A HEAVY MINERAL INVESTIGATION OF GLACIAL TILLS IN WESTERN NEW YORK

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Norman E. Wingard
1962

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By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Geology

1962

ABSTRACT

In western New York, sand-sized heavy minerals are a far-travelled and evenly distributed constituent of glacial drift. This suite serves as a useful criterion for the interpretation of processes of transportation and deposition of tills and glaciofluvial materials.

Variability of this assemblage in the tills is determined by petrographic and sedimentological examination of composite samples from selected sites in Livingston, Allegany, Ontario, Yates, Stuben and schyler and Chemung counties.

Variations in size distribution in the heavy mineral suite throughout this area indicate that systematic size reduction does not result from transportation processes. Also, the heavy mineral suite in the tills is indicated to be more stable with respect to disintegration than in the related glaciofluvial deposits.

The factor which most affects the interpretation of variability in the heavy mineral fraction is basal contamination. Additions to the sand-sized heavy mineral assemblage are caused by pre-existing concentrations, brought about by glaciofluvial and/or solely fluvial action.

The findings generally relate to the known glacial geology of the region. The results illustrate an effective application of heavy mineral studies for provenance

determination and process analysis. The technique may prove of particular value in supplementing knowledge in regions where geomorphic evidence alone is inadequate for a complete understanding of the glacial history.

ACKNOWLEDGEMENTS

The writer wishes to express his gratitude to Gordon Connally of the State University College, New Paltz, New York for suggesting the problem, providing assistance and guidance in the field and for reading and commenting on the manuscript. Thanks are also due to the following people, all of the Department of Geology, Michigan State University: Dr. Maynard Miller for criticism regarding content and organization, whose comments are liberally incorporated throughout the paper; Dr. James Trow for helpful advice concerning the laboratory research, and for reading the manuscript; Drs. J.E. Smith, C.E. Prouty and W.J. Hinze for their interest and advice.

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INTRODUCTION

Glaciation in western New York state has been an important factor in development of the present topography. This is an area in which many studies of glacial geology have been undertaken and where significant contributions have been made. Such papers include those by T.C. Chamberlain in 1883, W.J. Miller in 1914, V.E. Monnet in 1924, H.L. Fairchild in 1932, and more recently, those by P. MacClintock and E.A. Apfel (1944) and C. Holmes (1952).

Purpose and scope of study

The purpose of this study is to examine selected samples of glacial till for the purpose of determining the nature of depositional and post depositional processes that have been operative during the most recent glacial and intra-glacial stages of the Pleistocene. Particularly, it is intended to determine the degree to which each process has been important in producing the present distribution of the materials in glacial drift.

The sand-sized fraction of the heavy mineral suite in the drift is a far-traveled and evenly distributed constituent. Lighter materials, dominantly composed of rock particles show greater local variation. For this reason the sand-sized heavy mineral fraction has been chosen as the subject of this analysis.

Four possible causes of areal variability in the heavy mineral assemblages are considered. (1) provenance, (2) distance and mode of transportation, (3) effect of pre-glacial topography, and (4) effects of multiple glaciation.

Previous work

Little research has been carried out on the distribution of heavy minerals in tills. No such investigation has been previously conducted on the tills in the Finger Lakes region. As will be shown, it is possible to determine general variations over the area and to relate these to present knowledge of the glacial history. The relations found here may allow application of the heavy mineral technique in the interpretation of glacial geology in regions where previous geomorphological studies are not as extensive, or where adequate geomorphological evidence is lacking.

Numerous attempts to map the glacial deposits in central and western New York have been carried out since T.C. Chamberlain's description of the "terminal moraine" in 1883. But detailed laboratory analysis of the drift has not been done. A field classification or pebble count has usually been considered adequate. (MacClintock and Apfel, 1944; Holmes, 1952).

Quantitative studies of heavy minerals in drift have been made in Ontario and adjacent regions by Dreimanis, Reavely, Cook, Knox and Moretti (1957). Their purpose was to differentiate drift associated with major lobes of Pleistocene ice. The result was highly successful, since each lobe contained an assemblage reflecting a different provenance.

Samples of stratified drift in the Finger Lakes region have been studied by Connally (1959) with respect to heavy mineral content. The results of this investigation will be noted as they relate to findings in the present treatment.

FIELD DATA

Sampling method

Field sampling was accomplished by samples from a number of localities. The sample sites were chosen to coincide as nearly as possible to a grid of fifteen minutes of latitude by fifteen minutes of longitude. This corresponds to one location for each fifteen minute quadrangle - i.e. a sampling pattern considered appropriate for the determination of broad areal patterns in the distribution of heavy minerals in the tills. In many localities, lack of exposure of fresh, unweathered till prevented the grid distribution from being fully realized. Where exposures of undisturbed till were abundant, the samples were obtained at sites providing significant areal distribution.

To assure that local variations in the till could not affect the randomness of sampling, four samples were taken from each location. The necessity of this procedure was borne out, in terms of size distribution, by the subsequent mechanical analyses.

Sample localities

Samples of till were collected from parts of Livingston, Allegany, Ontario, Yates, Stuben, Schyler, and Chemung counties. These all lie in the western part of the Finger Lakes region, extending from Lake Ontario, southward to close to the Pennsylvania State Line (Map Plate 7.). In this region, five and possibly seven recessional sub-ages of the Wisconsin Glacial Age from Lower Cary to post Port Huron (Mankato) are represented.

Throughout the region the trend of major striae and the orientation of streamlined forms, such as drumlins, is from N20°W to N25°E. (Plate 19). Connally (1959) cites various lines of evidence to indicate that during Valley Heads (Upper Cary) glaciation and all subsequent readvances of late Glacial time, the mass transfer of ice was toward the southwest. As opposed to this, the geomorphic evidence cited in the following pages and the related data on heavy mineral distribution suggest that the ice movement was dominantly toward the southeast.

Site descriptions

Descriptions of the sample sites follows. The characteristic color of the till given in these descriptions is based on an arbitrary field classification. When compared with the Munsell Color Chart in the laboratory, the colors do not necessarily correspond. The field colors are listed as a prime guide to identity. The color chart comparison is noted in parentheses at the end of each description.

Site 1.

Stream-cut bluff formed by a small tributary to Bradner Creek, one mile north of Byersville. Seventy to 80 feet of silt-loam till exposed. The lower 35 feet of till very firm and blue-gray in color. The upper 40-45 feet oxidized brown till with no obvious stratigraphic break with the lower portion. This till contains many pebbles and cobbles up to 8 inches in diameter. (N 5.0).

Site 2.

This location not used in present analysis.

Site 3.

A small cutbank in Springwater Creek, 2 miles north of Wayland or 5 miles northwest of Dansville. Five feet of till is exposed. The lower 2 feet is blue silt-loam till, with cobbles 1 to 6 inches in diameter. Some cobbles show slight stream rounding. The till becomes finer upward and is overlain by 2 feet of lacustrine silt or silt till. The upper silty layer contains few pebbles, and incorporates cobbles at 3 up to 12 inches dimension. The till is calcareous and the cobbles exhibit the "bright lithology" described by MacClintock and Apfel (1944, pp. 1155-1156). Oxidation extends to a depth of 2.5 feet. Moderate leaching has occured in the upper 2 feet. Fifty feet downstream from this section, a drab gravel 3.5 feet thick appears to overlie the till. The gravel is leached and oxidized. (10.OYR4/2).

Site 4.

A pebbly gray till exposed in a 7-foot cutbank one-half mile west of Honeoye. The clasts range in size from less than 1 inch to more than 12 inches in diameter. The till is firm and calcareous. Oxidation extends to 5 feet, leaching to 3.5. All samples taken below the oxidized zone and over a lateral distance of about 100 feet. (10.OYR4/2).

Site 5.

A 10-foot bluff on a north tributary of the Canisteo River with exposed till of olive-brown appearance. Slightly calcareous and with a clay-loam matrix. Much local fragmental material is incorporated with a great many stream-rounded pebbles and cobbles. Oxidation extends to about 4 feet, though slump cover has obscured this observation. (2.5Y6/4).

Site 7.

Cut bank on a small tributary west of Deerlick Run, 2.5 miles north of Wheeler. This site can be seen on the map (Plate 7) about 5 miles west of Keuka Lake. The bank is 12 feet high, the upper 10.5 feet is covered with slump debris. The lower 1.5 feet had been freshly undercut, at the time of observation, exposing a pebbly chocolate-colored, calcareous till. (2.5Y5/4).

Site 8.

A 40-foot cutbank 1.5 miles south of Short Tract. This can be seen near the center of the map of Plate 7, about 4 miles east of the Genesee River. The lower 20 feet consists of deternating cross-bedded sands and gravels. The upper 20 feet is blue, calcareous, unleached till with silt matrix. Oxidation extends downward 12 inches. (5.0Y4/2).

Site 9.

Cutbank 1 mile west of Greenwood in Christian Hollow is about 25 miles west of Corning (Plate 7). A tan, calcareous, pebble-rich silt till is exposed in a bank 7 feet high. The upper 4 feet is oxidized till. Leaching has been effective to a depth of 2 to 3 feet. (2.5Y6/2).

Site 10.

An 8-foot cutbank on Trapping Brook, 1 mile east of Wellsville in the southeastern corner of the study area (Plate 7). A pebble-rich blue till, 2.5 to 3 feet thick, incorporates much local material. The bank had been freshly cut at the base but was badly slumped above, at the time of observation, therefore depth of oxidation was not determined. (5.0Y4/2).

Site 11.

Ten-foot cutbank on Salt Creek 1.5 miles northeast of Retsof, or 3 miles north of Geneseo on River Road (7 miles west of Conesus Lake, Plate 7). Eight feet of firm purple, calcareous and very pebbly till is exposed; the lower 4 feet is fresh, unoxidized; the upper 4 feet oxidized but unleached. Two feet of colluvium overlies the till. (5.0YR4/2).

Site 12.

A 20-foot cutbank 1 mile west of Buckbee Corner (10 miles southwest of Rochester, Plate 7), exposes firm, purple-brown, calcareous pebbly till. Lacustrine sands are intercallated toward the top. (5.0YR4/2)

Site 13.

Construction site for a shopping center 1 mile northwest of Pittsford, southeast of Rochester (Plate 7). A composite thickness of about 20 feet of firm, purple, pebbly sand till, with lacustrine sands, gravels and silts is exposed.* A 12-foot embankment discloses purple till as the basal member with intercallated sand layers with some gravel. The upper 6 feet of the bank shows a firm sandy brown till. Samples were taken from the lower unit. (75YR5/4).

Site 14.

Thirty-foot bluff 2 miles east of Woodhull on the south Branch of Tuscarora Creek (15 miles west of Corning, Plate 7). The lower 10 feet is slump covered, above is 10 to 15 feet of drab, olive, pebble-rich clay-loam till. Above the till is a layer of banded, oxidized sand, up to 8 inches

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*This description was through the joint effort of G.G. Connally (personal communication) and the author.

thick. Above the sand layer is another till, 15 to 30 feet thick, of which the upper 15 feet is oxidized. The till can be seen to incorporate the underlying sand layer, partially destroying the bedding. Samples were taken from the lower till. (2.5Y5/4).

Site 15.

A 10-foot cutbank on Meads Creek at the junction with Dry Run, 3 miles west of Coopers Plains and 7 miles northwest of Corning (Plate 7). The lower 5 feet is firm, olive-colored pebbly till with loam matrix. The drab looking pebble lithology and absence of "bright" materials (MacClintock and Apfel, 1944), suggest Olean age. The till is overlain by about 5 feet of massive oxidized sand. (2.5Y5/4).

Site 16.

A 40-foot cutbank one-half mile southeast of Catlin (5 miles northwest of Elmira, Plate 7). The bottom 1 to 1.5 foot exposes firm, very pebbly, olive-colored loam till, overlain by Olean-type gravel. The till contains a fairly large amount of "Binghamton-type" (MacClintock and Apfel, 1944) pebbles, including chert and red sandstone. (5.0Y4/2).

Site 17.

Located 4 miles north of Hammondsport, on the west side of Keuka Lake. A 30-foot cutbank with 3 feet of fresh, gray, pebbly silt-loam till exposed near the top. The remainder of the bank, when observed, was covered by slump material, mostly till, indicating considerable thickness. Samples taken from top of the unit. (N5.0).

Site 18.

Cutbank on Flint Creek one-half mile west of Seneca Castle, 5 miles west of Seneca Lake (Plate 7). The bluff is 30 feet high with 3 till units exposed. The lower unit is a firm, gray, pebbly silt till, extending up to 5 feet. Above is 25 feet of firm purple sandy till with "Binghamton lithology." This unit contains logs apparently of interglacial origin, although Connally (personal communication) suggests that they may be later contaminants. At approximately 10 feet from the top, this unit grades into a firm, sandy loam till. Sand lenses are found locally throughout the upper two units. These lenses are usually oxidized, probably as a result of recent ground water migration. Samples were taken from the middle unit. (5.0YR4/2).

Site 19.

A road cut on the southeast side of the village of Newark (Map, Plate 7), exposing 20 feet of firm, red loam till that is slightly calcareous. The upper 12 inches is oxidized. The till is pebbly and contains a number of erratic boulders. (5.0YR4/4).

Site 20.

Cutbank on tributary to Mud Creek 1.5 miles south of Vincent, and about 6 miles west of Canandaigua Lake (Plate 7). The bluff is 30 feet high and exposes a gray silt-loam till. The till contains many lenses or pods of sand which appear oxidized and to serve as channels of ground water migration. The till is firm, containing many pebbles. Many striated boulders are found along the bank and in the creek bed. The till is oxidized throughout the upper 8 feet. (N5.0).

Site 21.

Drainage ditch south of Sheldrake Creek, 4 miles southeast of Ovid, between Cayuga and Seneca Lakes (Plate 7). Six feet of firm, brown, calcareous, pebbly loam till is exposed. The till is unoxidized and unleached. (7.5YR4/4).

Site 22.

A 30-foot road cut 1 mile southeast of Italy, about 10 miles west of Keuka Lake (Plate 7). The lower 8 to 10 feet exposes blue silt till, which incorporates much of the local bedrock. An 8 to 12-foot sandy layer overlies the blue till and contains many pebbles and cobbles which are more abundant toward the base. The next 10 to 15 feet of the section is not visible, but near the top a firm tan loam till is exposed. Samples taken from the lowest unit. (N4.5).

Site 23.

A freshly eroded stream channel locally reported to have resulted from flooding three months previous. It is located near Canaseraga Creek, in the west central portion of the map area shown in Plate 7. A 30-foot bluff exposes 15 feet of blue silt-loam till. The till is pebbly, including both local shale and a large number of erratics. It is overlain by 6 feet of varved sand, silt and clay. Above the varved material lies about 10 feet of mottled gray to brown loam till. (N5.0).

Site 24.

A 60-foot stream-cut bluff located on the north side of Glen Creek, 5 miles west of Watkins Glen, near the south end of Seneca Lake (Plate 7). At the base of the section about 5 feet of lacustrine silt is exposed, followed by 10 feet of brown, pebbly, loam till and 15 to 20 feet of firm gray-brown pebbly silt-loam till (sampled). Overlying the till is 10 feet of coarse, oxidized gravel and 1 foot of brown, oxidized loam till. (5.0Y4/2).

With respect to the foregoing descriptions, with the exception of sites 13, 19, 21 and 22, all samples were taken from natural exposures resulting from stream erosion. Thus, most samples are from the sites of present-day valleys, with the above-noted four representing present-day interfluvial areas.

