SURFICIAL GLACIAL DEPOSITS OF THE MICHIGAN-SAGINAW LOBES IN THE GRAND RAPIDS AREA, MICHIGAN: A STUDY OF RELATIONSHIPS

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Laurence MackenzieWilson

1955

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LAURENCE MACKENZIE WILSON

A THESIS

Submitted to the School of Graduate Studies of Michigan
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ACKNOWLEDGMENTS

The writer wishes to express sincere appreciation and thanks to Dr. S. G. Bergquist for suggesting the problem, his direction in the field and laboratory, and for critically editing the manuscript.

He wishes also to thank Dr. B. T. Sandefur, Dr. J. Zinn, Dr. W. A. Kelly and Dr. J. W. Trow for their advice and suggestions.

He is also greatly indebted to Mrs. L. M. Wilson for her assistance in typing the manuscript and her many suggestions and encouragement.

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ABSTRACT

The use of pebble counts to distinguish between the drift sheets of different glacial stages had long been a practice of geologists. It was decided to analyze a series of samples from an interlobate area and determine if pebble counts could be used as a criteria of differentiation between lobes of the same glacial stage.

The interlobate of the Charlotte-Lake Border moraines was selected as having the requisite qualities for such an investigation. Samples from these moraines, in the area of their interlobate, were analyzed by pebble counts. The results were expressed in tabular and graphic form.

The study indicates that certain distinguishing differences do exist between the moraines sampled on the basis of percentages of certain lithologic types. Future work with other formations and areas may further establish such relationships.

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INTRODUCTION

The surficial glacial deposits specifically studied in the vicinity of the Grand Rapids area in Michigan were limited to segments of the Lake Border and Charlotte moraines. These features have been described by Frank Leverett and Frank B. Taylor (1915, pp. 204-214 and 222-232), and mapped by Frank Leverett (1924). In the following paper the application of a glacio-sedimentary technique, the pebble count, has been used to determine some of the relationships and differences in these features.

Location and Extent

The portion of the Charlotte moraine involved in this study extends from three miles north of Hastings, Michigan, T.4 N.,R.9 W., to the interlobate of the Lake Border and Charlotte moraines near Rockford, Michigan, T.9 N., R.10 W. The portion of the Lake Border moraine studied continues from this interlobate to a few miles north of South Haven, Michigan, T.1 N.,R.17 W. (Figure 1). These deposits are continuous for about 75 miles in linear extent with variable width ranging from a fraction of a mile to about eight miles.

Culture

The area is accessible by Federal and State highways, pointed out that the sieves sort grains according to shape as well as size. He illustrated his argument thus:

> The largest sphere that can pass through a given sieve has a diameter equal to the mesh, whereas a lath of any length theoretically, can pass through the sieve, providing only that its two smaller dimensions are less than the maximum dimensions of the mesh, including its diagonals.

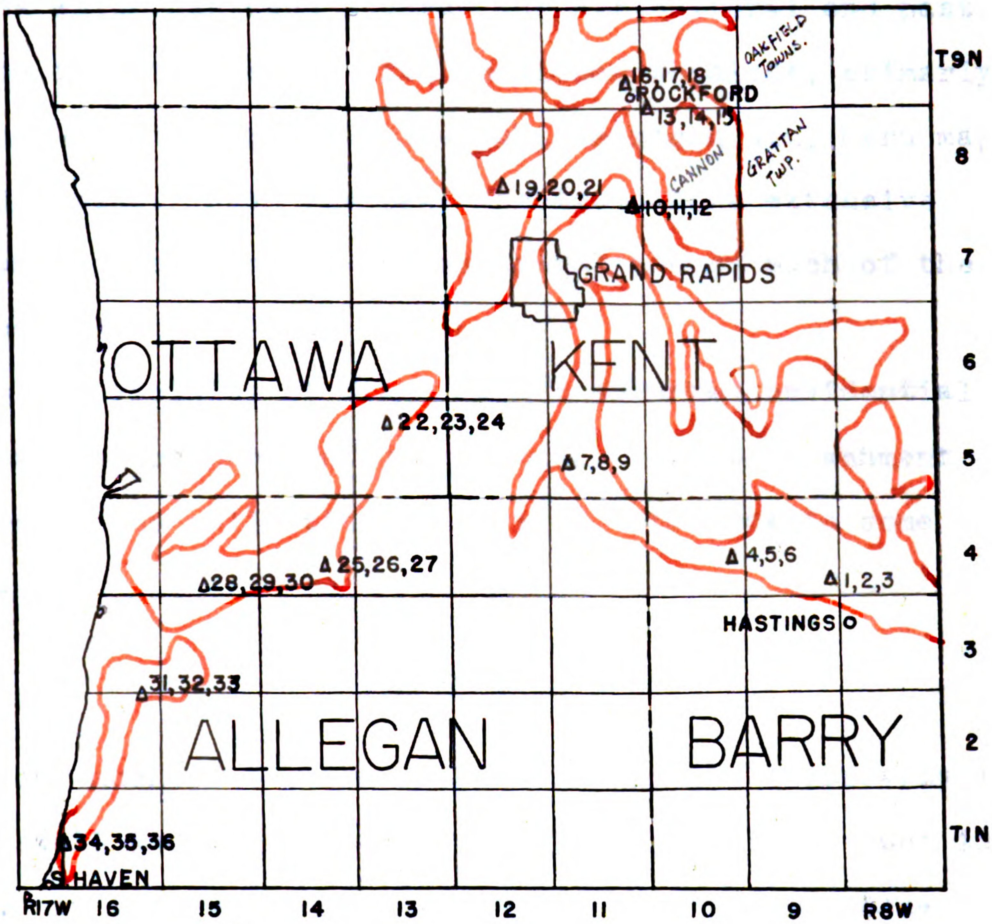
As may be seen, a long lath might have a much greater volume than a sphere of the same cross section, and hence if size is defined in terms of the nominal diameter, based on volume, the sieving process does not sort according to size.

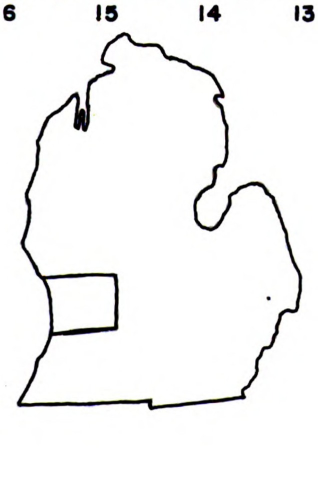
Despite the validity of this criticism sieving has been and still is a widely accepted practice and does serve a purpose. The criticism is included only to serve as a warning to those who study the graphs not to interpret them with a view toward the homogeneity or heterogeneity of the sample sections.

The sieving separated the samples so that a vital study of the pebble fraction might be undertaken.

Figure 1

Sketch Map of Sample Locations





county roads, farm roads and lanes. The major portion of the area which has been cleared for agricultural and pasturage purposes is interspersed with localized woodlots, primarly of second-growth timber; white oak, American elm, hard maple and white pine. Near the Lake Michigan shore extensive peach and apple orchards and vineyards occupy much of the land under cultivation.

In the vicinity of Grand Rapids suburban residential areas have encroached on the moraines. The encroachment has impeded the collection of data in this area to some extent.

Topography

Along much of the Charlotte moraine, the topography is of the swell and sag variety, with knolls 10 to 75 feet in height. In the reentrant angle of the Saginaw and Lake Michigan lobes there are a few prominent knobs which range from 100 to 200 feet in elevation. Among these Dias Hill, which rises to 1,032 feet above sea level or about two hundred feet above the surrounding country, has been studied as part of the problem.

The Lake Border moraine consists of till ridges that are interrupted by gaps in which sand plains occur, a series of low swells and shallow basins.

Lakes and Drainage

Both of the moraines under study are cut and drained by a number of streams which in some areas are lines of delimitation of the moraines. A number of lakes and swamps are found both in the moraines and on their borders.

DEFINITION OF THE PROBLEM

The Charlotte and Lake Border moraines have been correlated with two separate lobes of glaciation. This correlation has been on the basis of conspicuous reentrant angles, the conformation of glacial features to present marginal orientation, and patterns of outwash together with other criteria.

Pebble counts have been made as a basis of discrimination between drift sheets of different glacial stages. It is the purpose of this study to determine if pebble counts can be used to show some of the relationships or differences in moraines formed by different ice lobes.

FIELD PROCEDURE

The field work which was started in the late fall, 1954 extended into the early spring, 1955. A number of week-ends were spent in the area. After sample collecting had been completed the area was revisited to confirm certain aspects of the problem.

The field investigations were guided primarily by the Map of the Surface Formations of the Southern Peninsula of Michigan prepared by Leverett, Taylor and others; U. S. Geological Survey 15 minute series (topographic) maps; Michigan State Highway Department County Maps; and state and county maps prepared by the Automobile Club of Michigan were also used to good advantage in the determination of sampling locations.

Sampling areas were selected at approximately six to eight mile intervals along the linear extent of the moraines. Three samples were taken in each sample area at approximately one mile intervals (Figure 1).

All samples were collected by the channel method as described by W. C. Krumbein (1933, pp. 16-18). This method of collection insures a good sample where the average char acteristics of a deposit are to be determined.

The channel was cut about one foot wide, exposing a nearly vertical face, the sample collected was taken to a depth of three feet beneath the base of the leached zone. The base of the leached zone being determined by the hydrochloric acid test. At the base of the vertical sampling face a shallow indentation was cut and one edge of a small tarpaulin was inserted into the indentation. Next a mattock was used to scrape an even layer from the channel face, allowing it to drop and be caught on the tarpaulin. The thickness of the sample removed was equal to the diameter of the largest pebble encountered, thus giving a representative sample.

The tarpaulin with its contents was then removed from the channel and the sample was thoroughly mixed and placed into a conical heap. If at this point the total sample exceeded the capacity of the collection boxes, 264 cubic inches, it was divided into quarters and the two alternate quarters were then discarded. This reduced the sample to the capacity of the collection boxes and a quantity sufficient for laboratory analysis.

FIELD NOTES

CHARLOTTE MORAINE - Barry County

Sample #1

Locality: SW¼ Sec.24,T.4 N.,R.9 W. A road cut through the base of a gentle hillock.

Topography: Gentle swells and sags.

Depth of leaching: 39 inches.

Characteristics: Light brown, crumbly clay with paucity of pebbles.

Sample #2

Locality: NW¼ Sec.27,T.4 N.,R.9 W. Working face of a gravel pit in a kamic moraine.

Topography: High kamic feature above the valley of the Thornapple River.

Depth of leaching: 52 inches.

Characteristics: Kamic sand and pebbles over a pure white sand.

Sample #3

Locality: SW¼ Sec.36,T.4 N.,R.9 W. A road cut near the crest of a high ridge.

Topography: A high ridge cut by a number of gullies near the valley of the Thornapple River.

Depth of leaching: 45 inches.

Characteristics: A light brown, sandy clay with considerable pebble content.

Sample #4

Locality: SE$\frac{1}{4}$ Sec.23,T.4 N.,R.10 W. Working face of a gravel pit in a kamic moraine.

Topography: A single large kame separated from the mass of the moraine.

Depth of leaching: 48 inches.

Characteristics: Kamic gravels and sands.

Sample #5

Locality: NE$\frac{1}{4}$ Sec.24,T.4 N.,R.10 W. Road cut into a swell of the moraine.

Topography: A ridge cut by numerous gullies above ground moraine.

Depth of leaching: 51 inches.

Characteristics: Gravel grading into a very sandy clay with depth.

Sample #6

Locality: SW$\frac{1}{4}$ Sec.19,T.4 N.,R.9 W. Side of a 11 foot drainage ditch.

Topography: A clay plain in front of a ridge of the moraine, cut by numerous drainage ditches.

Depth of leaching: 39 inches.

Characteristics: Sandy clay with scattered pebbles.

CHARLOTTE MORAINE - Kent County

Sample #7

Locality: NW$\frac{1}{4}$ Sec.29,T.5 N.,R.11 W. Deep road cut on the east flank of Dias Hill.

Topography: To quote Frank Leverett (1915, p. 205):

> . . . an irregular mass covering scarcely two square miles. . . rises 1,032 feet above sea level, or nearly 200 feet above surrounding country.

A kame dominating this area of the moraine.

Depth of leaching: 89 inches.

Characteristics: Fine sand with some clay and scattered pebbles.

Sample #8

Locality: NE$\frac{1}{4}$ Sec.30,T.5 N.,R.11 W. Wall of a gravel pit near the crest of the Dias Hill complex.

Topography: Near the crest of a kame which dominates the moraine.

Depth of leaching: 73 inches.

Characteristics: Very light brown sand with clay bond; containing many pebbles and small cobbles.

Sample #9

Locality: $NW\frac{1}{4}$ Sec.20,T.5 N.,R.11 W. A road cut on the north flank of Dias Hill.

Topography: The kame merges into the swell and sag of the moraine.

Depth of leaching: 80 inches.

Characteristics: Sandy clay containing pebbles and cobbles.

Sample #10

Locality: $NE\frac{1}{4}$ Sec.2,T.7 N.,R.11 W. Road cut.

Topography: Gentle swells and sags with many lakes in the low areas.

Depth of leaching: 73 inches.

Characteristics: Sandy brown clay, few pebbles.

Sample #11

Locality: $SE\frac{1}{4}$ Sec.1,T.7 N.,R.11 W. A road-cut on the northwest base of a knoll.

Topography:

A kame on the edge of the valley of the Grand River.

Depth of leaching: 39 inches.

Characteristics: Kamic gravels and sand.

Sample #12

Locality: SE$\frac{1}{4}$ Sec.25,T.8 N.,R.11 W. Road cut on the southeast slope of the valley of the Grand River.

Topography: The moraine is cut by the Grand River, the valley is relatively flat and the walls or slopes are cut by tributary creeks of the river.

Depth of leaching: 39 inches.

Characteristics: Sands and fine gravels possibly kamic in origin.

Sample #13

Locality: SW$\frac{1}{4}$ Sec.31,T.9 N.,R.10 W. Road cut.

Topography: Gentle swells and sags dissected by many streams.

Depth of leaching: 14 inches.

Characteristics: Clay containing numerous pebbles.

Sample #14

Locality: SW$\frac{1}{4}$ Sec.31,T.9 N.,R.10 W. Road cut.

Topography: Kames above the valley of the Rouge River.

Depth of leaching: 60 inches.

Characteristics: Sand with scattered pebbles.

Sample #15

Locality:

NW$\frac{1}{4}$ Sec.6,T.8 N.,R.10 W. Road cut.

Topography: Kame on the ridge above the valley of the Rouge River.

Depth of leaching: 47 inches.

Characteristics: Sand with a paucity of pebbles.

LAKE BORDER MORAINE - Kent County

Sample #16

Locality: SW$\frac{1}{4}$ Sec.25,T.9 N.,R.11 W. Gravel pit.

Topography: Kamic moraine forming the bank of the Rouge River.

Depth of leaching: 43 inches.

Characteristics: Sandy gravel.

Sample #17

Locality: SW$\frac{1}{4}$ Sec.26,T.9 N.,R.11 W. Road cut in the flank of a kame.

Topography: Kamic moraine, the low areas containing small lakes.

Depth of leaching: 44 inches.

Characteristics: Kamic sands and gravels.

Sample #18

Locality: $NE\frac{1}{4}$ Sec.35,T.9 N.,R.11 W. Gravel pit.

Topography: Kamic moraine above the valley of the Rouge River.

Depth of leaching: 39 inches.

Characteristics: Kamic gravels.

Sample #19

Locality: $SE\frac{1}{4}$ Sec.4,T.7 N.,R.12 W. Road cut.

Topography: Gently rolling, considerable modified by urban development.

Depth of leaching: 30 inches.

Characteristics: Sandy clay with considerable pebbles.

Sample #20

Locality: $SE\frac{1}{4}$ Sec.9,T.7 N.,R.12 W. Cellar excavation for a residence.

Topography: Very gentle swells and sags.

Depth of leaching: 37 inches.

Characteristics: Fine sands and gravels.

Sample #21

Locality: $SW\frac{1}{4}$ Sec.21,T.8 N.,R.12 W. Channel cut in the bank of Indian Creek.

Topography: Gentle swell and sag, cut by numerous streams and modified by urban development.

Depth of leaching: 68 inches.

Characteristics: Sandy gravels.

LAKE BORDER MORAINE - Ottawa County

Sample #22

Locality: NE$\frac{1}{4}$ Sec.8,T.5 N.,R.13 W. Channel in the side of a drainage ditch.

Topography: Very gentle swells and sags and occasional interruptions in the form of sand plains.

Depth of leaching: 30 inches.

Characteristics: Sandy clay with occasional pebbles.

Sample #23

Locality: NE$\frac{1}{4}$ Sec.15,T.5 N.,R.13 W. Gravel pit in a large kamic mass.

Topography: A series of knobs perched on a ridge of the moraine.

Depth of leaching: 31 inches.

Characteristics: Kamic gravel and very sandy clay.

Sample #24

Locality: SE$\frac{1}{4}$ Sec.15,T.5 N.,R.13 W. Road cut through a kamic knob.

Topography: Kames perched on the moraine which rises as a ridge above a sand plain.

Depth of leaching: 33 inches.

Characteristics: Kamic sands and gravels.

LAKE BORDER MORAINE - Allegan County

Sample #25

Locality: SW¼ Sec.26,T.4 N.,R.14 W. Gravel pit in a kame.

Topography: Kame projecting above a sand plain.

Depth of leaching: 20 inches.

Characteristics: Kamic sands and gravels interspersed with layers of clay.

Sample #26

Locality: SE¼ Sec.26,T.4 N.,R.14 W. Abandoned gravel pit.

Topography: A kame isolated from the main ridge of the moraine by a small sand plain.

Depth of leaching: 21 inches.

Characteristics: Very sandy and kamic gravels.

Sample #27

Locality: NW¼ Sec.21,T.4 N.,R.14 W. The side of a drainage ditch.

Topography: A plain broken by occasional swells and hummocks.

Depth of leaching: 13 inches.

Characteristics: Light brown crumbly clay, containing few pebbles.

Sample #28

Locality: SE$\frac{1}{4}$ Sec.33,T.4 N.,R.15 W. Sidewall of a drainage ditch.

Topography: Generally flat plain or ground moraine.

Depth of leaching: 14 inches.

Characteristics: Chocolate brown clay, pebbles sparce.

Sample #29

Locality: SW$\frac{1}{4}$ Sec.28,T.4 N.,R.15 W. Road cut.

Topography: A hummock above the general level of the ground moraine.

Depth of leaching: 14 inches.

Characteristics: Reddish-brown clay containing few pebbles.

Sample #30

Locality: SE$\frac{1}{4}$ Sec.4,T.3 N.,R.15 W. Road cut.

Topography: Steep gullies cut into the ridge of the moraine that forms the north side of the Kalamazoo River valley. Many kames along the ridge.

Depth of leaching: 54 inches.

Characteristics: Kamic sand, scattered pebbles.

Sample #31

Locality: $NE\frac{1}{4}$ Sec.35,T.3 N.,R.16 W. Road cut.

Topography: Gentle ridges separated by sand plains.

Depth of leaching: 48 inches.

Characteristics: Sandy clay with a paucity of pebbles.

Sample #32

Locality: $NE\frac{1}{4}$ Sec.3,T.2 N.,R.16 W. Road cut.

Topography: Moderate swells and sags.

