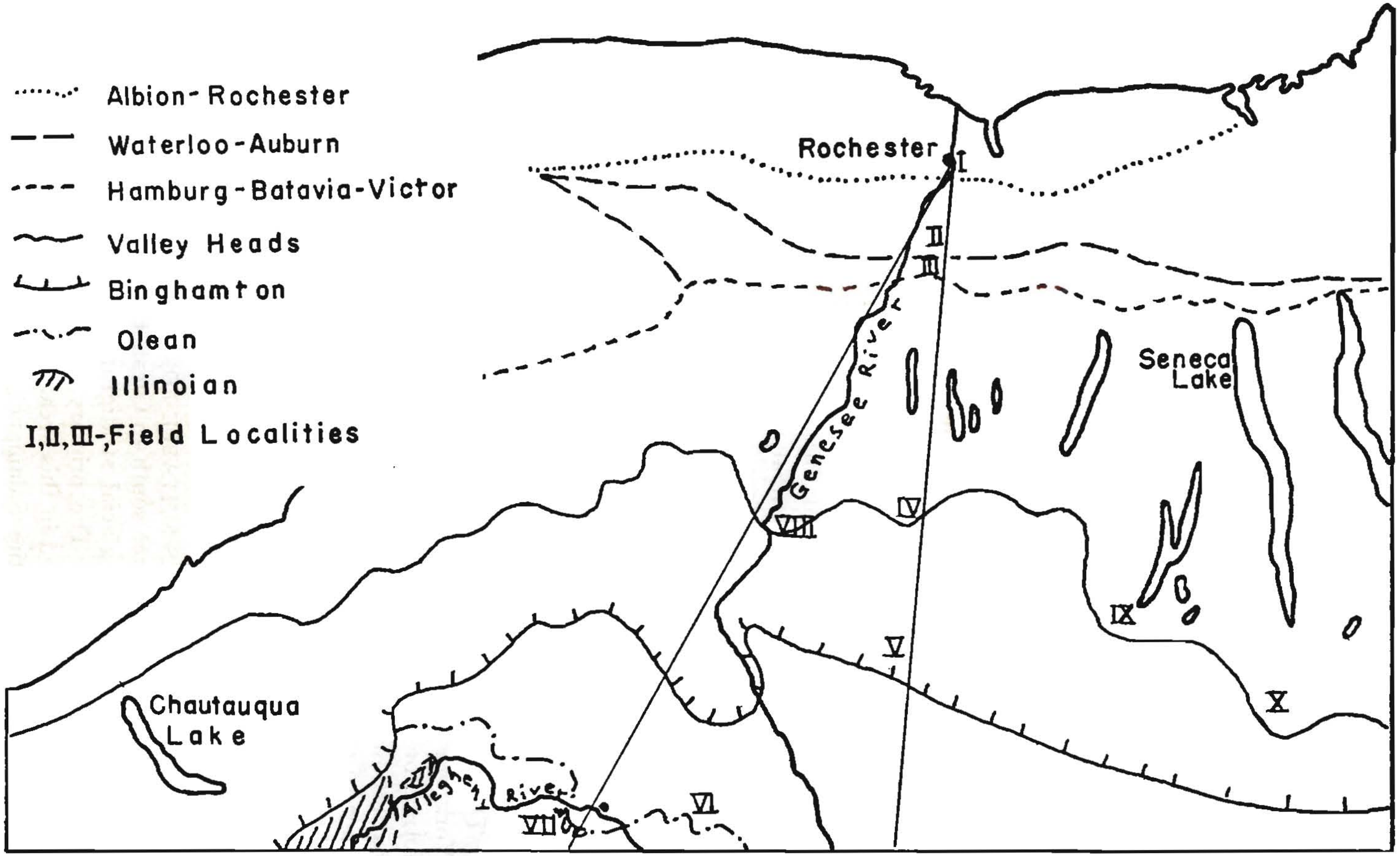
The evidence of glacial erosion in Canada consists of striations on the bedrock and gross topographic forms, both of which indicate a flow direction from north to south. Also, fragments of crystalline rock, the source of which is in Canada, are found in the morainal belts of the United States.

The first major attempt at a provenance study in western New York was made by Holmes (1952). From this study valuable information was gained about the dispersal of glacial debris from the basin now occupied by Lake Ontario. Holmes found that concentrations of characteristic rock types could be used to show that the ice of recent glaciations spread radially outward from the Ontario basin, even though the primary source was north or east of the basin itself. The flow pattern is supported by one of the sets of striations reported by Fairchild (1895).

AREAS SUITABLE FOR STUDY

The area from Rochester south to Olean (see Plate 1), lends itself very well to a study of glacial stratigraphy and heavy mineral stability, for two reasons. The primary reason is that seven distinct moraines may be observed in this area. The other reason is that the glacial stratigraphy of the Salamanca Re-entrant, representing the three southernmost moraines, was thoroughly studied by MacClintock and Apfel (1944).

PLATE 1



Outline Map of Western New York. The map shows the location of the terminus of each of the seven drift sheets and the sample localities (Roman numerals) in each drift sheet. Note the sector, from Rochester to the southern border, in which the initial samples were taken.

The building of distinct moraines, whether terminal or recessional, represents a distinct time interval during which the glacier was stagnant. Therefore seven separate time intervals are represented in the moraines of western New York. The sediments in these moraines, then, represent seven discreet samples from the glacial sediment supplied during the Illinoian and the latter part of the Wisconsin glaciations. By deducing the provenance of the material which comprises these moraines, at the specific times represented, it should be possible to build up a continuous picture of the changes in the centers of glacial outflow during this time interval. It should also be possible to note the effect of any progressive change in the material, due to the length of time it has been exposed to the process of, intrastratal solution. Consequent to the two aforementioned factors, it should be possible to define the moraines in the area chosen for study, and thereby to identify moraines in areas where the stratigraphic sequence is indeterminate from other evidence.

Due to the early reconnaissance of Fairchild (1932b) and to the subsequent work of MacClintock and Apfel (1944) and MacClintock (1954), there is at least a working hypothesis as to the specific stadium to which each moraine belongs. Gross correlation with the deposits of the Midwest and the small amount of radio-carbon work that has been done in New York, facilitate the calculation of the actual time interval that is represented between two various deposits. To carry this one step further, it should be possible to calculate the actual time necessary to cause changes in the heavy minerals of glacial drift.

GLACIAL FLOW DIRECTION

In an effort to take into account any difference between deposits that might be caused by differences in the amount of transportation undergone by each, the samples were taken in a line parallel to the flow direction of the glaciers. In this way the difference in the length of transportation can be taken as the actual map difference for two deposits having a common provenance, if the flow directions are coincident.

Evidence as to the direction of glacial flow during the deposition of the three southernmost moraines has either been destroyed or has gone unnoticed to the date of this writing. However, the flow direction for the Valley Heads moraine was inferred by the work of Holmes (1952). He pointed out that the flow direction is consistent with that indicated by the orientation of the drumlins observed on the southern shore of Lake Ontario, north of the Hamburg-Batavia-Victor moraine. The direction is also consistent with that inferred from the set of striations previously mentioned. Because the work of MacClintock (1954) showed that the three northern moraines are the result of

Mankato glaciation rather than recessional moraines of Cary age, the flow direction as determined by Holmes is valid for at least four of the seven moraines, and represents a constant flow direction for the two youngest stadia.

Holmes felt that the Ontario lake basin was the center of distribution for the Valley Heads and younger glacial lobes. If this is the case, then it is possible that the older glaciers flowed out from this same center. Thus control is established over distance of transportation for at least four of the seven moraines. A second set of striations, different from the first, were reported by Fairchild (1895) and later by Adams (1956, pp. 5–6) and will be discussed below.

As the drumlin orientation south of the northernmost moraine indicates a flow direction between S5°W and S25°W, the samples from the more southerly moraines were taken from the area bounded by these two limits as extended from the Pinnacle Hills, in Rochester (see Plate 1). Upon completion of the laboratory work on the first seven sets of samples, the study was extended to include analyses of lateral variations in a given moraine.

FIELD SAMPLING

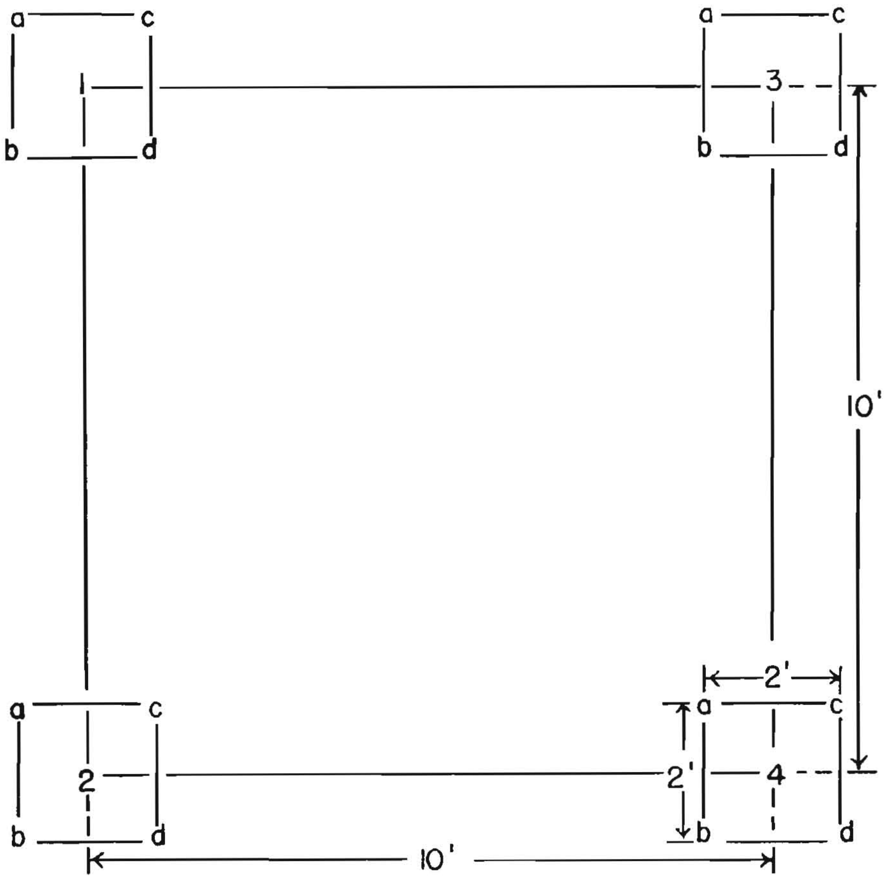
Most of the field work was done during the summer of 1958, with supplementary samples being taken in the spring of 1959. During the summer field work, seven localities were visited and sampled, one in each moraine. Each locality is situated at or near the terminus of each drift sheet. After completion of the laboratory work on the first seven sets of samples, three more samples were taken in the Valley Heads moraine.

One-quart samples of dry sediment were taken from the corners of a vertical grid which was superimposed on the face of each outcrop. Each sample was collected in a cylindrical ice cream container.

SAMPLING METHOD

The sampling method used was that of taking four composite samples from each locality, each composite sample being taken at the corner of a grid which measured 10 feet on a side. Each composite sample represents four spot samples which were subsequently combined. The spot samples were taken from the corners of a smaller two-foot grid. The center of each small grid was a corner of the larger 10-foot grid (see Plate 2). The method was found satisfactory for all the localities except II and VI (see Plate 1). The only available outcrop at locality II was too small in vertical extent to enable the taking of composite samples 2 and 4. The outcrop at locality VI would not yield fresh samples for sample 3 on the grid.