LABORATORY PROCEDURE

Following is a description of the methods and procedures used in the laboratory, preparatory to the sample analyses.

Mechanical analysis

Sixteen spot samples from four collecting sites were selected for mechanical analysis of the sand fraction. The purpose was to determine the size characteristics of the till and to find a size grade containing the largest amount of material.

Disaggregation was accomplished by means of a wooden rolling pin and a rubber pestle. The one quart spot samples were quartered to approximately 100 grams by means of a Jones sample splitter. The samples were then separated into Wentworth sand grades (ratio X2) by means of a nest of seives placed on a Ro-Tap shaking machine. Fifteen minutes of operation per sample was sufficient for the separation.

Disaggregation and dispersion of samples

In order to find a quick but adequate method to disaggregate and disperse the samples, and to determine a size grade containing a maximum number of heavy minerals, portions of the same 16 spot samples were separately treated with N hydrochloric acid, N/100 sodium oxalate, N/50 sodium carbonate, N/20 sodium carbonate, N/20 sodium hydroxide, and water. Each treatment was subjected to 10 to 20 minutes of stirring and from 10 to 18 hours of shaking in a reciprocal shaker. After drying, each sample was examined under a binocular microscope for degree of disaggregation and oxide stain. The most effective and least time-consuming procedure was 10 minutes of stirring, followed by wet sieving and 10 minutes of boiling in 1:4 HCl. There is no evidence to suggest that this procedure could significantly alter the distributions of heavy minerals.

Figure 1. Flow sheet of laboratory procedure.

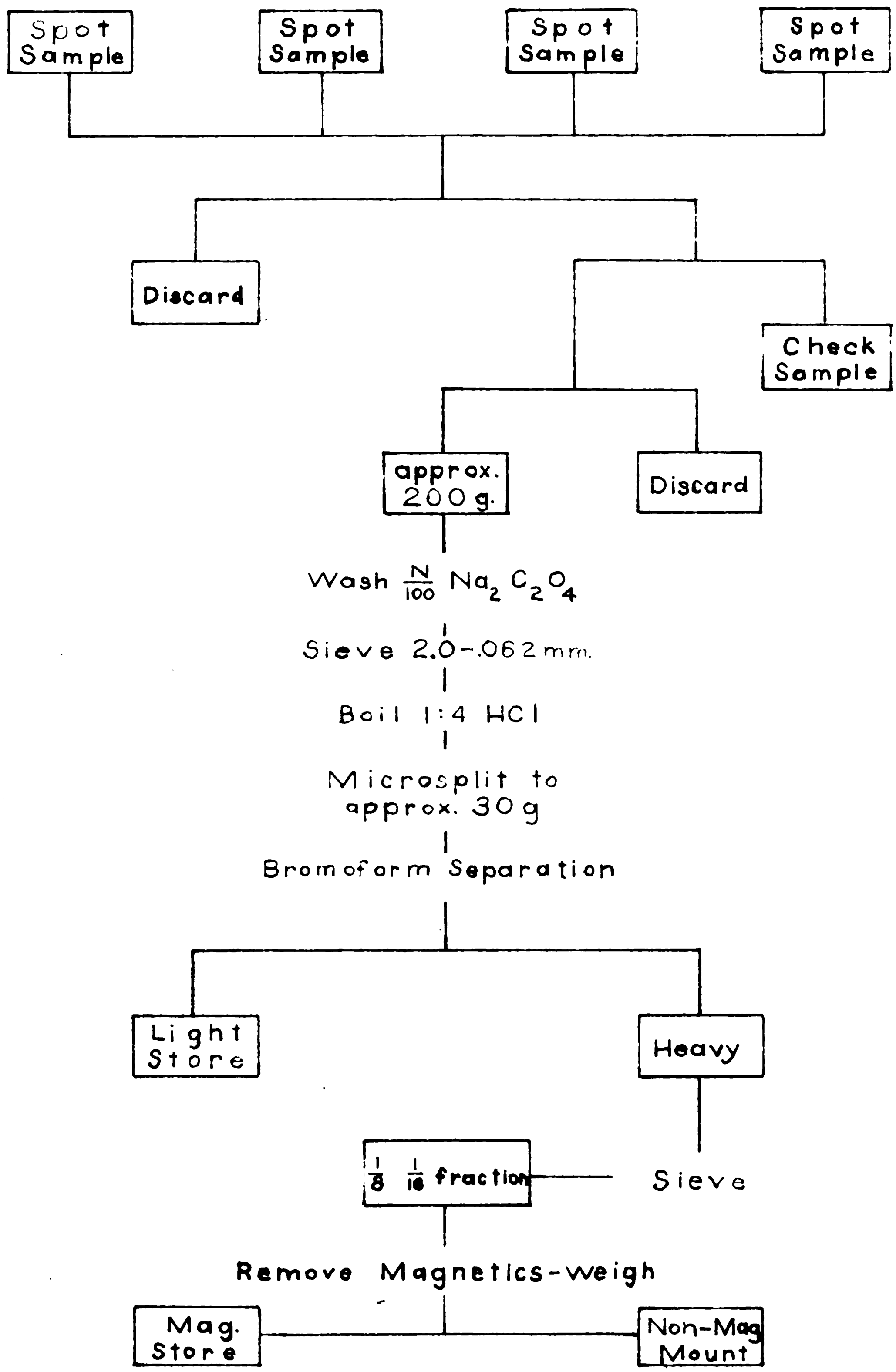


Figure 1. is a flow sheet showing the procedure used for all samples. Approximately 200 grams of till were placed in the sodium oxalate solution and stirred. To insure that no encrustation of clay occurred on the sand grains upon drying, and to eliminate the coarse fraction, the sodium oxalate solution was wet seived through 2.0 and .062 mm screens. The sand fraction was retained and boiled in acid.

Heavy mineral separation

The heavy minerals were separated from the light fraction by means of bromoform ($CHBr_3$), which has a specific gravity of 2.89 at 20° centigrade. The method used is that outlined by Krumbein and Pettijohn (1938, p. 335).

After acid treatment, each sample was dried and reduced to approximately 30 grams with an electric vibrating micro-split. The sample was weighed on an analytical balance before bromoform separation. After separation, the heavy mineral fraction was weighed and the weights recorded. From these values, percentages by weight of heavy minerals were calculated. The results are listed on Table 4.

The light fractions were stored for reference and the heavy fractions separated into the five Wentworth sand-size grades. The size separation of the heavies was accomplished with a nest of small, 3-inch diameter sieves. The sieves were agitated using the electric vibrator of the micro-split. Use of the small sieves in this way minimized loss of the mineral grains during separation. Each size grade was weighed on an analytical balance and the weight recorded. In every case, the greatest frequency of heavy mineral grains occurred in the 1/8 - 1/16 mm. fraction.

Magnetite was removed from the fine sand grade (1/8 - 1/16 mm.) with a small hand magnet. Weights of the magnetics were determined and recorded (Table 4) and the weight percentages of magnetics calculated. The remaining non-magnetic fractions were then mounted for microscopic examination.

Mounting and identification

The non-magnetic heavy minerals in the 1/8 to 1/16 mm. grade size were mounted on glass slides for petrographic examination. Piperine was chosen as the mounting medium because of its relatively high index of refraction (1.68). Since most heavy minerals have higher indices of refraction than do most of the lighter minerals, a medium with an index above that of Canada balsam (1.52) is necessary to be of value in identification. The higher index is particularly useful for the determinations of amphiboles and pyroxenes.

A petrographic microscope was used for identification. Mineralogic properties considered, in addition to refractive index, were color, pleochroism, dispersion, optic sign, birefringence, elongation, extinction angle, crystal form, habit, and 2V. To assure positive identification, many grains were examined in oils of known index. This allowed a more precise determination of indices and permitted the grains to be freely rotated, so that more than one index could be observed. References used in conjunction with the identifications are: Larson and Berman (1934), Bloss (1961), Rogers and Kerr (1942) and Wahlstrom (1955).

ANALYTICAL RESULTS

Mechanical analysis

The reason for carrying on a limited mechanical analysis of the tills was two-fold:

1. To determine if different spot samples taken from a single till exposure or horizon would have a uniform over-all size composition.

2. To determine whether or not systematic variations extend between different collecting stations.

A chi-squared test was used for the first of these. The weight percentage of each phi sand class interval was compared with the mean percentage for the four spot samples. In fifteen of the sixteen samples analyzed, the hypothesis of equal means between spot samples was rejected at the 95 per cent confidence limit.

Histograms and cumulative curves of the size distribution are shown in Plates 1, 2, 3 and 4. It can be seen that the middle sand grade (-1 to 2 on the Ø scale; 3 mm. to ¼ mm.), in every sample, contains only a very small proportion of the material (3 to 11 per cent) and is in relatively consistent proportion between spot samples for a given till. Exceptions to this consistency, even in this limited portion of the curve, can be noted. Sample 15-A is disproportionately high. As both extremes of sand size are approached, the correspondence becomes even less. The difference in percentage composition between spot samples in the coarse fraction (-2, -1 Ø) is from a maximum of 42.8

per cent in sample 22, which is the greatest difference, to a maximum difference of 8.3 per cent in sample 10, which is the smallest (Table 1).

Table 1. Difference in per cent composition of -2, -1 ∅ grade size.

Sample no.	Greatest %	Least %	Differences in % within grade
10	17.45	9.13	8.32
11	15.05	1.63	13.42
15	54.48	36.83	17.65
22	55.65	12.81	42.84

A similar heterogeniety in size distribution is found in the fine grades--the 3, 4∅ interval. Here, however, the smallest difference between spot samples is found in sample 22 as opposed to the greatest difference in the coarse grade.

The cumulative curves shown in Plates 3 and 4 are used to determine the first, second and third quartiles and the phi quartile deviation (QD∅). These values are given in Table 2. The quartile deviations show, as do the histograms, the very high degree of variability both within and between the tills.

The conclusion reached from the mechanical analysis is that individual spot samples do not show adequate correlation be means of gross mechanical analysis of the sand fraction. The fact that uniform size distribution does not extend even for a few feet, within the same deposit, testifies that long-distance correlation, between exposures is not feasible by this method.

Table 2. Quartile measures for size frequency distribution.

	$Q_1\phi$	$MQ\phi$	$Q_3\phi$	$QD\phi$	Average
10-A	.83	3.02	3.23	1.200	
10-B	1.67	2.80	3.35	.840	
10-C	1.80	3.05	3.42	.810	
10-D	1.15	2.95	3.31	1.080	.982
11-A	.29	2.50	3.42	1.855	
11-B	-.84	1.92	3.35	2.095	
11-C	0	2.48	3.24	1.620	
11-D	2.77	3.10	3.45	.340	1.477
15-A	-1.06	-0.10	3.08	2.070	
15-B	-1.82	-0.15	3.80	2.810	
15-C	-1.60	-1.20	0.70	1.150	
15-D	-1.62	-0.31	3.40	2.510	2.135
22-A	0.73	2.84	3.14	1.205	
22-B	-0.68	2.12	3.24	1.960	
22-C	-1.70	1.30	3.07	2.385	
22-D	-2.00	-1.30	2.68	1.440	1.747

Identification and description of minerals

The minerals identified for all sample localities are given in Table 3. A description of the minerals identified is also included in this table. The minerals found in the till, in their approximate order of abundance are: hornblende, magnetite, pyrite, hypersthene, leucoxene, clear garnet, monoclinic pyroxene, titanite, red garnet, enstatite, zircon, tremolite, rutile and muscovite. Those found only as a trace in a few samples are pigeonite, sillimanite, chlorite and epidote. The latter are not considered adequately abundant to represent their true statistical distribution.

Table 3. Heavy minerals identified.

Mineral	Indices	Description
Chlorite	α 1.57	Green to light green plates with low birefringence.
	γ 1.68	Produced off-center optic axis figure with small 2V and incomplete extinction.
Epidote (pistacite)	α 1.72	Greenish-yellow irregular grains. High birefringence.
	γ 1.75	Biaxial negative, 2V large (n90°). Most grains produced centered optic axis or typical "compass needle" figure.
Garnet	n 1.79	Colorless, purple, pink and red varieties. Isotropic, irregular fragments with conchoidal fracture. Colorless to purple varieties were counted as a group and pink and red as another.

Table 3 continued.

Hornblende	α 1.60 γ 1.70	Green to brown pleochroic, prismatic elongate. Oblique extinction, biaxial negative. 2V 60°- 90°, positive elongation. Some grains nearly opque being translucent only near the edges.
Hypersthene	α 1.69 γ 1.70	Light green to pink pleochroic; prismatic, stubby to acicular, parallel extinction, biaxial negative. 2V 60°-80°, positive elongation. Enstatite and bronzite, two members of the same isomorphous series, were found in minor quantities.
Muscovite	α 1.56 γ 1.60	Colorless cleavage flakes which produce a centered optic axis figure.
Pigeonite	α 1.68 γ 1.75	Colorless, low birefringence, biaxial positive, small 2V and extinction angle, positive elongation.
Monoclinic pyroxene	α 1.65 γ 1.75	Mostly diopside with some augite. Colorless to light green. Prismatic elongate to irregular worn fragments with dentate ends. Extinction angle 38°- 60°. Biaxial positive, 2V 35°-60°.
Rutile	α 2.90 γ 2.62	Red and yellow prismatic grains. Some display striae parallel and transverse to the length.
Sillimanite	α 1.65 γ 1.68	Colorless, fibrous, biaxial positive, parallel extinction. 2V=20°.
Titanite (sphene)	α 1.91 γ 2.03	Yellow-brown, slightly rounded grains with extremely high birefringence and consequent incomplete extinction. Biaxial positive, 2V small.
Tremolite	α 1.60 γ 1.63	Colorless, prismatic to irregular. High birefringence extinction angle 15°- 20°. Biaxial negative with positive elongation.
Zircon	α 1.99 γ 1.93	Colorless, prismatic euhedra, usually with numerous inclusions. May show a fair degree of rounding. Unaxial positive, parallel extinction, positive elongation.

Table 3 continued.

Opaque minerals	
Pyrite	Cubic, octahedral, dodecahedral and spherulitic forms were observed. A few grains of marcasite were counted under this heading.
Leucoxene	Leucoxene was counted under the heading of white opaques, as seen in reflected light. Most occurred as rounded grains with a rough or pitted appearance. A few grains were somewhat yellowish in color.
Hematite and Limonite	Red, red-brown, and grey metallic grains of hematite were counted with orange and red-orange grains of limonite. All occurred as irregular grains.
Dark opaques	This heading included all of the black or nearly black grains that appeared completely opaque. They were relatively rare and are thought largely made up of magnetite which may have escaped removal by the magnet.

Table 4. Percent by weight of heavy minerals in tills.

Sample	Sample weight (grams)	Weight Heavies (grams)	Weight Magnetics (grams)	Percent Heavies	Percent Magnetics
1	36.655	1.114	.0187	.030	.017
3	36.069	1.380	.0379	.038	.027
4	35.501	.869	.0134	.024	.015
5	23.838	.180	.0035	.007	.019
7	20.992	.208	.0048	.010	.023
8	26.227	.485	.0059	.018	.012
9	18.037	.116	-	.006	-
10	24.932	.307	.0007	.012	.002
11	28.838	.992	.0389	.034	.039
12	38.610	1.581	.0597	.041	.038
13	35.188	1.415	.0618	.040	.044
14	33.177	.133	.0005	.004	.004
15	29.793	.152	.0022	.005	.014
16	26.212	.488	.0151	.019	.031
17	28.321	.619	.0203	.022	.032
18	32.724	1.206	.0444	.037	.037
19	36.351	1.278	.0631	.035	.049
20	29.274	1.386	.0324	.047	.023
21	28.006	.709	.0326	.025	.046
22	38.776	.998	.0275	.026	.027
23	33.310	.682	.0135	.020	.020
24	25.204	.445	.0054	.018	.012

Heavy mineral percentages by weight

Sample weight and percentages of heavy minerals and magnetics are listed in Table 4. Plates 5 and 6 are isopleth maps showing the relations between weight percentage of heavy minerals (without magnetics) and the weight percentage of magnetics.