Depth of leaching: 12 inches.

Characteristics: Clay with pebbles, brown sandstone abundant.

Sample #33

Locality: $SE\frac{1}{4}$ Sec.3,T.2 N.,R.16 W. Gravel pit.

Topography: A kamic knob on a swell in the moraine.

Depth of leaching: 25 inches.

Characteristics: Kamic sand and gravel, brown sandstone predominating.

Sample #34

Locality: $NE\frac{1}{4}$ Sec.13,T.1 N.,R.17 W. Cut in a ridge.

Topography: Gentle swells and sags broken occasionally by sand plains.

Depth of leaching: 10 inches.

Characteristics: Heavy yellow clay with moderate quantities of pebbles.

Sample #35

Locality: SE$\frac{1}{4}$ Sec.13,T.1 N.,R.17 W. Clay cliff.

Topography: Steep clay cliffs above the Lake Michigan shoreline.

Depth of leaching: 11 inches.

Characteristics: Yellow clay containing numerous pebbles.

Sample #36

Locality: NE$\frac{1}{4}$ Sec.24,T.1 N.,R.17 W. Clay cliff.

Topography: Steep clay cliffs above the Lake Michigan shoreline.

Depth of leaching: 10 inches.

Characteristics: Clay with pebbles.

LABORATORY PROCEDURE

The purpose of the laboratory work associated with this problem was to ascertain the percentage by number and by weight of the pebble fraction of the specimens collected in the field.

Drying and Disaggregation

Since the field samples contained varying amounts of moisture all the samples were thoroughly dried upon being brought to the laboratory. Since a number of the samples consisted of unconsolidated sand and gravel they presented no disaggregation problem; however, some of the samples contained sufficient amounts of clay which upon drying produced hardened lumps. When such lumps were present, the sample was placed on a wooden board and crushed by a wooden rolling pin until no aggregates larger than a pea were present.

Laboratory Sampling

The laboratory samples were split from the field sample by an adaptation of the hand quartering system developed by F. J. Pettijohn (1931, pp. 432-455). Four rectangular sheets of paper were overlapped to form a square composed of one quarter of each sheet. The sample was then poured on the center of the square, in a circular heap, and the papers were then pulled apart. When necessary, the opposite quarters were recombined and the process repeated until a small enough split was obtained. A one kilogram quantity was selected as the standard laboratory sample under the rule set forth by C. K. Wentworth (1926), and quoted by W. C. Krumbein (1938, pp. 31-2):

> . . . a sample large enough to include several fragments which fall in the largest grade present in the deposit. Several fragments may be interpreted as a number sufficiently large so that the probability of a serious accidental deviation from the normal number of such fragments in a sample collected by a reliable random method is small.

Sieving

After drying, diaggregation and splitting the laboratory samples were sieved in two, six sieve sequences. The two sequences were subjected to 10 minute periods in the Ro-Tap sieving machine and the residue of each sieve size was weighed to the nearest hundredth of a gram. The twelve sieves used were: 6, 10, 14, 20, 28, 35, 48, 65, 100, 150, 230, 325 meshes per inch. Tables comparing the weights of the sieve sizes at all stations are shown in (Table I, page).

The sieving was done primarily to separate the sample into a convenient size unit for further study, and not as an instrument of mechanical analysis. The process of sieving involves numerous complexities that limit the accuracy of this system. W. C. Krumbein (1938, p. 124), cites arguments set forth by E. A. Mitschlerlich (1905, p. 37), who

TABLE I

Table of the weights of the residue of each sieve size from the one kilogram laboratory sample

Sieves	Sample #1	#2	#3	#4	#5	#6	#7	#8
6	81.09	230.22	56.65	672.00	319.20	142.88	192.55	339.00
10	93.14	149.27	20.42	84.03	93.52	20.06	15.35	158.83
14	88.09	49.86	8.42	34.77	54.76	12.70	7.80	72.79
20	81.09	40.31	20.19	31.28	92.32	23.75	14.30	72.42
28	89.06	58.98	33.05	36.35	133.28	39.12	62.22	76.98
35	99.66	174.79	102.39	35.89	125.88	57.99	87.95	82.55
48	97.95	218.54	346.88	33.51	87.88	228.06	168.38	84.65
65	93.65	62.24	208.14	22.24	44.87	182.39	202.02	45.91
100	94.18	9.11	71.96	14.19	19.76	103.78	91.50	22.89
150	113.86	1.48	38.37	8.97	9.57	65.42	54.32	14.81
230	48.12	.60	50.31	6.97	6.09	62.54	54.57	12.10
325	4.00	.32	28.68	4.27	2.64	48.99	36.45	10.88
Remainder	10.10	1.67	11.65	15.42	10.02	10.28	11.25	3.33
TOTAL	999.80	997.39	996.91	999.89	999.79	998.96	998.66	997.14

p.22 [illegible]

TABLE I (continued)

Table of the weights of the residue of each sieve size
from the one kilogram laboratory sample

Sieves	Sample #9	#10	#11	#12	#13	#14	#15	#16
6	213.90	91.20	248.90	509.80	452.95	228.30	376.69	468.75
10	67.11	64.28	108.70	131.60	135.95	25.47	24.30	79.40
14	94.96	86.35	49.50	62.40	60.20	19.20	292.85	35.85
20	86.47	85.14	53.20	79.60	63.90	36.30	59.15	43.96
28	61.76	86.05	63.60	70.75	69.50	64.40	176.80	47.58
35	134.30	122.75	83.50	60.80	66.10	121.05	31.30	60.90
48	55.45	118.30	133.10	44.30	62.50	214.10	2.21	83.10
65	52.70	127.30	107.30	19.60	38.40	166.30	4.14	72.70
100	95.63	91.50	51.90	7.20	18.20	55.15	13.31	42.80
150	88.75	41.45	28.20	3.10	10.30	26.65	9.00	24.50
230	26.20	53.40	29.80	2.20	8.70	22.05	3.33	16.40
325	19.54	24.75	10.00	1.50	3.35	6.60	2.63	5.25
Remainder	1.77	50.90	28.70	4.70	7.85	12.60	1.80	18.60
TOTAL	998.54	998.37	996.40	997.55	997.85	998.17	997.51	999.79

TABLE I (continued)

Table of the weights of the residue of each sieve size
from the one kilogram laboratory sample

Sieves	Sample #17	#18	#19	#20	#21	#22	#23	#24
6	159.00	156.20	349.40	151.90	168.90	143.80	624.30	511.60
10	82.80	50.10	173.50	82.60	25.70	136.20	119.95	142.00
14	39.70	26.90	77.10	42.90	18.67	54.60	57.20	56.40
20	49.70	40.60	58.60	40.70	33.40	44.90	38.45	51.50
28	59.80	55.90	45.10	46.50	57.90	39.00	35.65	50.70
35	89.20	98.50	45.00	100.30	108.70	33.40	34.95	48.30
48	181.00	259.70	43.23	263.20	151.70	145.90	32.20	40.90
65	173.50	184.70	55.65	162.10	190.90	170.00	21.30	29.00
100	69.70	64.10	32.60	69.50	114.40	86.00	13.40	22.60
150	30.20	24.34	42.50	25.00	43.30	32.60	5.40	11.30
230	26.10	16.00	54.70	7.90	42.50	70.20	4.10	9.20
325	9.50	5.10	8.60	1.70	13.40	26.40	1.85	3.40
Remainder	28.70	15.80	12.42	3.20	27.70	16.20	8.50	21.30
TOTAL	998.90	997.90	998.40	997.50	997.17	999.20	997.25	998.20

TABLE I (continued)

Table of the weights of the residue of each sieve size from the one kilogram laboratory sample

	Sample							
Sieves	#25	#26	#27	#28	#29	#30	#31	#32
6	265.50	130.05	193.10	175.30	273.40	144.10	236.60	243.80
10	52.20	130.20	171.00	204.50	153.70	109.90	38.62	114.50
14	41.10	66.70	72.90	92.90	76.70	57.00	35.70	61.70
20	43.80	55.30	63.70	79.90	65.20	56.10	42.37	60.40
28	43.00	58.20	53.50	69.70	55.00	56.60	69.50	58.10
35	77.70	152.50	53.40	98.70	58.30	119.00	113.40	67.30
48	194.70	140.40	64.00	111.80	143.60	276.50	231.72	137.70
65	163.40	187.40	114.80	124.30	102.80	91.50	121.20	139.60
100	64.50	52.40	77.20	16.70	30.40	29.10	37.45	52.80
150	37.30	11.50	39.90	7.85	11.00	17.00	20.95	27.10
230	6.50	5.70	48.10	7.30	14.60	13.70	33.04	19.60
325	1.90	2.10	20.90	4.00	6.80	11.30	6.96	7.10
Remainder	5.20	6.20	25.60	3.45	7.30	15.30	9.22	6.30
TOTAL	996.80	998.65	998.10	996.30	998.80	997.10	996.73	996.00

TABLE I (continued)

Table of the weights of the residue of each sieve size from the one kilogram laboratory sample

Sieves	Sample #33	#34	#35	#36
6	553.80	310.45	332.60	317.70
10	143.75	99.40	77.30	92.40
14	54.85	64.20	63.43	63.50
20	44.40	59.10	64.20	60.30
28	43.70	67.80	63.92	61.80
35	53.30	130.14	124.10	128.00
48	51.42	26.40	22.10	23.10
65	26.98	114.63	121.40	120.80
100	12.90	50.11	53.20	49.50
150	7.00	32.40	31.70	35.70
230	3.60	19.80	22.10	22.90
325	2.50	11.10	10.60	9.70
Remainder	1.50	13.10	12.00	12.70
TOTAL	999.70	998.63	998.65	998.10

APPENDIX

TABLE III

Generalized Classification of Sediments*

Composition		Quartz Chert	Quartz Chert Micas Chlorite		Quartz Feld-spar Clay
			Feldspar	Feldspar	
Texture		Quartz Conglomerate	Graywacke Conglomerate		Arkosic Conglomerate
Detrital Rocks (Clastic Texture)	Coarse Conglomerates		Low-Rank	High-Rank	
	Medium Sandstone	Quartz and quartzose sandstone	Graywacke		Arkose
			Low-Rank	High-Rank	
	Fine Shales	Quartzose Shale	Micaceous Shale	Chloritic Shale	Kaolinitic and Feldspathic Shale
Chemical Rocks	Sandy(clastic)	Limestone,Dolomite,Chert,Salt,Gypsum,Etc.			
	Pure(crystal-line)				

*After Pettijohn, Sedimentary Rocks, 1949, p. 186, from Krynine, Producers Monthly, vol.9, no. 3, Jan. 1945, pp. 12-22.

Pebble Count

Various terms in common use are likely to mean different things to different people; it is desirable, therefore, that they be codified or standardized. Thus a pebble shall be defined according to the system used by F. J. Pettijohn (1949, p. 12), as:

> . . . a rock fragment, larger than a coarse sand grain or granule and smaller than a cobble, which has been rounded or otherwise abraded by the action of water, wind, or glacial ice. It is therefore between 4 and 64 mm in diameter.

Also, it was necessary that a basis of megascopic classification be adopted in this work. The igneous rocks are classified by a system proposed by Cross, Iddings, Pirsson and Washington (1903, pp. 180-5), based on color, texture, and mineralogical composition (Table II). The sedimentary rocks are classified according to P. D. Krynine (1948, pp. 130- 165), based on textures and mineralogical composition (Table III). The metamorphic rocks are classified according to F. H. Pough (1953, pp. 23-5), and F. H. Lahee (1941, p. 786), based on texture and mineral composition (Table IV).

In a pebble count the specific mineral composition is generally of less interest than, or subordinate to, the composition as expressed in terms of the rock types. The results can be expressed in percentage by number, or the separated fractions can be weighed and the composition expressed in percentage by weight. In this study both methods of computing the results were used.

It was discovered after sieving, that the pebble fraction varied considerably above or below the intended number of pebbles to be used in the count. Thus the graphs prepared on the basis of weight of each sieve residue represent the true proportion of the sample. If less than the intended number of pebbles needed for the counts - one hundred, were found in the residue of the one kilogram sample then a second kilogram was sieved and only the pebble residue retained.

For each sample area a mass of more than one hundred pebbles was accumulated and then thoroughly mixed, In order to eliminate as much error as possible in the selection of the one hundred pebbles to be counted, the entire pebble mass was poured into a conical pile on a sheet of paper and separated into four quarters by cutting the pile along two diameters with the edge of a ruler. Alternate quarters were retained and combined, the process was then repeated until approximately one hundred pebbles remained.

Identification and Classification

The identification and classification of the pebbles counted were on the basis of a system described by F. H. Pough (1953, pp. 70-2). The first step was to determine the classification, if possible, as a igneous, sedimentary, or metamorphic rock type. Next, the constituent minerals were identified by the use of a table prepared by F. F. Grout (1940, p. 20), Table V).

With the classification and the major mineral composition determined, reference was made to the tables of rock classification for a more detailed identification; igneous rocks by Cross, Iddings, Pirsson, and Washington (1903, pp. 180-5), sedimentary rocks by P. D. Krynine (1948, pp. 130-165), and metamorphic rocks by F. H. Pough (1953, pp. 23-5), and F. H. Lahee (1941, p. 786).

When a total of one hundred pebbles had been identified and counted the results were prepared as percentage by number and the separate fractions were also weighed and the composition expressed in percentage by weight. It should be noted that when a pebble was fractured to obtain a fresh examination surface all the fragments were retained to ensure the proper percentage by weight.

The results of pebble counts for each sample have been prepared in both tabular form (Table VI, page 31), and in graphic representation (Figure 2, page 37).

TABLE VI

Table of the results of the pebble counts
by number and by weight

	Sample											
	#1		#2		#3		#4		#5		#6	
Rock Type	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Limestone	37	65.70	42	213.67	46	196.70	49	205.80	42	305.65	51	294.50
Brown sandstone									3	18.20		
Light quartzite	11	5.60	7	4.40	2	4.20			7	16.50	9	62.90
Red quartzite	6	4.25	1	10.45	12	6.90			1	9.73	2	8.70
Chert	12	10.30	11	15.75	10	9.50	12	19.70	12	25.85	12	6.90
Dolomite			3	90.50	2	10.30					6	40.65
Granite	11	13.30	9	12.20	6	4.10	13	17.60	7	10.90	4	46.60
Basalt	13	11.90	4	2.70	4	2.60	7	5.30	16	118.05	6	25.40
Diorite	4	21.55	3	9.45			3	30.00	3	7.80	2	3.15
White sandstone			5	13.00	8	11.80	5	8.65	1	61.30		
Schist	6	6.70	12	83.30			4	18.90	6	90.90	7	16.25
Gneiss			1	4.40	5	29.70	6	177.60			1	3.80
Shale			2	7.35	2	3.85			1	.60		
Conglomerate							1	7.90				
Pegmatite					2	16.65			1	4.90		
Phyllite					1	8.90						
Peridotite												
*Quartz fragment												
TOTAL	100	139.30	100	467.17	100	305.20	100	494.45	100	670.38	100	508.85

TABLE VI (continued)

Table of the results of the pebble counts
by number and by weight

Rock Type	#7 No.	#7 Wt.	#8 No.	#8 Wt.	#9 No.	#9 Wt.	#10 No.	#10 Wt.	#11 No.	#11 Wt.	#12 No.	#12 Wt.
Limestone	55	170.65	61	104.55	57	139.30	62	100.20	54	147.20	56	135.60
Brown sandstone												
Light quartzite	10	31.40	3	15.50	4	31.15	2	3.20	5	4.10	4	31.10
Red quartzite	6	2.70	2	.60	1	1.15			6	18.45	2	4.10
Chert	13	4.65	11	2.20	10	5.80	6	3.40	17	19.60	8	17.90
Dolomite					9	10.65	2	11.10	2	17.40	8	56.30
Granite	11	27.80	9	18.40	8	26.80	18	2.45	7	32.05	14	33.00
Basalt	5	4.75	5	1.10	4	6.40	3	50.50	4	2.90	7	10.00
Diorite			2	1.50			2	82.10				
White sandstone									1	8.15		
Schist			6	14.80	6	18.70	4	85.15	2	44.35		
Gneiss												
Shale											1	1.30
Conglomerate					1	4.80						
Pegmatite									1	5.85		
Phyllite			1	60.00					1	7.60		
Peridotite							1	81.20				
*Quartz fragment												
TOTAL	100	241.95	100	218.65	100	244.75	100	419.30	100	307.65	100	289.50

TABLE VI (continued)

Table of the results of the pebble counts
by number and by weight

	Sample											
	#13		#14		#15		#16		#17		#18	
Rock Type	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Limestone	43	201.60	40	211.25	35	115.20	15	84.40	4	48.10	9	64.40
Brown sandstone			1	1.35	2	7.95	20	103.50	38	116.80	42	128.05
Light quartzite	7	10.30	7	20.60	8	14.30	4	18.80	8	1.90	8	2.00
Red quartzite	8	12.60	9	17.70	5	7.80	3	27.70				
Chert	12	7.85	13	8.90	10	21.10	10	25.10	15	13.65	11	4.00
Dolomite	6	11.70	2	13.60			13	21.30	1	5.80	2	5.40
Granite	14	29.60	8	31.30	10	16.80	21	50.20	8	8.70	12	16.60
Basalt	6	14.30	10	8.65	12	14.10	6	11.00	12	21.95	10	6.20
Diorite			4	7.00	10	22.05			3	4.70		
White sandstone	1	2.70					4	15.50	1	3.40	6	37.00
Schist	1	45.60	3	28.20	8	27.80	4	82.85				
Gneiss			2	38.35					11	43.20		
Shale												
Conglomerate			1	17.40								
Pegmatite												
Phyllite	1	7.90										
Peridotite												
*Quartz fragment	1	.60										
TOTAL	100	344.75	100	404.30	100	247.10	100	440.35	100	269.20	100	263.65

TABLE VI (continued)

Table of the results of the pebble counts by number and by weight

	Sample											
	#19		#20		#21		#22		#23		#24	
Rock Type	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Limestone	2	10.10	5	1.20	1	2.60	2	147.40	4	60.10	17	69.40
Brown sandstone	60	194.00	59	26.60	60	207.75	82	315.80	56	197.40	63	215.10
Light quartzite	2	1.10	4	1.20	6	1.80	7	291.70	9	8.65	6	11.60
Red quartzite	1	.40	2	.30	3	.60			11	5.80		
Chert	11	21.15	5	3.25	7	8.65	5	27.30	3	4.10		
Dolomite												
Granite	9	8.75	13	2.90	12	30.72	1	104.20	7	19.90		
Basalt	6	6.70	3	1.60	4	3.10	2	3.50	3	1.40	6	25.75
Diorite	3	1.70	2	.50							2	104.90
White sandstone			1	1.40								
Schist	4	24.80	6	5.55	4	18.65	1	70.90	7	40.15	5	43.50
Gneiss					1	12.15						
Shale												
Conglomerate											1	11.20
Pegmatite	2	14.40										
Phyllite												
Peridotite					1	1.30						
*Quartz fragment					1	.60						
TOTAL	100	283.10	100	44.50	100	287.92	100	960.80	100	337.50	100	481.45

TABLE VI (continued)

