A SEDIMENTARY AND PETROGRAPHIC STUDY OF CERTAIN GLACIAL DRIFTS OF MINNESOTA.

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ABSTRACT.

The Pleistocene tills of Minnesota show differences in their heavy mineral accessories which may be used for correlation purposes. Studies indicate that there has been little post-glacial weathering and that the drifts have a mineral content very similar to that of freshly crushed igneous rock.

INTRODUCTION.

The object of this investigation was to make a comparative study of the various drift sheets that occur in Minnesota, with special reference to the petrographic differences between the red and gray drifts. It was suggested also that a petrographic study might show whether or not there is an appreciable difference in the degree of weathering of the young and the old drifts. Any differences might be detected by determining which minerals have been leached out and which have persisted in the glacial sediments.

The writer is especially indebted to Dr. Geo. A. Thiel of the University of Minnesota, who proposed the problem and whose counsel was of value throughout the period of study.

PLEISTOCENE CLASSIFICATION.

Thwaites[1] classifies the Pleistocene of the upper Mississippi Valley as follows:

Period	Epoch	Stage	Substage
Quaternary	Recent	.....	.....
	Pleistocene	Wisconsin	Later Mankato or Late Wisconsin (Fifth Wisconsin), "Young Gray"*
			Early Mankato or Late Wisconsin (Fourth Wisconsin), "Young Red"*
			Cary or Middle Wisconsin (Third Wisconsin)
			Tazewell or Early Wisconsin (Second Wisconsin)
			Iowan (First Wisconsin)
		Sangamon interglacial interval	
		Illinoian, "Old Red"*	
		Yarmouth interglacial interval	
		Kansan, "Old Gray"*	
		Aftonian interglacial interval	
		Nebraskan	

* Names in quotation marks are local descriptive terms not listed in Thwaites' classification.

[1] Thwaites, F. T.: Outline of Glacial Geology, p. 72, 1935.

GENERAL CHARACTERISTICS OF THE DRIFT SHEETS.

In the reports for the Natural History Survey of Minnesota, Winchell[2] noted the following: The Blue till is derived from the Cretaceous shales and has an abundance of soda, lime, magnesia, and potash; the till is tenaceous and impervious and therefore is responsible for the formation of many swamps. Red till, which is derived from the Cambrian sandstones, is high in iron oxides and has little alkali; in general it is low in calcareous matter.

Leverett and Sardeson[3] described the Kansan or "Old Gray" drift of the western part of Minnesota as a calcareous blue-gray till, containing rocks derived from limestone formations of southern Manitoba together with Cretaceous shales from Minnesota.

The Illinoian or "Old Red" drift is composed largely of gravelly material although it contains some clay. Most of the limestone has been removed. A few cherty nodules remain.

DISTRIBUTION OF SAMPLES ACCORDING TO MORAINIC SYSTEMS.
(After Leverett.)

Kansan Gray	Illinoian Red	Iowan	Wisconsin Red	Wisconsin Gray
#26	# 4	#25	Millacs Moraine	Bemis Moraine
#27	# 5	#32	# 1	#13
#28	# 6	#33	# 2	#15
#29	#36	#34	# 3	
#30	#37		#57	Altamount Moraine
#31	#38			#12
	#39		St. Croix Moraine	#14
	#45		#42	#24
	#46		#43	#35
			#44	Marshall Moraine
			#51	#16
			#53	#17
			#54	#18
			#55	#19
			#56	#20
				#21
				#22
				#23
				Crow River Moraine
				#47
				#48
				#49
				#50
				#52

[2] Winchell, H. V.: Minnesota Natural History Survey, Vol. 1, p. 126, Geology, 1872-1882.

[3] Leverett, Frank, and Sardeson, F. W.: Quaternary Geology of Minnesota and Adjacent States, U. S. G. S. Professional Paper 161, pp. 21-68, 1932.

The red color is due in part to its derivation from the ferruginous rocks around the head of Lake Superior; the percentage of this red material decreases southward from the lake.

The Wisconsin "Young Red" drift of the Millacs moraine is mainly clay till, though south of the ridge it is somewhat sandy. The St. Croix moraine is exceptionally stony and porous. It is not as clayey as the gray drifts and it is sorted into a sandy outwash plain.

The Wisconsin "Young Gray" drift of the Bemis, Marshall, and Altamount moraines in southwest Minnesota is loose-textured bouldery drift that contains sand lenses enclosed in the till. The Crow River moraine is clayey till.

METHODS.

For this investigation it was decided to limit the petrographic study to the sandy phases of the drifts. The areas from which samples were collected were planned in advance in order to avoid regions of clayey till and regions in which there were mixtures of red and gray drifts. An effort was made to obtain fresh samples, uncontaminated by surface agencies.

Field samples of about five hundred grams were collected, air dried, and rubbed with a hardwood block to break down lumpy aggregates. The samples were then quartered down to about one hundred grams. Ten gram portions of the reserves were treated with cold dilute hydrochloric acid until effervescence ceased; the percentage soluble in acid appears in Table I. The one hundred gram portions were screened in a Tyler Ro-Tap Shaker for ten minutes[4] and the size distribution determined.