These maps show a well defined north to south decrease in the over-all abundance of heavy minerals. The only deviation from the essential simplicity of this meridional pattern is the steep gradient between the high percentage at site 20 and the relatively low percentage at site 4. This is interpreted as a high percentage lobe centering around Canandaigua Lake and a lobe with a corresponding low percentage of heavy minerals north of Dansville. These lobes do not show well marked correlation with morainal termini (Connally, 1959, 1961; MacClintock and Apfel, 1944; Denny, 1956). The general trend of the percentage contours across the southern one-third of the area is related to morainal lobations only as both were affected by pre-existing topography.

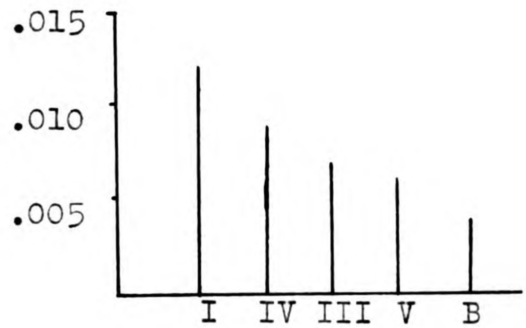
Six lines were chosen which intersect a maximum number of sample sites, with two lines being parallel to striae trending N 15 W and N 20 W. These striae were found near Lamoka Lake (Plate 7.), to the southeast of Keuka Lake. The mean deviation of the weight percentage or the "mean absolute deviation from the mean" (Dixon and Massey, p. 75) was calculated for the points along each of these transects. The mean deviation is expressed as the sum of the absolute difference between the weight percentage and the mean weight percentage.

$$\frac{[X - \bar{X}]}{N}$$

X = weight percentage
$\bar{X}$ = mean weight percentage
N = number of points on line

Values for the mean deviation can be read from the table in figure 2. The same figure shows these graphically as lines with proportional lengths.

Line	$\frac{[X - \bar{X}]}{N}$
I	.012
IV	.011
III	.009
V	.007
II	.006
B	.004



.01 unit of mean deviation = 1 inch

Figure 2. Weight percentage mean deviation

These lines are oriented on the map in Plate 7 in their respective directions. This illustrates the relative uniformity of weight percentage with respect to direction. It can be seen that the percentage distribution is least uniform in the inferred direction of glacier movement (i.e. two sets of striae), and becomes increasingly uniform as the angle from this direction is increased. The fact that the greatest deviation points in the direction of the striae indicates the probability of direct effect by transportation. When considered in view of the information presented in the next section, it can be seen that the variability shown here is the result of dilution of the heavy mineral suite. This, however, does not invalidate its usefulness as an indicator of the direction of former ice movement.

Percentage of magnetics

The distribution of magnetics is quite similar to that of the weight percentage of heavy minerals. Again, the pattern is particularly well developed at sites 3 and 4.

This well defined north-south pattern shown by the percentage of magnetics suggests that geophysical methods of measuring magnetic deviations in drift can be of value in glacial mapping of this region. Geophysical studies of this type have been conducted by T.A. Lawler and Dr. W.J. Hinze over the lower penninsula of Michigan (personal communication).

Heavy mineral percentages by count

Heavy minerals identified, their relative abundance, and the total number counted for each sample site are given in Table 5. The order of the sample sites, as listed in the table, is from north to south.

The percentages of heavy minerals calculated from the entire assemblage reveals that the quantity of opaque minerals generally increases toward the south. This increase, however, is rather sporadic. Connally (1959) has reported that stratified drift is also diluted by opaques in the southern part of the area studied. In the present investigation the mineral percentages are calculated with respect to all heavies and also without the opaques. The latter is done to eliminate the effects of dilution and to expose possible systematic variations in the remaining assemblage over the study area.

Percentage profiles have been drawn along lines parallel and transverse to the assumed direction of glacier movement. The minerals considered are hornblende, hypersthene and garnet. (Plates 8, 9, 10, and 11). There is a general but irregular decrease in hornblende from north to south. A good correspondence exists between the proportions for the southern part of I - I' (sites 20, 22, 17, and 15). No such correspondence is apparent along III - III' (Plate 10).

Along the northernmost east-west line (A - A', Plate 8) there is close correspondence between percentage of hornblende and hypersthene. Garnet, however, shows an inverse relationship. The more southerly of the east-west lines, (C - C') does not show the hornblende and hypersthene correspondence, but it does reveal the inverse relationship between hypersthene and garnet.

Table 5. Distribution and frequency of minerals

Sample Site	Hornblende	Monoclinic Pyroxene	Hypersthene	Pigeonite	Enstatite	Tremolite	Clear garnet	Red garnet	Titanite	Zircon	Rutile	Sillimanite	Muscovite	Chlorite	Pyrite	Leucoxene	Dark opaques	Hematite and limonite	Epidote	Greenalite(?)-serpophite(?)	Total
13	A	S	C		S	R	S	S	R	R	R				R	R	S	R			332
12	A	F	C		S	R	F	R	S	R						R	R	R	R		301
19	A	C	F		R		C	S	R	R	R				R	S	S	S			371
18	A	C	C				C	R	R		R	R			R	S	S	R		R	329
11	A	F	F		R		C	R	R	R	R				R	S	F	R			330
20	A	F	F		R		F	R	R						A	R	F	R			325
4	A	C	S		R	R	C	F	R	R	R				R	S	F	R			312
3	A	F	F		R	R	F	R	R	R		R	R	R	A	R	F	R			306
21	A	A	F		R		C	S	R	R	R				R	S	F	R			352
22	A	C	F	R	R		F	R	R	R					C	S	F	R			333
1	A	F	F	R	R	R	F	R	S				R		A	S	S				343
23	A	F	C		R	R	C	R	R	R					F	R	S	R			331
17	A	S	F		R	R	F	S	R	R			R		A	F	F	R		R	351
7	A	F	S			R	C	S	S		R					S	A	R			332
8	A	F	F		R	R	F	R	R	R	R				C	F	F	R			320
5	A	F	F		R	R	C	R	S				R		R	A	F	R			303
24	A	F	S		R	R	F	R	R				R		A	R	F	R			342
15	A	R	S		R	R	S	R	R	R	R		S		F	A	S	R			429
16	A	F	S		R	R	C	R	R	R	R		R		C	F	F	R		R	342
9	A	R	S		R		S	R	R	R	R				S	A	S	S			362
10	A	R	R		R	R	S	R	R	R	R			R	R	A	R	S			469
14	C		R				R		R	R	R	R	F		R	A	S	R		F	478

A	18%	Abundant
C	12 - 18%	Common
F	6 - 12%	Frequent
S	3 - 6%	Scarce
R	1 - 3%	Rare

To determine if these values constitute a pattern relating to a direction of ice movement, a statistic is calculated that measures the degree of regularity of change in the proportion of heavy minerals over the entire area. This is then compared to the same statistic along given lines. The statistic used is Pearson's <u>Coefficient of variation</u> (Moroney, p. 64) defined as:

$$v = \frac{100\,S}{\bar{X}}$$

where v = coefficient of variation
S = Standard deviation
$\bar{X}$ = Sample mean

This statistic shows the deviation about the mean, in proportion to the size of the sample. It thus provides a measure of variance by which the different minerals can be compared. The coefficients of variation are listed in table 6.

Table 6. Coefficient of variation of heavy mineral percentages.

Mineral	all samples	Along V - V'	Along I - I'	Along A - A'	Along C - C'
Hornblende	11.3	9.4	15.3	7.9	10.6
Monoclinic pyroxene	43.3	35.4	61.3	20.3	35.9
Hypersthene	37.8	15.1	17.1	25.5	34.9
Clear garnet	35.2	28.3	25.6	17.1	15.5
Red garnet	52.5	2.6	28.7	67.5	42.3
Titanite	51.1	43.2	49.7	51.2	34.4
Total	231.2	134.4	197.7	189.6	182.6
Mean	38.5	22.4	32.9	31.6	30.4

In comparing the values for the coefficient of variation for all samples with those along specified lines in conjunction with the four profile lines, it is apparent that the variations are not sufficiently consistent with areal distribution to have arisen from purely mechanical effects of transport. Distribution of grain size and shape further indicate that in the drift transportation effects are non-systematic. Similar results have also been shown by Connally (1959).

When considered with respect to the glacial stratigraphy of the study area the heavy mineral percentage profiles do not show clear-cut relationships to the drift sheets as delineated by Connally, (1961).

Along north-south line I - I' there is a linear decrease in hornblende. This is true only across the northern half of the region (sites 13, 20, and 22). At site 22, however, the percentages of the three minerals plotted are nearly identical to those at site 15. In contrast, those at site 17 are nearly the same as at site 20. Examination of the map in Plate 7 shows that site 17 is well above the terminus of Valley Heads glaciation. Site 22, however, is positioned near the terminus. The low content of heavy minerals, here, would at first view seem to indicate a possible relation to older tills to the south.

It is probable that this apparent correlation between proportions of heavy minerals in the till and known glaciations is coincidental since it does not hold true for a large number of samples. The evidence is inconclusive and there are many exceptions. If such a correlation does exist, it is more likely due to erosive and depositional conditions during the respective glaciations.

The pattern along III - III' is not as well displayed due to the high garnet percentage at site 4, and the relatively high hornblende percentage at site 9. Site 4 occurs again along line A - A', causing the same apparent inverse relationship between garnet and the other two minerals, hornblende and hypersthene. This relationship is further displayed along line C - C' at site 7, with respect to garnet and hypersthene.

The percentage isopleth map of garnet distribution is given in Plate 12. This was drawn from data including the opaque minerals. It shows a distribution with a general alignment in a north-northwest/south-southeast direction, and an over-all north to south decrease. Hornblende, (Plate 13), the most abundant and uniformly distributed mineral when similarly calculated, shows a north-south decrease with only a small high percentage lobe in the north. Hypersthene, Plate 14, in this case does not appear to be distributed by any sensible pattern.

When the opaques are subtracted and the percentages determined on the basis of non-opaques only, the influence of the north-south decrease in total percentage is reduced and the pattern stands out more strongly. The map showing garnet percentages has been drawn (Plate 15) to show that a corresponding relation between heavy mineral distribution and drainage lines is strongly suggested. This correspondence may not be as close as is suggested by the map. Alternate contouring methods could cause this relationship to be less obvious but not eliminated. Many more stations would have to be examined to determine how close a correspondence truly exists.

The distribution of hypersthene, when re-calculated to eliminate the influence of opaque minerals, indicates a possible east-west lobal pattern. The significance of this pattern, if any, is not readily apparent (Plate 16).

Hornblende, with dilution by opaques eliminated, is very evenly distributed over the area of study as shown in Plate 17.

The sample from site 14, has been strongly influenced by an exotic heavy mineral suite. It has, therefore, been excluded from the consideration of percentages of garnet and hypersthene. These minerals have been so strongly diluted that their percentage frequency is misleading.

Variability

Three possible causes of variability among heavy mineral assemblages are attrition during glacial transportation, post-depositional alteration of unstable minerals, and local contamination. Each of these factors is considered with reference to the western Finger Lakes region.

1. Attrition: Attrition of heavy mineral grains, if a significant factor, would result in increase or decrease in the proportion of one or more minerals. The distribution would be either a linear or an exponential function in the direction of ice movement. It should also be more or less uniform parallel to the glacier front. In this investigation, the relationships between mineral content at sample sites show no such distribution pattern.

2. Chemical Alteration: Pettijohn (1949, p. 676) points out that in going from older to younger sediments in the geoligic column, heavy mineral suites appear to increase in complexity. The appearance of minerals in the younger rocks is in reverse order of their chemical stability "as determined by other independent observations" (e.g. the Bowen reaction series).

Decay by the process of intrastratal solution is believed by Connally (1959) to have taken place at an accelerated rate during the Pleistocene. He has reported decomposition of heavy minerals in reverse order of their stability as a cause of mineral frequency in stratified drifts of western New York. In the better sorted and comparatively coarse glaciofluvial deposits, it appears that rapid decomposition can take place, while in dense, heterogeneous tills, intrastratal solution is greatly retarded.

3. Contamination: Progressive dilution of the light mineral fraction is well known to exist in glacial deposits. According to Holmes (1952) in west central New York "more than 90% of the exposed drift was transported less than 50 miles." In the region investigated, the drift is dominantly composed of material derived from the underlying Devonian sediments.

Possible sources of contamination

The bedrock of the western Finger Lakes region consists largely of shales and siltstones which could not contribute great amounts to a sand-sized heavy mineral suite. There are, however, seven lithologic units which crop out in the area of investigation that contain one or more sandstone beds. These are the Sherburne Flagstone and the Ithaca Shale members of the Genesee Formation. Also included are arenaceous beds in the Hatch and Grimes sandstones and shales and the Nunda Sandstone, all of the Portage (West Falls) Formation. Other arenaceous units are the Prattsburg Sandstone, the Oneota Sandstone, Portage or Chemung in age and the Wellsville Sandstone of Chemung age. It is not inconceivable, then, that some contamination of the sand fraction of the heavy minerals could occur from the local bedrock. The local Devonian sediments may be the source of the increase of opaque minerals toward the south. On this basis, the dilution effects of opaque minerals may be largely eliminated by re-calculation of heavy mineral values excluding the opaques.

It is not clear to what extent the remainder of the heavy mineral assemblage has been altered by contributions from the bedrock.

In a petrologic study of the sediments of the Genesee Gorge in Rochester, Alling (1946) found that the formations from the Queenston through the Lockport contained rather large amounts of Pyrite, marcasite, leucoxene, and zircon, as well as, minor amounts of hypersthene, diopside, rutile, magnetite, garnet and other heavy minerals. Many of these minerals do not, however, occur in sand-sized grains. The Grimsby does contain sand-sized materials and some of the heavy minerals mentioned above. The overlying Thorold, thought to be re-worked Grimsby, contains a richer suite of heavy minerals, although somewhat finer grained than the Grimsby.

Mica peridotite dikes have been found in the vicinity of Ithaca and along the west side of Cayuga Lake (Williams, Tarr and Kindle, 1909). The emplacement of these dikes is controlled by a generally north-south joint system. Their strike is within the directional variation of glacier movement previously mentioned. The original peridotite has been highly altered (Johansen, in Williams, Tarr and Kindle). Olivine has been altered to serpentine or talc. One of these dikes, exposed in Glenwood Creek, west of Cayuga Lake, has produced some alteration of adjacent shale and sandstone. A similar intrusive might be responsible for the unusually high mica content (10%) at site 14. The sample at this locality also contains the mineral tentatively identified as greenalite or serpophite. The latter could be an alteration product of olivine.

Igneous bodies such as a pipelike mass in Syracuse, reported as a possible diatreme by Apfel, Maynard and Ploger (1951), could even provide other sources of contamination if undiscovered similar bodies were to occur in the area being considered.

From the available evidence, these possible sources of drift contamination cannot be discounted.