Table of the results of the pebble counts by number and by weight

	Sample											
	#25		#26		#27		#28		#29		#30	
Rock Type	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Limestone	1	9.65	1	1.70							1	119.40
Brown sandstone	61	194.60	63	280.60	59	196.80	76	209.10	88	503.80	86	210.60
Light quartzite	8	9.55	6	7.75	11	7.15	6	23.30	3	.53	2	2.20
Red quartzite	11	3.60	5	3.45	3	2.60						
Chert			11	9.15	14	8.80	4	19.40			3	11.30
Dolomite			8	10.80	3	10.80			2	11.10		
Granite	7	23.10	12	27.10	2	18.70	5	31.30			5	69.60
Basalt	5	2.40			6	7.80	6	17.85	3	3.52		
Diorite	2	9.00										
White sandstone	1	1.10									1	3.00
Schist					2	18.80	2	31.60	1	9.30	2	54.90
Gneiss	2	27.30										
Shale									2	158.60		
Conglomerate									1	32.00		
Pegmatite												
Phyllite	2	14.80										
Peridotite							1	40.85				
*Quartz fragment												
TOTAL	100	295.10	100	340.50	100	271.45	100	373.40	100	718.85	100	471.00

TABLE VI (continued)

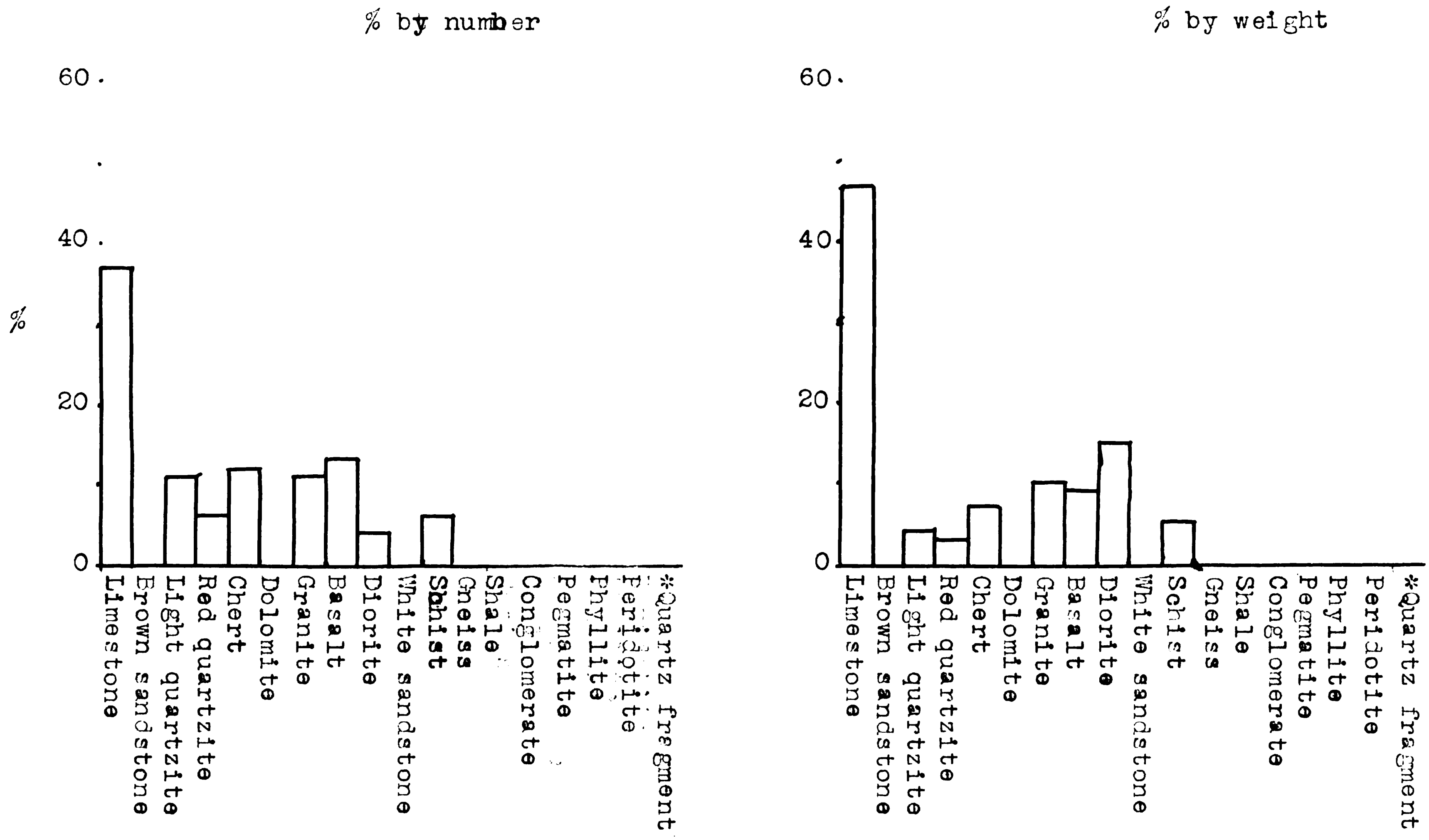
Table of the results of the pebble counts
by number and by weight

Rock Units	#31 No.	#31 Wt.	#32 No.	#32 Wt.	#33 No.	#33 Wt.	#34 No.	#34 Wt.	#35 No.	#35 Wt.	#36 No.	#36 Wt.
Limestone	4	.90					2	4.30	3	3.10	8	30.20
Brown sandstone	42	63.20	81	283.30	79	337.50	48	162.70	40	144.90	42	156.80
Light quartzite	3	2.50					7	2.15	7	12.75	5	10.50
Red quartzite			2	11.90	1	6.70	6	30.10	3	10.80	8	112.20
Chert	21	11.75	7	14.70	4	8.70	9	26.10	14	43.10	10	41.25
Dolomite												
Granite	8	4.75	4	48.60	6	30.40	8	70.60	5	39.20	11	143.50
Basalt	12	11.80	4	13.85	2	24.70	11	17.25	12	80.60	7	149.25
Diorite	1	12.00					3	4.40	1	2.15	2	4.55
White sandstone												
Schist	6	16.10	2	28.10	7	32.50	4	120.05	6	103.85	5	120.65
Gneiss												
Shale	2	1.60					1	1.15	4	4.20		
Conglomerate									1	6.80		
Pegmatite									3	20.15	1	26.40
Phyllite									1	18.25	1	31.40
Peridotite					1	16.40	1	30.80				
*Quartz fragment	1	.30										
TOTAL	100	124.90	100	400.45	100	456.90	100	469.60	100	489.85	100	826.70

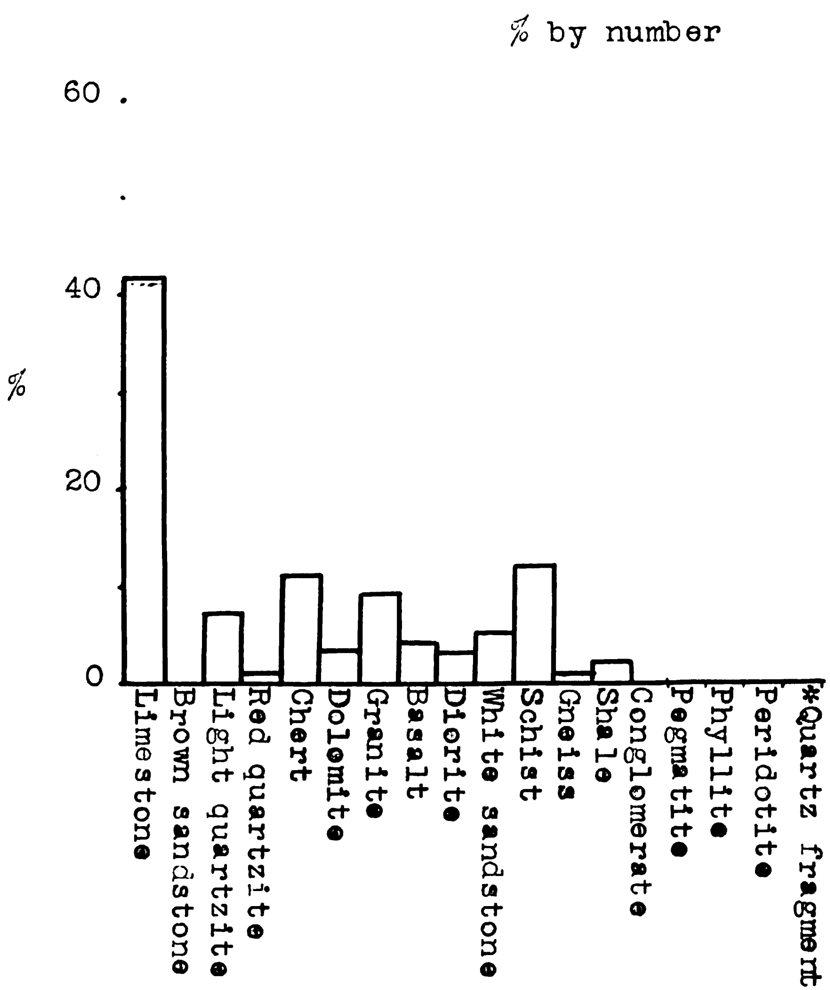
FIGURE 2

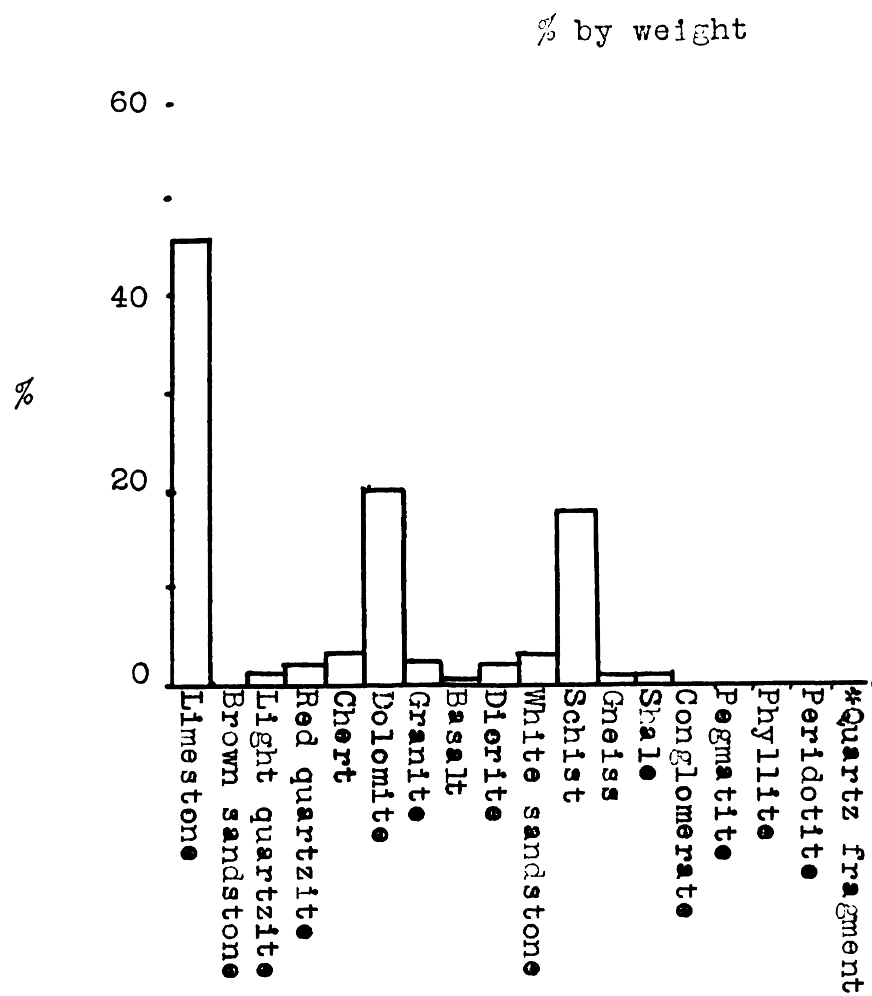
Graphs of the results of the pebble counts - percentage by number and by weight