The sieves used were graduated upwards from 1/16 millimeter openings, increasing on a ratio of two, according to the Wentworth classification. In order to show the relations between grain size and heavy mineral composition, bromoform (sp. gr. 2.88) separations were made on each sieve size. Slides were made with representative portions of both the heavy and light weight fractions. The light minerals that remained after acid treatment consisted almost entirely of quartz and feldspars.

In grains as small as 1/16 millimeter in diameter, such properties as cleavage, refraction, and birefringence are difficult to

[4] Optimum sieving time was ascertained by previous experimental sieving.

determine on microscopically similar materials such as quartz and feldspars. The most accurate method of distinction between quartz and feldspars is the use of the Becke line in conjunction with the interference figure. This optical technique was impractical because there were too many slides to be counted. In a recent paper, Russell[5] described a method for

TABLE I.

SOLUBLE CARBONATE CONTENT OF VARIOUS DRIFTS.

Percentage by weight assuming all loss to be $CaCO_3$.

Kansan Gray		Ill. Red		Iowan		Wisc. Red		Wisc. Gray		Questionable	
Sample No.	Loss %	Sample No.	Loss %	Sample No.	Loss %	Sample No.	Loss %	Sample No.	Loss %	Sample No.	Loss %
26	4.3	4	3.3	25	28.7	1	1.1	12	11.5	9*	0.0
27	8.3	5	1.8	32	50.2	2	2.3	13	14.5	7	14.6
28	7.0	6	0.0	33	31.6	3	2.2	14	17.9	8	12.8
29	7.4	45	7.0	34	37.8	42	0.0	15	17.5	40	17.2
31	18.9	46	2.0			43	1.2	16	8.1	41	26.1
		36	1.7			44	3.0	17	14.9		
		37	2.2			51	8.6	18	15.0	*Omitted	
						53	0.4	19	19.0	from	
						55	0.4	20	10.2	average	
						54	1.8	21	15.1		
						56	0.5	22	9.8		
						57	0.0	23	24.6		
								24	19.5		
								35	24.9		
								47	11.2		
								48	9.9		
								49	12.1		
								50	20.0		
								52	26.9		
Av.	9.2	Av.	1.8	Av.	37.0	Av.	1.7	Av.	15.9	Av.	17.7

etching mineral grains with hydrofluoric acid. His method of treatment was used with slight modifications.[6] When the light minerals are treated with hydrofluoric acid followed by sodium cobaltinitrite the quartz remains clear and the soda and lime feldspars show a white opaque etched surface, whereas the potash feldspars take on an intense yellow coating. Obviously this method greatly reduces the amount of mechanical work in counting.

[5] Russell, R. Dana: Frequency Determinations of Detrital Quartz and Feldspar, Journal of Sedimentary Petrology, Vol. 5, p. 109, 1935.

[6] The etching was found to be better controlled when dilute hydrofluoric acid was used.

Laboratory Data.

SOLUBLE CARBONATE CONTENT OF VARIOUS DRIFT SHEETS.

The average percentage loss in cold dilute hydrochloric acid is given in Table I. The Illinoian Red drift lost 1.8 per cent as soluble carbonates; the Wisconsin Red, 1.7 per cent; the Kansan Gray, 9.2 per cent; the Wisconsin Gray, 15.9 per cent; and the Iowan, 37.0 per cent.

The above figures bring out two points. First, the drifts which came from the northwest and which were derived from the sediments of the Dakotas and Manitoba, contain more soluble carbonate; and second, the gray drifts have not been greatly leached. They still contain considerable carbonate. This is perhaps due to their clayey impervious character which has prevented rapid percolation of water. The difference in the percentage of carbonates of the "Old Gray" drift and the "Young Gray" drift suggests that the older drift has been leached more completely. The figures in Table I are of the same order of magnitude as those compiled by Thiel.[7]

TEXTURAL AND PETROGRAPHIC RELATIONSHIPS.

A study of the sieve fractions revealed the anticipated heterogeneity of the drifts both texturally and mineralogically. Occasionally there were samples quite similar in texture even though taken at various horizontal intervals. Such samples, however, represent very local conditions. Others are, as a rule, very different in texture. One should not expect to obtain a series of uniform sieve analyses from glacial material collected over a wide area.

Manner of Distribution of Heavy Minerals in Various Grade Sizes of Representative Samples.

Size in mm.	Wisconsin Gray Drift		Kansan Gray Drift		Wisconsin Red Drift		Illinoian Red Drift	
	% by wt. of whole sample	% by wt. of heavy minerals	% by wt. of whole sample	% by wt. of heavy minerals	% by wt. of whole sample	% by wt. of heavy minerals	% by wt. of whole sample	% by wt. of heavy minerals
1/16–1/8	4.8	3.42	21.6	2.86	28.1	3.03	34.8	2.11
1/8 –1/4	0.8	5.68	8.0	3.78	25.3	4.06	10.3	6.54
1/4 –1/2	0.4	6.33	4.1	5.24	7.4	13.09	3.6	5.17

[7] Thiel, Geo. A.: A Correlation of Marl Beds with Types of Glacial Deposits, Journal of Geology, Vol. XXXVIII, Number 8, p. 717, 1930.

Heavy mineral separations were not made on the fractions coarser than ¼ mm. because the larger grains do not consist of single mineral fragments; neither were separations made of the silt and clay sizes.

The erratic nature of the distribution of heavy minerals may be partially correlated with the degree of sorting of the sediment. The well sorted phases of the drifts contain a lower percentage of heavy minerals than the tills.