The over-all distribution of heavy minerals in these tills indicates basal contamination. It is suggested that during phases of the multiple glaciation in the western Finger Lakes region, the glaciers picked up and transported sand-sized material from interstadial deposits

of glaciofluvial and/or fluvial sands and gravels. Such deposits would serve as local sources of concentrated sand-sized heavy mineral grains. Nearly the entire area of this study is located in the northern portion of the well-dissected Allegheny Plateau. The mature topography of this plateau provided many valleys in which thick deposits of sand and gravel formed. These conditions are further suggested by the following:

VonEngeln (1929) described a fluvial gravel in sandstone flutings in the Sixmile Creek valley, southeast of Ithaca. He considered this deposit interglacial, and the consequence of northward ponding of the stream by glacial re-advance. Later erosion excavated most of the channel filling. The gravel then became incorporated as part of the englacial debris, much of it being re-deposited as till.

Another incidence of an interglacial gravel in central New York has been cited by Schmidt (1947). This deposit contains rounded till stones. A glacier, overriding such a deposit, would incorporate grains having a degree of rounding commensurate with those which had later been carried southward from their common provenance. In the present considerations, such conditions are borne out by the fact that nowhere is an increase in angularity observed.

In summary the areal distribution of heavy mineral percentages, their relationship to fluvial drainage channels and to directions of former glacial movement (as shown by isopleth maps) are explained by the processes of basal contamination in glacially transported, waterlaid sands and gravels.

Heavy mineral ratios

Ratios between the percentages of heavy minerals are calculated for the purpose of determining whether or not the process of intrastratal solution has been effective in the rapid decomposition of the till. The abundance of each mineral which occurs in sufficient quantity to be considered statistically valid is proportioned to the abundance of every other mineral. In no case are the heavy mineral ratios found to differ significantly with the age of till. The chemically unstable amphiboles and pyroxenes are found to be no less frequent with respect to garnet in the older tills than they are in the youngest. With the completely overlapping range of values, no confidence limit can be chosen that will significantly differentiate them.

By plotting the ratio values as isopleths, it is apparent that most of them display a roughly inverse pattern to the percentage of garnet. The clear garnet/red garnet ratio, however, does show an increase in red garnet in the area near the center of the map (Plate 18). This parallels, and is nearly superimposed on, the area of Honoye Creek and the Cohocton River. This area corresponds with that of the high over-all garnet content which has been discussed earlier (illustrated in Plate 15).

SUMMARY AND CONCLUSIONS

The tills sampled in this investigation contain a heavy mineral suite characteristic of the Grenville metasediments of eastern Ontario and the Adirondack region of New York. A common provenance is thus inferred for the heavy minerals in each of the drift sheets considered. The drift of the western Finger Lakes region is related to that of the Erie-Ontario Glacial Lobe, as differentiated from the Huron Glacial Lobe by Driemanis, et. al. (1957) on the basis of heavy minerals.

Observations made from the present study, regarding the distribution of component materials of the tills, are summarized below:

A. The size frequency distribution of sand-sized material is nonsystematic. This supports previous knowledge that rapid change of materials in the light fraction takes place during transport.

B. Heavy mineral assemblages by weight can be evaluated in terms of direction by means of calculating the mean deviation of the percentage by weight along chosen lines. Such analysis reveals the greatest mean deviation in a south-southeast direction. This deviation becomes less as a line normal to this direction is approached.

C. Percentages of specific heavy minerals, as calculated from the total heavy mineral assemblage, reveal an inverse relationship between garnet and hypersthene and a direct relationship between hornblende and hypersthene (Plates 8, 9, 10, and 11).

D. The distribution of heavy minerals along specific map transects can be compared with the regional distribution by using Pearson's coefficient of variation. The values are not sufficiently consistent with the areal distribution to have resulted from purely mechanical changes due to transport. Nor do they reveal any relationship to known ages of the drift.

E. The ratios between different heavy minerals in undisturbed tills of Pleistocene age indicate that decomposition of unstable minerals is taking place at a much slower rate than in relatively coarse, waterlaid glacio-fluvial deposits of the same age.

F. Patterns revealed by the heavy mineral isopleth maps can be placed in one of four categories:

1. A general north to south decrease in weight percentages: shown by both magnetics and nonmagnetics (Plates 5 and 6) and by percentages of hornblende to hypersthene as calculated from the entire assemblage including opaque minerals (Plates 13 and 14).

2. North-northwest/south-southeast alignment: revealed, principally, by the garnet distribution (Plates 12, 15, and 18).

3. A more or less east to west variation: displayed by hypersthene. This pattern is not well defined (Plates 14 and 16).

4. Random-uniform distribution: shown by the distribution of the most abundant mineral, hornblende, after eliminating the effect of dilution by opaques (Plate 17).

Although an element of subjectivity is involved in the construction of contour maps from any such data, the writer considers that the south-southeast alignment in the percentage distribution of heavy minerals is nevertheless well justified. It is significant that this alignment is especially revealed in the distribution of garnet, a relatively stable mineral. This indicates that fluvial control of the distribution of heavy minerals, by concentrating sand-sized material from former drift in selective drainage channels, is probably the most important factor in the present distribution. It is also compatable with the findings to state that movement of ice has taken place largely in a southeasterly direction; in conformity with many of the geomorphic patterns, including some of the bedrock striations.

On the Ontario Plain, to the north, a southwesterly trend of glacial movement is indicated by the orientation of drumlins. On the Allegheny Plateau, however, deviations from the dominantly southeastward trend were probably minor and locally controlled. These somewhat opposing directions of movement in the two areas appear not unreasonable when the influence of pre-glacial topography is considered. The ice which emerged radially from the Ontario Basin

(Holmes, 1952) streamed outward in a direction parallel to the main drainage channels which today form Honeoye Creek, the Cohocton and Canisteo rivers and those streams that were deepened and widened by the passage of ice to form the present-day finger lakes of Cayuga, Seneca and Hemlock.

The impermeable nature of the undisturbed tills considered in this study, has prevented extensive percolation of ground water. The process of intrastratal solution, which appears to have produced substantial disintegration of unstable minerals in the more permeable stratified sands and gravels studied by Connally (1959), has apparently not occurred within the tills. It follows that age dating of the glacial drift by means of heavy minerals must be confined to the better sorted glaciofluvial deposits.

In tills of western New York, important contributions to the heavy mineral suite have been distributed and concentrated in accordance with the main drainage lines and the regional topography.

SUGGESTIONS FOR ADDITIONAL RESEARCH

This study is considered preliminary to further research in the distribution of materials in glacial tills. It illustrates that heavy mineral analysis of tills can be useful in differentiating drift sheets of different provenance.

The applicability of methods, such as the mean deviation of the weight percentage of heavy minerals as an indicator of direction of glacial transport, needs verification by further analysis of carefully located samples in areas where the directions of former ice movement can be, or have been determined by other evidence.

Heavy minerals from closely-spaced, carefully chosen samples of till, obtained along lines of known glacial or interstadial drainage, should yield detailed information regarding the association of heavy minerals in tills conditioned by earlier fluvial and/or glaciofluvial action. Such knowledge can be of value in the reconstruction of glacial history in areas where subsequent advances producing later tills, have altered or destroyed other lines of evidence.

REFERENCES

Alling, H. L., 1946, Quantitative petrology of the Genesee gorge sediments, Proc. Roch. Acad. Sci., vol. 9, no. 1, pp. 5-64.

Apfel, E. T., J. E. Maynard and L. W. Ploger, 1951, Possible diatreme in Syracuse, New York (abs.): Geol. Soc. Am. Bull., vol. 62, no. 12, pt. 2, pp. 1421, Dec.

Bloss, F. D., 1961, An introduction to the methods of optical crystallography: Hold, Rinehart and Winston, New York.

Chamberlin, T. C. 1883, Terminal Moraine of the second glacial period: U. S. Geol. Survey, 3rd Ann. Rept., pp. 351-360.

Connally, G. G., 1962, The glacial geology of the western Finger Lakes region, New York: Progress rept. no. II (unpublished paper).

Connally, G. G., 1959, Heavy minerals in the glacial drift of western New York: Proc. Roch. Acad. Sci., vol. 10, no. 5, pp. 241-278.

Denny, C. S., 1956, Wisconsin drifts in the Elmira region, New York and their possible equivalents in New England: Am. Jour. Sci., vol. 254, pp. 82-93.

Dewitt, Walace Jr., and G. W. Colton, 1959, Revised correlations of Lower Upper Devonian Rocks in western and central New York: Am. Assoc. Petroleum Geologists, vol. 43, no. 12, pp. 2810-2828.

Dixon, W. J., and F. J. Massey Jr., 1957, Introduction to statistical analysis, second ed., McGraw Hill Book Co., Inc., New York.

Dreimanis,-A., G. H. Reavely, R. J. B. Cook, K. S. Knox and F. J. Moretti, 1957, Heavy mineral studies in tills of Ontario and adjacent areas: Jour. Sed. Pet., vol. 27, no. 2, pp. 148-161.

Fairchild, H. L., 1932, New York, moraines: Geol. Soc. Am. Bull., vol. 43, pp. 627-662.

Holmes, C. D., 1952, Drift Dispersion in west-central New York: Geol. Soc. Am. Bull., vol. 63, pp. 993-1010.

Krumbein, W. C. and F. J. Pettijohn, 1938, Manual of sedimentary petrography, Appleton-Century-Crofts, Inc., New York.

Larsen, E. S., and Harry Berman, 1934, The microscopic determination of the nonopaque minerals; Second ed., U.S. Geol. Survey Bull. 848, U.S. Govt. Printing Off., Washington.

Lawler, T. A., 1962, A field investigation of the magnetic disturbances from glacial drifts in Michigan; Masters Thesis, Michigan State University (in manuscript).

MacClintock, Paul and E. A. Apfel, 1944, Correlation of the drifts of the Salamanca re-entrant, New York: Geol. Soc. Am. Bull., vol. 55, pp. 1143-1164.

Miller, W. J., 1914, Geological history of New York State: New York State Mus. Bull. 168.

Milner, H. B., 1940, Sedimentary Petrography: Third ed., Thomas Murby and Co., London.

Monnett, V. E., 1924, Finger Lakes of central New York: Am. Jour. Sci., vol. 8, pp. 33-53.

Moroney, M. J., 1960, Facts from figures: Third revised edition, Penguin Books. Baltimore.

Pettijohn, F. J., 1957, Sedimentary rocks: Harper and Bros. New York.

Rogers, A. F., and P. F. Kerr, 1942, Optical Mineralogy, Second ed., McGraw Hill Book Co., New York.

Schmidt, V. E., 1947, Boulders of interglacial conglomerate in central New York: Am. Jour. Sci., vol. 245, no. 2, pp. 127-133.

Tarr, R. S., 190 , Drainage features of central New York: Geol. Soc. Am. Bull., vol. 16, pp. 229-242.

Twenhofel, W. H., and S. A. Tyler, 1941, Methods of study of sediments: McGraw-Hill Book Co., New York.

VonEngeln, O. D., 1929, Interglacial deposit in central New York: Geol. Soc. Am. Bull., vol. 40, pp. 469-480.

Wahlstrom, E. E., 1955, Petrographic Mineralogy: John Wiley and Sons, Inc., New York.

Williams, H. S., R. S. Tarr, and E. M. Kindle, 1909, Description of the Watkins Glen-Catatonk district: U.S. Geol. Survey, Geol. Atlas, Folio no 169, 33 p.

Plate 1. Histograms of size frequency distribution.

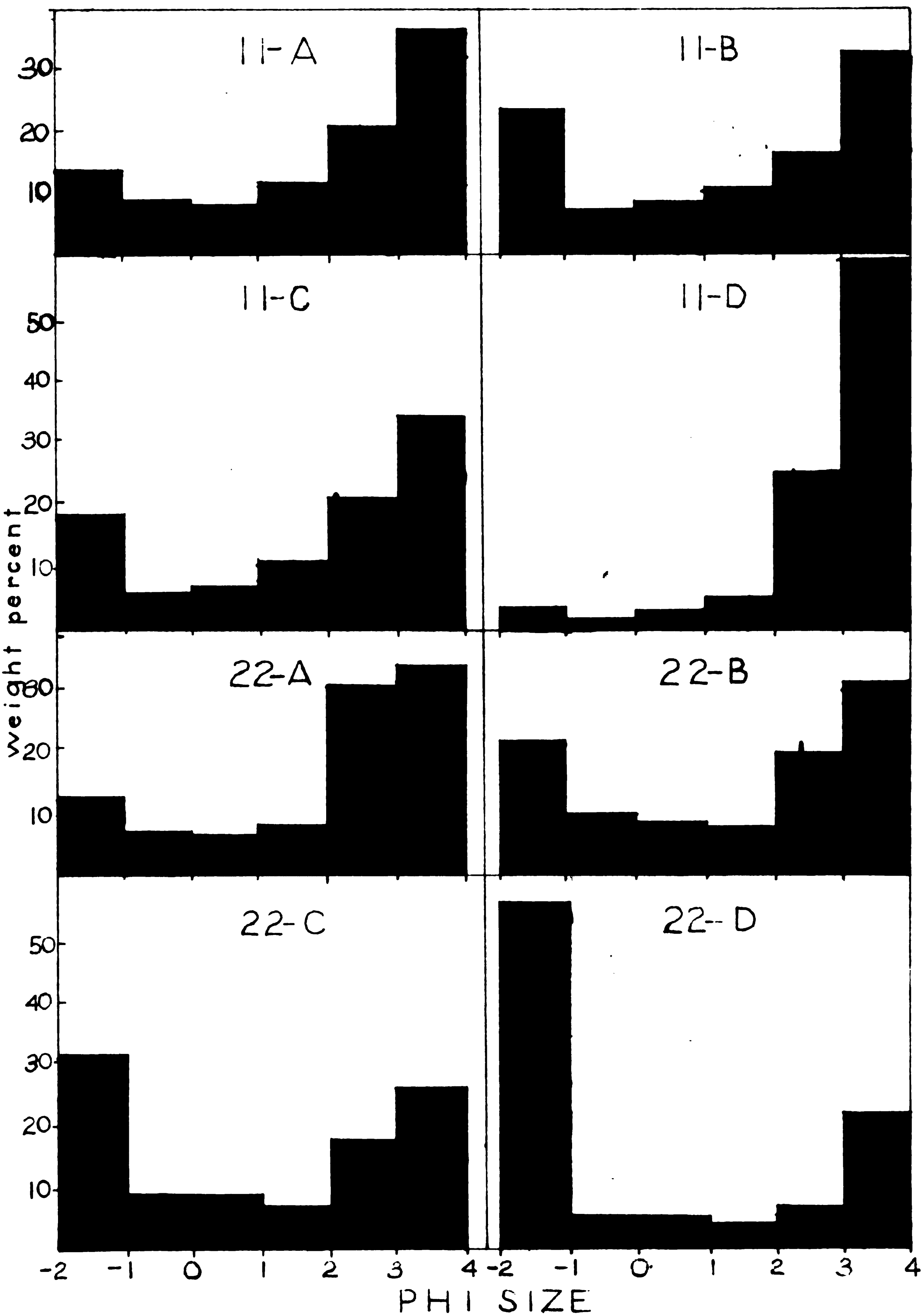


Plate 2. Histograms of size frequency distribution.