Sample #1



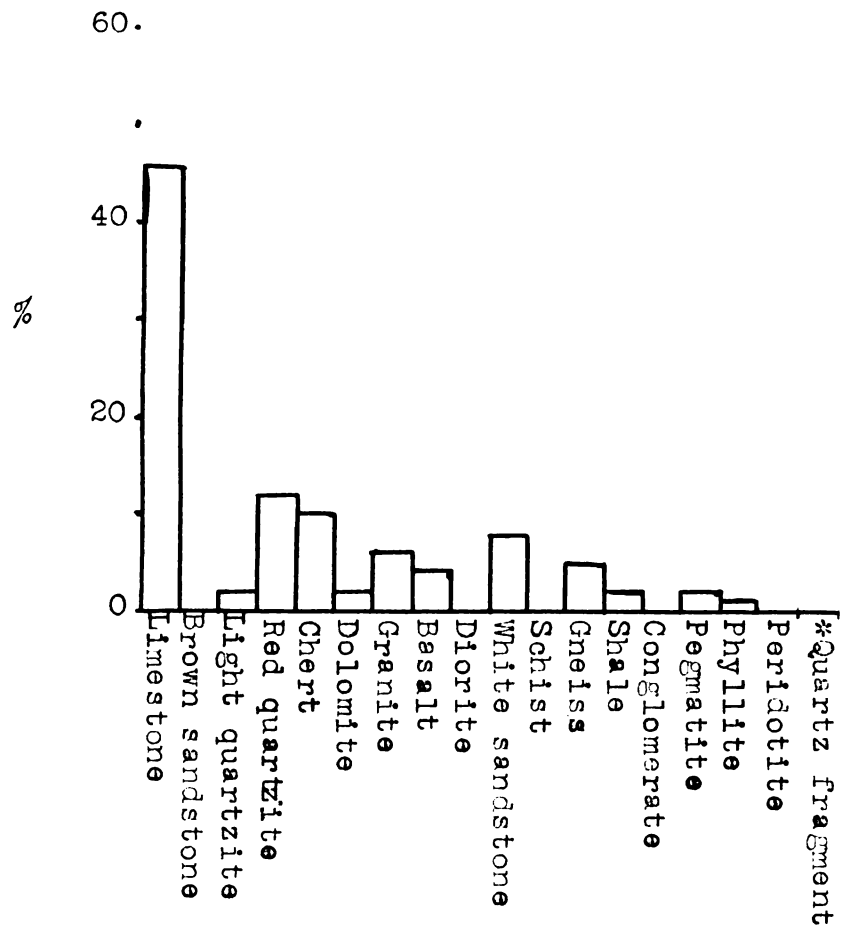
Sample #2


% by number
%
60
40
20
0
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

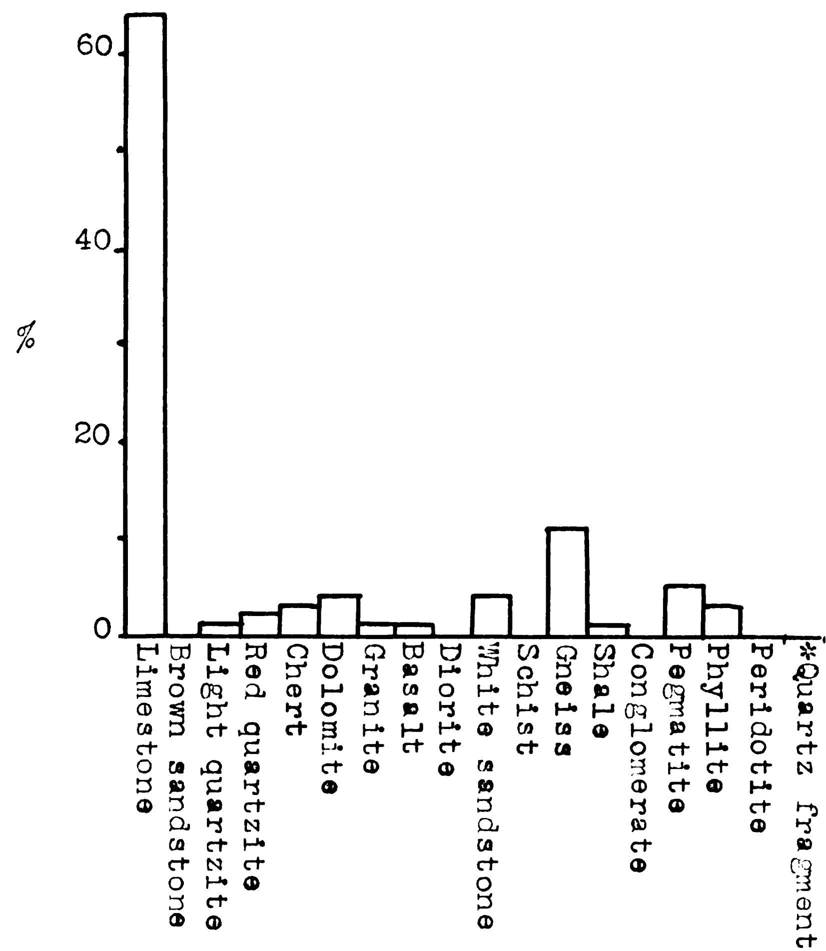

% by weight
%
60
40
20
0
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

Sample #3

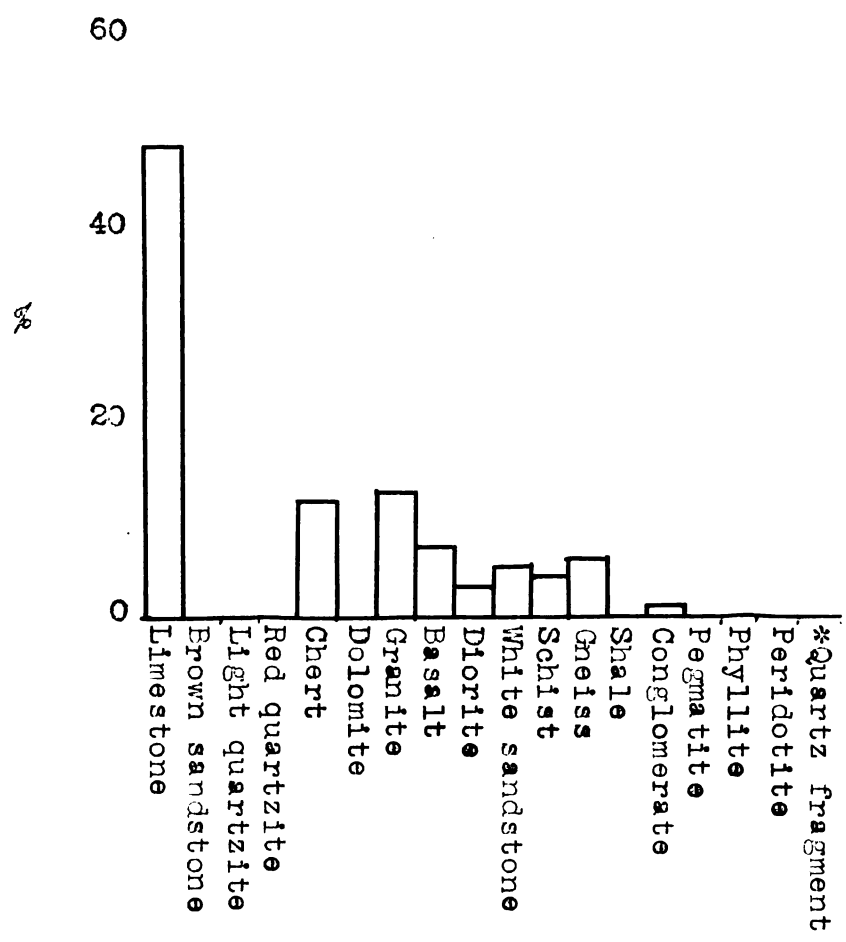
% by number

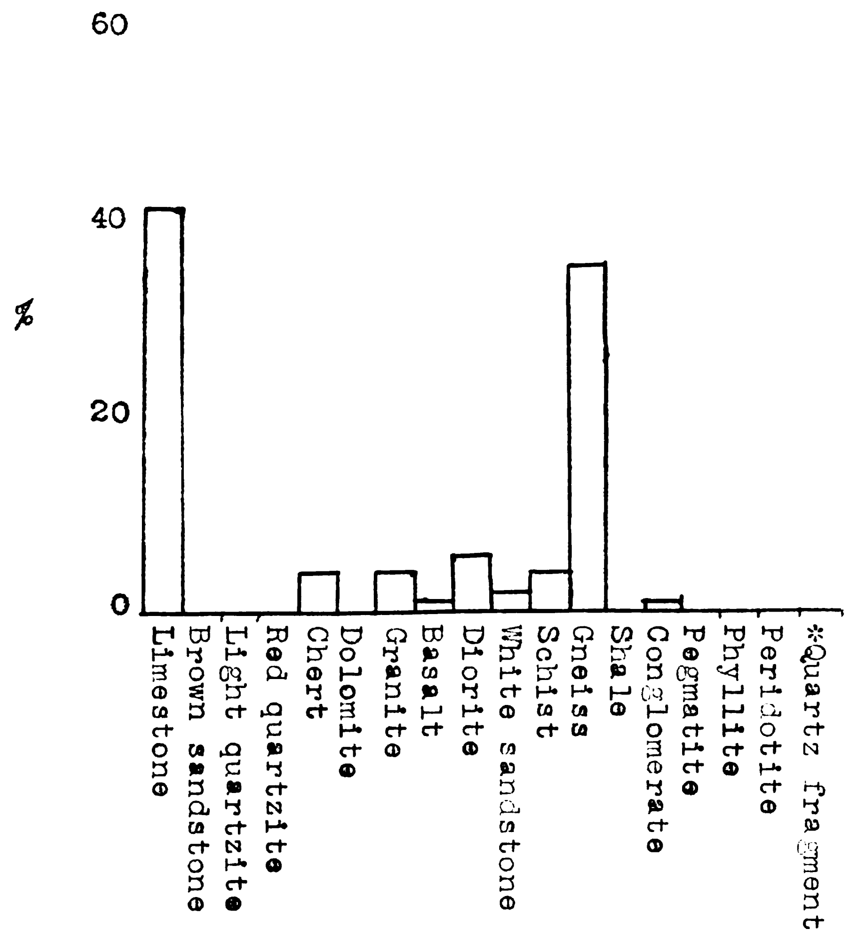


% by weight



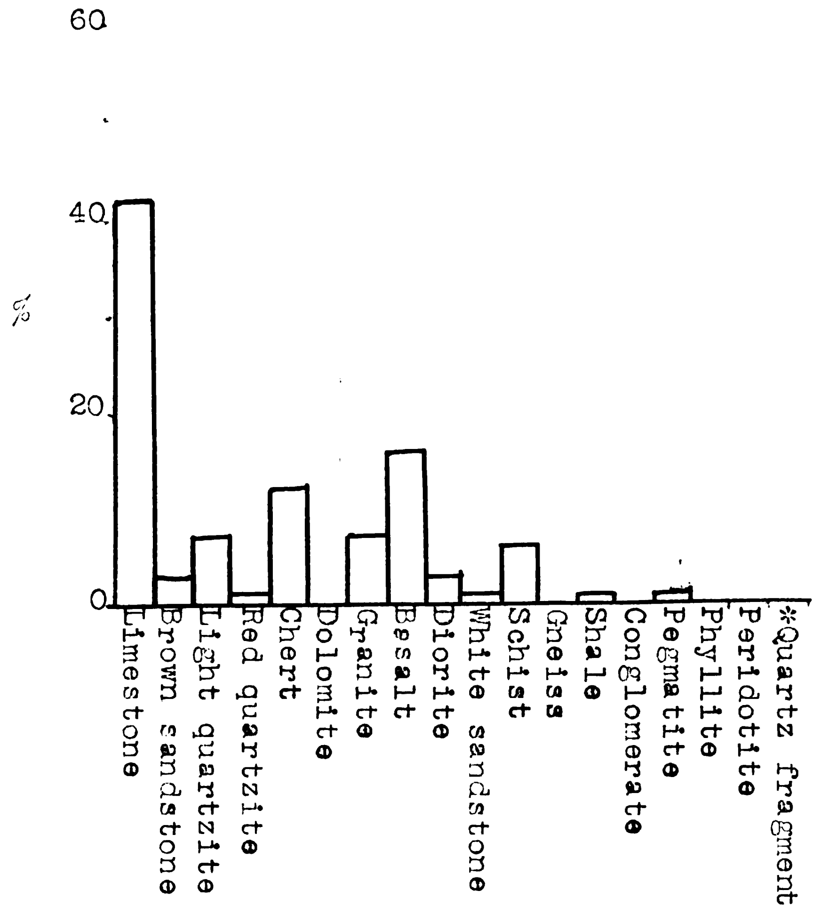
Sample #4


60
40
20
0
%
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

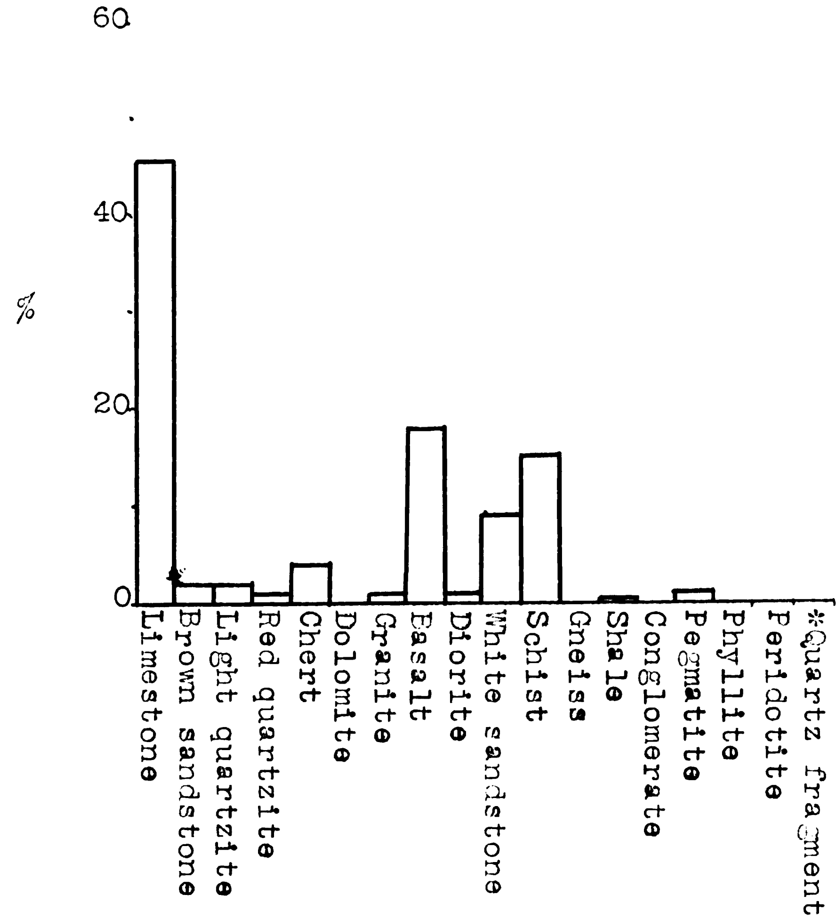

60
40
20
0
%
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

Sample #5

% by number

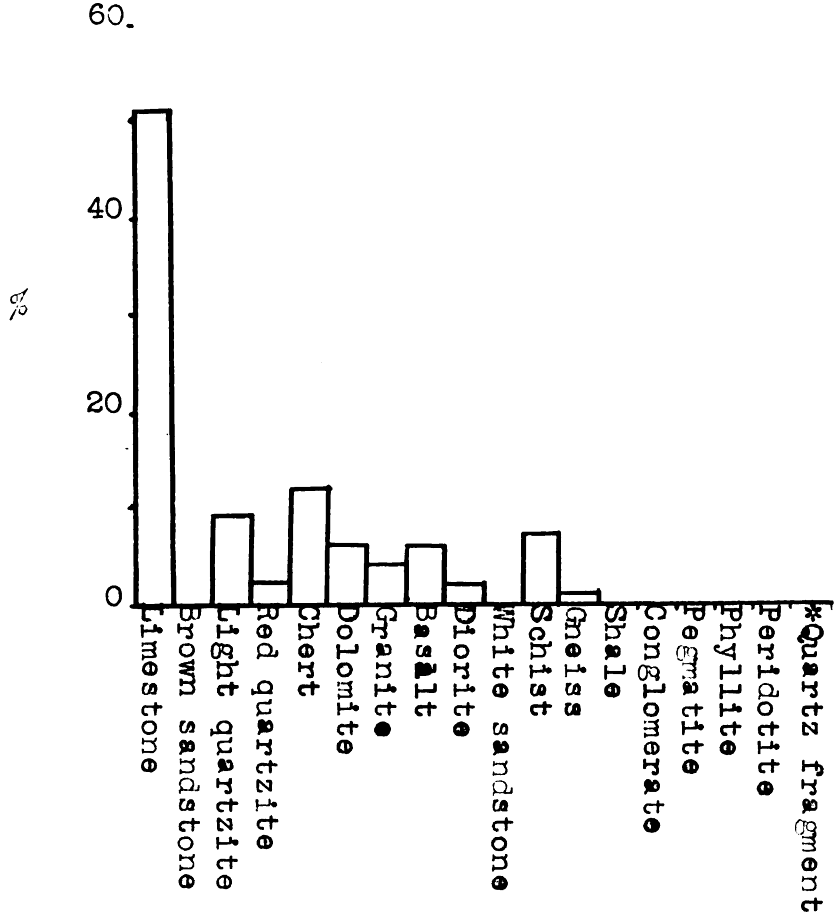