As a broad generalization one may say also that the coarser sizes have the higher percentages of heavy minerals. These tend to be limonitic. Mineral counts of various sizes of the same drift specimen showed that in the majority of cases the magnetite is concentrated in the finer fractions as is shown in Table VIII.

The coarser fractions have a smaller variety of heavy minerals than the finer fractions.

DISTRIBUTIONS OF HEAVY MINERALS.

The frequency distributions of heavy minerals in the sandy phases of the various drift sheets are shown in Tables II to VIII. The heavy minerals in the Wisconsin Red drift contain an abundance of igneous rock minerals such as augite and magnetite. This suggests a marked contribution from the basic igneous rocks of the region of the Lake Superior Highlands. In samples No. 1, No. 2, No. 3, and No. 57 (See Table II) obtained north of the Grantsburg Lobe of the Late Wisconsin, augite and magnetite were more abundant than in the Wisconsin Red drift farther south. This indicates that the drift became contaminated with material from other sources as the ice moved farther southward.

The Illinoian Red till has by far the highest percentage of iron oxides. In the Illinoian drift material studied, 75 per cent of the heavy minerals were iron oxides, mainly hematite and limonite. (See Table III.) Such minerals as augite, hornblende, and apatite are conspicuously absent. This lack of variety in heavy minerals suggests considerable leaching and oxidation.

The Kansan, Iowan, and Wisconsin Gray drifts of the southwestern part of the state have more apatite, tourmaline, hornblende, biotite, and chlorite than the Illinoian and Wisconsin Red drifts. Biotite is very abundant in the Iowan drift.

The samples which contain the most garnet were obtained

from the central part of the state directly south of the schist areas which are famous for garnet and staurolite metacrysts. The Kansan, Iowan, and Wisconsin Gray drifts contain many of the minerals that are typical of the crystalline schists.

The average of the combined iron oxide content of the heavy mineral separates was as follows: Kansan, 45.4 per cent;

TABLE II.

DISTRIBUTION OF HEAVY MINERALS IN THE WISCONSIN RED DRIFT.

Percentages based on the number of grains counted.

	Fraction retained between the 1/8–1/16 mm. screens												Fraction retained between the 1/2–1/16 mm. screens		
Sample No.	#1	#42	#43	#44	#44′	#51	#53	#54	#54′	#55	#56	#57	#2	#3	#3′
Apatite	2	x	1	2	1	2	9	5	2	x	..	1	1	1	3
Augite	20	24	13	8	..	4	7	5	..	8	5	..	9	10	12
Biotite	1	1	..	..	..	3	1	..	1	..	2	..	..	..	..
Epidote	8	23	24	11	13	20	30	17	23	35	47	13	8	7	7
Garnet	3	..	1	3	2	4	..	2	1	1	1	2	1	1	3
Hornblende	5	5	13	12	9	22	10	10	16	16	9	5	2	3	6
Hematite Limonite Leucoxene	5	13	9	29	38	6	10	15	10	14	9	32	 12	 6	 7
Magnetite Ilmenite	44	22	25	21	26	24	21	33	36	12	15	44	 53	 63	 55
Tourmaline	3	3	3	1	..	2	1	6	..	2	1	..	.. x	.. ..	.. 3
Zircon	3	3	4	3	4	3	9	..	6	4	x	3	4	3	..
Chlorite	..	x	x	..	1	2	..	1	..	x	9	2	..	..	..
Kyanite	..	..	x	2	..	x	..	..	..	..	..	..	..	..	..
Monazite	..	..	x	2	1	..	..	2	..	1	..	..	..	..	..
Olivine	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pyrite	..	..	..	..	..	..	3	..	..	..	..	..	..	..	..
Rutile	..	x	..	2	..	x	..	..	..	x	..	1	1	1	1
Titanite	3	x	x	..	..	2	..	1	x	..	..	..	3	3	x
Zoisite	..	x	x	..	..	x	..	2	..	x	..	..	..	..	..
Undetermined	3	4	x	4	3	4	..	6	4	4	2	..	3	3	3

x = Amounts less than 1.0%.

Illinoian, 78.0 per cent; Iowan, 32.0 per cent; Wisconsin Red, 43.3 per cent; Wisconsin Gray, 32.4 per cent. There were gradational mixtures of the oxides hematite, limonite, magnetite, leucoxene, and ilmenite—hence they were combined because of the difficulty of identification.

In preparing the samples for sieving, they were rubbed between hardwood blocks to break down aggregates. This treatment was not sufficiently severe to cause attrition of individual mineral particles. No excess of earthly limonite due to rubbing was found in the fine screenings.

Although ferric oxides color the Wisconsin Red drift, all samples taken from that drift contain more magnetite and ilmenite than limonite and leucoxene, whereas the Kansan Gray drift is higher in limonite and leucoxene than in magnetite and ilmenite. The iron oxide of the Illinoian Red drift consists mainly of limonite. Much of this iron oxide was, no

TABLE III.

DISTRIBUTION OF HEAVY MINERALS IN THE ILLINOIAN RED DRIFT.

Percentages based on the number of grains counted.