PLATE 2



Grid Pattern. The grid used in field sampling as it would appear in a vertical position. The composite samples are 1, 2, 3, and 4, while the spot samples are a, b, c, and d.

For the lateral check samples the method was altered so that one composite sample was taken by combining four spot samples from the corners of the larger grid.

The purpose of collecting samples for combination into a series of composite samples (Krumbein and Pettijohn, 1938 pp. 13–20) was to get a series of four average samples for each locality. The composite sample presents the advantage of masking any unique variations that might be present in small pockets within a deposit or within single laminae of the cross-stratification common to the moraines of this area. By taking four such composite samples on a grid larger than that of the spot samples, major variations in a single deposit will not be ignored. These major variations will reveal the lack of homogeneity of the deposit.

The purpose of taking samples from the corners of a superimposed grid pattern is to insure the randomness of the samples. Without the grid, the writer would have been strongly tempted to collect only those samples which were most easily attainable, or those which possessed uniform characteristics. This would have created a bias which might have been reflected in the results of the statistical analysis.

The grid, in a vertical position, was traced on the face to be sampled. Thus variations due to lateral changes within a single bed, or to vertical changes due to a relative difference in the time of deposition would be observed over the grid interval.

Due to the instability of some minerals, care was taken to extract the uppermost samples well below the overlaying zone of weathering. Unaltered drift (zone 5 of Leighton and MacClintock, 1930) was easily recognized in all localities except VI. The oxidized zone was characterized by brown iron stains on the pebbles and sand grains, so samples were taken only where stains were absent. The writer was not assured of the freshness of the samples from locality VI until they were subjected to microscopic examination in the laboratory.

Because the samples had to be taken below the zone of weathering and well above the base of the outcrop to avoid contamination from slumped sediment, exposures of drift extensive enough to allow the use of the grid were limited to actively worked gravel pits. Therefore very little material had to be removed from the face of the outcrop in order to insure the freshness of the samples.

A one-quart container was bored into the prepared face with a rotary motion, until it was filled with sediment. Next, the material was removed from around and under the container and the latter was removed, capped, and sealed.

LOCALITIES SAMPLED

The location of the pits to be sampled was determined by noting all the suitable pits situated within the moraines of the area to be studied, and choosing the most recently worked from among these. For the location of the sample localities see Plate I.

The selectivity of the writer, in choosing localities to be sampled, was necessary in order to use a grid for assuring randomness in the actual sample collecting. The writer feels that any bias created by selectivity is negligible.

Locality I is situated 500 yards NW of the intersection of Highland and Clinton avenues in Rochester (latitude 43°08′N, longitude 77°35′30″W) and is either a kame or an esker (Anderson, 1956) in the Albion-Rochester moraine. The outcrop face is 75 feet high with cross-bedded sand at the top and a gravel-bearing sand at the base. The light-tan sand at the top, from which the samples were taken, exhibits small scale cross-bedding (for an illustrated example see Plate 3a). The attitude of the beds could not be observed.

Locality II is situated 7 miles south of Rochester, 700 yards SW of the intersection of Pinnacle and Lyons Roads (latitude 43°N, longitude 77°37′30″W), in the Waterloo-Auburn moraine. The deposit is an esker fan. The outcrop face is 20 feet high and composed of cross-bedded sandy gravel dipping 20°SW (see Plate 3b). Boulders of cross-bedded sandstone and pebbles of graphite-bearing limestone were noted in the deposit.

Locality III is situated east of Five Points on Five Points road, 200 yards east of Works Road (latitude 43°57′30″N, longitude 77°38′W) in the Hamburg-Batavia-Victor moraine. The topographic expression of the deposit is kame-like, however the internal stratification (see Plate 4a) suggests a deltaic origin. The outcrop face is 45 feet high and is composed of coarse sand, gravel, and clay beds dipping 24°SW. Pebbles and boulders of igneous and metamorphic rocks were noted.

Locality IV is situated one mile south of Dansville on the west bank of Stoney Creek (latitude 42°32′30″N, longitude 77°42′30″W) in the Valley Heads moraine. The deposit is a horizontally bedded kame terrace (see Plate 4b). The outcrop face is 40 feet high and composed of interbedded cobbles, and fine tan or gray sand. The sand beds exhibit small scale cross-bedding similar to that noted at locality I. Festooned cross-bedding and intrastratal contortion (Pettijohn, 1957 p. 190) indicative of soft sediment deformation are present in the upper beds (see Plate 5a). Because the contortions tend to flatten out toward the top and base of the bed, the structure is interpreted as intrastratal flowage. This could be a type of ice-contact structure (Flint, 1945 pp. 143–147) caused by readjustment of the sediment to a change in slope due to the retreat of the ice from direct contact with the deposit.

Locality V is situated at the north end of the town of Almond (latitude 42°19′30″N, longitude 77°44′W) in an isolated group of kames (see Plate 5b) belonging to the Binghamton drift sheet. The deposit consists of beds of gravel, fine and coarse sand which dip 10°S, and are exposed on an outcrop 160 feet high. Small-scale cross-bedding was noted in the fine sand.

Locality VI is situated one mile SW of Little Genesee on the west bank of Little Genesee Creek (latitude 42°19′30″N, longitude 77°44′W) in a terminal deposit of the Olean drift. The outcrop face is 40 feet high and exhibits a rough stratification which dips 32°W. Each "bed" however, exhibits a till structure (see Plate 6a). Although boulders and cobbles are predominant, no crystalline rocks were noted, most of the rocks being gray shales of a local character.

Locality VII is situated south of Salamanca, at the Bird Creek gravel pit (latitude 42°05′N, longitude 78°32′30″W) in a kame terrace composed of Illinoian drift. The outcrop face is 80 feet high and exhibits the foreset bedding of MacClintock and Apfel (1944) as well as small scale cross-bedding. The beds are horizontal and are composed of tan-colored sand, gravel, and light-brown silt or clay. Many small-scale faults (see Plate 6b) are also present and are interpreted as ice-contact structure. This deposit was originally described by MacClintock and Apfel (1944) as a kame of Tazewell age, however E. H. Muller (personal communication) and this writer, believe this may be an Illinoian kame terrace. An Illinoian age is proposed because igneous rock fragments are present here; they are rare in Tazewell drift, and the deposit is situated at a higher altitude than that at which Tazewell is known to occur.

Localities VIII, IX, X are situated in kames, or kame terraces, in the Valley Heads moraine. Locality VIII is one mile SE of Portageville and one mile east of the Genesee River. Locality IX is at the north end of the town of Hammondsport. Locality X is two miles SW of Ithaca on Route 13.

LABORATORY PROCEDURES

Preparation of the samples entailed drying, combining the spot samples into composite samples, sieving the composite samples to obtain the desired sand size, and splitting the sand fraction into samples of about 10 grams. During each step (see Plate 7) in the preparation of the sample, a portion equal to that portion used was stored for future examination or for reruns in case of experimental error. In each case, the portion to be used was determined by a toss of a coin.

PREPARATION OF SAMPLES

The four spot samples (a, b, c, and d in Plate 2) were unsealed, dried, and halved using a Jones Sample Splitter (Krumbein and Pettijohn, 1938, p. 45). One fraction of each spot sample was used for the composite sample. The two-quart composite sample was then thoroughly mixed and quartered, one quarter being used for sieving.

From preliminary laboratory analyses, the writer found that 80 percent of all the heavy minerals in the sand (Wentworth-Udden grade scale) of the Pinnacle Hills kames occur in the sizes between .062 mm. and .350 mm. These size limits were used because the grains could easily be identified by microscopic examination. Also, transportation of similar sediment (*e.g.*, to the position of the more southerly moraines) could only reduce constituent grain size (see "Provenance", below). Therefore at least 80 percent of the heavy minerals in the sand fraction of the more southerly moraines, which represent the same provenance that the Pinnacle Hills sand represents, should also be studied.

The desired sand fraction was obtained by sieving each sample for 10 minutes in a Ro-Tap automatic shaking machine (Krumbein and Pettijohn, 1938, pp. 137–141).

The sand obtained after sieving was then split with a microsplit until a fraction weighing between 6.5 and 13 grams was obtained. A sample of 6.5 grams yielded a sufficient quantity of heavy minerals for study, so samples over 13 grams were split into finer fractions. Next the sample was weighed on an analytical balance, accurate to one milligram, and stored in a stoppered bottle, ready for separation.

HEAVY MINERAL SEPARATION

The heavy fraction of the sand was separated using purified bromoform ($CHBr_3$) having a specific gravity of 2.87 at 20°C. The separation was carried out by the standard method for heavy liquids outlined in Krumbein and Pettijohn (1938, pp. 335 and 343).

A funnel, stoppered at the bottom with a length of rubber tubing and a stop-cock, was filled to within a centimeter of the top with bromoform. The prepared sand was poured onto the surface of the liquid and gently agitated until all the heavy minerals collected at the bottom of the funnel. When the separation was complete the stop-cock was opened long enough to allow only that portion of the liquid seen to contain the heavy minerals to pass through. The heavy mineral grains dropped onto a conical filter paper, and the bromoform was allowed to drain off. The grains were then washed with ethyl alcohol (C_2H_5OH) and allowed to dry.

The dry mineral grains were transferred to a 50 ml beaker and weighed on an analytical balance. From these figures as compared with the weight of the unseparated fraction, the percent by weight of the heavy minerals present in the sample was calculated (see Table 1).

SEPARATION OF MAGNETICS

The magnetic grains in the heavy fraction were removed for two reasons. The primary reason was to concentrate the non-opaque minerals for optical study. More than 99 percent of the heavy minerals that were attracted to the magnet were opaque, so this separation eliminated many of the opaques, which were treated as an undifferentiated group. The secondary reason is that the percent by weight of the magnetic grains could easily be determined in this manner.

The heavy minerals were spread evenly on a flat filter paper, adjacent to a clean filter paper. A small hand magnet, covered with a clean filter paper, was passed over the heavy mineral grains and then over the adjacent filter paper. The magnet was removed from behind the covering paper and the magnetic grains were allowed to fall to the clean filter paper. This process was repeated until all the magnetic grains had been removed. The magnetic fraction was then weighed on an analytical balance and stored for future reference. From these figures the percent by weight of the magnetic grains present in the heavy minerals was calculated (see Table 1).

IDENTIFICATION

The heavy minerals, minus the magnetic fraction were quartered and three of the quarters were examined, the fourth being stored. The sample was quartered by spreading the grains evenly on the center of four overlapping pieces of cardboard. When the pieces were separated three of the quarters were chosen for examination by tossing a coin.

The remaining three quarters were mounted individually on separate petrographic slides using Canada Balsam (n=1.54) cooked on a small hot plate.

The minerals were identified with a petrographic microscope using crystal form, cleavage, fracture, color, pleochroism, extinction, elongation, interference figure, optical sign, and 2V as definitive characteristics. Positive identification was made by comparing the observed properties with descriptions of minerals given by Krumbein and Pettijohn (1938), Rogers and Kerr (1942), and with the chart from the report of the Committee on Sedimentation, National Research Council (1942).

The minerals identified were:

Common	**Less common**	**Trace**
Garnet	Chlorite	Zircon
Hornblende	Apatite	Sillimanite
Hypersthene	Tremolite	Titanite
Monoclinic pyroxenes		Tourmaline
Opaques		Rutile
		Epidote
		Monazite

Garnet is present as grains which exhibit conchoidal fracture and very little rounding. Red, orange, pink, purple and colorless varieties are all present. The garnets are divided into two categories for the purpose of indicating provenance. The red, orange and pink varieties exhibit a distinct color and were counted as red garnet, while the colorless and purple garnets appear to grade into one another and were counted as purple garnet. The garnet was distinguished by its color and isotropism.