% by weight

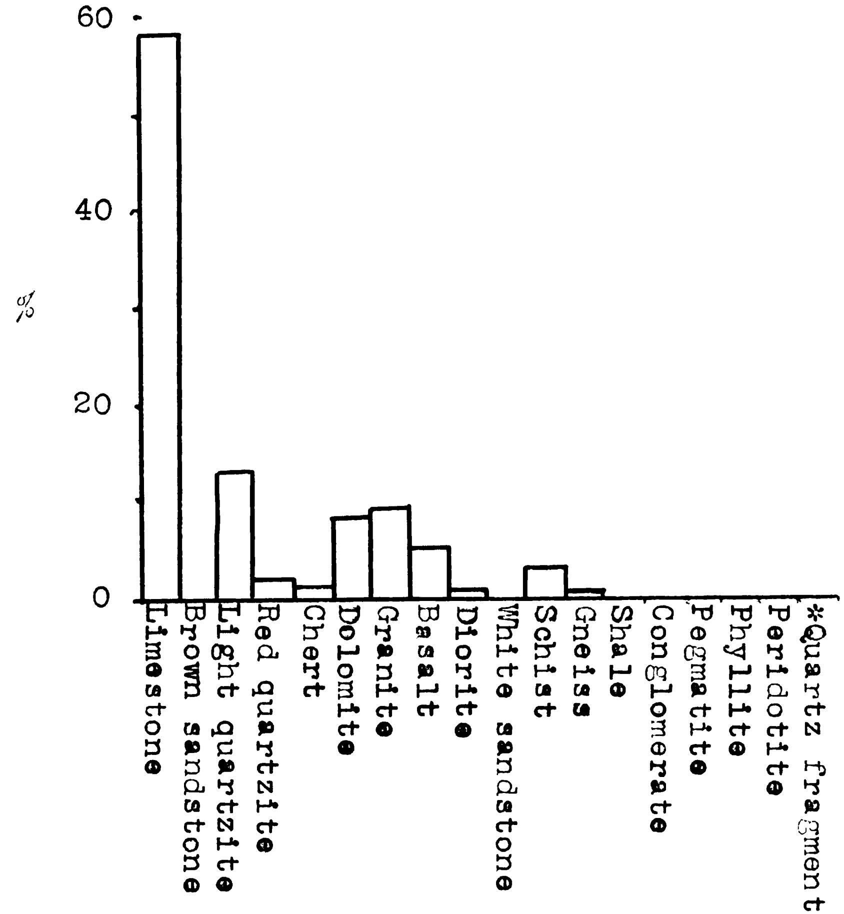


Sample #6

% by number

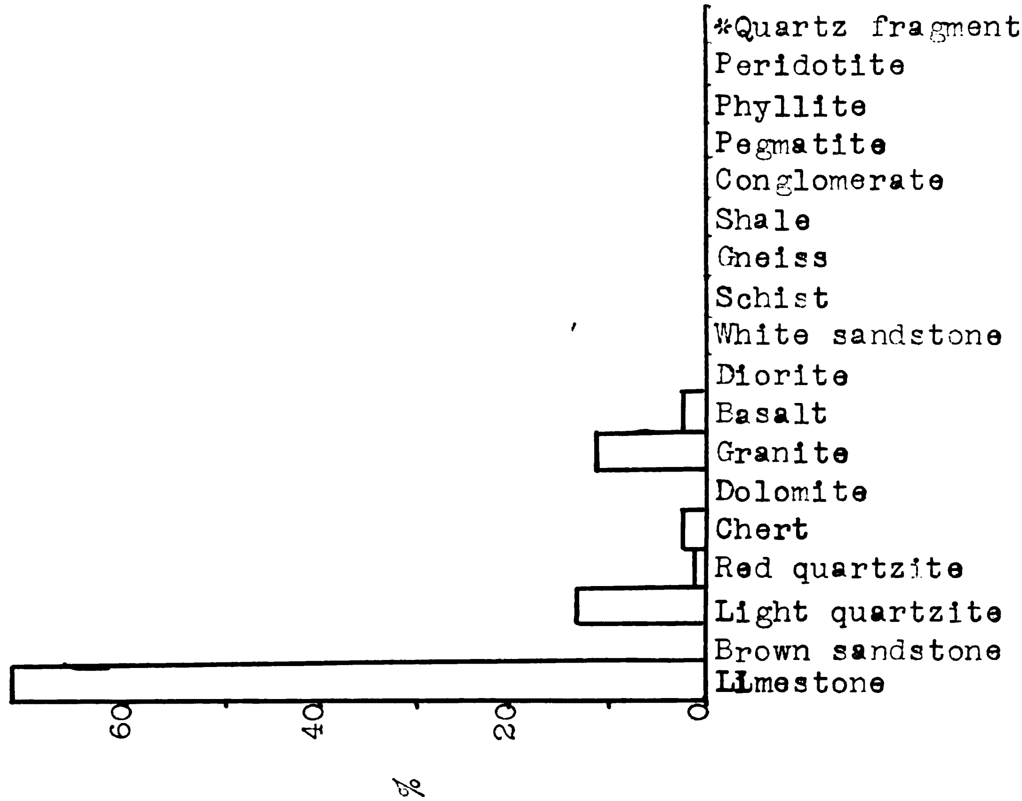


% by weight

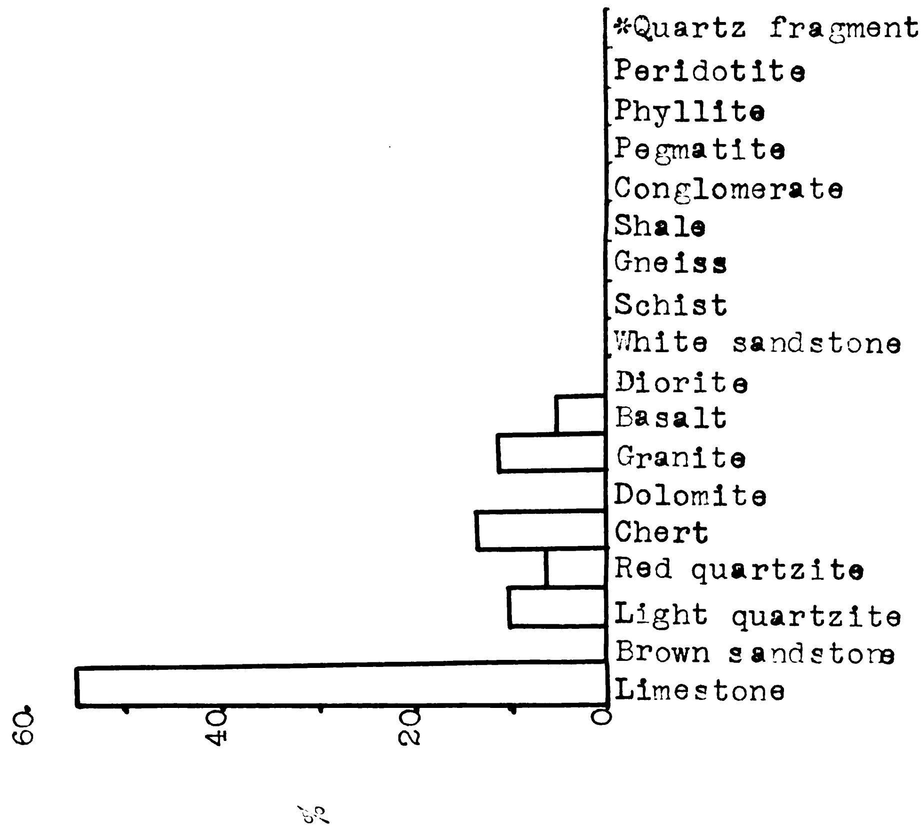


Sample #7

% by weight

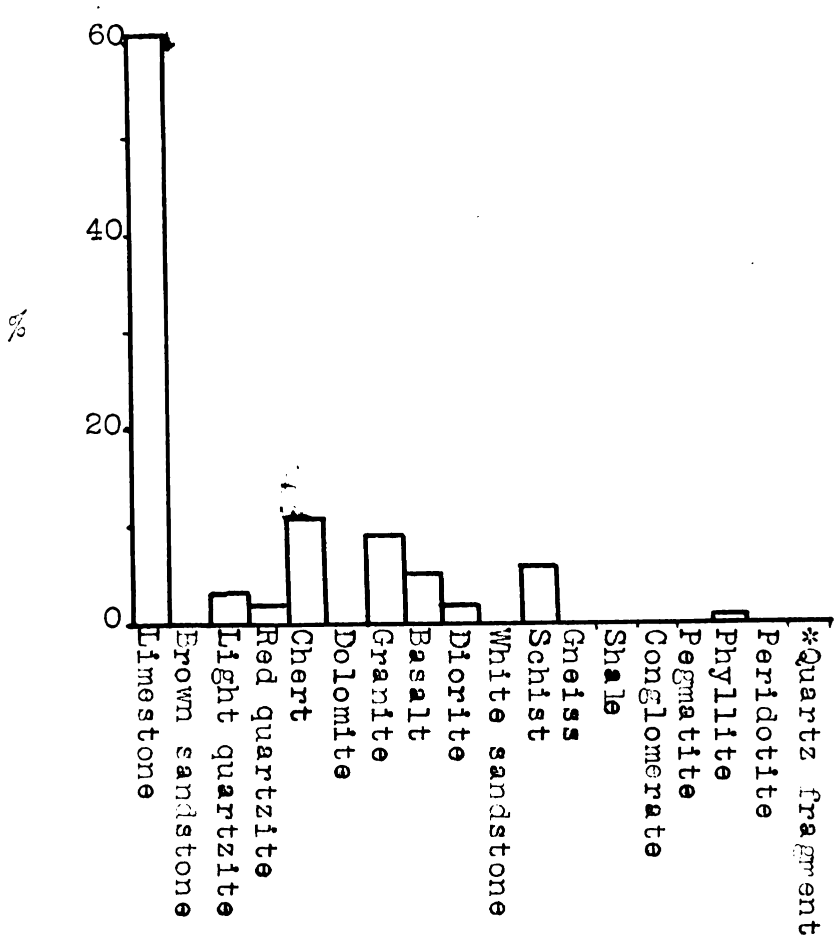


% by number

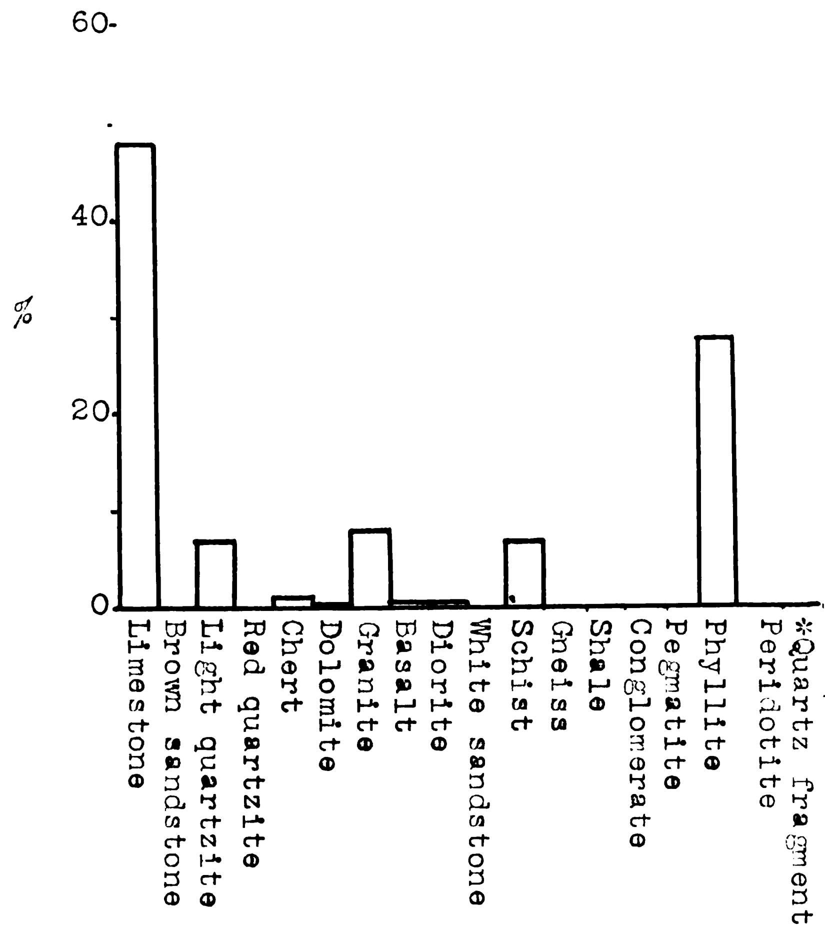


Sample #8

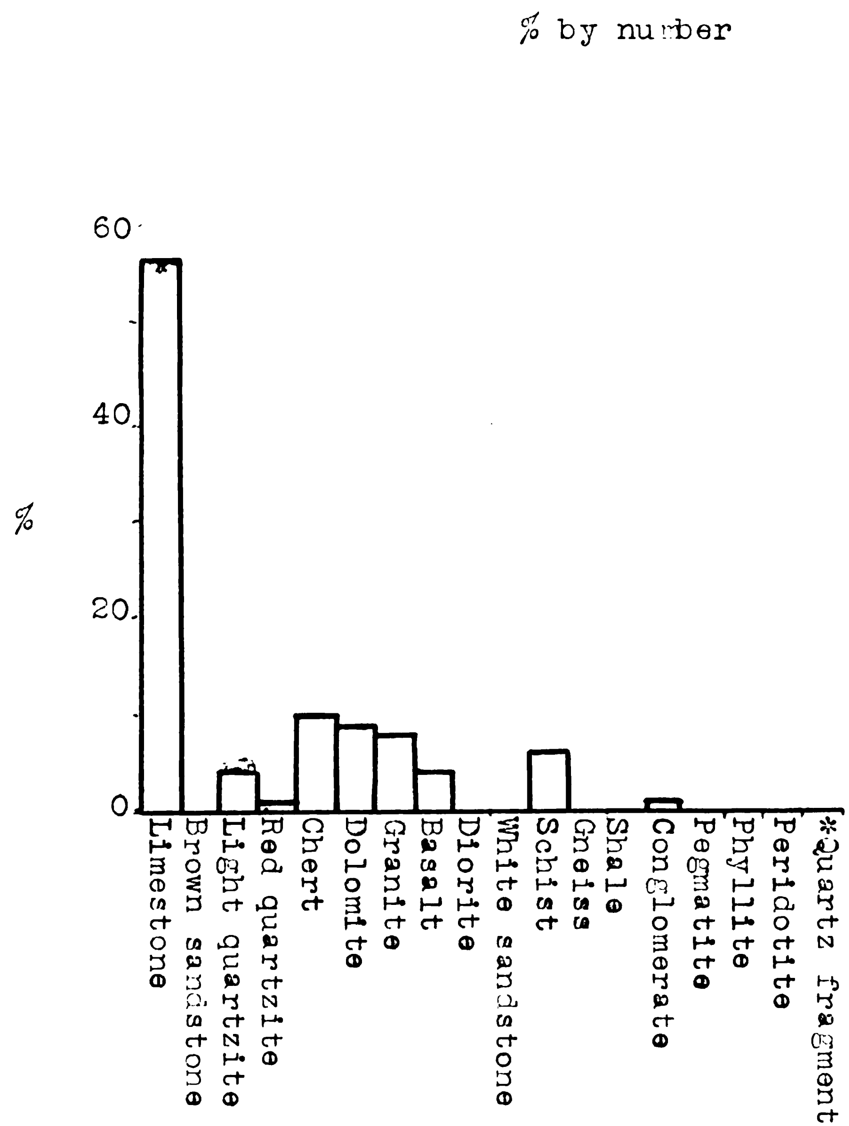
% by number



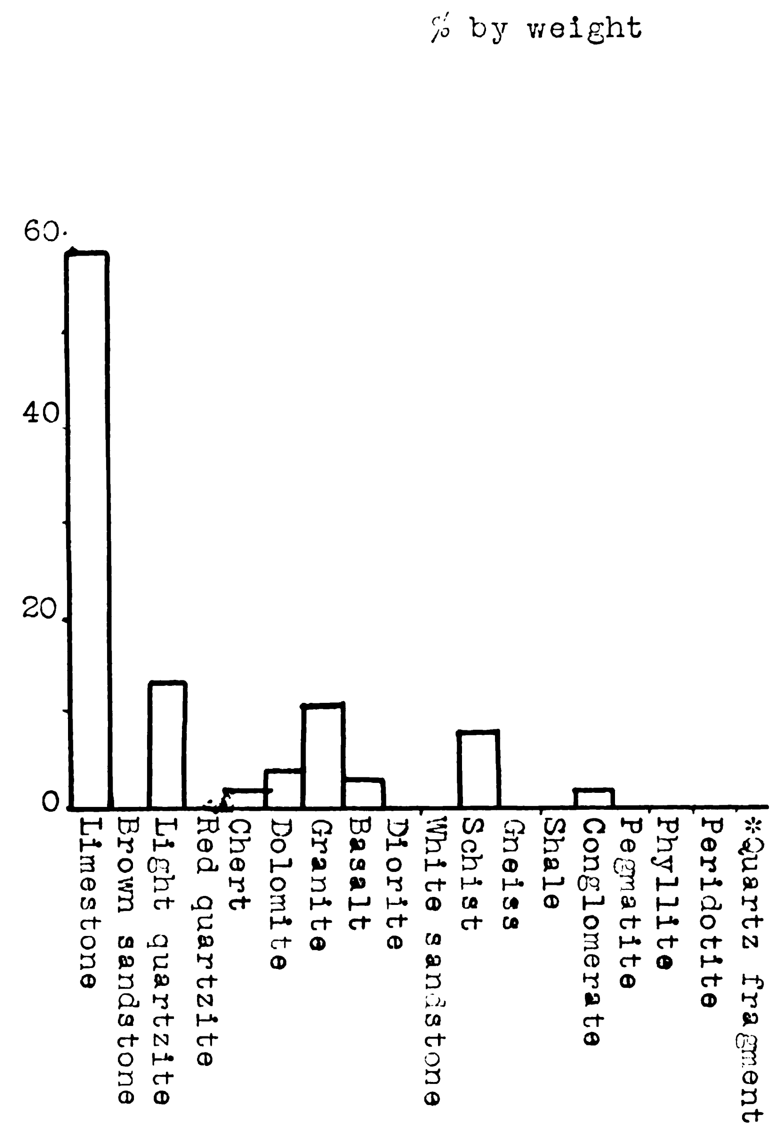
% by weight



Sample #9



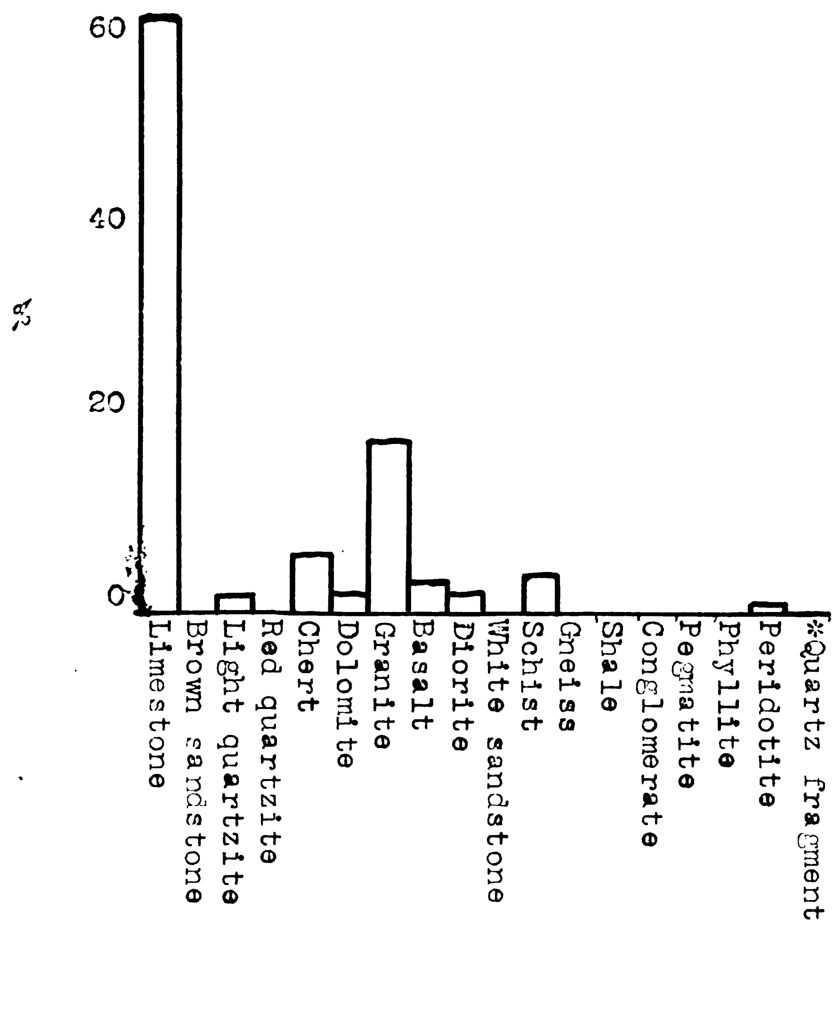
% by number
%
60
40
20
0
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment



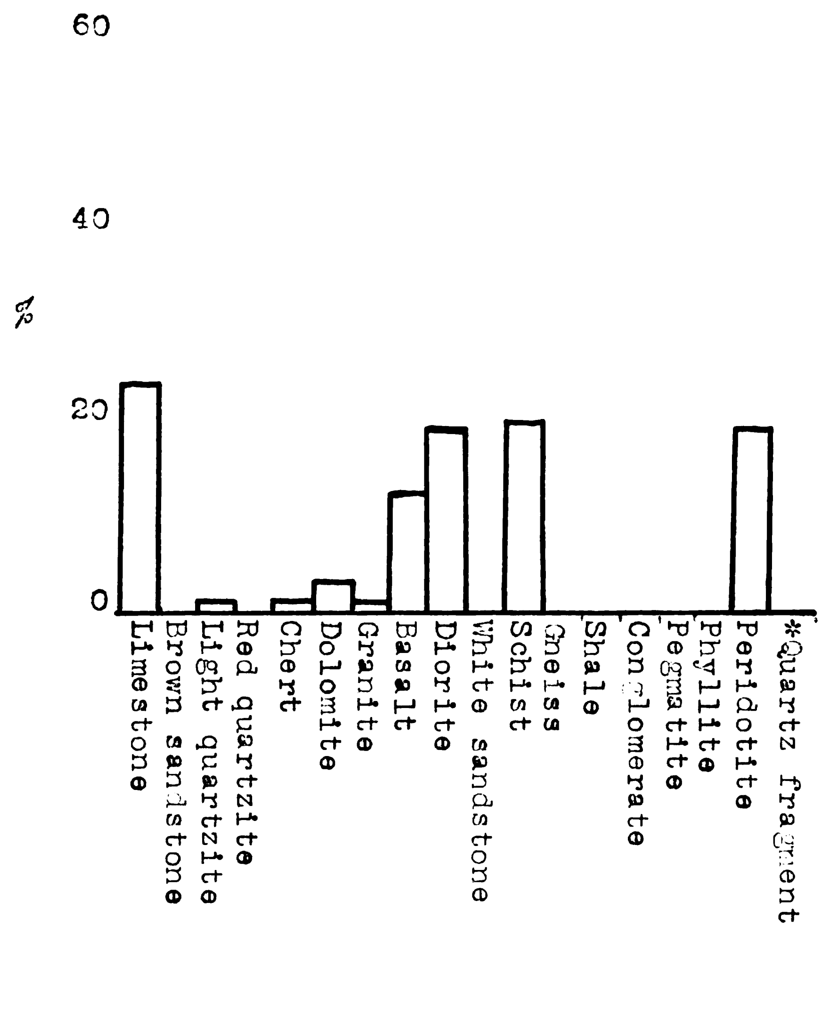
% by weight
60
40
20
0
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