	Fraction retained between the 1/8–1/16 mm. screens					Fraction retained between the 1/2–1/16 mm. screens			
Sample No.	#4	#36	#37	#45	#46	#5	#5′	#6	#6′
Apatite	x	..	x	3	..	x	..	..	..
Augite	..	..	..	6	..	..	..	..	..
Biotite	x	1	x	1	..	..	..	..	..
Epidote	13	11	9	19	8	3	4	7	6
Garnet	x	..	..	x	1	4	6	2	2
Hornblende	14	6	7	10	9	7	4	..	..
Hematite, Limonite, Leucoxene	19	65	80	29	50	30	41	78	81
Magnetite, Ilmenite	47	12	..	8	27	43	30	7	7
Tourmaline	x	1	x	2	..	x	2	4	3
Zircon	2	..	1	5	1	10	10	1	x
Chlorite	..	4	1	5	1	..	..	..	..
Kyanite	..	..	..	2	..	..	..	..	..
Pyrite	..	..	..	..	..	..	..	..	x
Rutile	..	..	..	2	..	x	..	..	..
Titanite	..	..	..	x	..	..	..	..	..
Zoisite	..	..	..	x	..	..	..	..	..
Undetermined	3	..	..	9	3	1	1	x	x

x = Amounts less than 1.0%.

doubt, derived from the iron formations of the Lake Superior region. The Wisconsin Gray drift is variable in its oxide content, but most of the opaque minerals are magnetite and ilmenite.

The Wisconsin Gray drift and Iowan drift, both derived from the rocks to the northwest, have the lowest iron oxide content of all the samples studied. They contain an average of 32 per cent iron oxide in the heavy fractions. These are mainly opaque grains of ilmenite and magnetite. The iron oxides of the Kansan Gray drift are mostly of the hydrated

oxides. Although hematite, limonite, and leucoxene were combined in the tabulation, the grains from the "Old Red" drift are dominantly limonite rather than leucoxene.

The old drifts may contain weathered iron oxide derived from pre-glacial residual soils. The abundance of iron oxides does not necessarily mean that they have suffered more post-glacial weathering. The younger drifts were probably abraded from less weathered source rocks which were uncovered by earlier ice advances and hence the younger drifts contain more fresh magnetite and less limonite.

THE LIGHT FRACTIONS.

The distribution of the quartz and feldspars is extremely irregular. In the staining method used, white opaque grains result from minerals containing sodium and calcium and yellow grains from minerals containing potassium.

It is evident then that aggregates of clay minerals would also give similar reactions. This may explain the unexpected high figures for feldspars obtained in counts of the gray drifts.

It is possible that the gray drifts may be influenced by local outcrops of granite gneiss and contain considerable amounts of igneous rock materials in addition to their lime content which is necessarily of sedimentary origin. Such local outcrops of igneous rocks may well account for the great variety of heavy mineral species that occur.

AVERAGES OF LIGHT MINERAL COUNTS ON 1/16-1/8 MM. SIZE.
Percentages based on the number of grains counted

	Quartz	Yellow "orthoclase"	White Opaque "plagioclase"
Kansan Gray	54	9	36
Wisconsin Gray	47	6	47
Wisconsin Red	62	8	27
Illinoian Red	46	21	32

G. W. White[8] gives the following average mineral composition of the ¼-⅛ mm. grains washed from soils derived from Wisconsin and Illinoian tills sampled in northcentral Ohio.

	Wisconsin Drift	Illinoian Drift
quartz	87%	32%
"pellets"	8%	66%
hornblende	3%	2%
feldspar	2%	0%

[8] White, G. W.: Soil Minerals as a Check on the Wisconsin-Illinoian Drift Boundary, Science, Vol. 79, p. 549, 1934.

Table IV.

Distribution of Heavy Minerals in the Wisconsin Gray Drift.

Percentages based on the number of grains counted.

	Fraction retained between the 1/8–1/16 mm. screens																Fraction retained between the 1/2–1/16 mm. screens		
Sample No.	#15	#15′	#16	#17	#18	#19	#20	#21	#22	#23	#24	#35	#47	#48	#48′	#49	#12	#13	#14
Apatite	6	6	7	6	4	5	4	2	1	3	2	3	7	5	5	3	3	6	3
Augite	..	..	..	..	..	..	x	..	..	..	..	..	x	..	..	..	..	2	1
Biotite	x	x	..	..	..	x	..	..	..	..	1	3	x	..	..	..	..	..	2
Epidote	17	21	30	23	19	27	13	8	15	18	21	14	15	10	10	19	22	19	15
Garnet	4	1	7	2	5	6	4	5	5	1	7	4	5	6	10	5	9	12	9
Hornblende	43	34	18	32	34	26	51	15	36	34	27	25	38	24	22	38	33	31	25
Hematite Limonite Leucoxene	10	12	12	15	11	12	8	35	15	18	11	18	11	9	9	9	14	10	25
Magnetite Ilmenite	11	19	18	12	17	19	7	21	11	12	15	15	11	33	36	10	12	11	16
Tourmaline	..	..	..	..	4	x	2	..	3	..	7	5	3	..	1	2	1	2	2
Zircon	6	4	4	2	3	1	6	4	4	6	5	6	4	5	3	4	6	4	2
Chlorite	..	..	..	2	x	..	..	5	2	4	..	x	x	2	..	4	..	..	x
Kyanite	..	..	..	..	..	..	..	1	2	..	..	3	..	2	..	2	..	..	..
Monazite	..	..	..	..	..	..	..	..	..	..	..	x	..	1	..	..	..	..	..
Pyrite	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Rutile	..	..	..	..	x	..	..	..	x	..	..	x	x	1	x	x	x	..	..
Titanite	1	x	..	1	..	..	..	..	1	3	..	x	..	..	..	1	x	x	x
Undetermined	2	1	4	2	1	2	4	4	2	2	4	2	3	2	3	2	..	..	..

x = Amounts less than 1.0%.