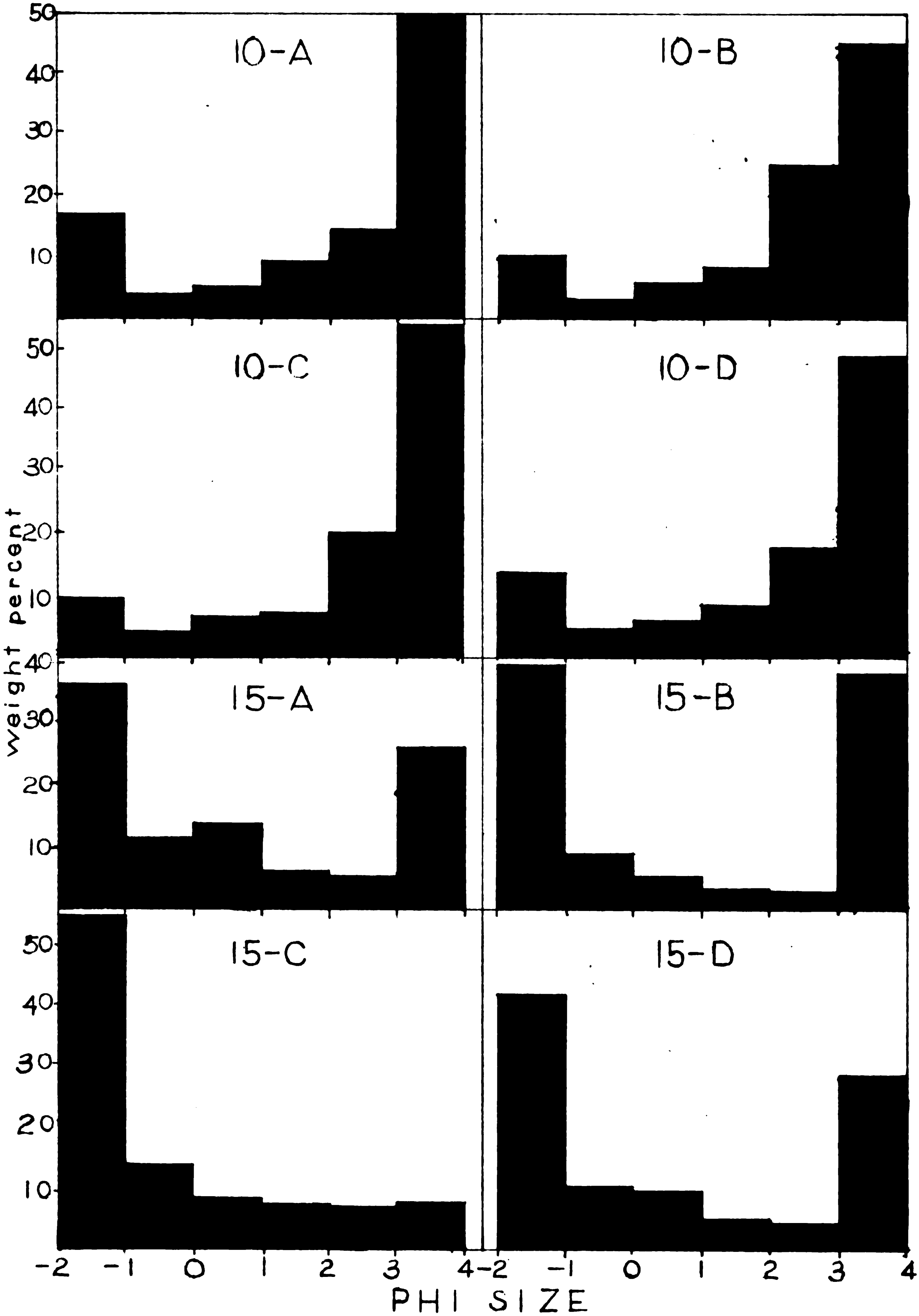


Plate 5. Cumulative curves of size frequency distribution.

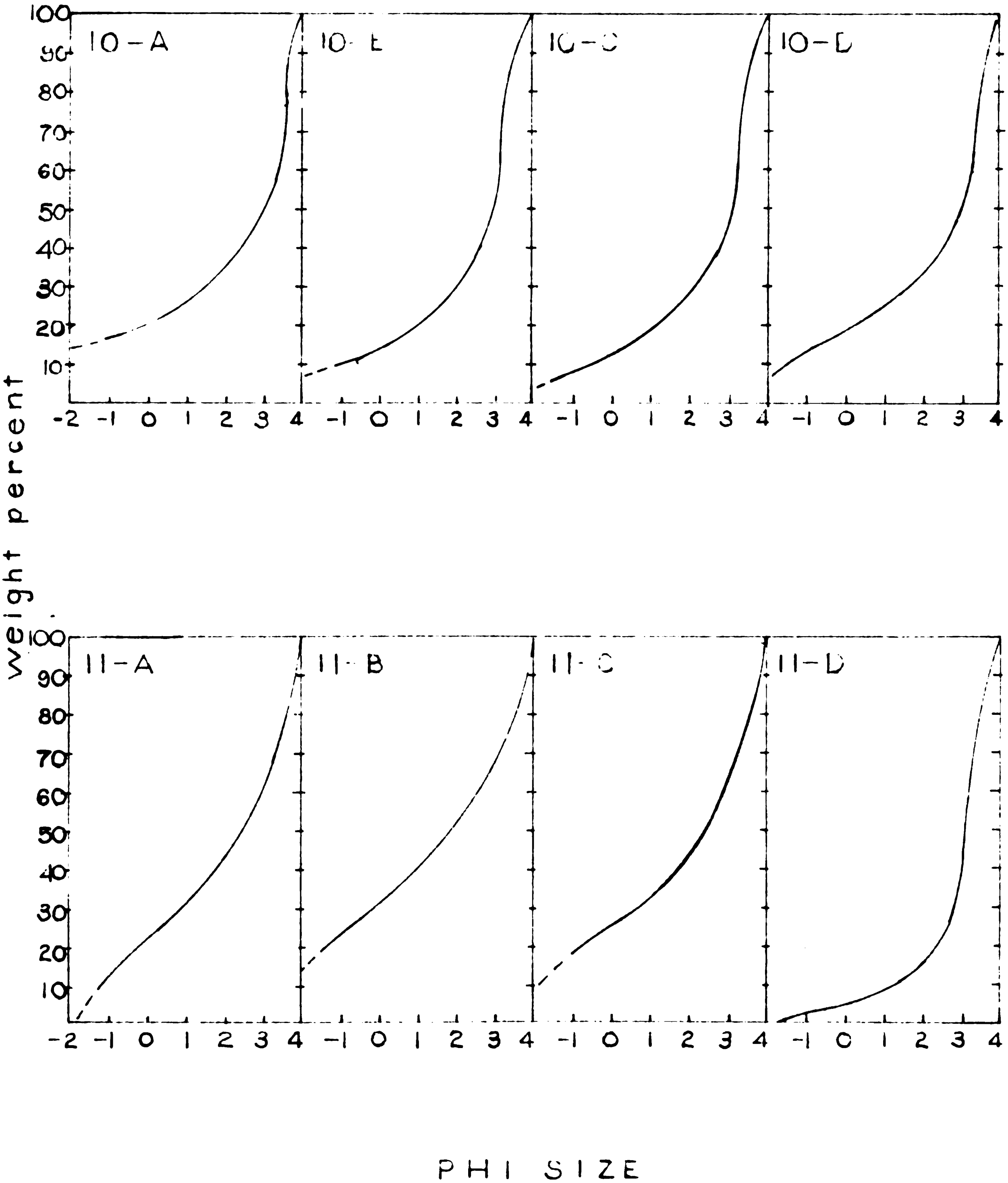


Plate 4. Cumulative curves of size frequency distribution.

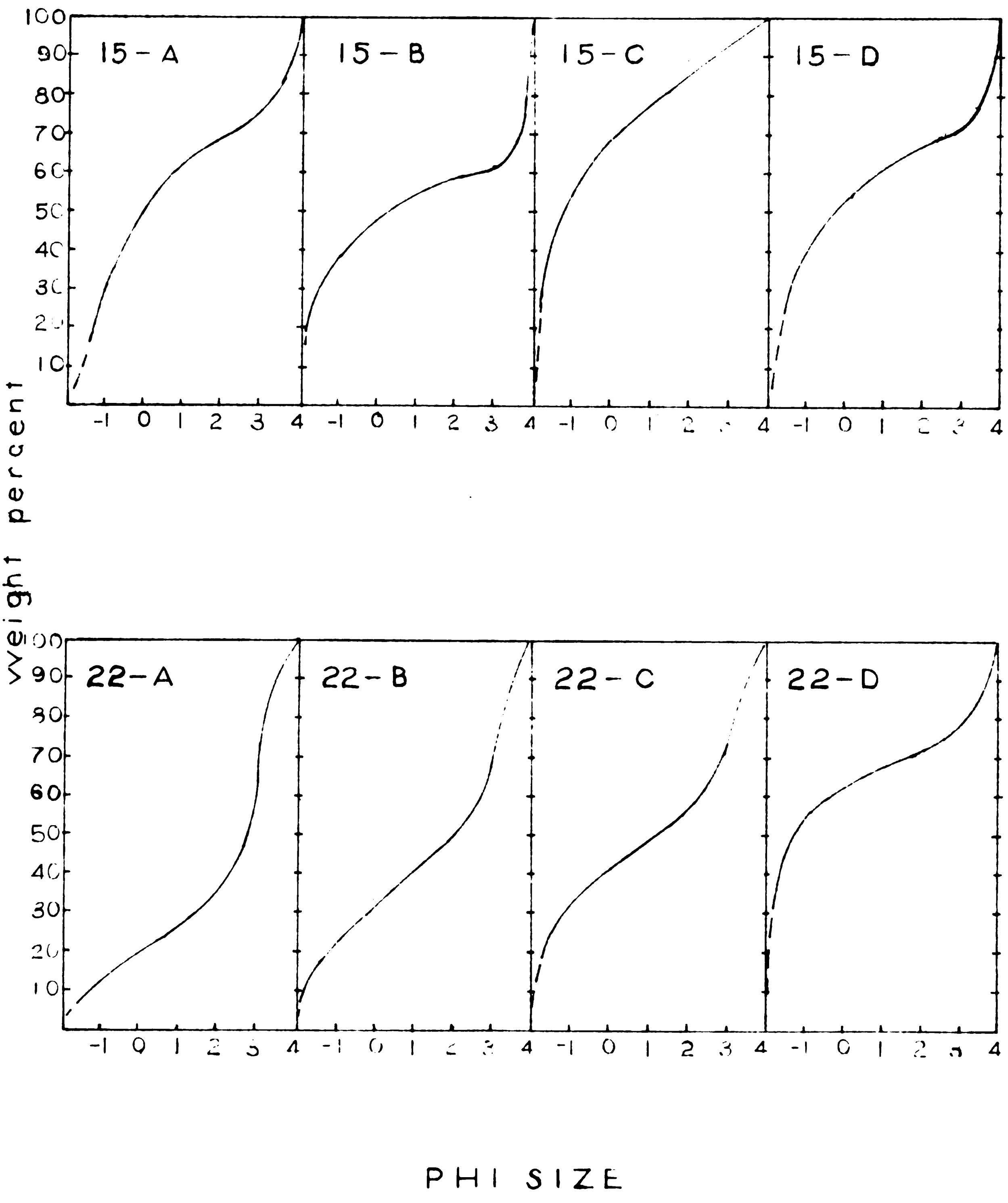


Plate 5. Isopleth map showing percentage by weight of heavy minerals. Sample sites are indicated by number.

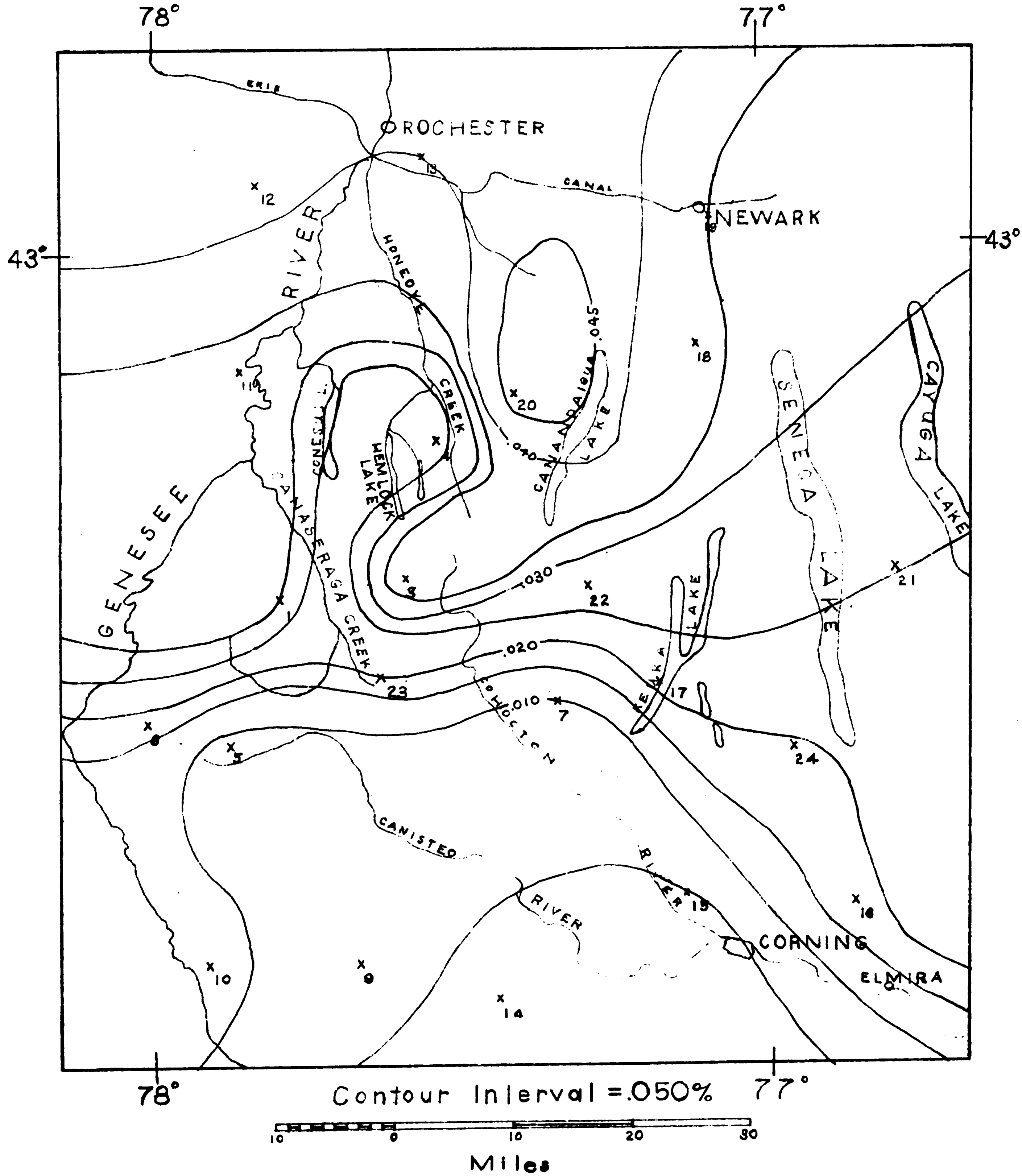


Plate 6. Isopleth map showing percentage by weight of magnetics.