Hornblende is present as prismatic grains with rounded ends and an extinction angle less than 20°, or in some instances as irregular grains. The grains vary from those that are translucent to those that are opaque in the center and translucent only on the edges. All the grains exhibit pleochroism, with most of the grains being light green to dark green or light brown to dark green-brown. A few grains were noted that possessed yellow-green to blue-green pleochroism.

Hypersthene, and enstatite, are members of the isomorphous series of orthorhombic pyroxenes. This series is present as stubby prismatic grains predominantly pleochroic from light green to pink or red (hypersthene) or in a few instances colorless (enstatite). Some of the grains of hypersthene possess inclusions of brown plates in parallel alignment (schiller structure) which distinguish the variety; bronzite. The series was counted under the heading of hypersthene and was recognized by the pleochroism and by parallel extinction.

Monoclinic Pyroxenes, including augite and diopside, are included in one group and are present as worn elongate cleavage fragments. The grains are light green in color and have an extinction angle of about 55° with respect to elongation. Some of the grains have a fine ruling structure (herringbone structure) at an angle with elongation. The grains were distinguished by their extinction angle and lack of pleochroism.

Opaque Minerals were counted as a group and were identified individually only for localities VI and VII. In these two localities the difference between red grains of hemetite and yellow-brown grains of limonite was noted.

Chlorite is present as light green or green basal plates which yield an off-center optic axis figure. The grains were distinguished by their low birefringence and incomplete extinction.

Apatite is present as worn prismatic grains or as nearly circular grains with a pitted surface. The grains were distinguished by their white color and their extremely low birefringence.

Tremolite, and actinolite, are end members of an isomorphous series and were counted as a group under the heading tremolite. Tremolite is present as colorless or very light green prismatic grains exhibiting an extinction angle less than 20°.

Trace Minerals: Zircon is present as colorless, unzoned euhedral prisms and sillimanite as irregular or prismatic, fibrous grains. Titanite (yellow-brown), tourmaline (pleochroic from light brown to dark brown), rutile (deep red), epidote (lemon-yellow) and monazite (white) are present as well rounded grains.

MINERAL FREQUENCY

Between 400 and 1700 grains were counted for each sample. The frequency with which each of the above described categories was present was recorded and converted to a percentage. The percentages are recorded in Table 2; note that for all trace minerals present in quantities less than 0.5 percent, the figure 0.1 percent has been entered.

The counting was done with the aid of a petrographic microscope and a square grid pattern superimposed on the face of the slides. It was sufficient to count the grains in every third square of the grid. The particular pattern of squares to be counted was determined by drawing numbers for each slide. The grains on all three slides were counted for each locality and the combined figures were used for each sample.

STATISTICAL INFERENCE

The broad field of statistics can be divided into two areas, descriptive statistics and statistical inference. The field of descriptive statistics comprises the collecting and calculating of data which defines or describes a population sample. Statistical inference is the field in which descriptive statistics are used to deduce information about a population.

The result obtained by the use of statistical inference is dependent on the randomness of the sample used. A random sample is one that is taken from a population in such a way that every individual (observation) in the population has an equal chance of being represented. From such random samples, descriptive statistics, such as sample mean, sample variance, etc., may be computed. By statistical inference the descriptive statistics, which define a random sample taken from a population, may be used to approximate, within limits, the parameters which define the entire population.

For each statistic which defines a population sample there is a corresponding parameter which defines the population. A statistic, *e.g.* sample mean, is not necessarily equal to its corresponding parameter (population mean). One of the methods, however, that may be used to approximate, within limits, the population parameter is the calculation of a confidence interval.

CONFIDENCE INTERVAL

The method used in this study is the calculation of a 90 percent confidence interval about the sample mean. This interval is calculated from the sample mean and an unbiased estimate of population variance. The confidence coefficient 90 percent, indicates the degree of belief that the interval contains the population mean. In other words there is a 90 percent probability that the population mean lies within the interval.

The confidence interval presents the advantage of being easily represented graphically by a bar chart. The confidence interval is plotted vertically, on the ordinate, with the sample mean as its center. The sample localities are plotted on the abscissa. If a real difference exists between two population means, the respective bars will not overlap. If the difference is only apparent, the respective bars will overlap.

FORMULAS

First the sample mean "$\bar{y}$", must be computed from the formula

$$\bar{y} = \Sigma y / n \tag{1}$$

where "Σy" is the sum of all the sample observations, and "n," is the number of sample observations.

Next an unbiased estimate of population variance "s^2", is computed from the formula

$$s^2 = \Sigma (y - \bar{y})^2 / v \tag{2}$$

where "v," is the degrees of freedom (Li, 1957, p. 66),

$$v = n - 1 \tag{3}$$

From the sample mean (1) and the unbiased estimate of population variance (2) the limits for the 90 percent confidence interval about the sample mean may be computed. This computation is based on the inequality

$$-t_{.05} < (\bar{y} - \mu) / \sqrt{s^2/n} < t_{.05} \tag{4}$$

where "$-t_{.05}$", and "$t_{.05}$", are statistics that may be obtained from a table for Student–t distribution (Li, 1957, p. 87 & 520) for a given "v," (3), and "μ" is the population mean. The .05 probability level for "t", is used to obtain a 90 percent confidence interval.

By manipulation, formula (4) becomes

$$\bar{y} - t_{.05}\sqrt{s^2/n} < \mu < \bar{y} + t_{.05}\sqrt{s^2/n} \tag{5}$$

from which the 90 percent confidence interval for the population mean "μ", may be computed by substituting the actual value for "t."

Results for the analyses of the percent of heavy minerals in the samples, and the percent of magnetic grains in the heavy fraction, are given in Table 3. The graphic representation of these results is given in the chart of Table 4, where the arrows indicate the sample means.

PROVENANCE FACTORS

In a study of the provenance of heavy minerals, it must be possible to differentiate between those minerals which have been derived from the primary source of the sediment and those which have been added while the sediment was in transit. When dilution of the assemblages occurs, the provenance may be masked by the minerals that have diluted the primary assemblage.

DILUTION

As noted previously, much of the glacial ice that covered New York State had its origin in Canada. Thus the metamorphic bedrock of Canada will be reflected in heavy mineral assemblages having this area as their provenance. The assemblages will consist mainly of garnet, amphiboles, and pyroxenes (Dreimanis, *et al.,* 1957). The area between the Canadian metamorphic provinces and the sites of deposition of the four northern moraines of western New York is underlain by a sequence of fine-grained Paleozoic sedimentary rocks. With the exception of the Silurian Grimsby sandstone, these rocks could contribute only negligible quantities of sand-size mineral grains by which glacial sediments could be diluted.

Hoyt (1943) reported that the dominant non-opaque heavy minerals in the Grimsby were tourmaline and zircon. As these minerals comprise less than one percent (see Table 2) of the assemblages found in the glacial sediments of western New York, dilution of the major constituents is taken to be negligible.

The southern part of western New York is also underlain by fine-grained Paleozoic siltstones and shales. With one exception, these rocks are also unable to contribute significant quantities of sand-size mineral grains. The heavy fraction of the samples from the Binghamton drift (V), Olean drift (VI), and Illinoian till (VII) are progressively diluted by opaque minerals. An examination of the opaque minerals from these samples shows that the assemblages are diluted by fine-grained aggregates of hematite and limonite. The source for these fine-grained rock fragments must be the siltstones of southern New York.

If the heavy fraction is being diluted by these rocks, the light fraction must also be affected. As illustrated by the data in Table 1, the percentages for heavy minerals in the southern moraines are less than the percentages for the northern moraines. A cursory examination of the light fraction, under a binocular microscope, reveals that the light minerals of the southern moraines are also diluted. The light fraction is diluted by fine-grained fragments of siltstone and shale. This dilution is as great as 50 percent in the Binghamton drift and Illinoian till, and almost 100 percent in the Olean drift.

TRANSPORTATION DISTANCE

To be sure that the decrease in the percent of heavy minerals in the southern moraines is due to dilution and not to differential transportation, the writer examined the rounding of the grains in the light fraction. The degree of rounding is similar for all seven moraines, implying the absence of preferential transportation.

The sorting of the sediments was also examined in a super-composite sample, made from the composite samples for each locality. These samples were sieved on a Ro-Tap automatic shaking machine. The sieves were nested according to half-sizes of the Wentworth grade scale. The percent by weight of sediment present in each half-size class of the sand fraction was recorded (Krumbein and Pettijohn, 1938, pp. 138–142) and a cumulative frequency curve was constructed for each locality. From these curves a geometric sorting coefficient (So; of Krumbein and Pettijohn, 1938, pp. 232–236) was computed for each locality. These sorting coefficients are:

Locality	So
I	2.54
II	4.05
III	3.07
IV	2.58
V	3.65
VI	9.64
VII	2.60

Localities I–V and VII show essentially no difference in their degree of sorting, while locality VI shows much less sorting than the others. Therefore, with the exception of locality VI, transportation distance appears to have caused little, if any, difference between sediments of different deposits.

GARNET RATIOS

Dreimanis, *et. al.*, (1957) found that the tills of western Ontario could be differentiated by heavy mineral content. The ratio of purple garnet to red garnet was employed to differentiate these tills. In studying the tills immediately adjacent to the metasediments of the Grenville province, northeast of Lake Ontario, the garnet ratio was found to be greater than 1.0. In studying the tills adjacent to the meta-igneous rocks of the Canadian shield area north-to-northwest of Lake Ontario, the garnet ratio was found to be less than 0.5. When this study was extended to other tills, the garnet ratios were consistent with the known source.

In 1958, Dreimanis (personal communication) found that the tills from a source south of (or in) the Adirondack mountains had a garnet ratio less than 1.2. Dreimanis also analyzed a sample of sediment from the

Olean drift and found that the garnet ratio was 1.0. On the basis of this analysis, and an analysis of the calcite and dolomite content of the sample, Dreimanis concluded that the provenance of the Olean drift is south of the Adirondacks.

With this previous work as a basis, the writer determined the provenance for the samples taken in New York State. The mean garnet ratios (purple/red) are listed below.

Locality	Purple/red
I	1.92
II	1.96
III	1.66
IV	1.58
V	2.02
VI	.30
VII	2.41

From these ratios the writer concludes that samples I–V and VII have a provenance in the Grenville meta-sediments, northeast of Lake Ontario. The ratio for sample VI, the Olean drift, illustrates a provenance either in the Canadian shield or south of the Adirondack mountains. If the provenance of this deposit is north of Lake Ontario, then the sediment can be expected to exhibit the same degree of sorting and dilution as the other deposits. However, the poor sorting evidenced in the Olean drift suggests a closer provenance than that of the other deposits. Also, the greater dilution noted in the light fraction of sample VI suggests that the Tazewell glacier traversed the sedimentary rock of southern New York for a greater distance than the other glaciers.

The evidence, although incomplete, suggests a provenance south of the Adirondacks for the heavy minerals of the Olean drift.