Sample #10

% by number

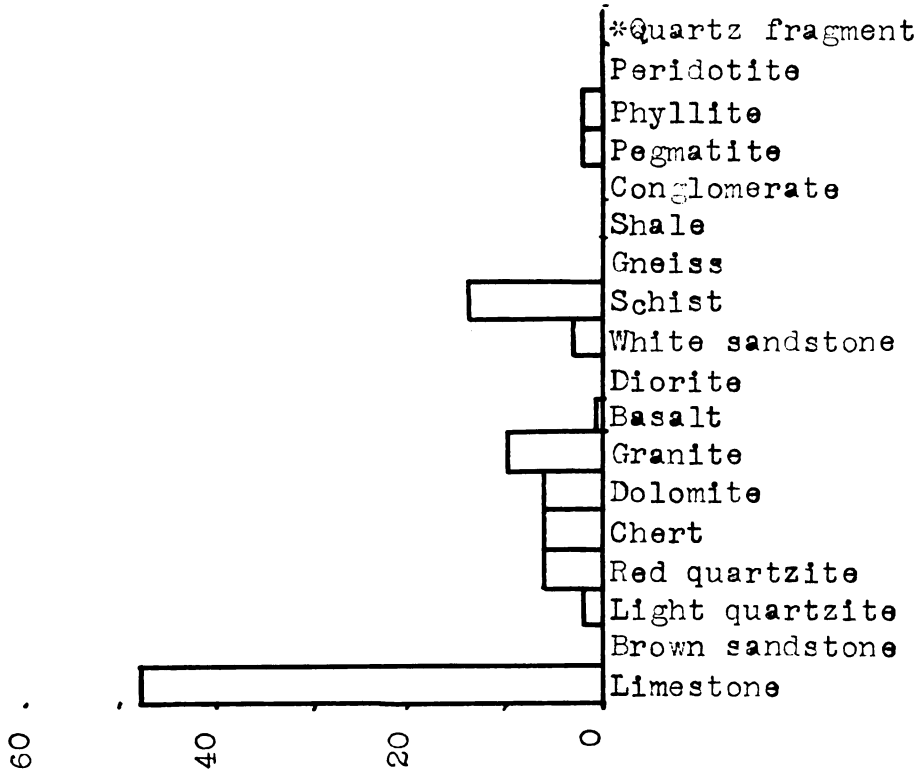


% by weight

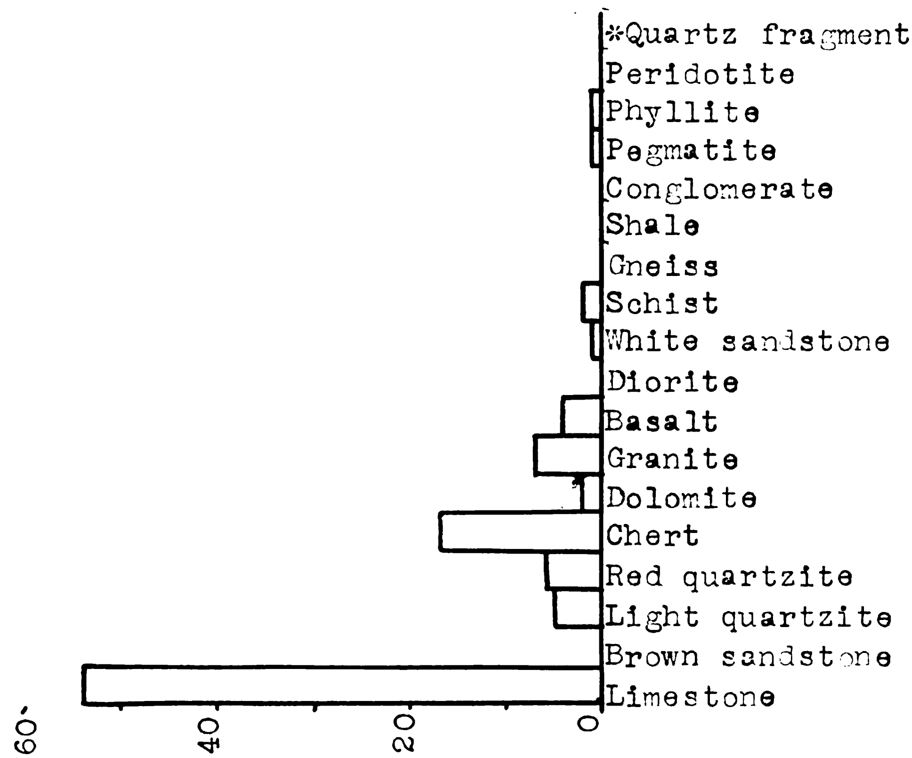


Sample #11

% by weight

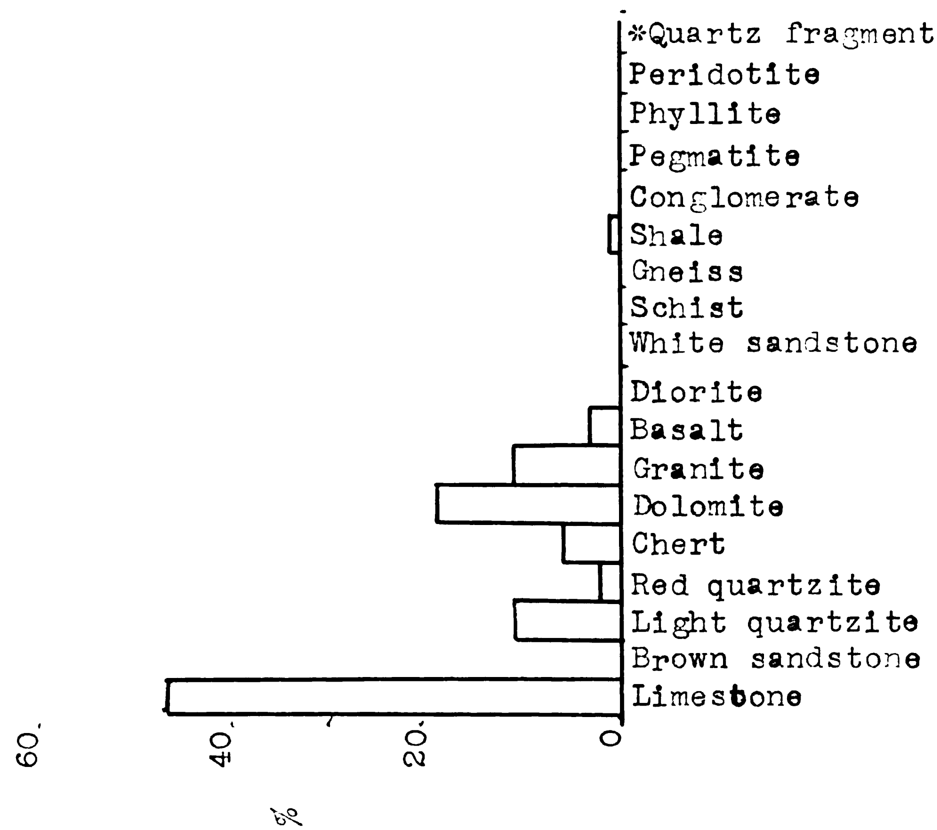


% by number

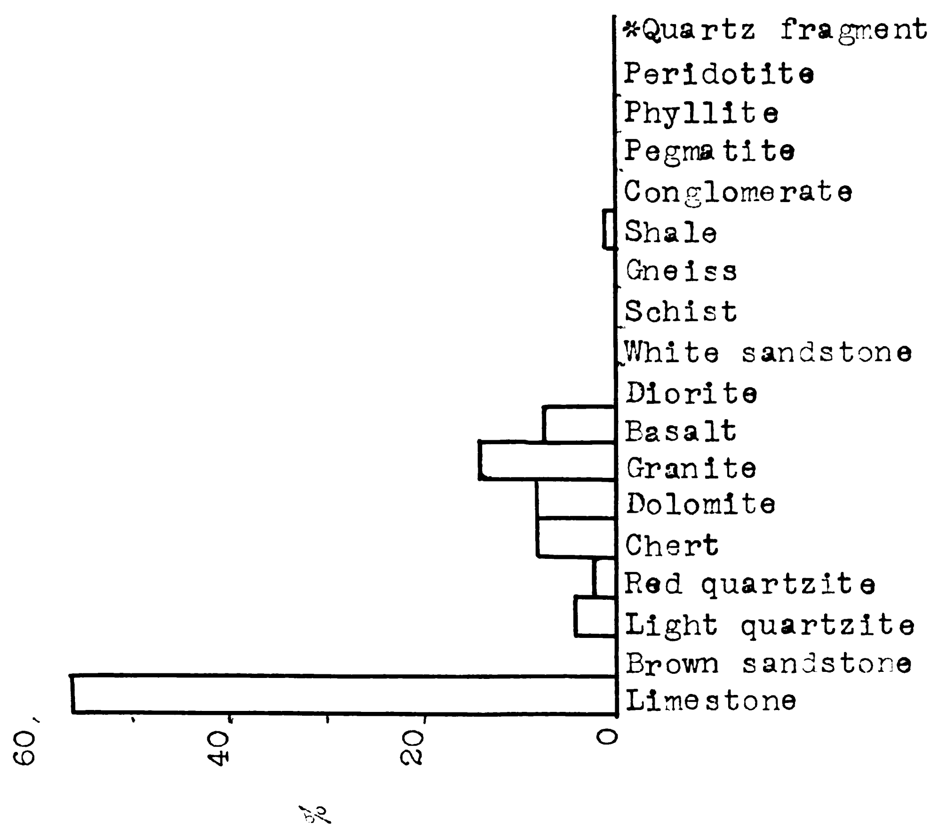


Sample #12

% by weight



% by number



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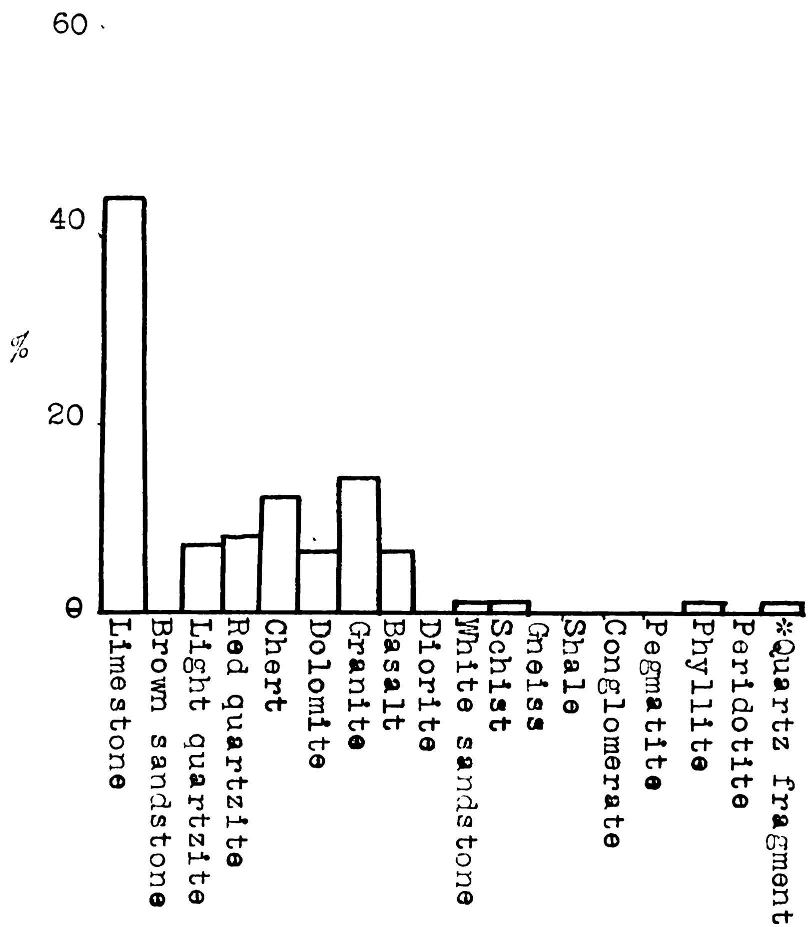
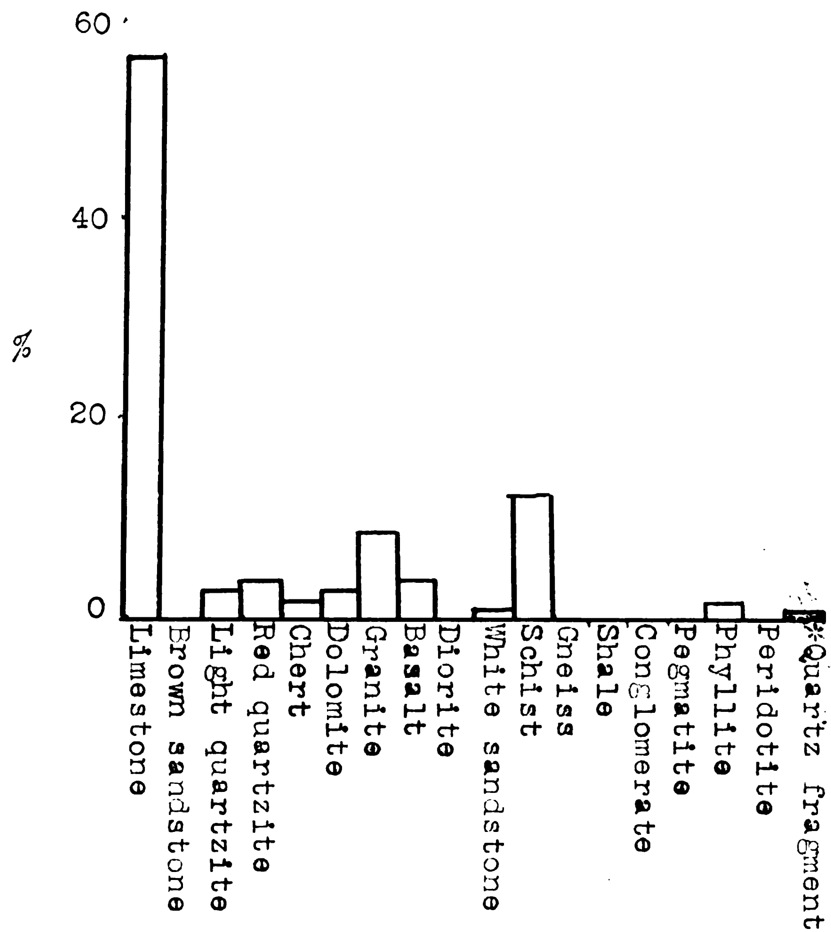


% by weight



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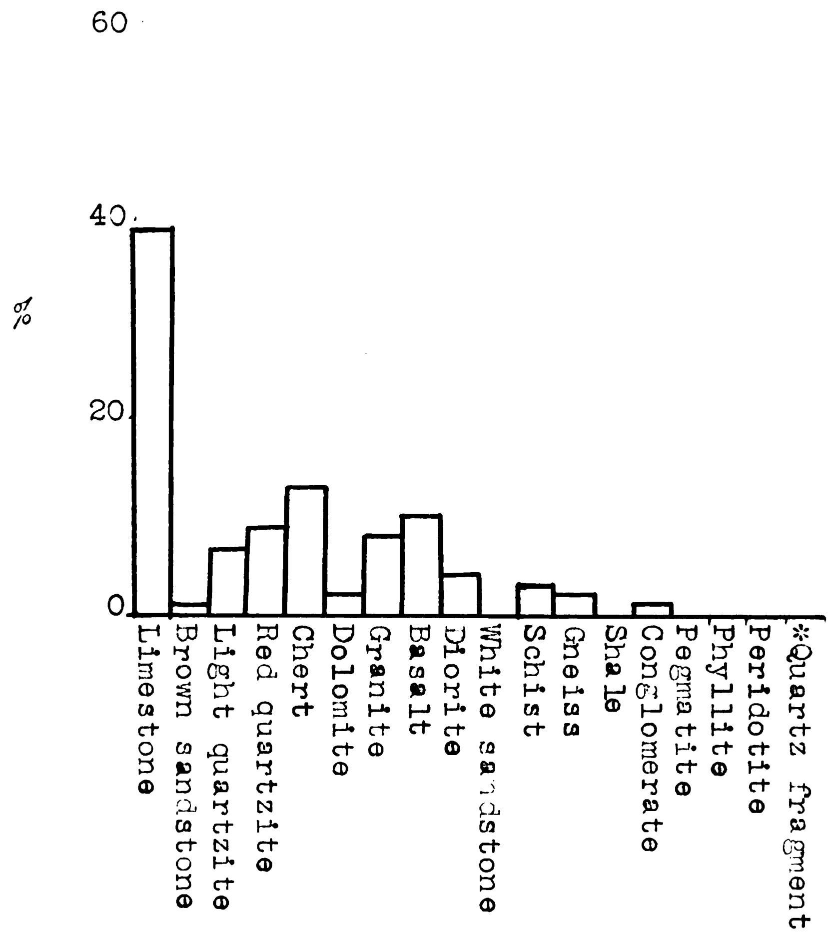
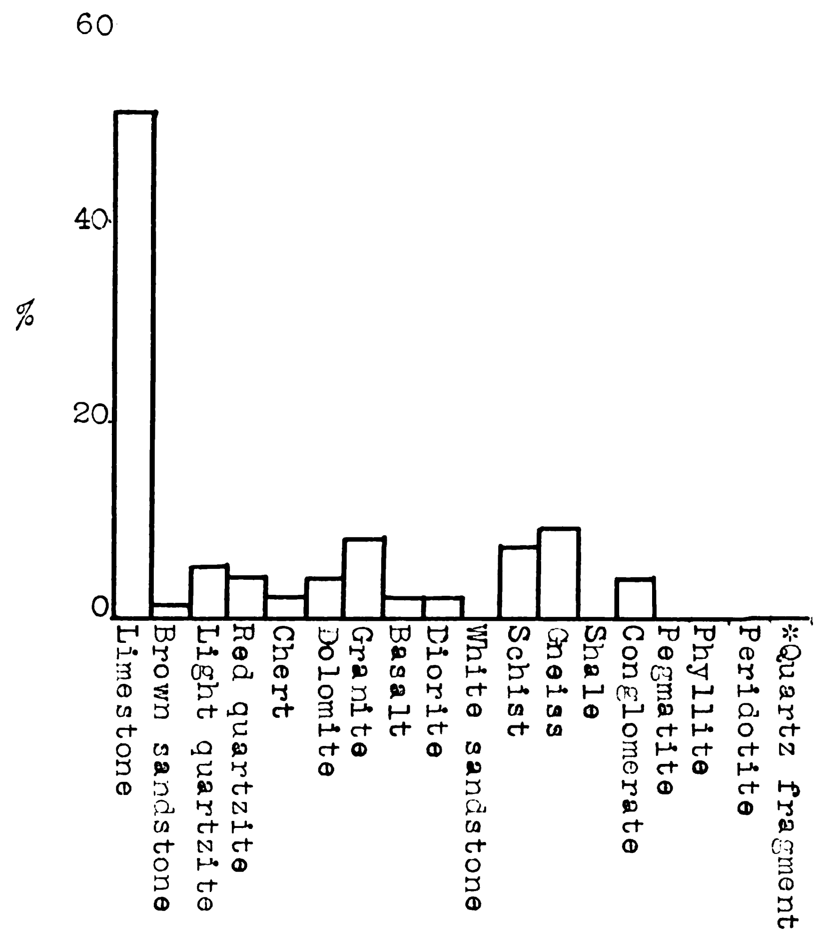
% by number



% by weight



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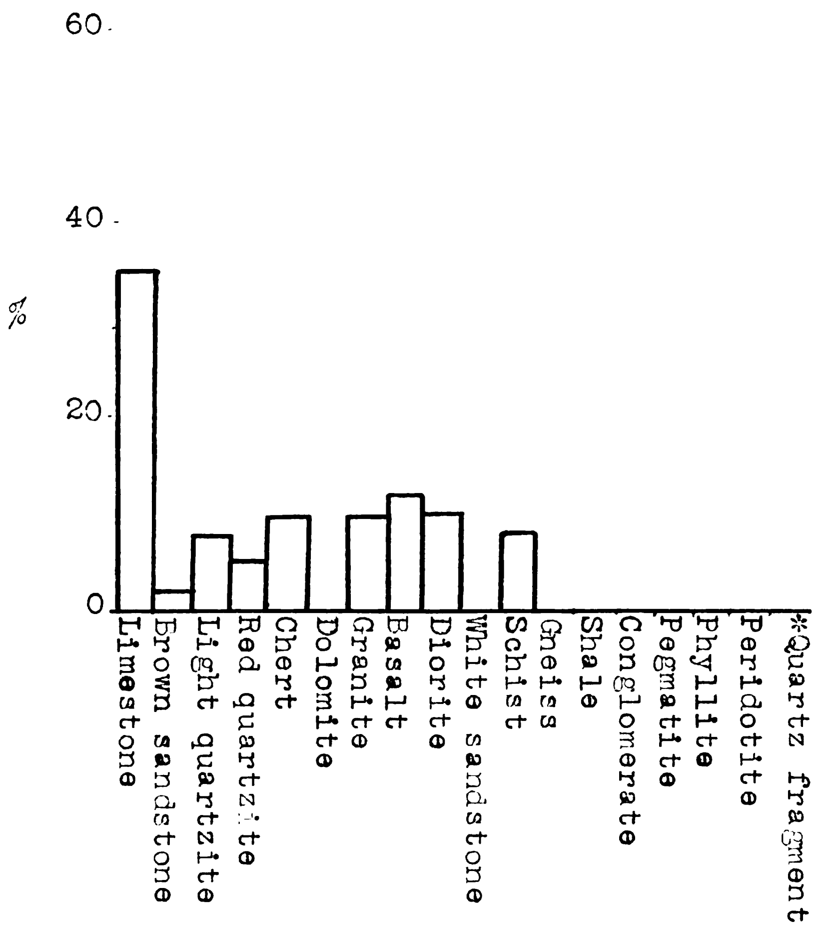
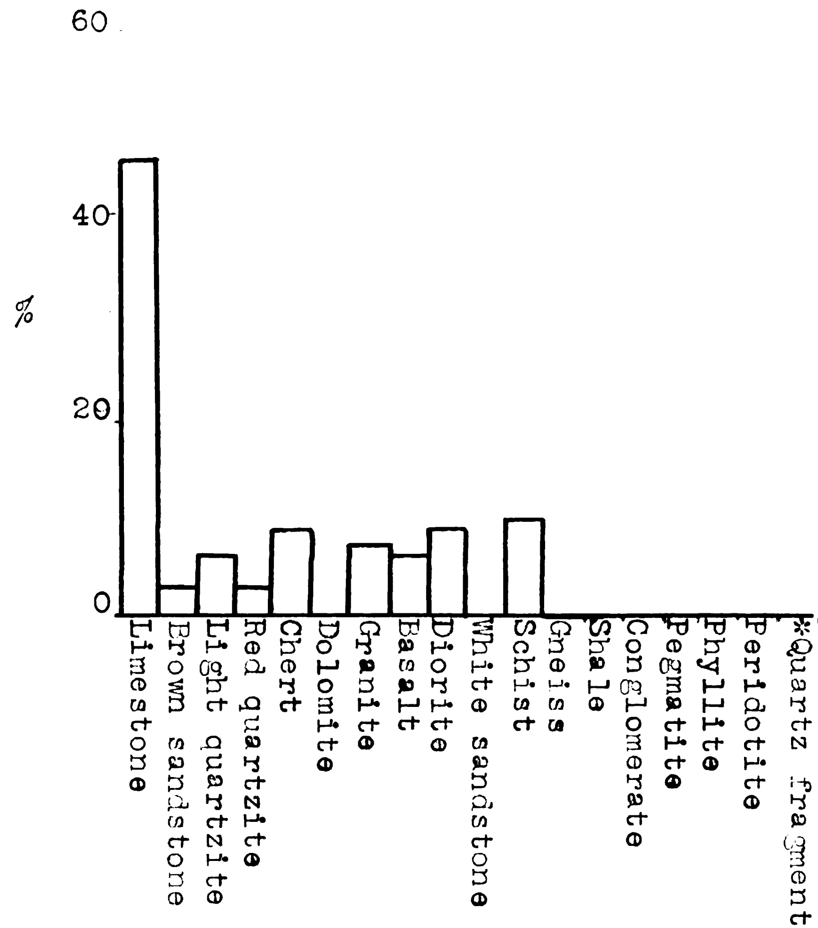
% by number