"Pellets" are defined as fine mineral grains cemented with iron oxides that stand up as aggregates. White does not list other minerals that must have been present in the samples.

A glacial map of the United States shows that although the Wisconsin and Illinoian glaciers had different sources of materials they both must have passed over large areas of sedimentary rocks before depositing their tills in Ohio. This would tend to keep the proportions of quartz and lime carbonate high.

Percentages obtained by counting light mineral grains in drift samples from Minnesota do not approach the figure of 87 per cent for the mineral quartz as reported by White. One may perhaps conclude that the low quartz ratios would signify, in the main, that rocks other than sediments had been the sources of Minnesota tills.

W. F. Hoover[9] describes the petrography of a till in Kansas and reports dominantly silicious materials and only a trace of feldspars. Similarly it would be expected that glacial materials of Kansas would be derived largely from areas of sedimentary rocks and accordingly lack crystalline rock minerals.

NATURE OF THE ROCK AND MINERAL FRAGMENTS IN THE COARSER FRACTIONS.

An examination of the coarser sizes of random samples was made to find the probable rock sources of the various minerals in the smaller screen sizes. A binocular microscope was used for this study of loose grains.

Samples of the Wisconsin Red drift from the northern part of the state showed about two-fifths of the entire sample composed of dark igneous rock fragments. Some of the quartz grains were well rounded and appeared as though they might have been of sedimentary origin, but most of the grains were sub-angular.

The Wisconsin Red drift from the southern part of the state contained abundant igneous rock fragments but not in the amounts contained to the north of the Grantsburg Lobe of late Wisconsin Gray drift. The amount of iron oxide staining had also decreased. The majority of the quartz grains were well rounded and frosted suggesting that they had been

[9] Hoover, W. F.: Petrography and Distribution of Highly Weathered Drift in the Kansas River Valley, Journal of Sedimentary Petrography, Vol. 6, p. 198, 1936.

TABLE V.

DISTRIBUTION OF HEAVY MINERALS IN THE KANSAN GRAY DRIFT.
Percentages based on the number of grains counted.
Fraction retained between the 1/8–1/16 mm. screens

Sample No.	#26	#27	#28	#29	#31
Apatite	3	2	2	3	7
Augite	..	..	..	x	x
Biotite	8	x	1	..	..
Epidote	11	23	11	10	10
Garnet	4	2	3	2	5
Hornblende	28	24	30	18	38
Hematite, Limonite, Leucoxene	17	16	21	36	18
Magnetite, Ilmenite	21	20	19	21	9
Tourmaline	2	1	2	1	2
Zircon	7	2	7	3	4
Chlorite	3	x	..	2	3
Kyanite	1	x	x	..	x
Rutile	x	2	2	x	..
Titanite	1	..	x	..	..
Undetermined	1	..	1	x	3

x = Amounts less than 1.0%.

TABLE VI.

DISTRIBUTION OF THE HEAVY MINERALS IN THE IOWAN DRIFT.
Percentages based on the number of grains counted.
Fraction retained between the 1/8–1/16 mm. screens

Sample No.	#25	#32	#33	#34
Apatite	11	3	4	x
Augite	..	..	..	..
Biotite	5	3	13	5
Epidote	19	18	14	4
Garnet	2	1	7	x
Hornblende	24	27	14	10
Hematite, Limonite, Leucoxene	14	28	10	11
Magnetite, Ilmenite	15	7	23	20
Tourmaline	3	1	3	x
Zircon	4	x	..	x
Chlorite	..	5	2	..
Kyanite	..	3	1	..
Monazite	..	1	..	..
Rutile	..	..	2	..
Titanite	..	x	..	..
Undetermined	3	3	2	48

x = Amounts less than 1.0%.

derived from the sedimentary rocks of the Cambrian Croixan series.

The Illinoian "Old Red" drift was typically composed of iron oxide pellets and quartz grains which were not well rounded; they were sub-rounded to sub-angular in shape. The coarser materials were igneous rock fragments.

Samples of the Wisconsin "Young Gray" drift contained

TABLE VII.

DISTRIBUTION OF HEAVY MINERALS IN QUESTIONABLE DRIFT.

Percentages based on the number of grains counted.

	Fraction retained between the 1/8–1/16 mm. screens				Fraction retained between the 1/2–1/16 mm. screens		
Sample No.	#8	#8′	#40	#41	#7	#9	#9′
Apatite	4	3	2	5	2	..	..
Augite	1	..	..	1	1	..	..
Biotite	x	x	..	x	2	1	..
Epidote	14	14	16	18	14	4	5
Garnet	4	4	5	1	3	..	..
Hornblende	25	16	20	34	24	8	5
Hematite, Limonite, Leucoxene	37	36	35	18	43	82	73
Magnetite, Ilmenite	13	12	18	8	7	3	17
Tourmaline	1	5	3	4	..	..	..
Zircon	3	3	2	2	2	..	..
Chlorite	..	..	2	5	..	..	..
Kyanite	..	..	..	x	..	..	..
Monazite	..	..	..	x	..	..	..
Rutile	x	x	x	x	..	..	..
Sillimanite	..	..	x	..	..	..	..
Staurolite	..	..	x	..	..	..	..
Titanite	x	x	..	1	x	..	..
Undetermined	1	2	4	x	..	..	..

x = Amounts less than 1.0%.

a predominance of pieces of schist and limestone as well as many angular quartz grains. Igneous rock fragments were scarce. A spotted galuconitic sandstone was a very predominant component of these samples. It was probably derived from outcrops of the Dresbach formation.