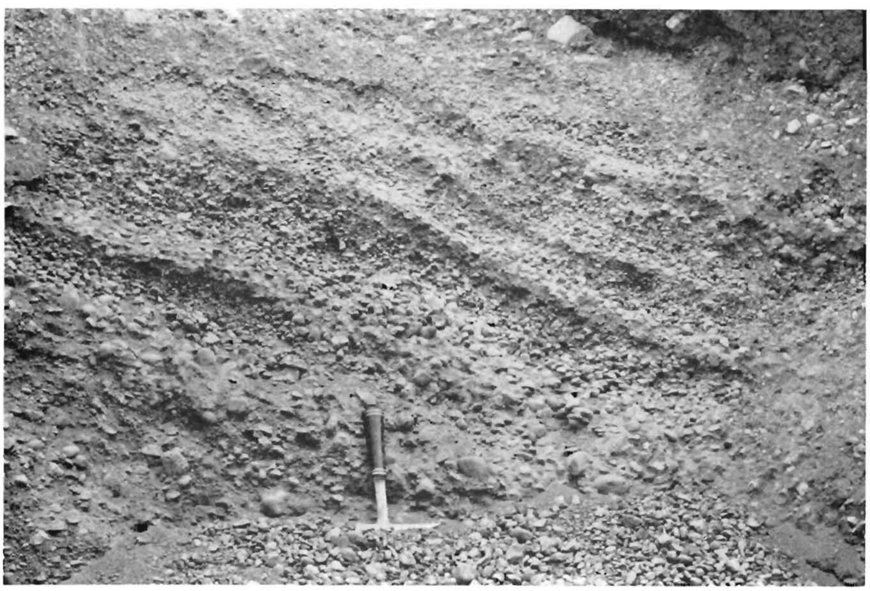
If the source of the ice which deposited the Olean drift is in the Adirondacks then the flow direction indicated by the second set of striations reported by Fairchild (1895) are explained. These striations trend N120°W and may be erosional evidence of the Tazewell glaciation.

INCORPORATION OF OLDER DEPOSITS

In order to determine the validity of the above conclusions, the possibility of incorporation of older deposits in the deposits of younger glaciers must be examined. This possibility can not be discounted altogether; however, the writer feels that the effect is minimal in this study.

Incorporation of older deposits takes place beneath the glacier so that till deposited under a glacier may be expected to show this to some degree. However, the samples in this study were taken from stratified material which had its origin (except locality II) in superglacial streams, thus

a: *Small Scale Cross-Stratification.* A bed, 14 inches thick, in a kame at locality V, which exhibits small scale cross-stratification.



b: *Large Scale Cross-Stratification.* Cross-stratification on a large scale in the esker fan at locality II.

PLATE 4

a: *Deltaic Bedding.* A northwest view of the internal stratification seen at locality III. Note the tractor tire in left foreground for scale.

b: *Horizontally Bedded Kame Terrace.* A north view of the kame terrace at locality IV. Contortion is seen in the upper beds.

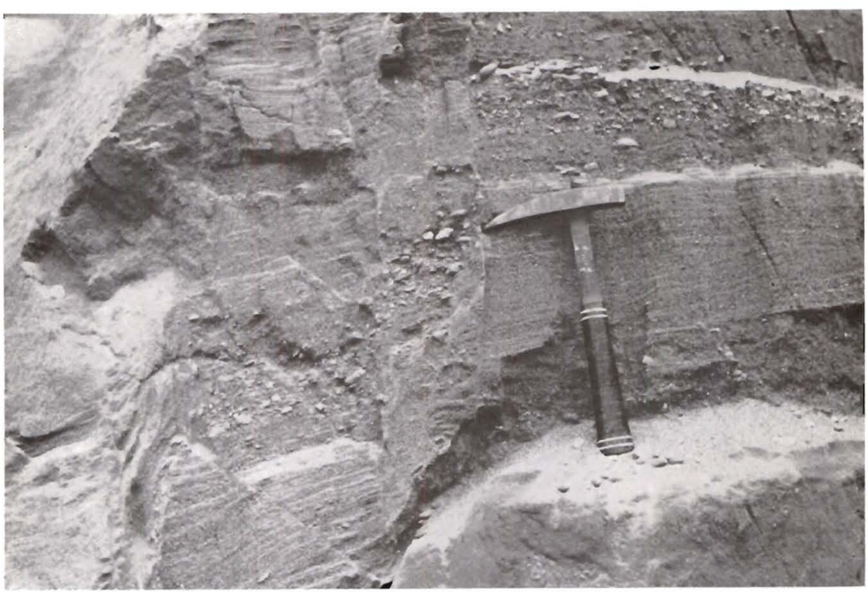
PLATE 5

a: *Intrastratal Contortion.* A section, three feet thick, of the contorted bedding at locality IV. Note the flattening of the contortion toward the base of the bed.

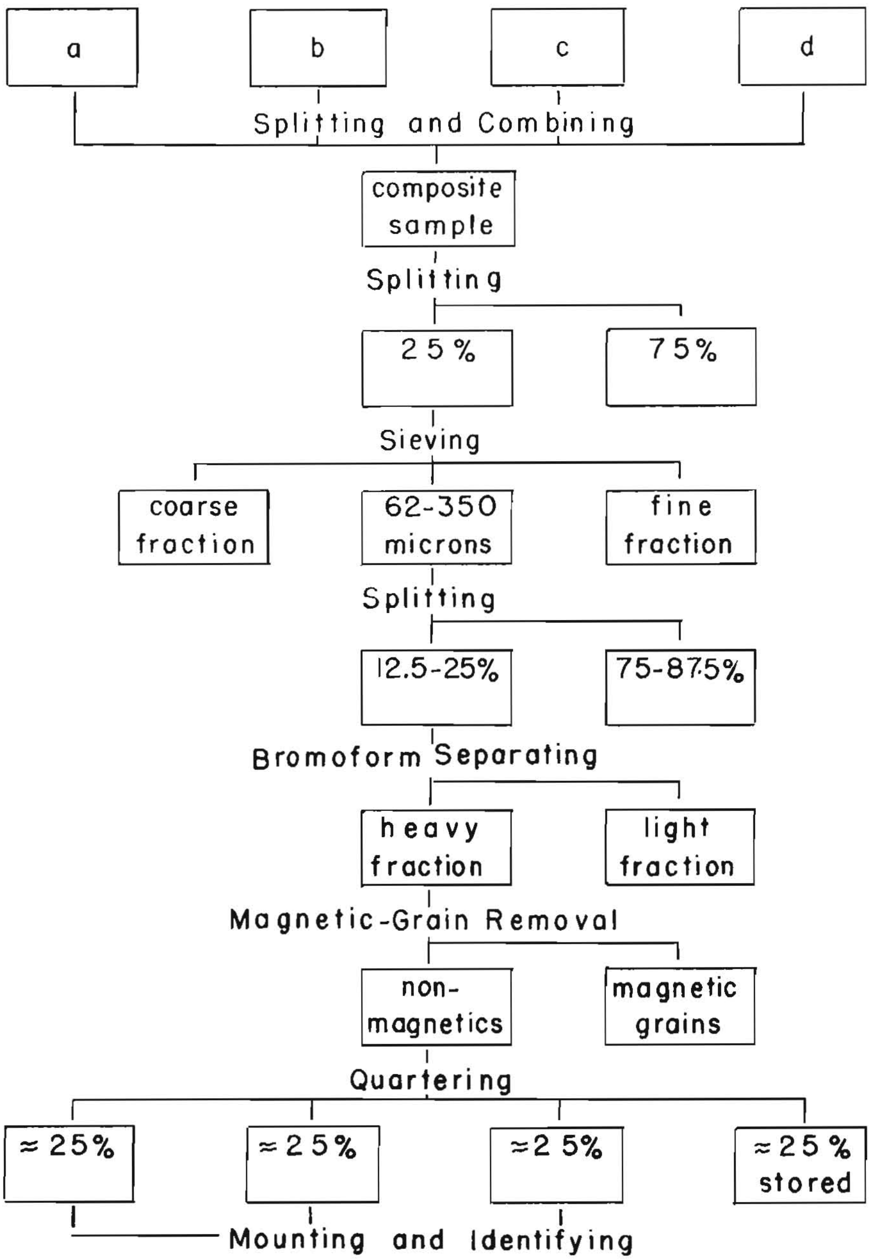
b: *Kame Topography.* A southerly view of the gently rolling kame topography at locality V.

PLATE 6

a: *Till Structure.* A west view of the rough stratification in the till-like beds at locality VI. The face is about 30 feet high. Note the flat shale boulders that are present in the deposit.

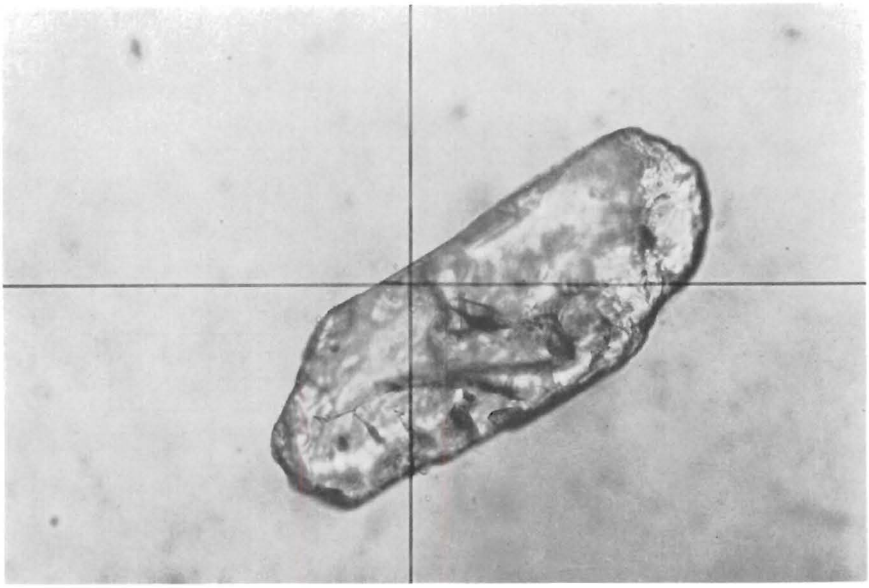


b: *Ice-Contact Structure.* Faulted beds of sand in the horizontally bedded kame terrace at Locality VII.

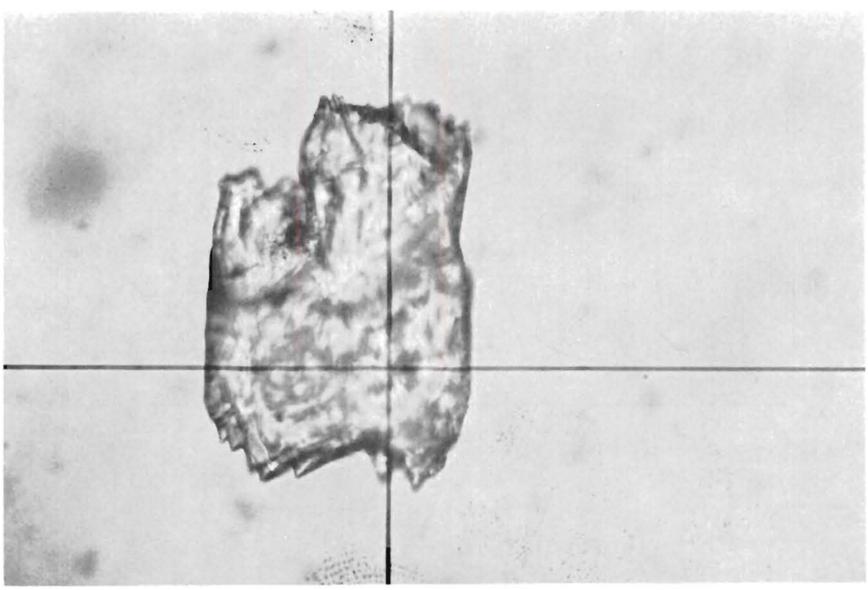


Flow Sheet for laboratory work on the dried samples.