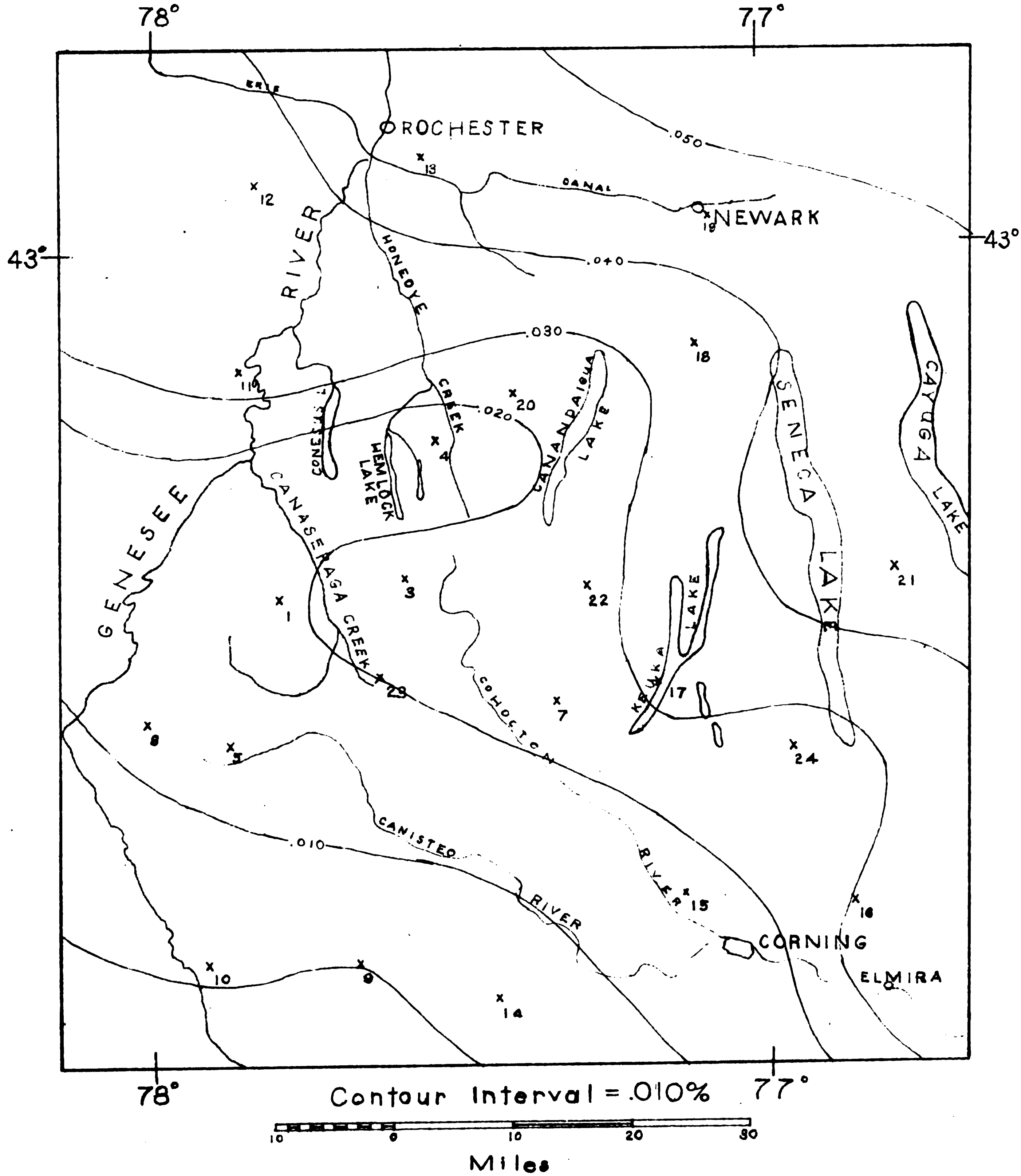


Plate 7. Index map showing [illegible] profile lines [illegible] which the [illegible] of the [illegible] calculated. Length of the barbed lines depicts [illegible] direction. Terminal [illegible] localities. [illegible]

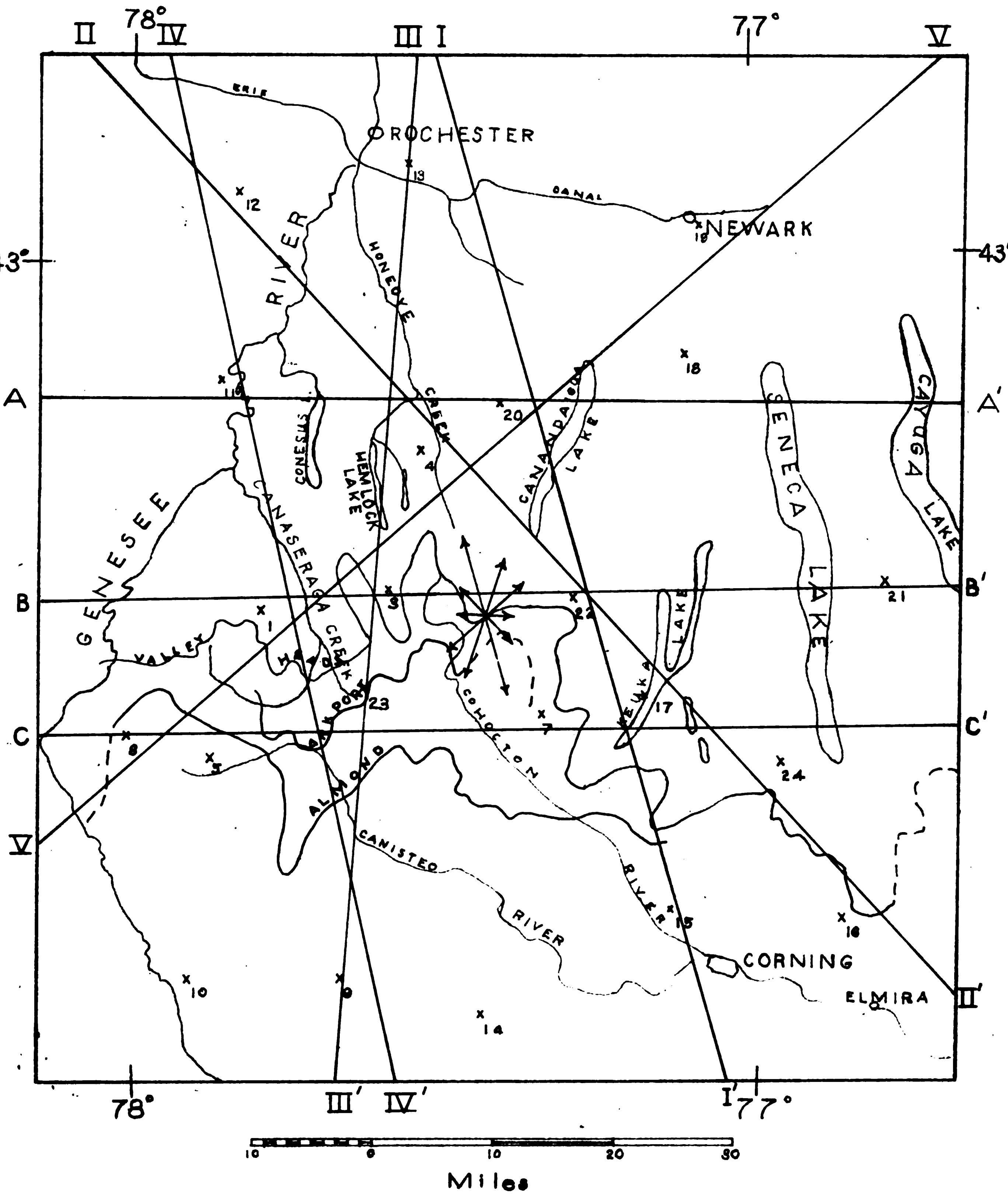
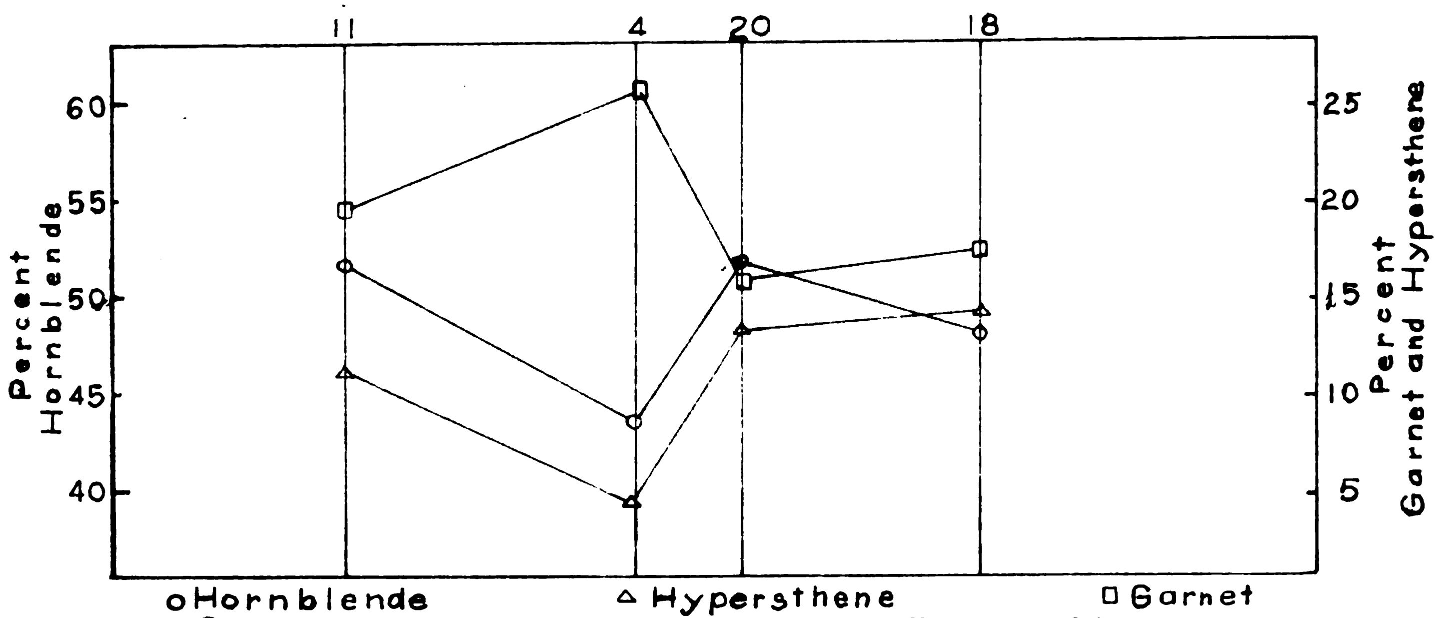


Plate 8. Percentage profile along A - A'.



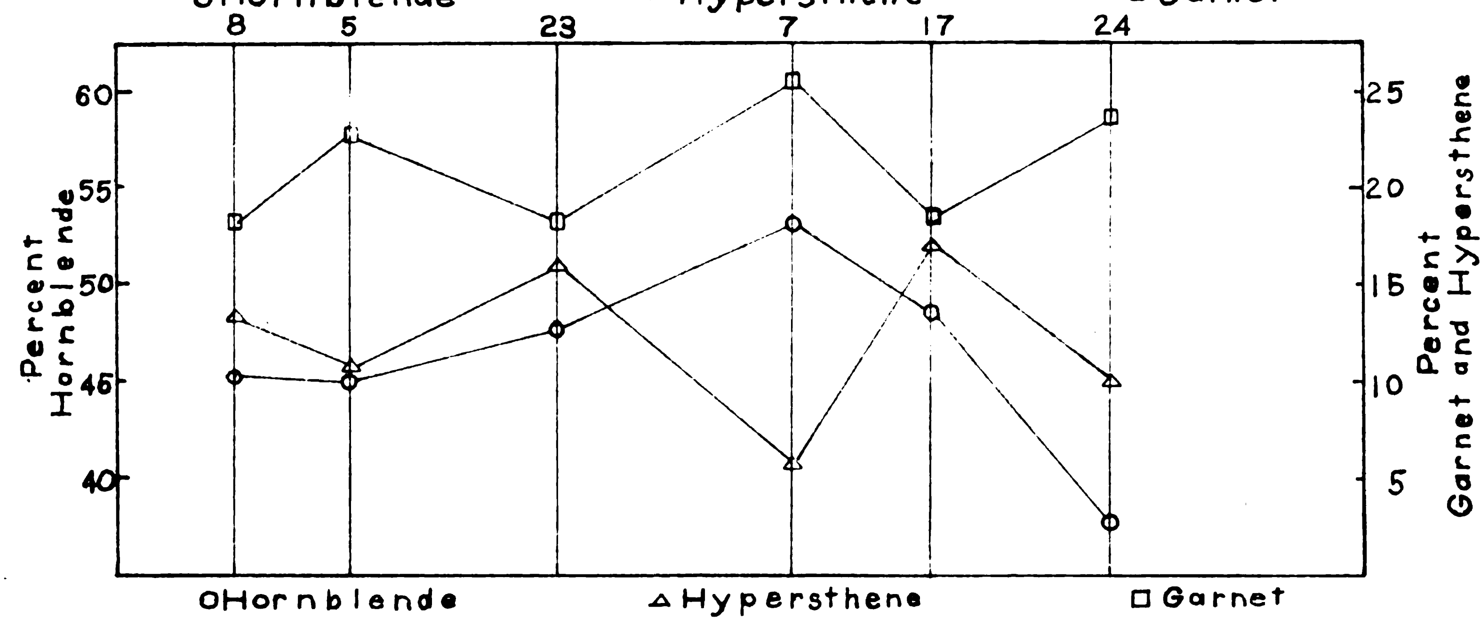
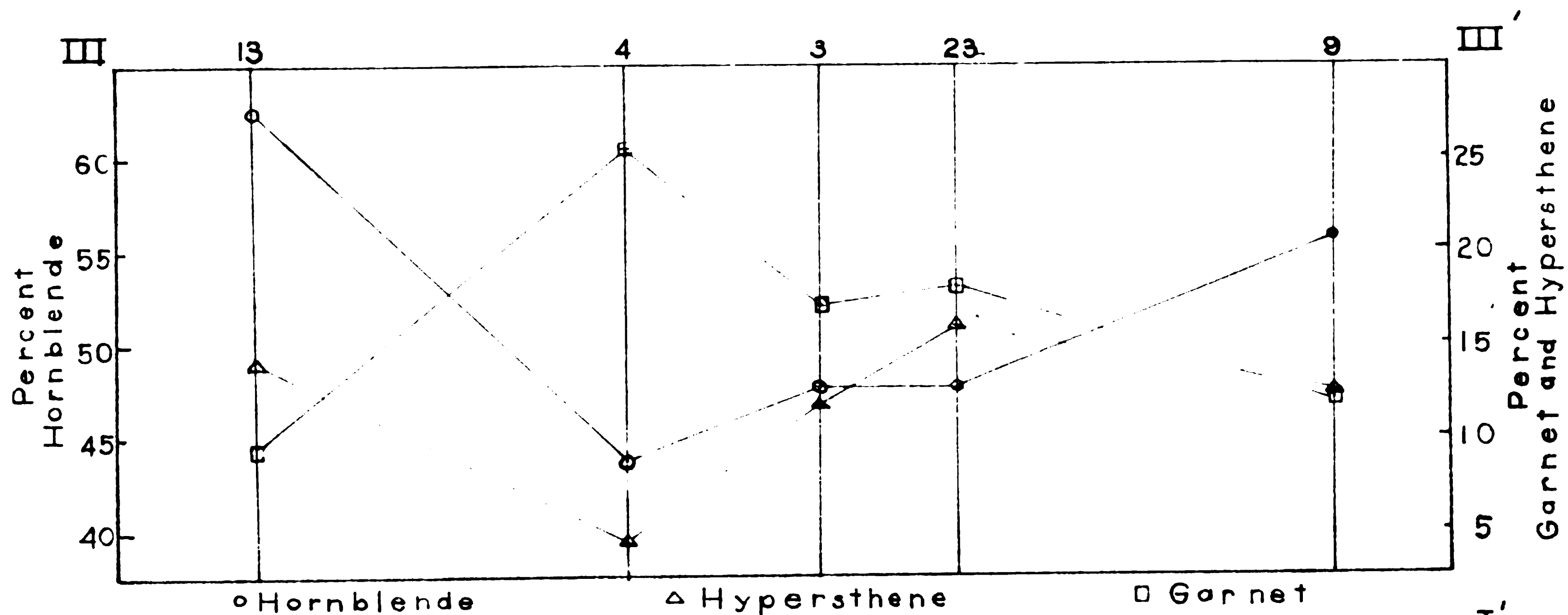


Plate 9. Percentage profile along C - C'.