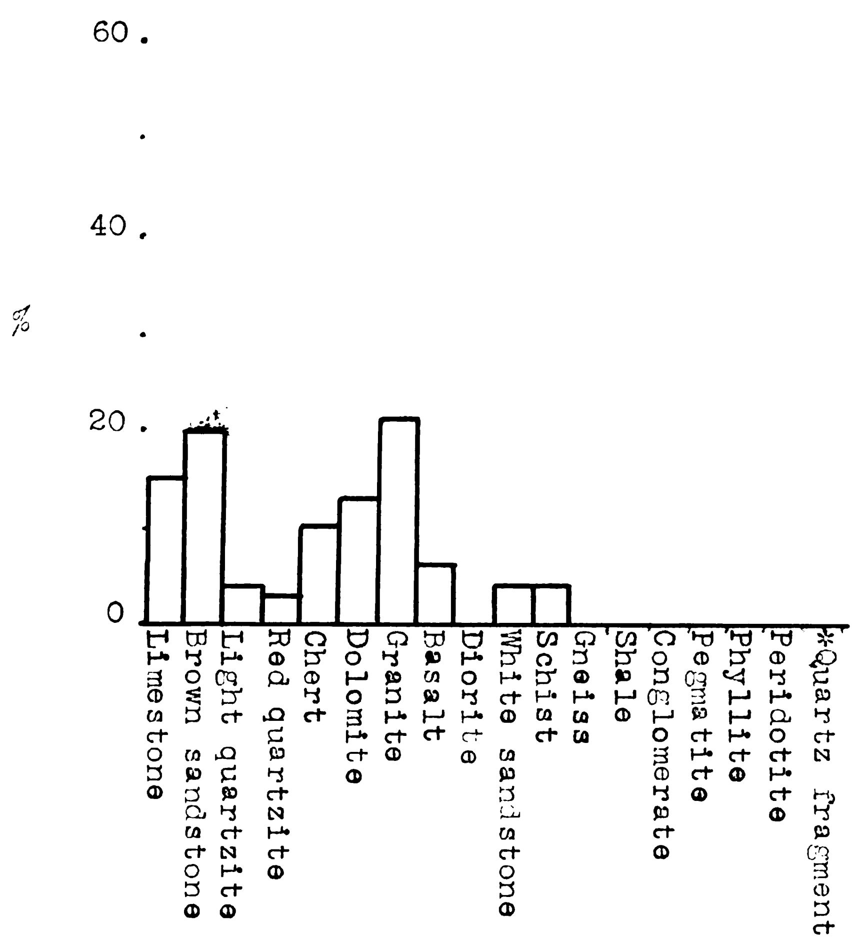


% by weight

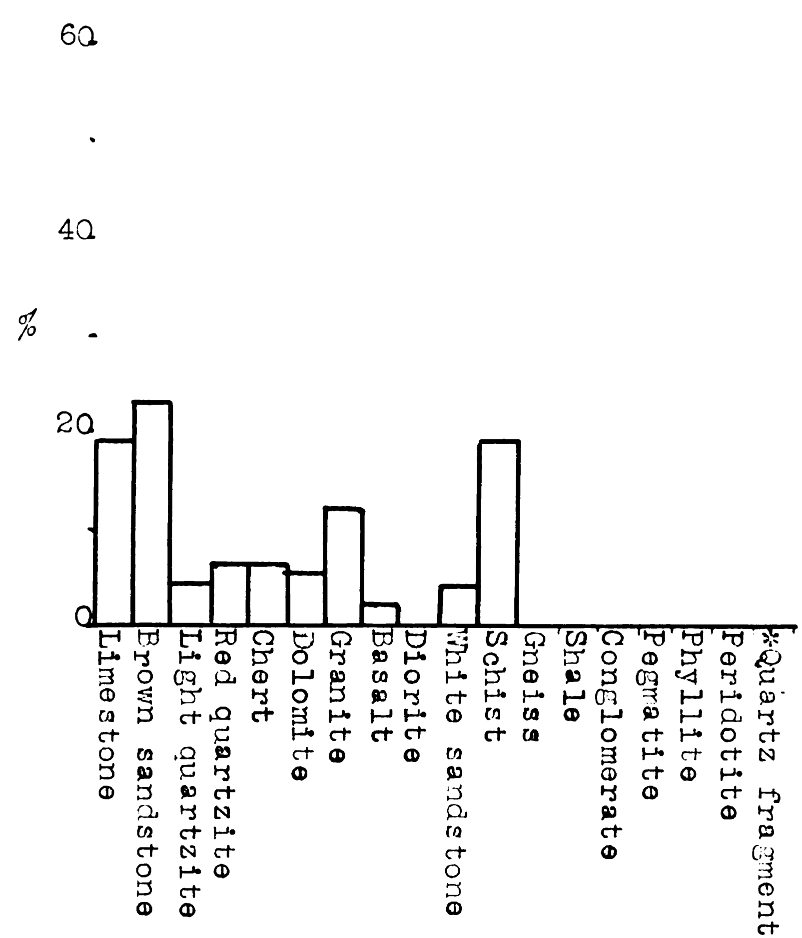


Sample #16

% by number

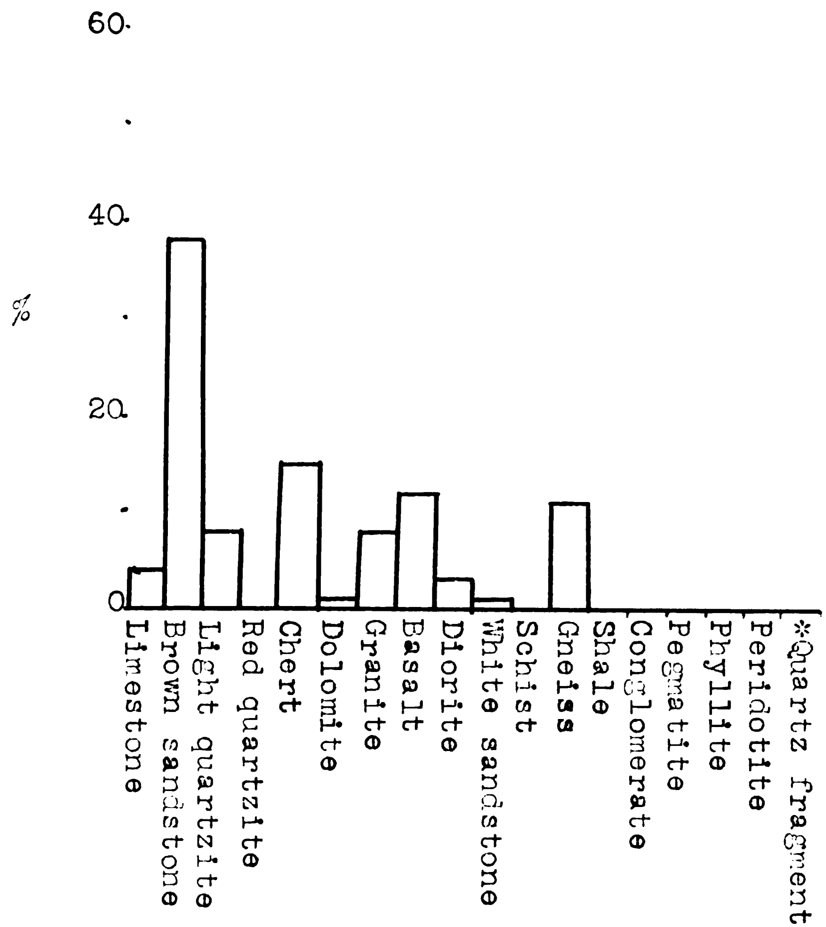


% by weight

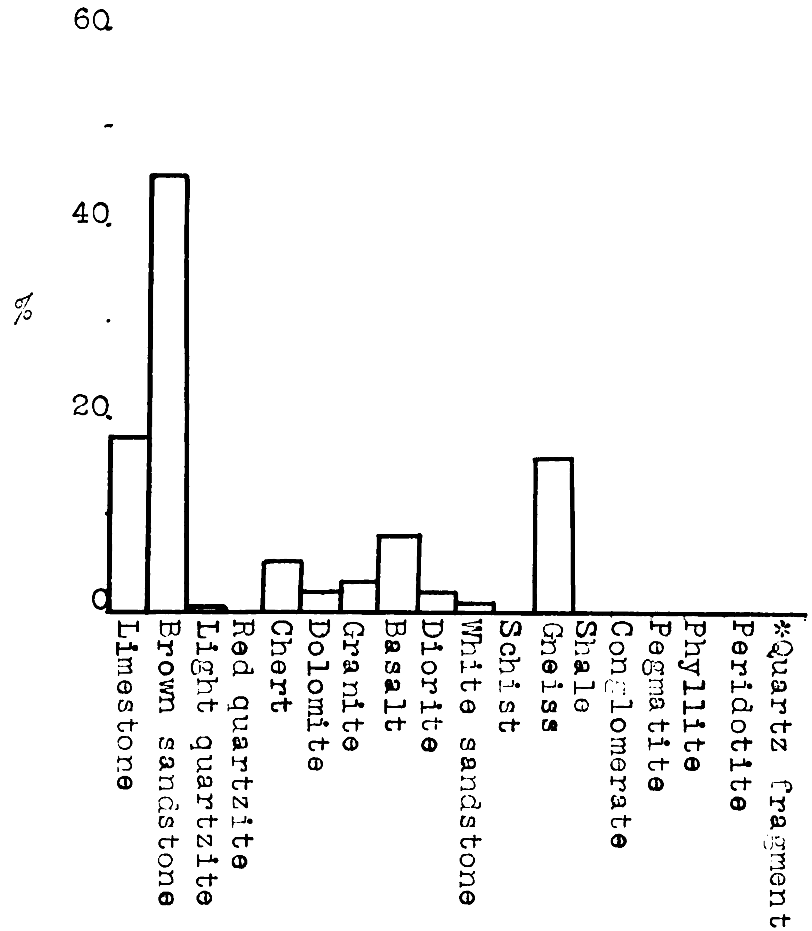


Sample #17

% by number



% by weight



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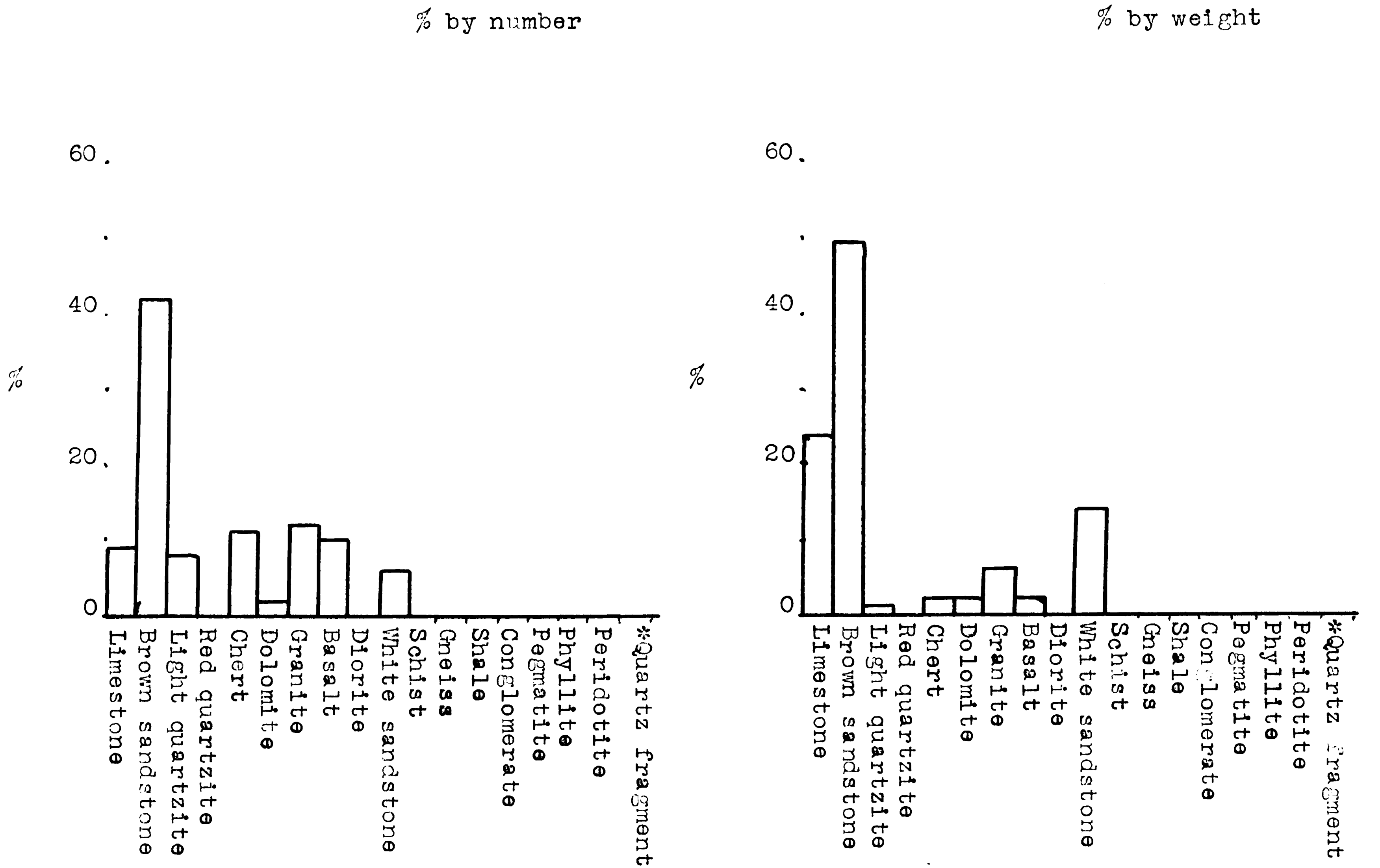
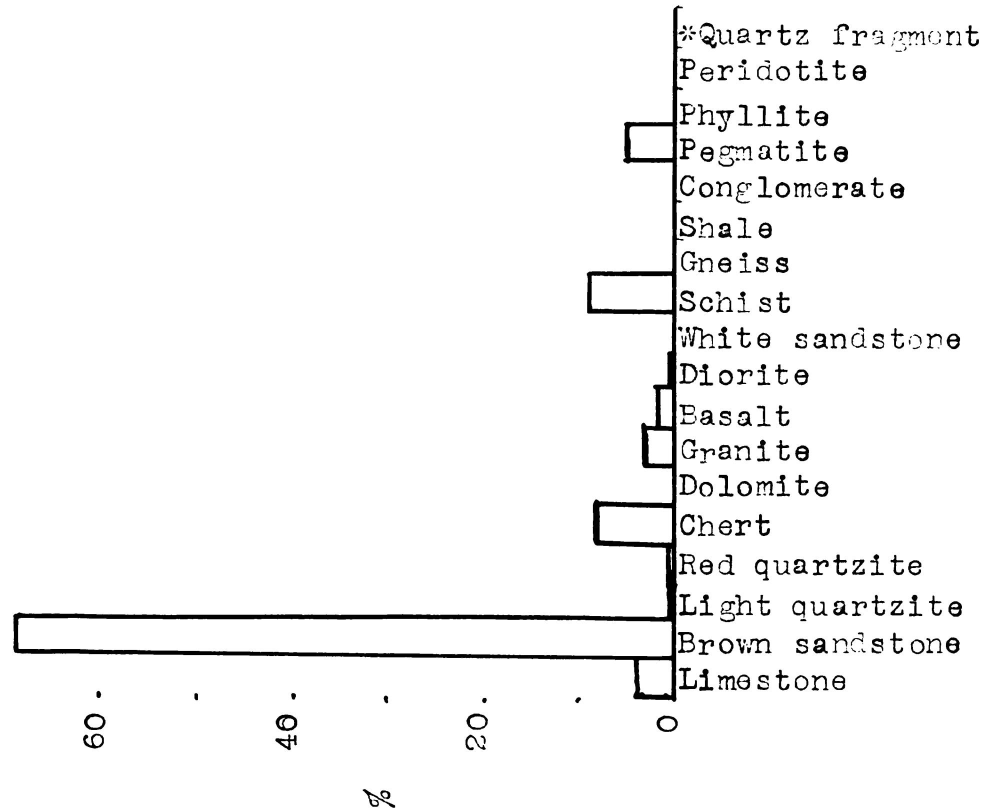
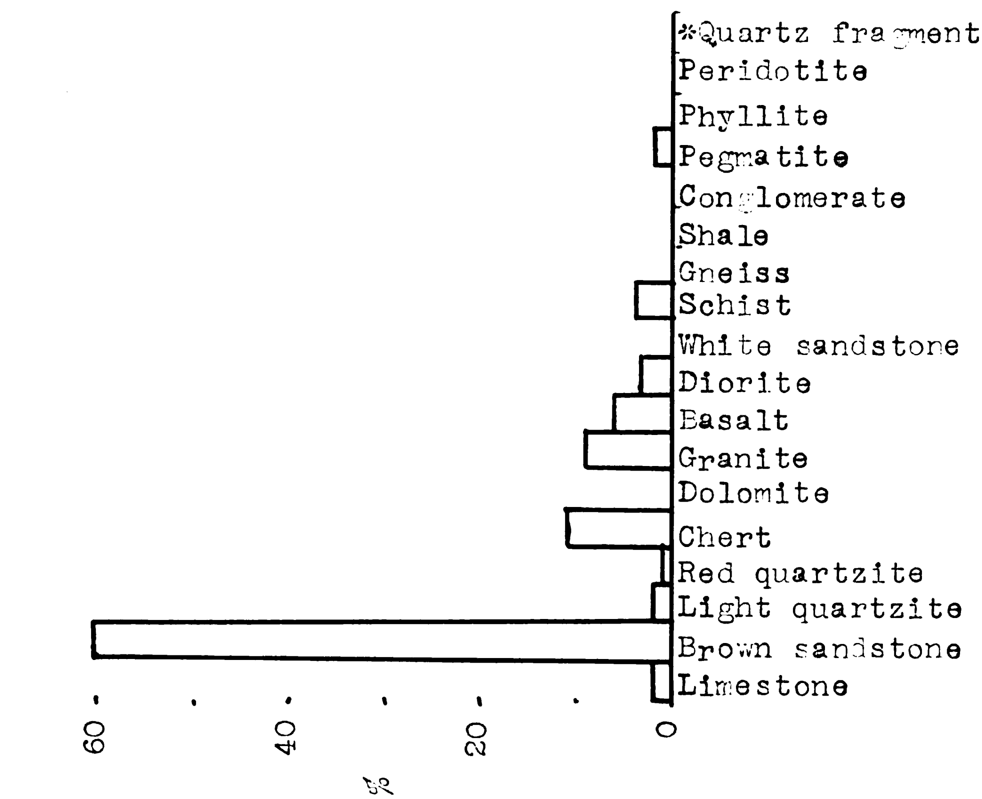

% by number
% by weight
60
40
20
0
%
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