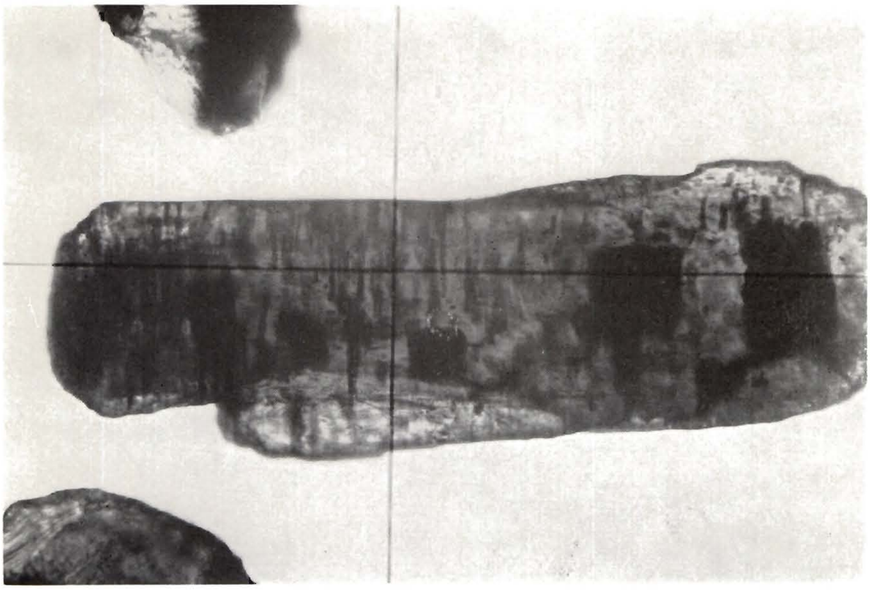
PLATE 8



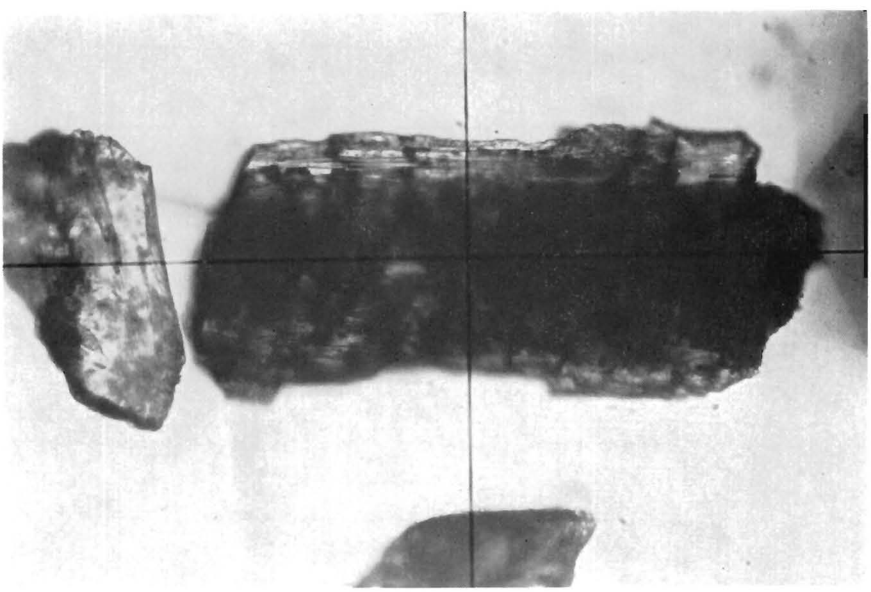
a: *Monoclinic Pyroxene* (1000 X) from the Albion-Rochester moraine. Note the well-rounded ends and the fresh appearance.



b: *Monoclinic Pyroxene* (1000 X) from the Binghamton drift. Note the dentate ends which are attributed to intrastratal solution.

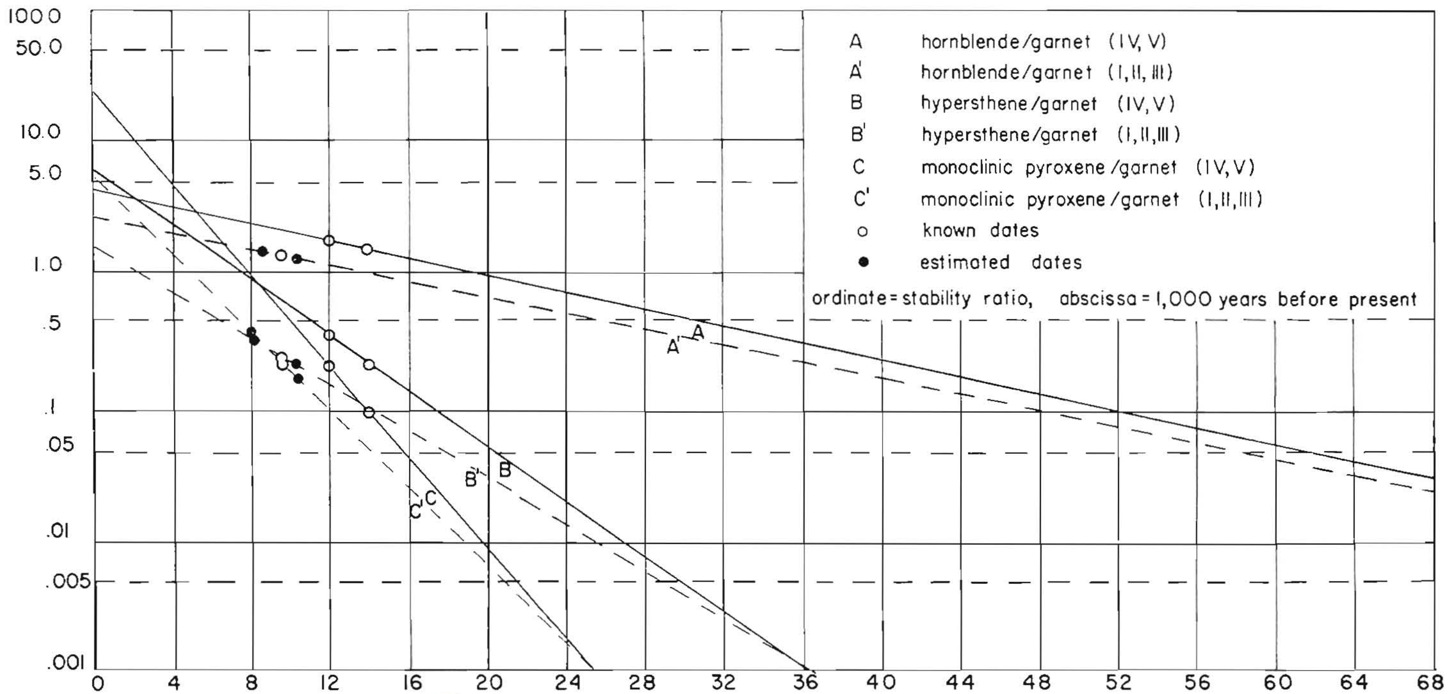


a: *Hypersthene, variety bronzite* (1000 X) from the Waterloo-Auburn moraine. Note the fresh appearance of the parallel inclusions.



b: *Hypersthene, variety bronzite* (1000 X), partially altered, from the Binghamton drift. Note the clouding in the center of the grain which obscures many of the inclusions.

PLATE 10



Stability Curves for hornblende, hypersthene, and monoclinic pyroxene plotted on a semi-logarithmic graph.

minimizing any such contamination. This reasoning is supported by the garnet ratios of the various deposits. If Olean drift (VI) was incorporated in Binghamton drift (V), then dilution of the dominantly purple garnet in the Binghamton, by the dominantly red garnet in the Olean, would lower the garnet ratio in the Binghamton drift. The garnet ratio in the Binghamton drift however, is the second highest (2.02) among all the deposits.

STABILITY

As stated above, there is a noted decrease in stability of certain heavy minerals with respect to the age of the deposit in which they are found. If a stability relationship is present in the glacial deposits of western New York, it is due only to the increasing age of the various deposits.

APPARENT STABILITY

To examine assemblages for a possible stability relationship, it is necessary to study sediments of differing ages, that have been similarly affected by transportation, and have a common provenance.

It has been shown that transportation had little differential effect on the sediment examined in this study. Because the garnet ratios show a common provenance the stability relationships for the heavy minerals in the sediments of localities I–V and VII can be determined. Locality VI represents a different provenance and is not included in this analysis.

The percentages of the more common heavy minerals in Table 2 reveal a decrease (in percent) of the less stable minerals. Hornblende, hypersthene, and monoclinic pyroxene are examples. Moreover, these data reveal that various minerals decrease at different rates.

A change in form is displayed by hypersthene and monoclinic pyroxene. In the younger deposits monoclinic pyroxene (Plate 8) appears as rounded prismatic grains with smooth ends. In the older deposits however, monoclinic pyroxene occurs as stubby prisms with dentate ends. The dentate ends are attributed to intrastratal solution by Ross, Miser, and Stephenson (1929). The change in hypersthene is less striking but occurs chiefly in the variety, bronzite (Plate 9). In the older deposits the parallel inclusions in bronzite grains have been altered until they are almost obscured by clouding in the central portion of the grains.

STABILITY RATIOS

Although the decrease in percentages of the less stable minerals is evident, there is also a decrease in the percentage of more stable garnet. Due to the dilution of the heavy mineral assemblages by opaque minerals, the absolute frequency of the minerals is of little value.

To eliminate the effect of dilution, stability ratios are computed for the major constituents. These ratios are computed by dividing the amount of hornblende, hypersthene, and monoclinic pyroxene by the total amount of garnet (red and purple) in each sample. The mean ratio for each locality and their 90-percent confidence intervals are recorded in Table 5.

Garnet is used because it is the most stable mineral present in the assemblages studied; however, a progressive decrease in the ratios represents instability in relation to garnet only. There is no apparent change in the garnet in the older deposits. However if garnet is unstable in the time interval studied, the ratios underestimate a decrease in persistence rather than accentuate it. In the charts for the stability ratios (Table 6), two trends are noted. The break between the two trends is interpreted as the slight shift in the center of glacial outflow proposed by Dreimanis and Terasmae (1958) during the latter part of the Wisconsin glaciation.

In examining the trend illustrated by samples IV and V (Table 6) a real difference in the ratios is noted for hypersthene and monoclinic pyroxene. A trend for the hornblende ratios is only suggested, as the confidence intervals overlap by a considerable margin. However the fact that the hornblende ratios follow the same trend as the other ratios suggests that a real difference exists between hornblende ratios also. The same reasoning can be applied to the trend illustrated by the younger samples (I, II, and III) as this trend is the same as for samples IV and V. It is not possible to tell which trend is followed by sample VII.

It seems clear from the stability ratios that there is a definite stability relationship evidenced between localities of differing ages.

USE OF STABILITY RATIOS

Fortunately radiocarbon dates for the Valley Heads moraine and the Binghamton drift have been determined. These dates are approximately 12,000 (Geological Research in New York State, 1957) and 14,000 (Rubin and Alexander, 1957) years, respectively. By plotting the relationship between the stability ratios for these deposits it is possible to extrapolate back to that point in time at which the less stable minerals should disappear from similar sediments.

Only two points are available so that the type of relationship which exists between the ratios is not apparent. As a linear relationship shows the ratios approaching zero at a very rapid rate, the writer proposes an exponential decay relationship between the ratios.