Plate 10. Percentage profile along III - III'.



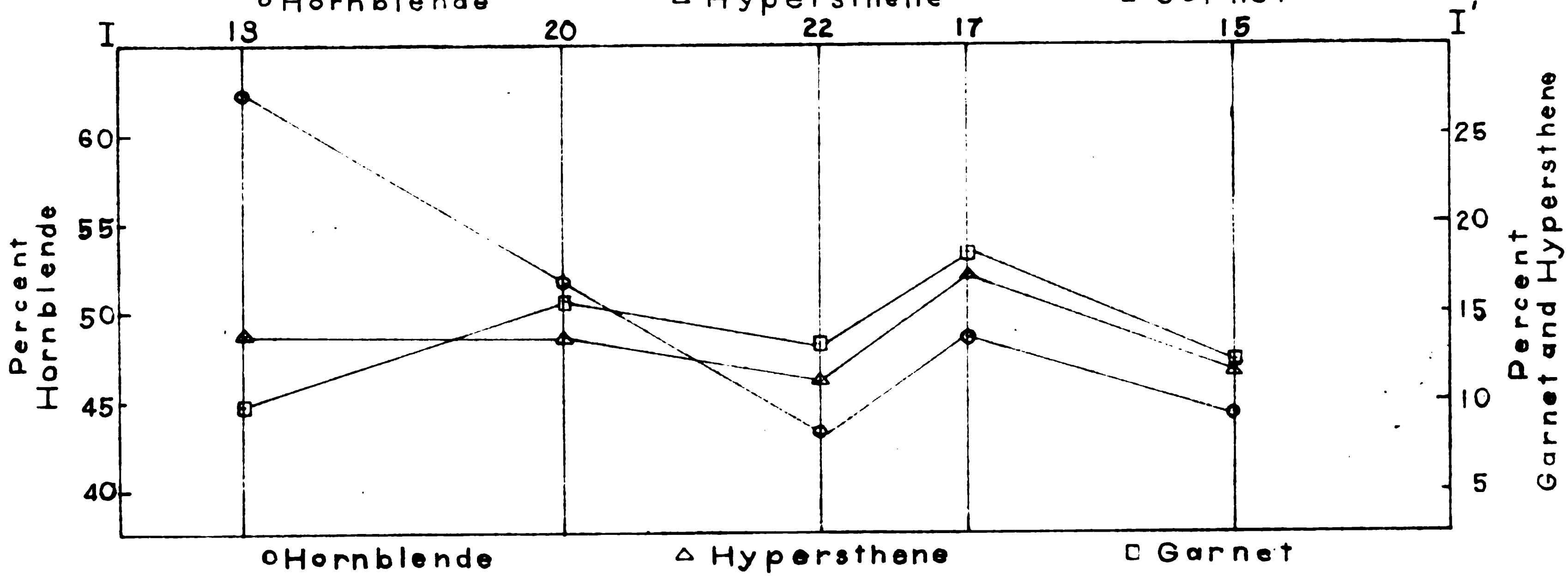


Plate 11. Percentage profile along I - I'.

Plate 12. Isopleth map of garnet percentage, including the opaque minerals.

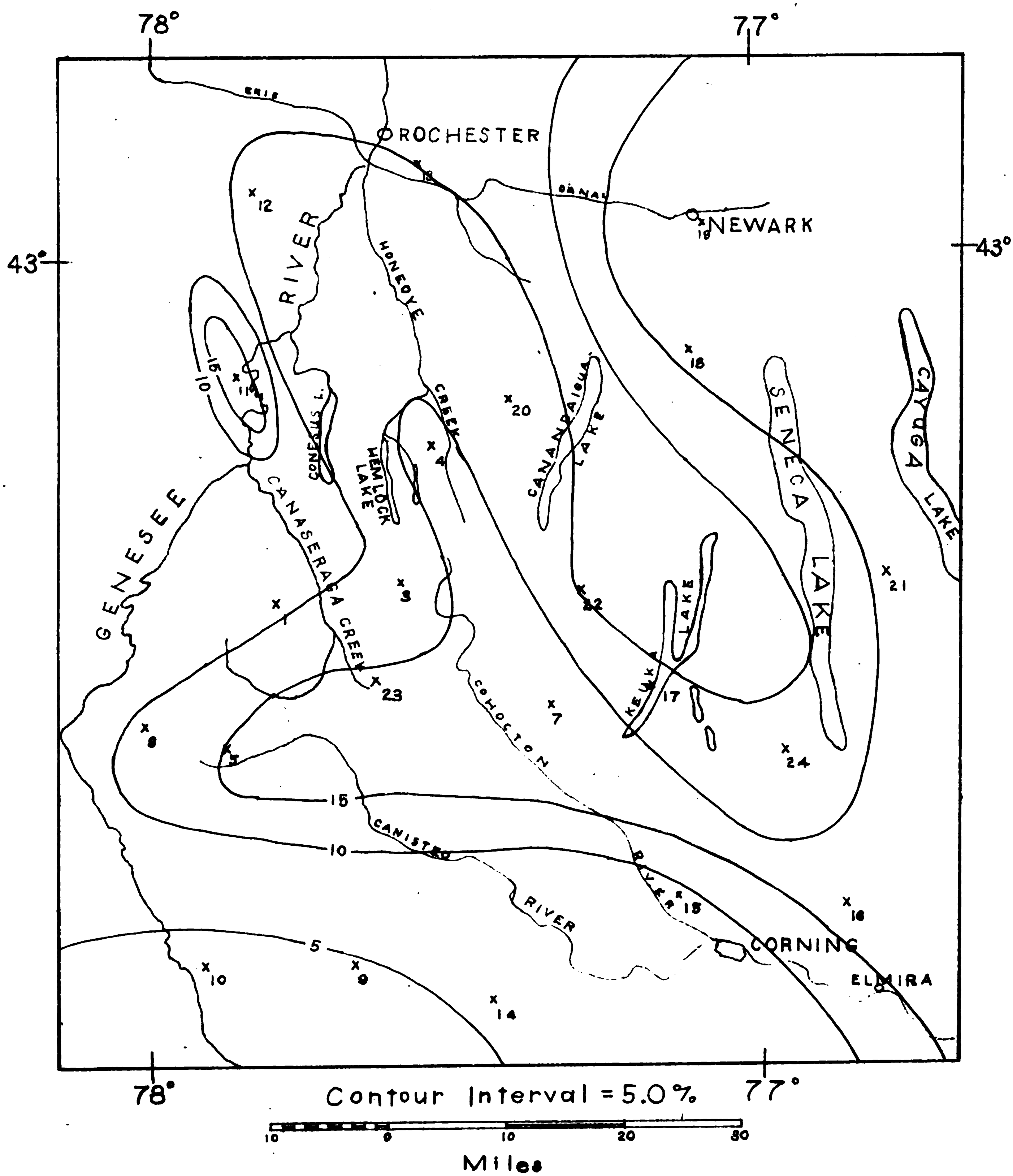


Plate 13. Isopleth map showing percent hornblende. Opaque minerals included in calculation.

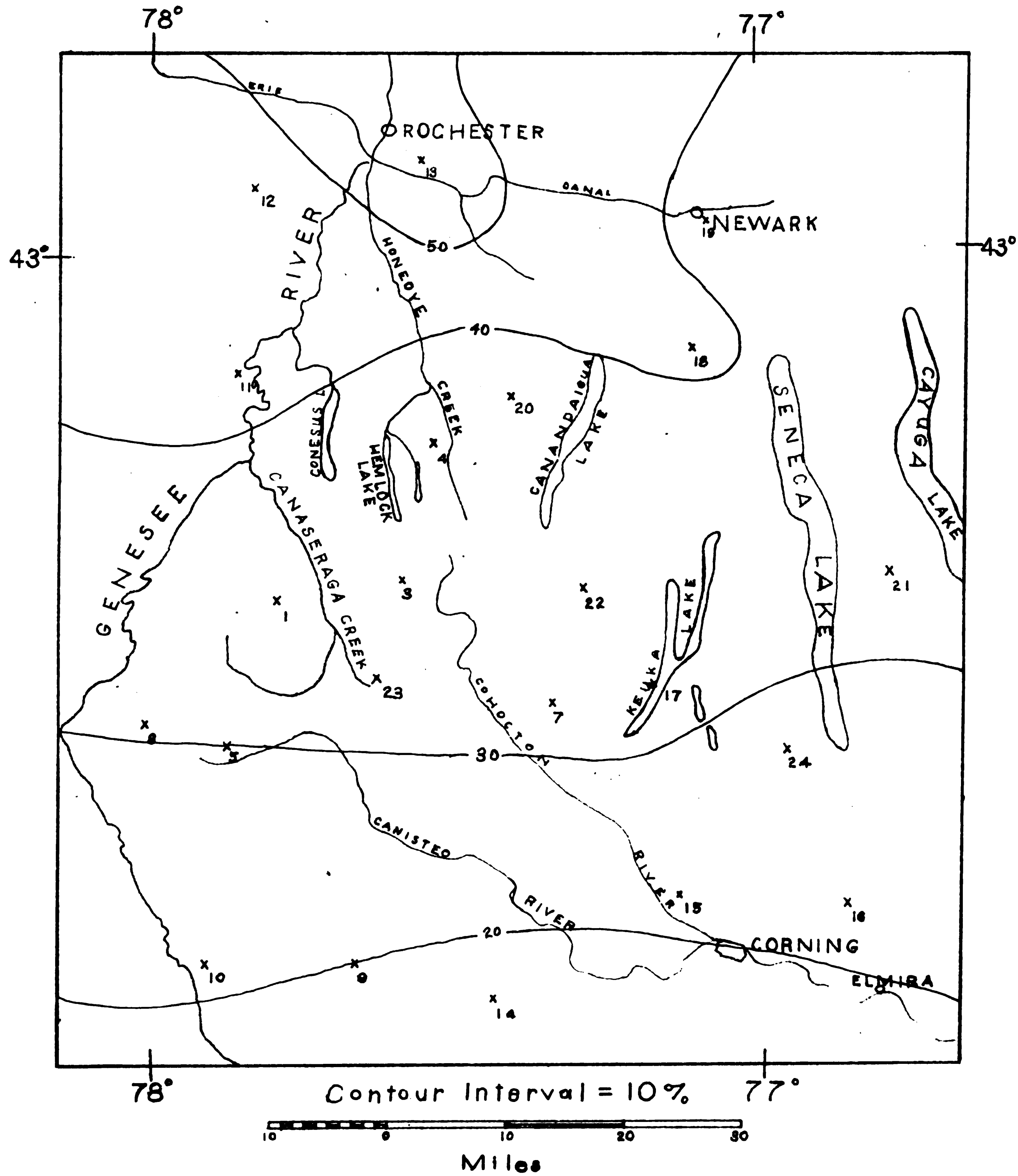


Plate 14. Isopleth map of percent hypersthene. Opaque minerals included in calculation.

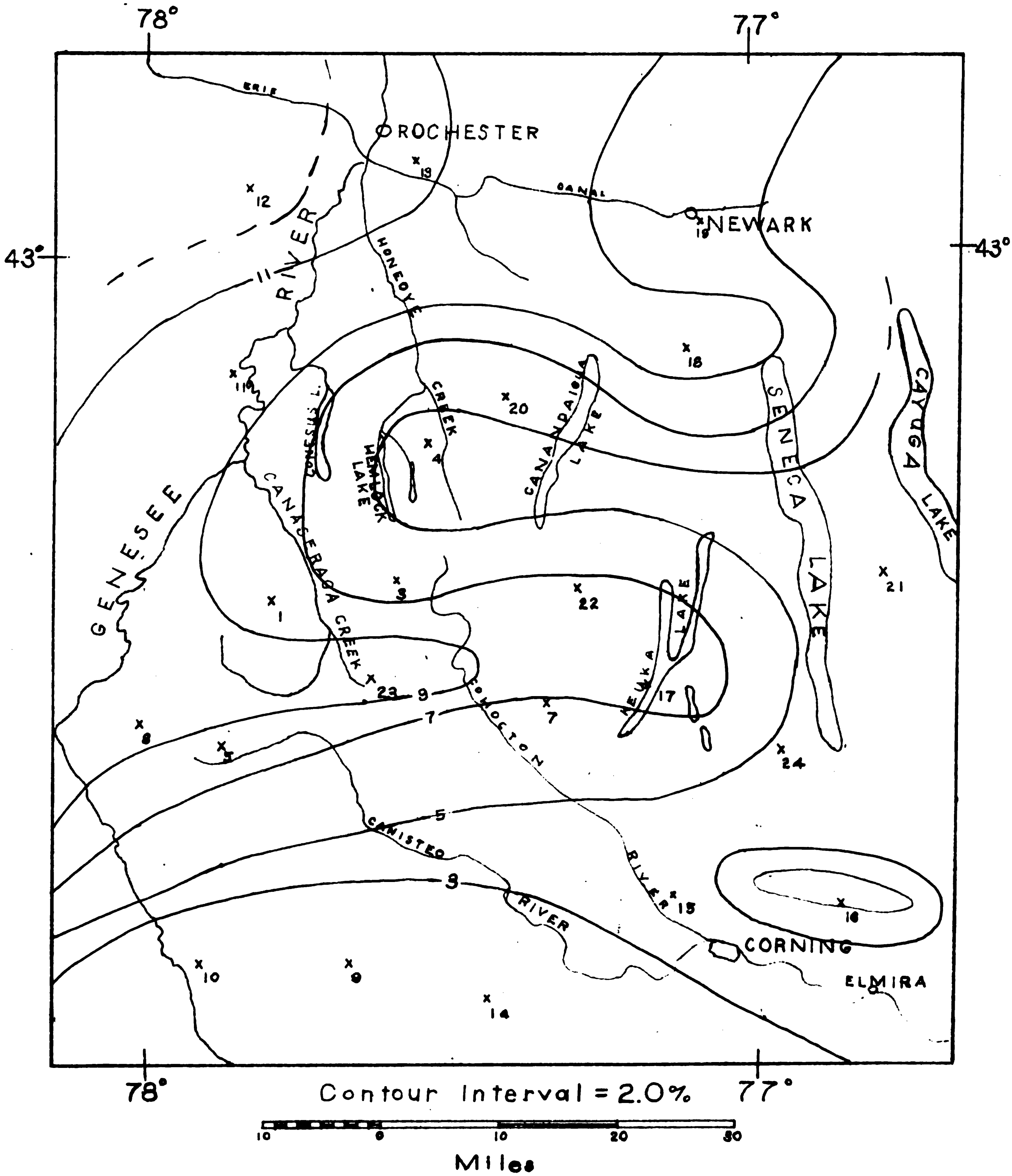


Plate 15. Isopleth map of percent garnet, excluding opaque minerals.