The Kansan "Old Gray" drift had conspicuous quartz with needle-like inclusions, suggesting quartz from schists rather than from a granite. The limestone fragments showed pitted surfaces. All of the components were more or less rounded.

TABLE VIII.

FREQUENCY DISTRIBUTION OF HEAVY MINERALS IN VARIOUS SIZES OF REPRESENTATIVE SAMPLES.

Percentages based on the number of grains counted.

Sample No.	#15 Wisc. Gray			#27 Kan. Gray			#1 Wisc. Red			#53 Wisc. Red			#4 Ill. Red			#25 Iowan			#8 Questionable		
Size in mm.	1/16–1/8	1/8–1/4	1/4–1/2	1/16–1/8	1/8–1/4	1/4–1/2	1/16–1/8	1/8–1/4	1/4–1/2	1/16–1/8	1/8–1/4	1/4–1/2	1/16–1/8	1/8–1/4	1/4–1/2	1/16–1/8	1/8–1/4	1/4–1/2	1/16–1/8	1/8–1/4	1/4–1/2
Augite	..	1	..	..	2	2	20	22	15	7	5	7	..	..	..	..	..	..	1	..	..
Apatite	6	4	4	2	..	1	2	x	..	9	2	..	x	..	..	11	3	..	4	2	..
Biotite	x	4	..	8	3	2	1	..	..	1	1	x	x	..	..	5	3	2	x	x	..
Epidote	17	21	7	23	14	4	8	12	9	30	10	10	12	5	4	19	21	12	14	13	12
Garnet	7	2	7	2	3	1	3	2	1	..	1	..	x	2	2	2	x	2	4	6	5
Hornblende	43	20	36	24	18	12	5	5	13	10	13	4	14	10	5	24	25	18	26	9	9
Hematite, Limonite, Leucoxene	10	24	21	16	38	58	5	31	51	10	42	59	19	45	59	14	23	44	37	58	62
Magnetite, Ilmenite	12	24	21	20	8	6	45	16	6	21	12	12	47	35	18	15	19	16	13	9	7
Tourmaline	..	2	..	1	..	2	3	x	..	1	x	..	x	..	..	3	1	..	1	2	..
Zircon	5	..	..	2	1	..	3	3	1	9	4	..	2	..	x	4	..	..	3	x	x
Chlorite	..	..	..	x	..	2	..	x	..	..	2	x	..	2	..	..	..	3	..	..	..
Fluorite	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Kyanite	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Monazite	..	..	..	..	..	1	..	..	..	..	..	x	..	..	..	..	1	..	x	..	..
Olivine	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pyrite	..	..	..	..	..	..	..	..	2	3	..	..	..	..	..	..	..	..	..	..	..
Rutile	..	..	..	2	..	1	..	..	..	..	..	..	..	..	..	..	..	..	x	..	1
Titanite	1	..	..	..	..	..	3	2	..	..	x	x	..	..	..	..	..	..	x	..	..
Zoisite	..	1	..	..	..	1	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..
Undetermined	2	..	..	..	11	9	3	7	..	..	5	5	3	..	1	3	3	4	1	..	1

x = Amounts less than 1%.

The Iowan drift contained interlocked quartz and biotite as in schists in addition to predominant sedimentary materials. There were few dark constituents; the quartz was not rounded.

Samples of the questionable drift had rock fragments which appeared to be altered and aggregated. Pieces of a fine-grained sandstone and a granite showed evidences of weathering. Some rounded pebbles of dark massive rock showed slight alteration.

CONCLUSIONS.

1. The drifts of Minnesota can be separated on the basis of their carbonate content. The Wisconsin Gray, Iowan, and Kansan Gray drifts contain a higher content of soluble carbonates than the Wisconsin Red and Illinoian Red drifts. (See Table I.)

2. The mineral composition of the various drifts is complicated. This complexity is undoubtedly due to the admixtures and reworking of the earlier soils and tills as well as the great variety of rocks over which the glaciers had passed. In spite of the great number of minerals present, there are a few that appear to be diagnostic of certain drift sheets. For example, the Wisconsin Red drift is high in augite and magnetite, whereas the Illinoian Red drift possesses an abundance of limonite. Garnet, hornblende, and apatite are prominent constituents of the Wisconsin Gray, Kansan Gray, and Iowan drifts. An abundance of the micaceous minerals is also characteristic of these latter three drifts.

3. The amounts of soluble carbonates and the assemblage of the heavy minerals may be correlated with the origin of the drift and serve as a fairly satisfactory means for determining the various drift sheets. Thus the boundaries may be mapped more accurately.