The three sets of ratios are plotted against age on semi-logarithmic graph paper (Plate 10) and extrapolated back to .001. As an average of only 800 grains were counted for each sample, one grain in 1,000 grains would be essentially zero. From the curves for these three ratios, the ages at which hornblende, hypersthene, and monoclinic pyroxene should be completely removed from similar sediments are 25,000 years, 36,500 years, and 120,000 years respectively. If the composition of the monoclinic pyroxenes is taken to be that of diopside, the order of decreasing stability (garnet, hornblende, hypersthene, monoclinic pyroxene) corresponds to that observed by Pettijohn (1941) in the geologic column as a whole.

By extrapolating the curves forward to the present, the ratios of the minerals can be observed before mineral decay started. Thus the ratios for the assemblages in the provenance for the heavy minerals can be approximated. These ratios are:

Hornblende/garnet	4:1
Hypersthene/garnet	6:1
Monoclinic pyroxene/garnet	28:1

Stability ratios may also be used to date a sequence of deposits where only one date is known. Flint (1956) reported a radiocarbon date of approximately 9,600 years for Lake Warren, in New York State. Fairchild (1932b) showed that the Waterloo-Auburn moraine was deposited in the water of Lake Warren. Thus the date of 9,600 years may be used to approximate the deposition of the Waterloo-Auburn moraine (locality II). The dates for the other two moraines (I and III) are unknown, but can be determined from the stability curves (Plate 10).

By using the zero points determined above for the three ratios, and the date for locality II, the curves may be extrapolated forward to the ratio for locality I. By interpolating the date for locality III both unknown dates are obtained. These dates are:

	Locality I	Locality III
Hornblende/garnet	8,500 years	10,000 years
Hypersthene/garnet	8,200 years	10,000 years
Monoclinic pyroxene/garnet	8,000 years	10,300 years

It is realized that these dates are a little younger than may seem reasonable, however this may be attributed to the uncertain position for the 9,600-year date. Nevertheless, the range of dates for the last pre-Iroquois deposit (I) and for the Valders maximum (III) does not exclude these as valid dates. The consistency of the dates from the three sets of ratios lends considerable support to the proposal that a real stability trend exists between the assemblages of the deposits.

It is obvious that the curves decrease far faster than the relationships indicated by Pettijohn (1941). However, glacial deposits are unique in the geologic record and should not be expected to follow the trends exhibited by other sedimentary deposits. It is clear from the above data that heavy minerals do decrease in persistence, with age as the only variable operative. This is probably due to the fact that older deposits have been subject to physical attack by such forces as ground-water solution, for longer periods of time.

As previously mentioned, glacial deposits are subject to erosion from the time of their deposition. Therefore it may be that the decay rate for unstable minerals in glacial deposits (particularly stratified drift) represents a maximum value. Thus the decay rates observed in other sedimentary deposits are lower due to prohibition by such factors as depth of burial, rather than accentuation by them.

It is not possible to accurately determine what processes actually cause the decay of unstable heavy minerals. However, it is clear that the amount of time that the processes are allowed to operate is reflected in the stability ratios. It also seems probable that the rate at which decay occurs is related to the depositional environment of the sedimentary deposit and the conditions under which it was preserved. The writer realizes that the construction of stability curves based on only two points, relatively close together, can not be expected to yield accurate values. However, the agreement of the values obtained from these curves indicates that a stability relationship can be demonstrated from these curves whether or not true values have been obtained.

DIFFERENTIATION OF DRIFTS

It is evident that the Olean drift (VI) can be differentiated from the other glacial deposits by any one of the methods used in this study. The Olean drift differs from the other deposits in sorting, composition of the light fraction, and garnet ratio. It is also evident that there is a real difference between the Binghamton drift (V), the Valley Heads moraine (IV), and the other deposits. These two moraines may be differentiated on the basis of the stability ratios for hypersthene and monoclinic pyroxene.

It is also probable that the Illinoian drift can be differentiated from all the other deposits using stability ratios, even though these ratios do not fit into either of the two patterns established in this study.

The overlapping confidence intervals (Tables 2 and 4) for the three youngest moraines make it doubtful that they could be differentiated by the methods outlined in this study. However, it may well be that a larger number of samples will reduce the confidence intervals for these moraines. It appears that these moraines differ, but the degree of difference is only crudely established here.

The above discussion does not hold true for all of western New York, as more than one source may have supplied sediment to different parts of a single moraine. To examine the possible variation within a single moraine, lateral samples were taken from the Valley Heads moraine. As the Upper Cary ice moved through each of the north-south valleys in western

New York, and was essentially isolated within each valley, differences between assemblages, if they are present, should be manifested in this moraine. The values obtained for the lateral samples are listed in Table 7.

The values all fall within the confidence interval determined for locality IV. Thus the provenance of these assemblages, and probably the ice source itself, was constant throughout the area studied. From these results it becomes clear that the Valley Heads moraine can be defined by stability ratios for much, and possibly all of its length. These results suggest that the other moraines in western New York may also be defined by stability ratios, and thereby differentiated.

CONCLUSIONS

1. The Albion-Rochester, Waterloo-Auburn, Hamburg-Batavia-Victor, and Valley Heads moraines, the Binghamton drift, and the Illinoian till have a common provenance which is illustrated by the dominance of purple garnet over red garnet. The source of the ice that deposited these sediments was northeast of Lake Ontario.

2. The provenance of the Olean drift is different from that above as illustrated by a distinctive garnet ratio, sorting coefficient, and the composition of the light fraction. The source of the ice that deposited this sediment may be south of (or in) the Adirondack mountains as proposed by Dreimanis (1957).

3. The morainal deposits in western New York increase in age from north to south. Accompanying this age increase is an increasing alteration of hypersthene and monoclinic pyroxene which is manifested in the appearance of the grains. There is also a decrease in the relative amount of the unstable minerals from north to south. From the above observations it is concluded that a lack of stability is demonstrated by hypersthene, monoclinic pyroxene, and hornblende, with respect to the age of the deposit in which they occur.

4. The instability of the minerals can best be represented by stability ratios. These ratios are computed by dividing the amount of unstable mineral by the amount of stable mineral (garnet in this study).

5. From the stability curves, dates may be obtained, beyond which the unstable minerals should cease to persist in similar deposits. These dates are 25,400 years for monoclinic pyroxene, 36,500 years for hypersthene, and 120,000 years for hornblende. The order of persistence observed in this study (garnet, hornblende, hypersthene, monoclinic pyroxene) is consistent with that noted by Pettijohn (1941).

6. From the stability curves, the dates for the deposition of the Albion-Rochester and Hamburg-Batavia-Victor moraines may be obtained. These

dates are between 8,000 and 8,500 years and between 10,000 and 10,300 years respectively.

7. The stability ratios remain constant throughout most of the length of the Valley Heads moraine and may be used to define this moraine.

8. The results from the Valley Heads moraine suggest that stability ratios may be used to define all the moraines in New York State.

FURTHER STUDY SUGGESTIONS

The writer feels that the results of this study justify expansion of the study to cover lateral samples in all moraines, at much closer intervals than those used here for the Valley Heads moraine. From an expansion of the present study it should be possible to determine any lateral changes, if present, in the source of the glaciers. It should also be possible to reduce the confidence interval about the population mean in the stability studies.

Particular attention should be paid to the Tazewell drift and Illinoian till. From lateral studies of the Tazewell drift the possibility of an Adirondack source can either be supported or discounted. Further study of the Illinoian till may make it possible to date the deposits by means of refined curves for the stability ratios.

A study, similar to the one presented here, could be completed on the Oswego moraine to determine possible equivalence with the deposits of this study.

A study of the stability ratios in the till of the drumlins of western New York might be used to establish the stadium in which the till was originally deposited. From a study of this type, information may be gained as to the origin of drumlins.

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Table 1

Locality	Percent of Heavy Fraction in Sample	Percent of Magnetics in Heavy Fraction
I-1	5.26	9.35
I-2	1.99	9.15
I-3	4.72	11.75
I-4	1.52	12.58
II-1	5.58	15.15
II-3	5.05	17.26
III-1	4.70	14.25
III-2	4.65	15.51
III-3	4.52	15.34
III-4	4.64	14.05
IV-1	4.18	11.92
IV-2	3.29	10.36
IV-3	2.61	9.04
IV-4	3.09	8.82
V-1	2.25	10.45
V-2	3.53	14.90
V-3	4.31	11.68
V-4	3.51	13.91
VI-1	1.18	4.27
VI-2	1.51	1.94
VI-4	1.25	3.23
VII-1	2.80	6.27
VII-2	2.32	8.33
VII-3	2.62	8.58
VII-4	2.90	9.84
VIII	2.42	25.89
IX	2.83	15.79
X	1.79	23.07

Table 2

Percentage of Mineral in Locality

Mineral	I–1	I–2	I–3	I–4	II–1	II–3	III–1	III–2	III–3	III–4	IV–1	IV–2	IV–3	IV–4	V–1	V–2	V–3	V–4	VI–1	VI–2	VI–4	VII–1	VII–2	VII–3	VII–4	VIII	IX	X
Red Garnet	8.7	10.7	8.4	9.5	9.1	10.3	12.3	11.0	13.8	9.9	10.6	10.7	8.0	9.3	10.1	8.4	8.5	7.4	2.6	3.3	2.8	3.7	3.3	3.5	4.3	4.3	4.7	5.7
Purple Garnet ...	14.3	16.8	19.5	19.2	19.1	18.8	18.3	19.1	18.3	20.2	17.0	14.1	13.9	15.4	16.5	21.7	18.0	16.1	.1	1.3	.9	7.8	8.8	9.0	10.4	10.5	12.5	14.5
Hornblende	28.3	40.0	41.3	43.3	42.5	37.0	40.4	37.3	40.1	41.8	40.6	43.7	48.3	46.8	42.3	40.8	44.5	40.9	22.4	17.5	8.2	17.2	18.0	14.7	14.3	24.31	29.6	35.3
Hypersthene	10.8	8.8	6.1	4.7	5.0	6.0	7.9	5.2	6.6	6.0	8.0	8.7	9.3	7.5	5.6	5.6	6.8	4.6	.9	.1	—	1.1	1.6	1.7	.6	5.1	6.7	8.1
Monoclinic Pyroxenes	12.2	9.6	7.7	6.6	5.0	6.6	4.5	6.7	4.6	4.4	4.8	4.5	5.9	7.5	2.8	2.7	3.3	2.7	.1	.1	—	1.2	.5	.1	1.0	4.2	4.8	5.7
Opaques	14.8	6.9	8.5	5.9	9.6	6.4	8.8	11.9	9.7	9.3	10.4	10.7	9.3	9.0	18.2	17.5	14.8	26.5	72.8	76.0	86.5	68.6	66.5	70.0	68.5	51.7	41.8	30.8
Chlorite	9.3	4.7	5.5	7.2	4.6	7.2	5.4	6.0	4.4	6.1	5.2	3.9	1.5	1.6	.1	.1	.6	—	.1	—	—	—	—	—	—	—	—	—
Apatite	.6	2.3	1.1	2.2	3.2	3.0	.7	.1	—	.7	.1	1.0	.8	.1	—	.1	.6	—	—	.1	.1	—	—	—	—	—	—	—
Tremolite	.1	—	.1	—	.1	.5	1.3	1.4	1.9	.1	.7	1.6	1.3	.9	3.8	1.0	.8	1.5	—	—	—	—	—	—	.1	—	—	—
Zircon	—	.5	.1	.1	1.0	1.5	.1	.1	.1	.1	1.0	.1	.1	.1	—	.1	—	.1	.1	.6	.1	.1	.1	.1	.1	—	—	—
Sillimanite	.1	.1	.1	.1	.7	.1	—	.1	.9	.1	.1	.1	.6	.1	.5	.5	.6	.1	—	—	—	—	—	—	—	—	—	—
Titanite	.1	.1	.1	.1	1.0	1.0	.1	.1	—	.1	.1	.1	—	—	—	.1	—	—	—	.1	—	—	—	—	—	—	—	—
Tourmaline	—	—	.1	—	—	—	—	—	—	.1	.1	.6	.1	—	—	.1	.6	—	.1	.1	.1	—	.1	.1	—	—	—	—
Rutile	—	—	—	—	—	.1	—	—	—	.1	.1	—	—	.1	—	.1	.6	—	—	—	—	—	.1	.1	.1	—	—	—
Epidote	—	—	—	—	—	—	—	—	—	.1	.1	.6	.1	—	—	—	—	—	—	—	—	—	—	—	.1	—	—	—
Monazite	—	—	—	—	—	—	—	—	—	.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