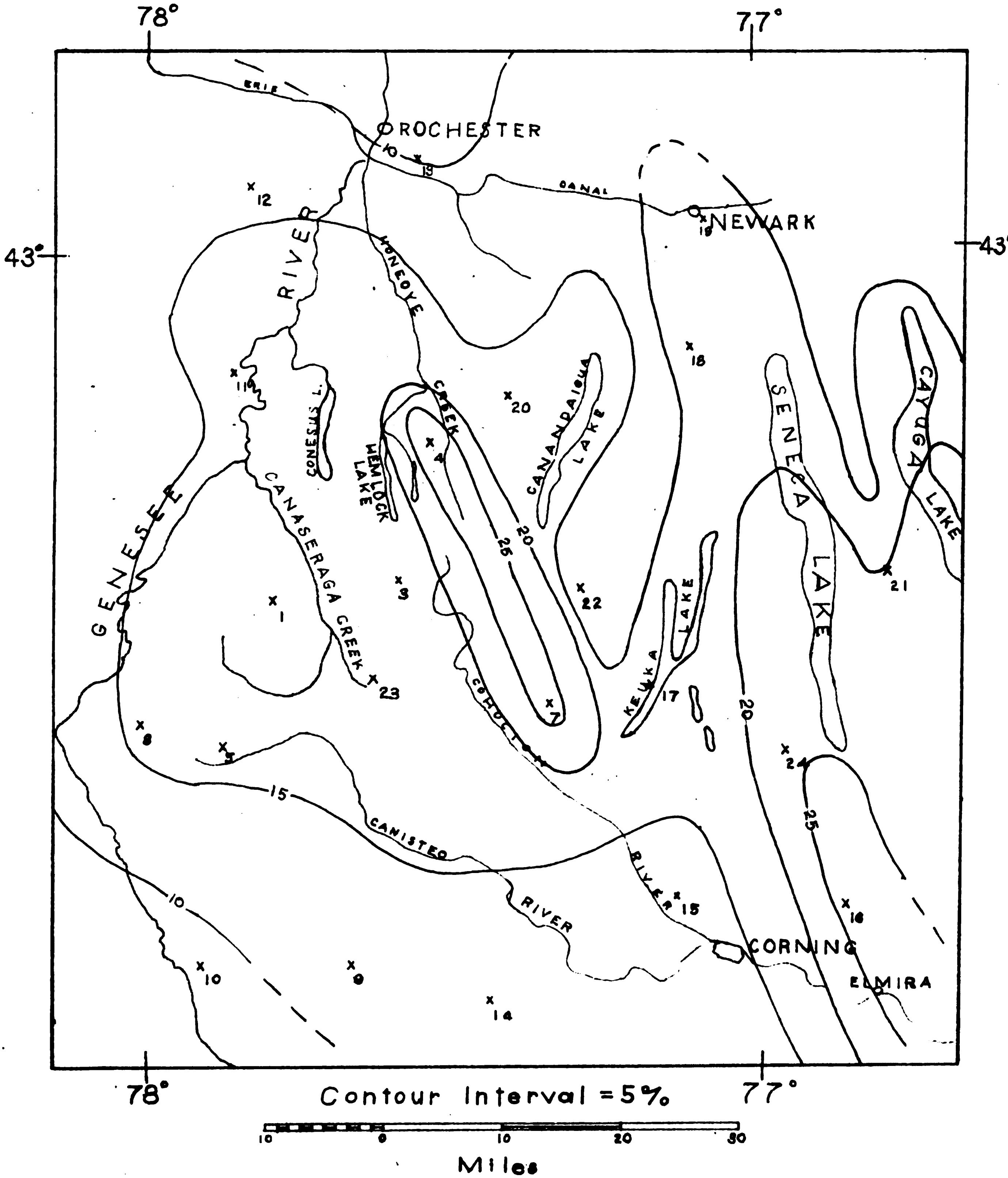


Plate 16. Isopleth map of percent hypersthene, excluding opaque minerals.

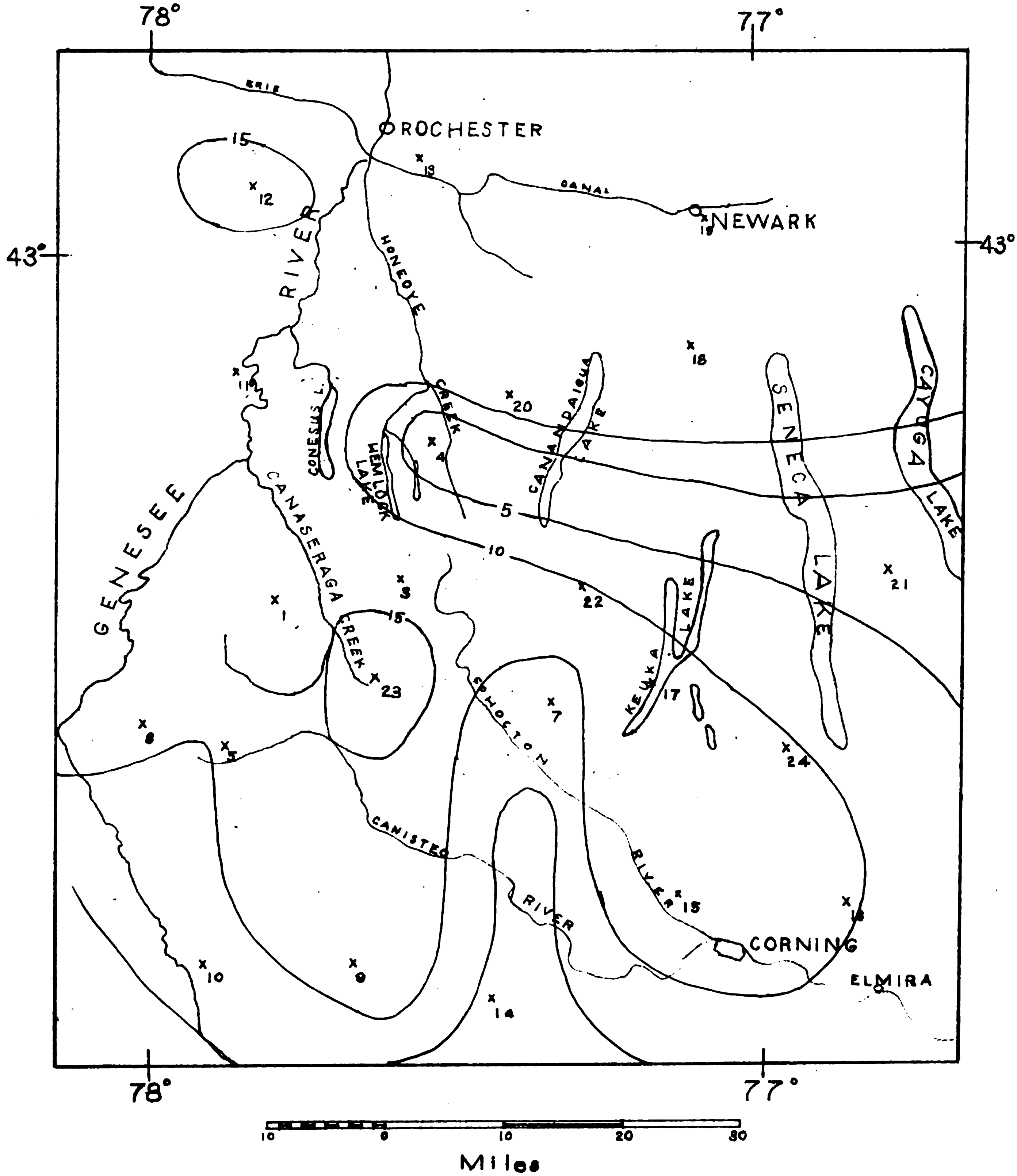


Plate 17. Isopleth map of percent hornblende, excluding opaque minerals.

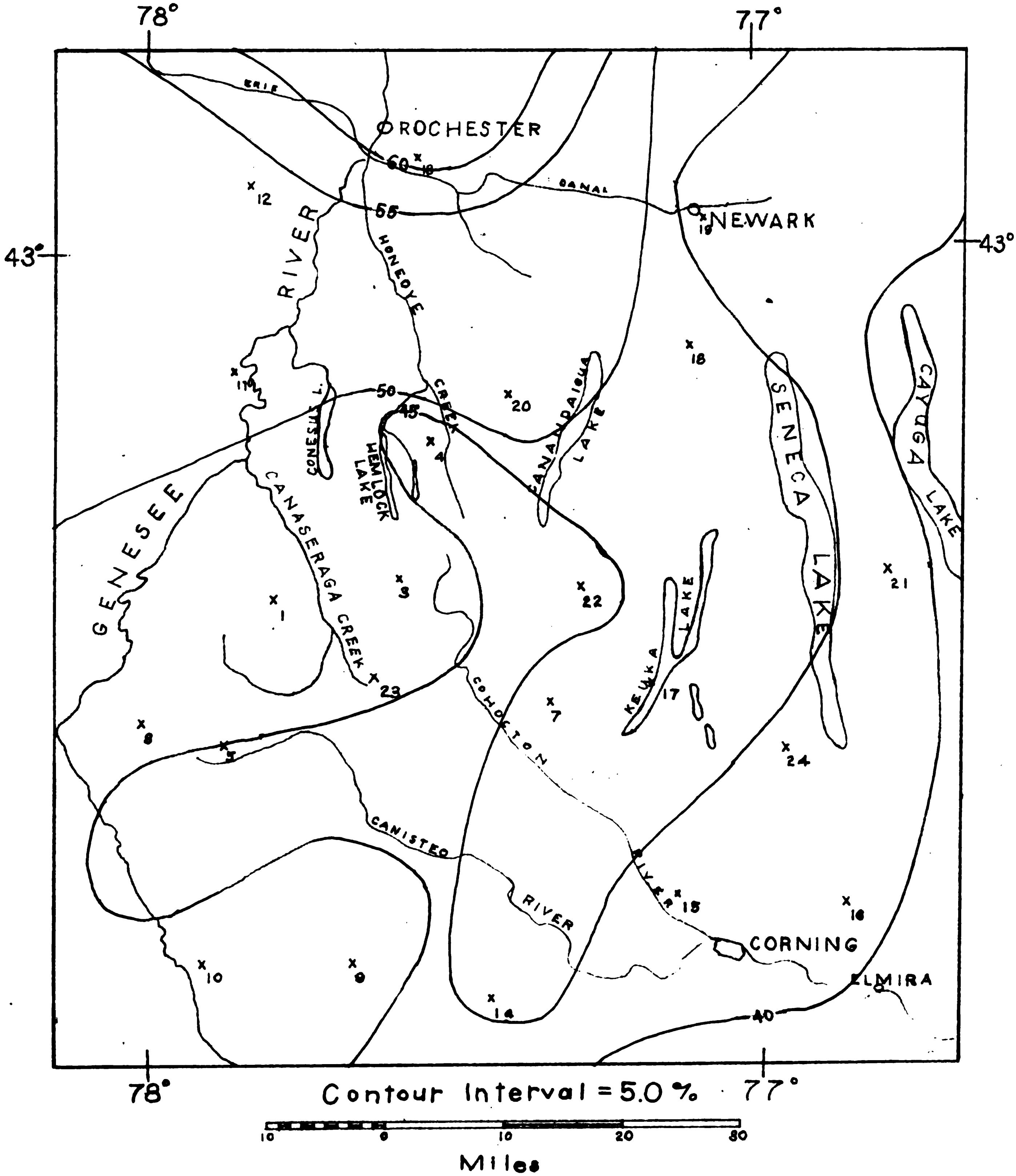


Plate 18. Isopleth map of clear garnet-red garnet ratio (C/R).

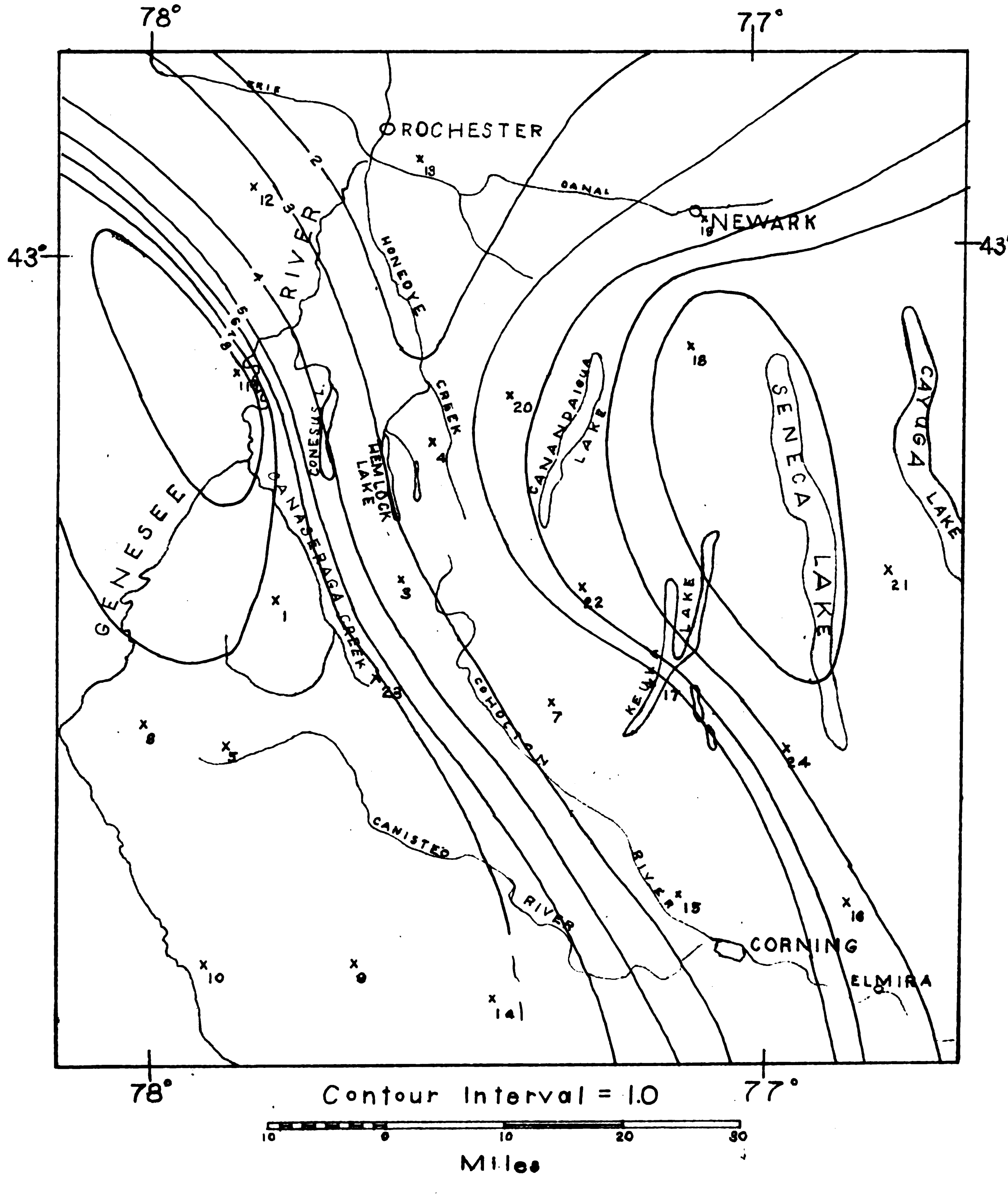


Plate 1[illegible]. Map of western Finger Lakes region showing the range of directions of glacial movement indicated by bedrock striae.