For example, in comparing the properties of Sample No. 9, which came from outside the area mapped as Illinoian drift, with the very similar properties of the Illinoian Red drift, it is seen that Sample No. 9 should probably be classed as Illinoian Red drift. In the field this sample was described as reddish till. Treatment with acid yielded no effervescence. The mineral assemblage of Sample No. 9 resembles the mineral distribution of the Illinoian Red drift. If this sample is really uncontaminated Red drift, then its location near Dodge Center would necessitate moving the Illinoian Old Red drift boundary south-

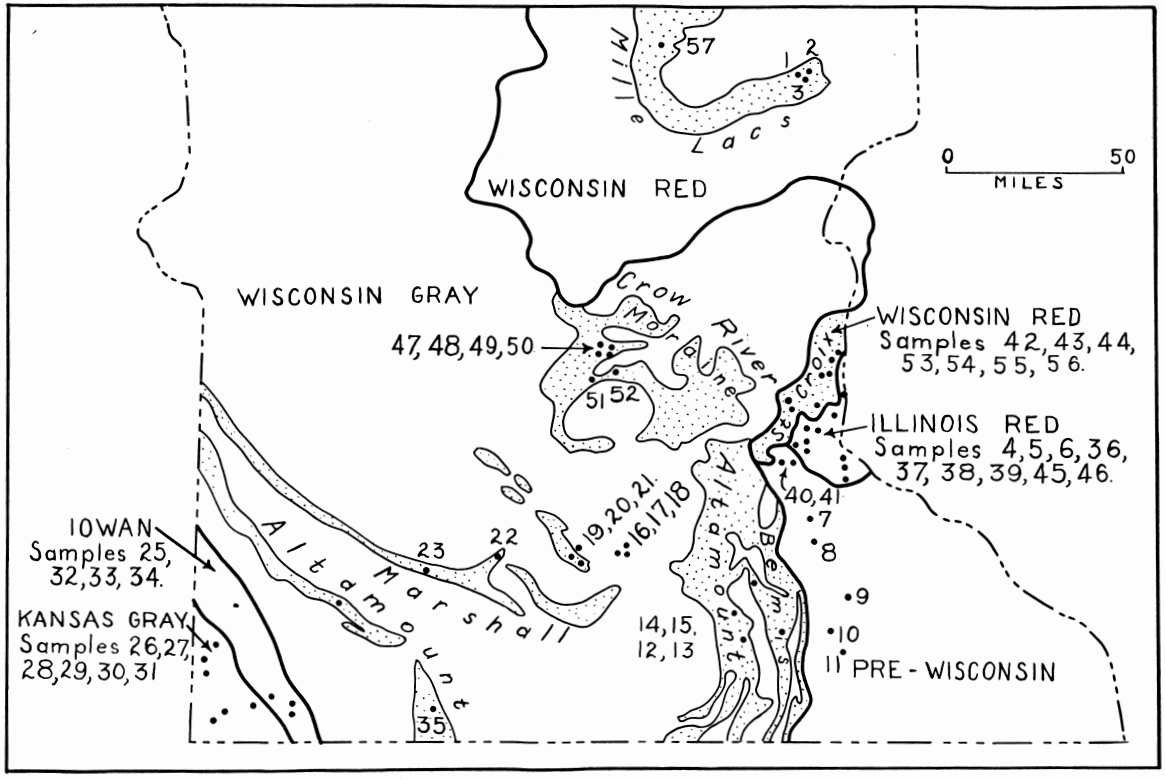

Fig. 1. Map of southern Minnesota showing the distribution of glacial formations and moraines, and the location of samples. (After Leverett.)

ward about twenty-five miles. (See Fig. 1.) If this material had been sandy outwash rather than till, there might be some explanation of its transportation by water. However,

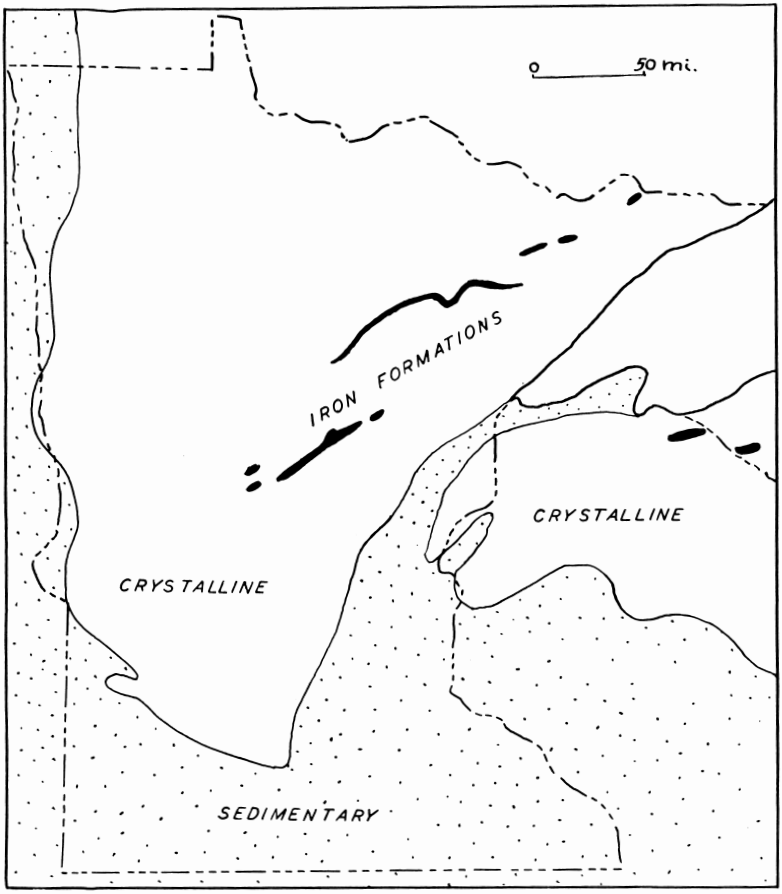

Fig. 2. Map of Minnesota showing the distribution of rock types.

more complete sampling should be done before definite conclusions can be reached.