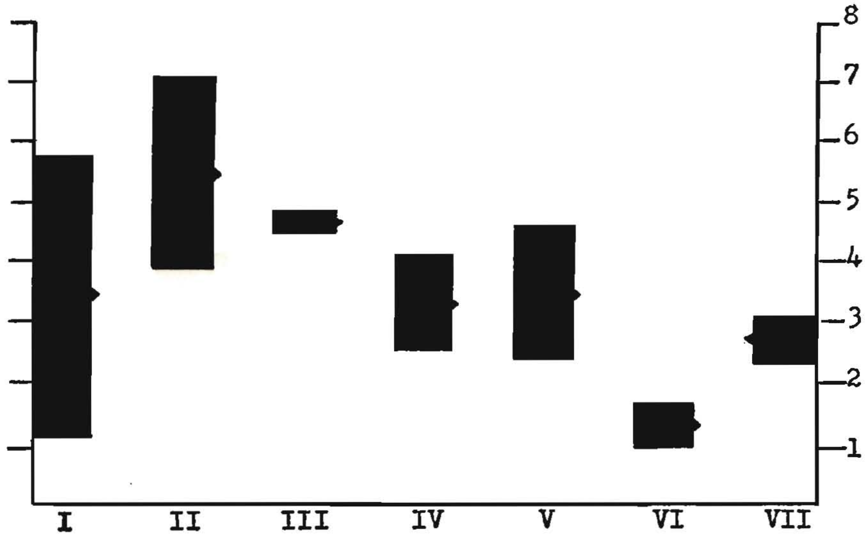
TABLE 3

Locality	Percentage of Heavy Fraction: Sample mean	Percentage of Heavy Fraction: Confidence interval	Percentage of Magnetics: Sample mean	Percentage of Magnetics: Confidence interval
I	3.37	1.17–5.61	10.71	8.67–12.75
II	5.32	3.65–6.99	16.20	9.54–22.86
III	4.63	4.54–4.72	14.85	13.96–15.72
IV	3.29	2.52–4.06	10.04	8.36–11.72
V	3.40	2.37–4.43	12.74	10.35–15.13
VI	1.31	1.02–1.60	3.15	1.54– 4.76
VII	2.74	2.42–3.06	8.26	6.42–10.10

TABLE 4

BAR CHARTS FOR TABLE 3

Percentage of heavy fraction in sample
90 percent confidence interval



Percentage of magnetics in heavy fractions
90 percent confidence interval

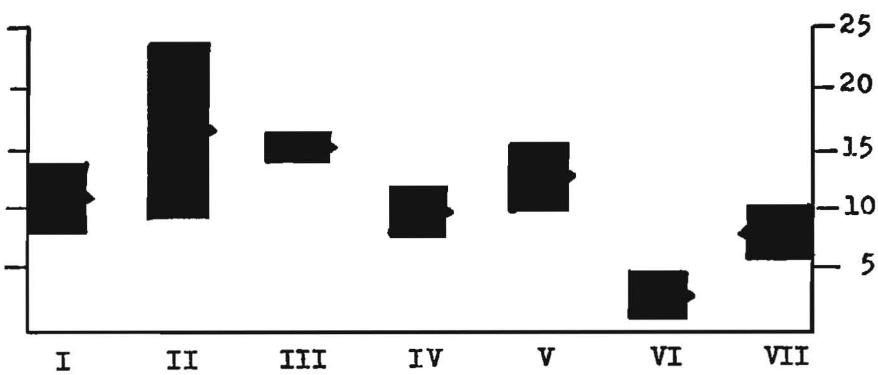


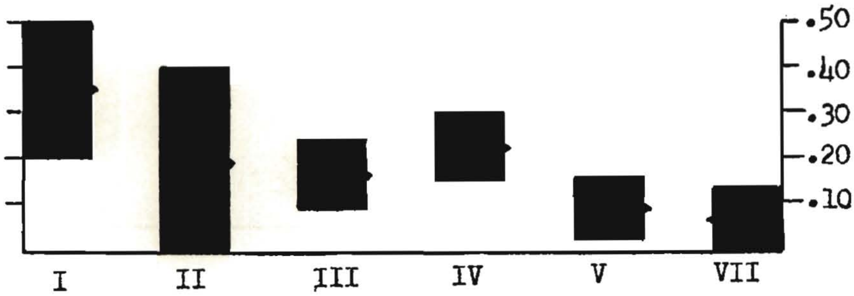
TABLE 5

Locality	Mean	90 percent confidence interval
	HORNBLENDE/GARNET	
I	1.43	1.28–1.58
II	1.38	.72–2.04
III	1.36	1.19–1.41
IV	1.84	1.52–2.16
V	1.60	1.39–1.81
VII	1.41	1.10–1.72
	HYPERSTHENE/GARNET	
I	.30	.15– .45
II	.22	.02– .42
III	.21	.14– .28
IV	.34	.27– .41
V	.21	.14– .28
VII	.09	.02– .16
	MONOCLINIC PYROXENE/GARNET	
I	.35	.20– .50
II	.20	.00– .40
III	.16	.09– .23
IV	.23	.16– .30
V	.10	.03– .17
VII	.06	.00– .13

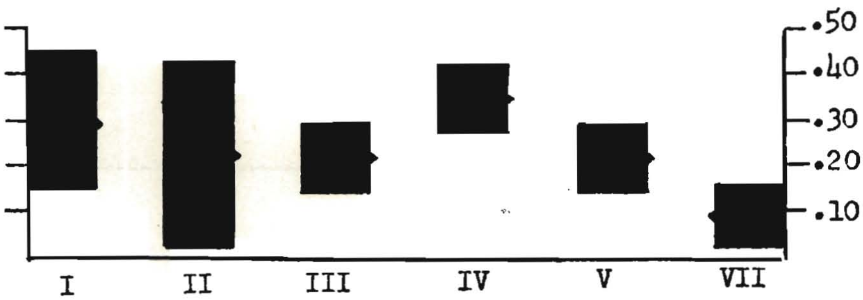
TABLE 6

BAR CHARTS FOR TABLE 5

Monoclinic pyroxene/garnet



Hypersthene/garnet



Hornblende/garnet

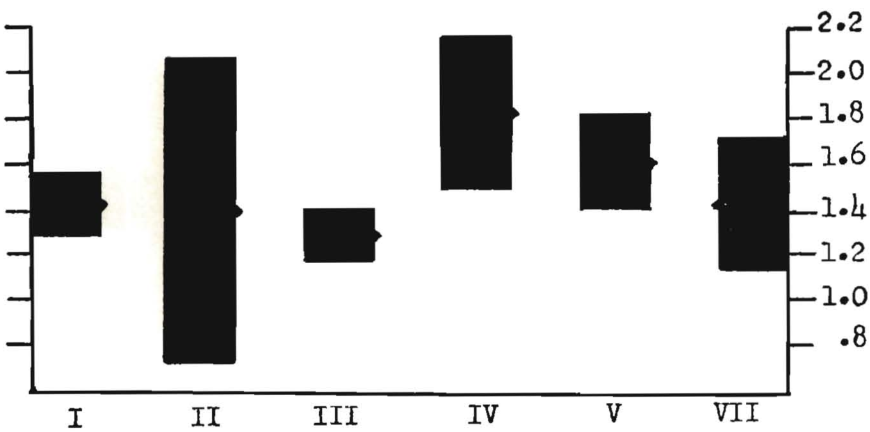


TABLE 7

HORNBLENDE/GARNET

Locality	Mean	90 percent confidence interval
IV	1.84	1.52–2.16
VIII	1.66	
IX	1.73	
X	1.76	

HYPERSTHENE/GARNET

Locality	Mean	90 percent confidence interval
IV	.34	.27– .41
VIII	.37	
IX	.39	
X	.40	

MONOCLINIC PYROXENE/GARNET

Locality	Mean	90 percent confidence interval
IV	.23	.16– .30
VIII	.28	
IX	.28	
X	.28	

ROCHESTER MOONWATCH 1959 ANNUAL REPORT

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CONTRIBUTOR

Smithsonian Astrophysical Observatory

Western Satellite Research Network

The worldwide Moonwatch project was organized in 1956 by the Smithsonian Astrophysical Observatory for the acquisition of newly launched earth satellites. As part of this program, the Rochester station was established in 1957 with fifteen 5 x 50mm instruments with 11° fields arranged in a meridian fence, and so used in 1958. Experience proved the setup was inadequate in several respects. The optics were not powerful enough to pick up the faint U.S. satellites for which the station had been established. Further, the brighter satellites of the U.S.S.R. rarely crossed the "fence" since their tracks were nearly parallel to it.

In late 1958, the Moonwatch program was extended beyond the end of the I.G.Y. with new objectives: in addition to acquisition of newly launched satellites, teams were requested to undertake regular visual tracking, particularly of fainter satellites, and to develop techniques for special assignments. The Rochester team re-registered in April, 1959, and initiated major changes to improve its performance. Substantial results were achieved. The 116 observations obtained in 100 sessions during 1959 are listed in the appendix [not included here—Ed.] along with appropriate comments on the various satellites.

Sites: The original site, 047, at the home of Dr. Alexander Dounce on Edgewood Avenue, Brighton, was augmented by an additional site, 8564, at the home of Clark Butler, Alpine Road, Greece. Due to the uncertain Rochester weather, team members always are called out on less than 2 hours' notice even for the predawn sessions, making it imperative to have conveniently located sites.

Techniques: The meridian fence was dismantled in May. The small instruments were remounted on portable tripods with elevation circles, and divided between the two sites. They have been used for observing the Sputnik III and Discover VI satellites which are relatively bright and in generally North-South orbits.

Refined techniques were developed for observing the fainter satellites with high power, narrow field telescopes. First, Rochester circumstances are derived from general orbital elements in the form of a "tracking schedule" in which the optical fence is shifted with time to bracket the satellite track in the sky. Considerable skill is required in pointing the telescopes since the fence often has been 2° or less for the fainter satellites such as 1958 Epsilon. Circles have been added to aid the pointing operation but reference to a star chart is made on meridian observations.

Stop watches and radio time signals are used to time the transits to an accuracy of 0.1 seconds.

Satellite positions are measured in celestial coordinates obtained from star charts with an accuracy of 0.1°.

Our results are reported by airmail or telegraph to the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts as soon as they have been obtained.

A weekly report is telephoned to the Western Satellite Research Network in Downey, California. Late in the year, the Rochester team was invited to join this network which is a group of Moonwatch teams organized to facilitate satellite tracking. The teams included are, Rochester, N. Y., Sacramento, California, China Lake, California, Albuquerque, N. M., Stockton, California, Walnut Creek, California, Whittier, California, Spokane, Washington and San Jose, California. The Aero-Space Laboratory of North American Aviations Missile Division supplies Rochester circumstances computed by an IBM 704 as the various satellites become visible to us. They also supply weekly corrections for erratic orbital accelerations. These data have increased the performance of the team remarkably since the number of observations had been limited by the involved computation required for each transit.

ACKNOWLEDGMENTS

Director: The Moonwatch Team was established by Ralph Dakin in 1957 and competently directed by him through the hectic early days of the Space Age. His mounting responsibilities in the Astronomical League led him to resign as director in May, 1959, but he has continued active in the program, particularly in instrumentation for apogee observing of faint satellites. Russell Jenkins has directed the team since his resignation with invaluable help in various phases of the program as acknowledged below:

Team Leaders: Richard Karlson, George Schindler, Clark Butler, Dr. Alexander Dounce.

Computations: Richard Karlson, George Schindler, William Graves, Clifton Field.

Instrumentation: Ralph Dakin, Dr. Alexander Dounce, Walter Whyman, Richard Karlson, George Keene, Herb Searles, Clark Butler.

Observers: Those above, Jack Smith, Ben Cleveland, Edwin Root, Stanley Wright, Eric Dounce, Kenneth Brown, Ralph Sutherland, Jackson Thomas, Ephriam Robbins, Donald Zimmerman, William Haynie, William Hollingsworth, Paul Haka, Martin Josephs and Myron Cucci.

Financial support from the Rochester Academy of Science was used for mailing expenses and miscellaneous supplies. The telescopes and timing equipment are owned by team members.

CITATIONS IN THE ROCHESTER ACADEMY OF SCIENCE

1959

ROBERT L. NICHOLS, PH.D.

Honorary Member

GEOMORPHOLOGIST—EXPLORER—TEACHER

Morphology has to do with shape, and until we have a satellite that will permit us to back off and study the Earth, geomorphology has to be done down here. Such a pursuit has taken this candidate over many terrains. He has conducted field work in Patagonia and the Antarctic and compared their bleak evidence with that of Alaska, Greenland and the Arctic. He has also taken advantage of indications in regions of the United States like New Mexico, where geologic formations open the book to the Earth's story.

He believes in going to the source of the latest information, because his particular interest is vulcanology. And for those who want science to be practical, we should note that he is a specialist in the subject of alumina clays.

He is Professor of Geology at Tufts College, where he obtained a Bachelor's degree in 1926. His work for the doctorate was done at Harvard. He now shares his experiences and information with many students, thus gaining one of the chief rewards of the explorer. Satisfaction can also be his from membership and fellowship in the leading organizations for geophysicists and geology teachers.

For his contributions to science and education through his important role in these fields, we are pleased to confer Honorary Membership in the Rochester Academy of Science upon Robert L. Nichols.

H. EVEREST CLEMENTS

Fellow

CONSERVATIONIST

With this single word the multifarious avocational energies of our candidate for honor in the Rochester Academy of Science can be reduced to its essence. His efforts go beyond action as trustee, officer and member of numerous nature and ornithologic groups. He has lead drives for forest preservation and for purchasing such areas as the Reed Road Sanctuary and tracts in the Bergen Swamp. He owns

Bass Island and leases Gull Island, operating them as wildlife refuges. The latter supports the only inland colony of double-crested cormorants in New York.

He succeeded in moving the National Grange to endorse the model Hawk and Owl Law proposed by the National Audubon Society—it is now incorporated in the Conservation Law of New York State.

Members of our Academy are thankful for his endeavors. Amid the pressures of a necessary and inevitable civilization, a wildlife refuge becomes also a sanctuary for the human spirit. Uncertainties subside at the sureness of a trillium's reappearance. Or we can be reassured by the long streamers of flying geese and realize that some forms of Life know where they are going. Accordingly, we are cordially welcoming H. Everest Clements as Fellow.

Alexander L. Dounce, Ph.D.

Fellow

Bio-Chemist—Author—Telescope Builder

Man lies in size about midway between the molecule and the universe. This gives us plenty of scope for intellectual curiosity. Seldom do we find, however, a man like the next candidate—for he is investigating both limits. He obtained his doctorate at Cornell University. He is now Associate Professor of Bio-chemistry at the University of Rochester and is the producer of numerous papers in the field. His current research deals with his specialty, cyto-chemistry. He has gained world renown for his work with nucleic acids and in the synthesis of proteins.

He has won top awards for his 7½- and 8-inch telescopes, and is particularly adept in designing and constructing mountings. This has aided him in obtaining excellent photographs of the moon and Mars. He has even finished a 16-inch mirror and is building the rest of the telescope. This is truly an ambitious project for an amateur telescope maker.

He donated his backyard to the Rochester moonwatch team during the IGY. For his abilities and skills and for his generous companionship with other members of the Astronomy Section, we are happy to elect Alexander L. Dounce a Fellow in the Rochester Academy of Science.

Robert M. Eaton

Fellow

Amateur Mineralogist and Paleontologist

One of the characteristics of our Academy Members is the urge to learn from their hobbies. This is highly exemplified by the activities of the next elected Fellow. He has not been content with collecting minerals and local fossils, for he has made himself an expert on them. He has passed valuable information along to his fellow collectors all over the world through papers, exchanges, lectures and discussions with Scout groups. He has loaned many of his specimens for displays and has prepared and filled exhibits for the Rochester Museum of Arts and Sciences.

His interest is avocational; he is the Manager of a large photofinishing plant in Rochester. So far there is no record of his having fogged a batch of films by enthusiastically turning an ultraviolet mineral light in one of the darkrooms.

In addition to the scholarly manner in which he pursues his hobby, he is tireless in his support to our Mineral Section. He has been a member for many years and has held every office in it. He is currently Chairman of the Field-trip Committee and will surely maintain the interest of the Section. Robert M. Eaton fully deserves our official Fellowship.

Mary Metzger Slifer

Fellow

Conservationist—Botanist

Conservation is a "portmanteau" activity; and Alice's expressive word best describes the interests of our next candidate. She has been wholeheartedly involved with the preservation of wildernesses, forests, national park areas, landmarks, nature, birds and wildflowers. In addition, her devotion to the profession of nursing shows that hers is not a detached pastime but a true desire to promote the awareness of the balm of nature in her fellows.

The best place to begin is in the home, and she has shown how wildflowers in danger of being engulfed by the bulldozer can be transplanted to bring nature into the city. She has gained the recognition of garden, nature, and conservation societies for her efforts.

It is only to be expected that we should find her helping to provide the next step in the appreciation of nature. She has served as Chairman of the Conservation Committee of the Burroughs-Audubon Nature Club. And it was she who provided the driving force which lead to the formation of the Bergen Swamp Preservation Society Incorporated in 1936.

As an articulate and energetic member of our Botany Section, Mary Metzger Slifer fully deserves our gratitude and the election to the Academy's Fellowship.

1960

MELISSA E. BINGEMAN

Life Member

HUMANITARIAN—POET—AMATEUR SCIENTIST

The sciences and the humanities are becoming increasingly aware of their interdependence. It is rare, nevertheless, to find an intense concentration of both outlooks in one person. This candidate, after primary schooling at her birthplace—Ontario, Canada—and special courses at Cornell University, served as assistant secretary of the Rochester Chamber of Commerce. There, almost fifty years ago, she pioneered projects like womens' classes in first aid, diet, and home nursing. She had a keen international appreciation and organized exhibitions of the works of ethnic groups in Rochester and directed programs of information, naturalization and legislation for aliens.

Retirement in 1945 enabled her to intensify her scientific activities, especially in the hydrology of the Great Lakes. And too, she did not abandon sociological awareness in a cleaned-out desk. She is even now concerned with the practical means for ameliorating juvenile behavior codes. Those who have known her keen enthusiasm and have been revived by her abundant energy are not surprised to learn that, characteristically, her voice in both matters has reached as far as governmental hearings.

Her "Two Studies Concerning the Levels of the Great Lakes" appeared in Volume 10, Number 1, 1953 of our Proceedings. These extensive papers have been quoted in several important articles since. She is a member of the Rochester Poetry Society and a regular contributor to its annual anthology, The Gleam.

Needless to say, she has given much time to Academy affairs, serving on the Council and officiating in the Mineral and Weather Science Sections. Because of the work she has done for the Rochester Academy of Science and for the prestige she has brought to it, we wholeheartedly welcome Melissa E. Bingeman to Life Membership.

LAVERNE L. PECHUMAN, PH.D.

Honorary Member

ENTOMOLOGIST—ARCHAEOLOGIST—BOTANIST

Professional pressures and the increasing complexities of any given scientific field make the avoidance of a constricting specialization difficult. It is stimulating, then, to find a scientist like this candidate, for he is not only a world authority on horseflies, but also active as an archeologist and expert on local wild plants. And he has accomplished all this since completing his doctorate at his Alma Mater, Cornell University, in 1939, and while advancing to the district managership for an important chemical spray corporation.

He has published forty papers in eighteen different scientific journals. Members will recall his intensive work on the Tabanidae of New York State which appeared in Volume 10, Number 3, 1957, of our Proceedings. It recorded twenty-five years of painstaking collection and study of horseflies and deerflies. Nine species of insects have been named in his honor. He is often called upon to identify specimens in museum and other collections.

He is a pick-carrying member and former officer of the Morgan Chapter of the New York State Archeological Association. He also is on the rolls of eight other learned international, national and local societies. Perhaps the rarest tribute for a man of this stature is his welcome as a guest at Tonawanda and Tuscarora ceremonies, although his contact with 4-H Clubs and high school science groups must give him great satisfaction too.

One of his hobbies is collecting trilliums and he has naturalized many rare mutations. He has also exchanged specimens with botanists in Japan and it is intriguing to see these flowers growing in his native Lockport.

We cordially confer the Honorary Membership of the Rochester Academy of Science on Laverne L. Pechuman.

RUSSELL E. JENKINS, M.SC.

Fellow

AMATEUR ASTRONOMER—MOONWATCHER

Seldom have the eyes of the scientist and the eyes of the layman been so intently focused on the same object as they have been on earth satellites. It is natural then, that the Rochester Moonwatch Team should be nonprofessionals. And it is gratifying that, as the most northerly post, they play a very important role in providing unique and accurate data for the program. That they are active and successful is due largely to the sound directorship provided by this candidate.

He was born in Sharon, Massachusetts and graduated from Worcester Polytechnic Institute, 1946, and continued for a M.Sc. in chemical engineering. He joined the Astronomy Section in 1955 and was Chairman during the 1957–58 season. He has represented the Section in many presentations to scout troops, high school classes, and adult groups. He participated in a television series dealing with the universe.

For his scientific achievements and for his advancement of the aims of the Rochester Academy of Science and his additional personal interest in civic education, we are pleased to extend Fellowship to Russell E. Jenkins.

PROCEEDINGS OF THE ROCHESTER ACADEMY OF SCIENCE

ESTABLISHED 1881

The pages of the Proceedings are open mainly for the publication of original articles on any aspects of the Natural Sciences of Western New York and the adjacent areas; for the publication of articles by the scientists of the region; and for biographical articles on the scientists of this area or those who have contributed to our knowledge of the Natural History of Western New York. Other articles will be considered by the Publications Committee. Further, the Proceedings will publish the official news, notes and activities of the Academy, its Sections and Members. Authors are requested to submit their articles to any member of the Publications Committee. Members should submit News and Notes to the Secretary of the Academy or the Secretaries of the various sections. Authors may obtain reprints by placing the order when returning proofs, and are furnished 25 reprints free of charge. For larger numbers than this, author obtains reprints at cost.

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