Samples No. 7, No. 8, No. 8′, No. 40, and No. 41 of glacial drift were taken in the field from an area that was mapped by Leverett as Kansan and mapped by others as Iowan. (See Fig. 1.) These samples collectively show a soluble car-

bonate content of 17.7 per cent which is nearer that of 9.2 per cent of the Kansan drift than that of 37.0 per cent of the Iowan drift. In total iron oxides these samples have an average of 45.4 per cent; the Kansan drift coincidentally has 45.4 per

TABLE IX.

DISTRIBUTION OF HEAVY MINERALS IN GRANITES, DRIFTS, AND SEDIMENTS OF MINNESOTA.

Percentages based on number of grains counted.

						Glacial Drifts†										
Minerals	Saganaga Granite*			Giant's Range Granite*		Wisc. Gray	Kan. Gray	Wisc. Red	Ill. Red	Iowan	St. Peter Sandstone‡		Cambrian Sandstones§			
Apatite	2	2	..	5	5	1	2	5	x	4	..	..	..	..	..	
Augite	..	..	..	..	..	..	..	5	..	..	..	..	..	..	..	
Biotite	..	8	51	26	..	..	x	..	1	13	..	..	..	..	..	
Chlorite	23	30	2	1	3	2	..	1	4	2	..	..	..	..	..	
Epidote	9	5	1	10	14	15	11	16	11	14	..	..	..	..	..	
Garnet	..	..	..	..	..	5	3	2	..	7	..	..	41	25	15	
Hornblende	64	55	44	18	36	36	30	16	6	14	..	..	..	..	..	
Hematite, Limonite, Leucoxene	..	..	..	..	..	15	21	10	65	10	..	..	..	..	..	
Magnetite, Ilmenite	..	..	1	36	13	11	19	33	12	23	..	..	..	..	..	
Rutile	..	..	..	..	..	x	2	..	..	2	70	6	2	..	2	
Titanite	..	..	..	1	9	1	x	..	..	..	..	1	..	..	..	
Tourmaline	..	..	..	..	..	3	2	3	1	3	7	30	32	15	16	
Zircon	2	..	1	1	x	4	7	3	..	..	18	59	23	60	62	
Miscellaneous	..	..	..	x	x	2	1	5	..	1	..	..	1	..	..	
Undetermined	..	..	..	1	2	2	1	5	..	2	..	..	..	..	..	

x = Amounts less than 1.0%.

* Unpublished notes of Dr. F. F. Grout.

† Random representative samples of drifts.

‡ Thiel, Geo. A., Sedimentary and Petrographic Analysis of the St. Peter Sandstone, Bulletin G. S. A., Vol. 46, p. 579, 1935.

§ Graham, W. H. P., A Textural and Petrographic Study of the Cambrian Sandstones of Minnesota, Journal of Geology, Vol. 38, p. 713, 1930.

cent while the Iowan drift has 32.0 per cent. The mineral compositions of the Iowan and the Kansas drifts are similar in all respects (See Tables V and VIII), but the questionable samples show about the same degree of oxidation as does the Kansan drift. It seems that wider sampling in this disputed area would provide illuminating data.

4. The distribution of the heavy mineral grains in all of the drifts is strikingly similar to the distribution of the heavy minerals in freshly crushed granites. The percentages of tourmaline, rutile, and zircon are low in most igneous rocks.

The same is true of the glacial sediments. This is the opposite of what is found in the marine sedimentary rocks, in which the durable heavy minerals such as tourmaline, rutile, garnet, and zircon occur much more abundantly. (See Table IX.)

The similarity of the mineral distribution of the drifts to that of freshly crushed igneous rock suggests that the processes of leaching and weathering of glacial deposits, even in the older drift sheets have not progressed very far. The only suggestions of weathering in the older drift are first, the abundance of hydrated oxides of iron; second, fewer varieties of mineral species; and third, lesser amounts of carbonate than in the fresh young drifts. Field observations show the same point. For example, many surfaces of quartzite, schist, jasper, slate, granite, or limestone that were highly polished by the glaciers some 30,000 years ago still retain that polish.

It is possible that the weathered nature of the older drifts is due to the incorporation of the pre-glacial residual soils in these earlier tills. Krynine[10] has shown that a supposed ancient till is composed of glacial debris admixed with 75 per cent of the underlying weathered soil.

From the minor changes observed in the minerals of the drift sheets, one must conclude that the normal processes of weathering in a moderate climate, produce little change unless long periods of time are involved—time much longer than the post-glacial epoch.

[10] Krynine, P. D.: Age of Till on "Palouse Soil" from Washington, This Journal, Vol. 33, p. 215, 1937.

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