Sample #19

% by weight

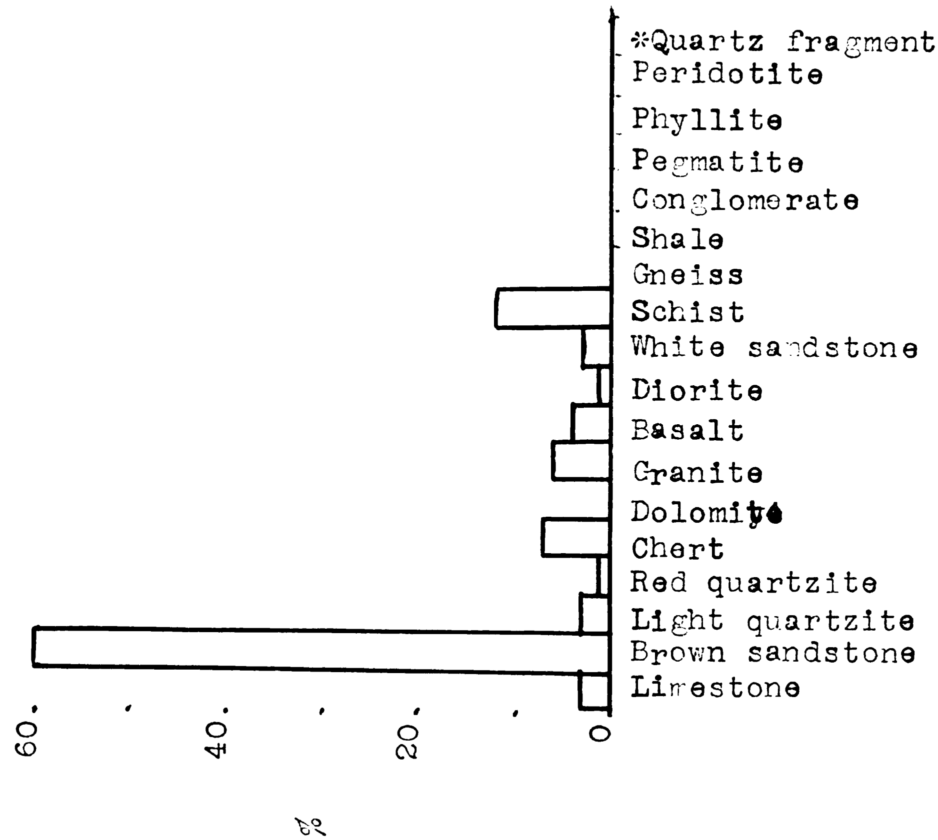


% by number

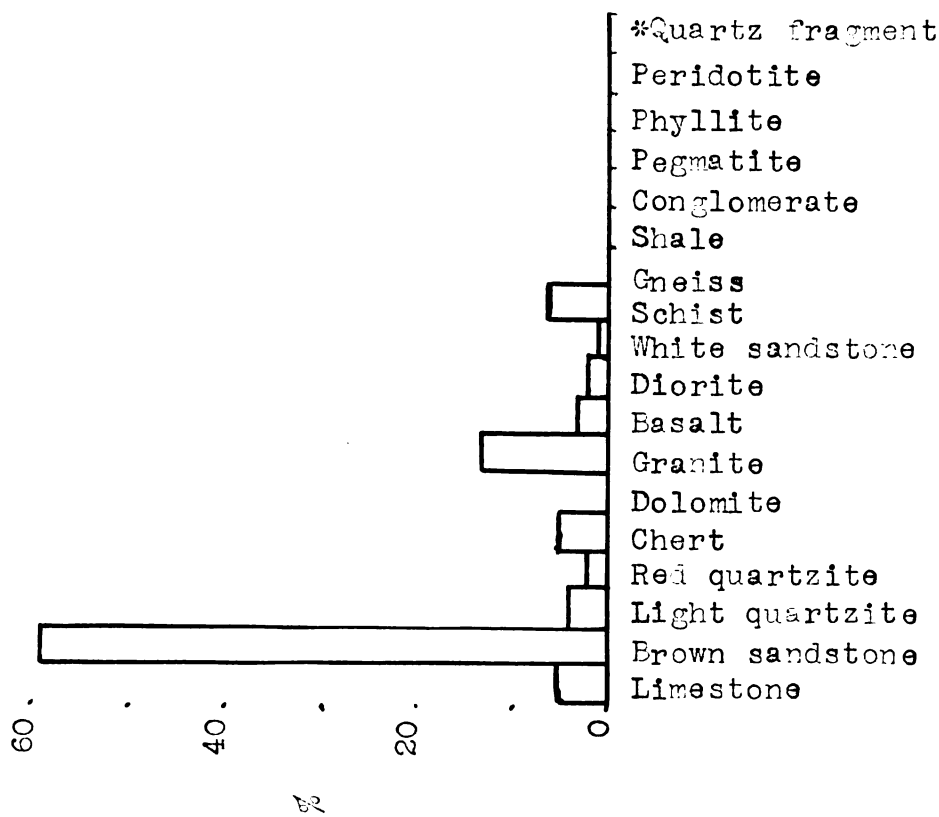


Sample #20

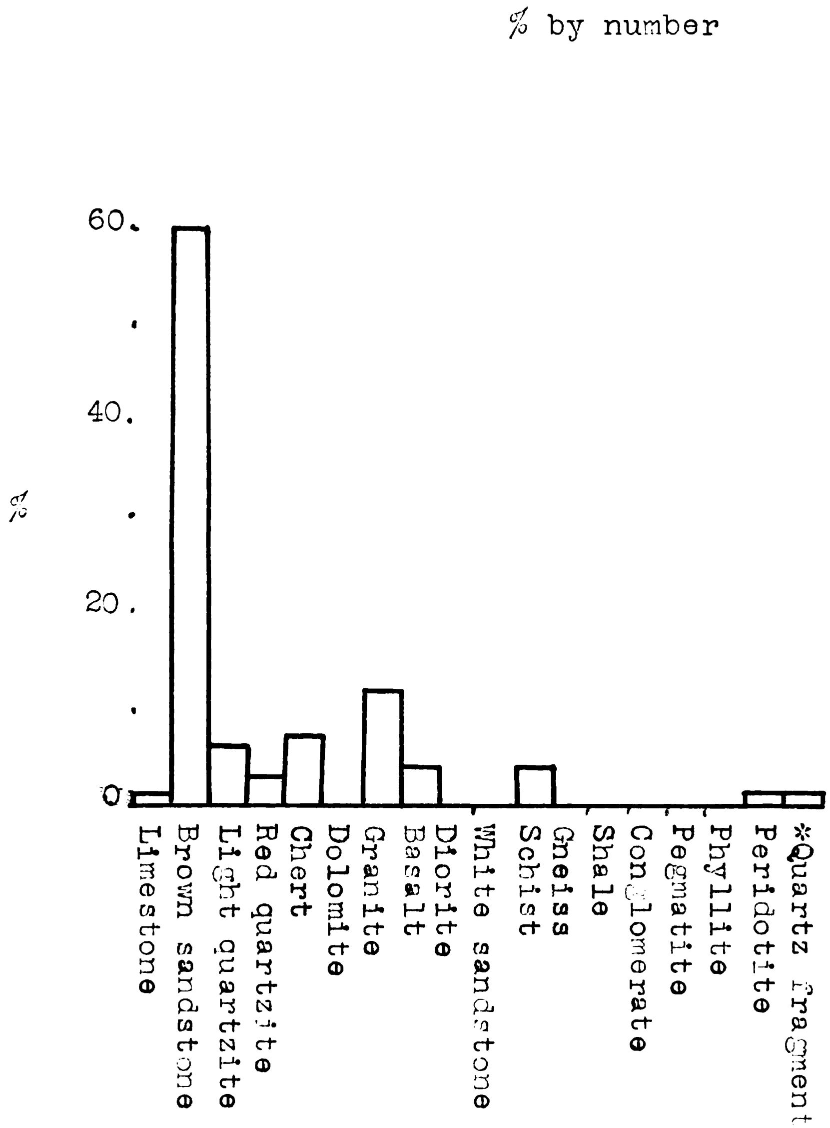
% by weight

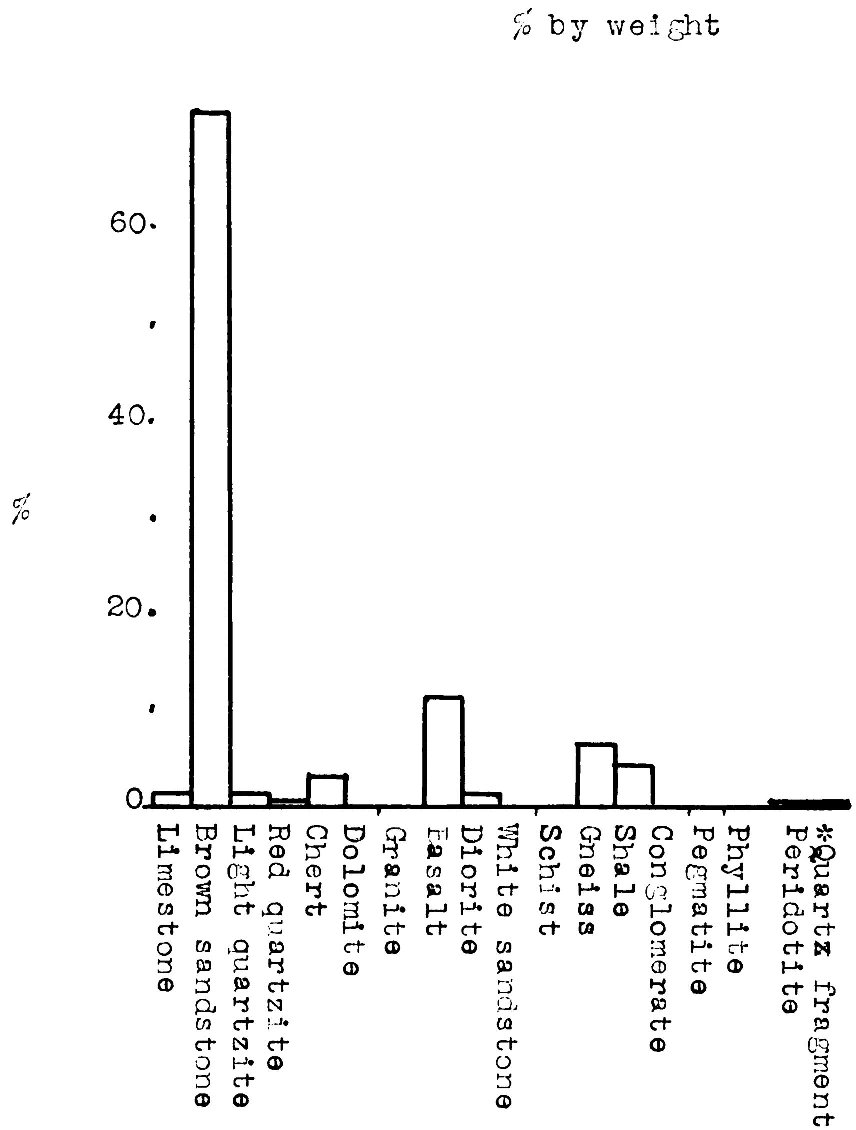


% by number



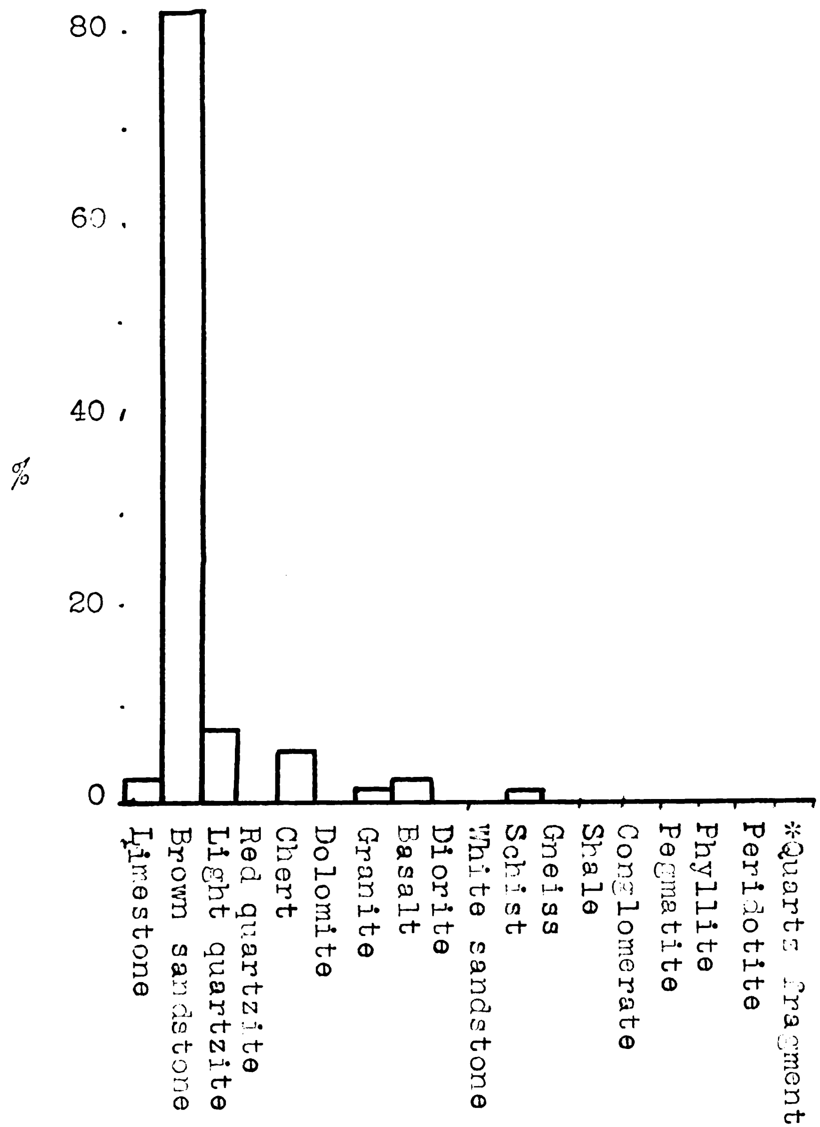
Sample #21


% by number
60.
40.
20.
0
%
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

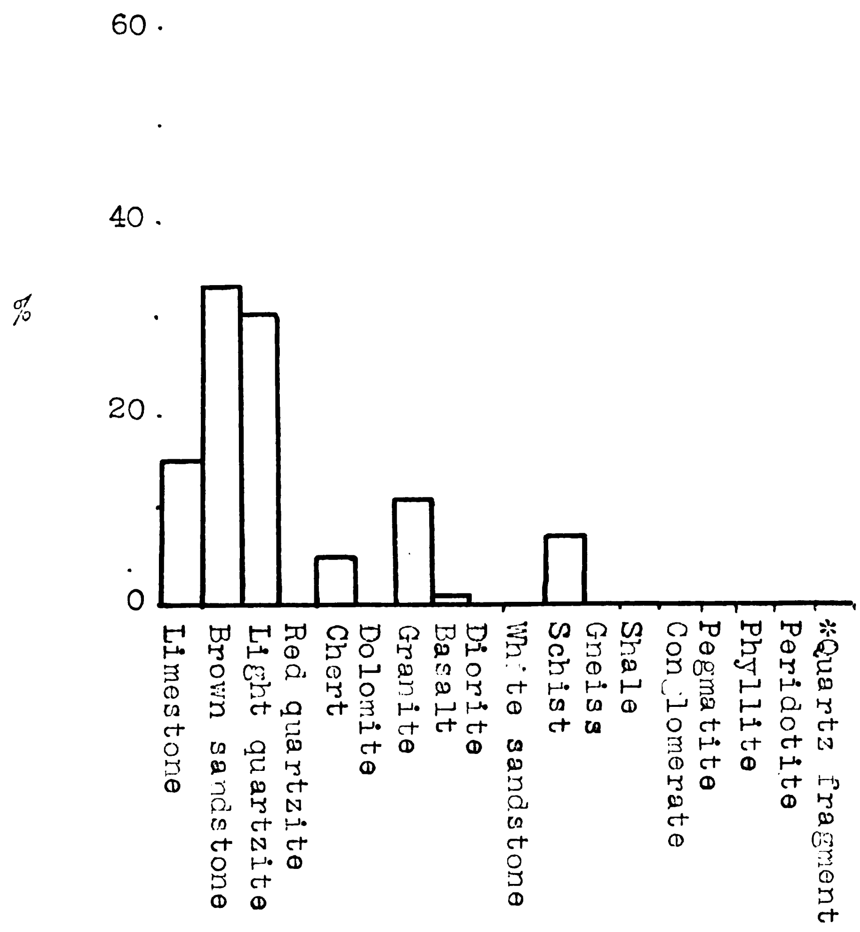

% by weight
60.
40.
20.
0
%
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

Sample #22

% by number

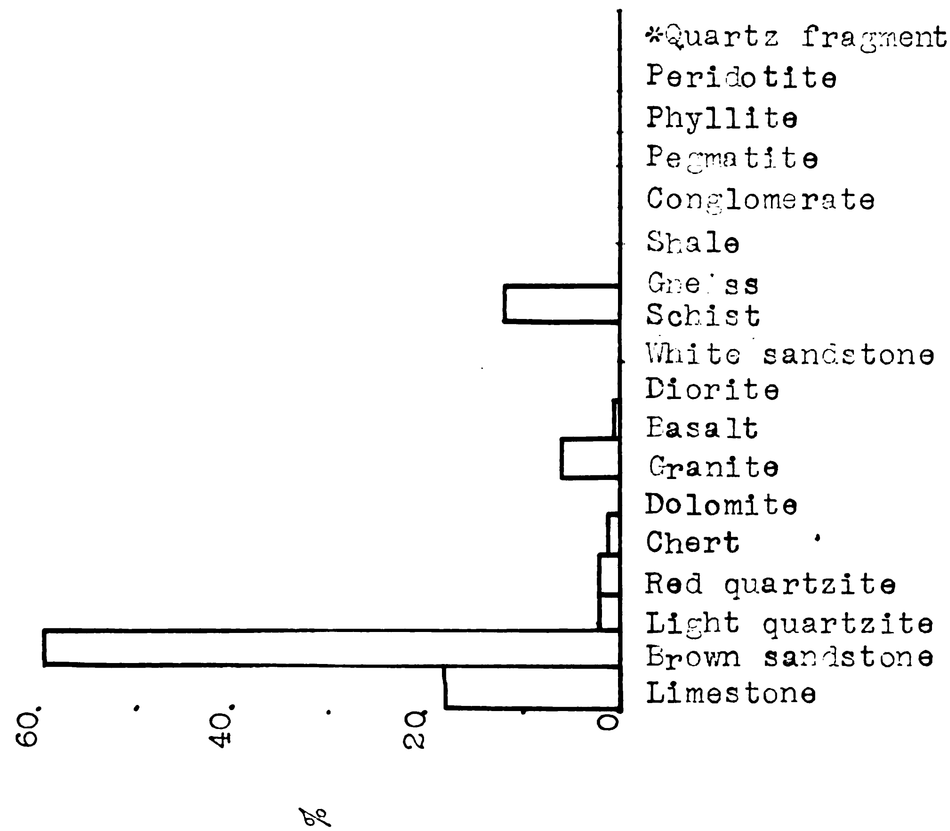


% by weight

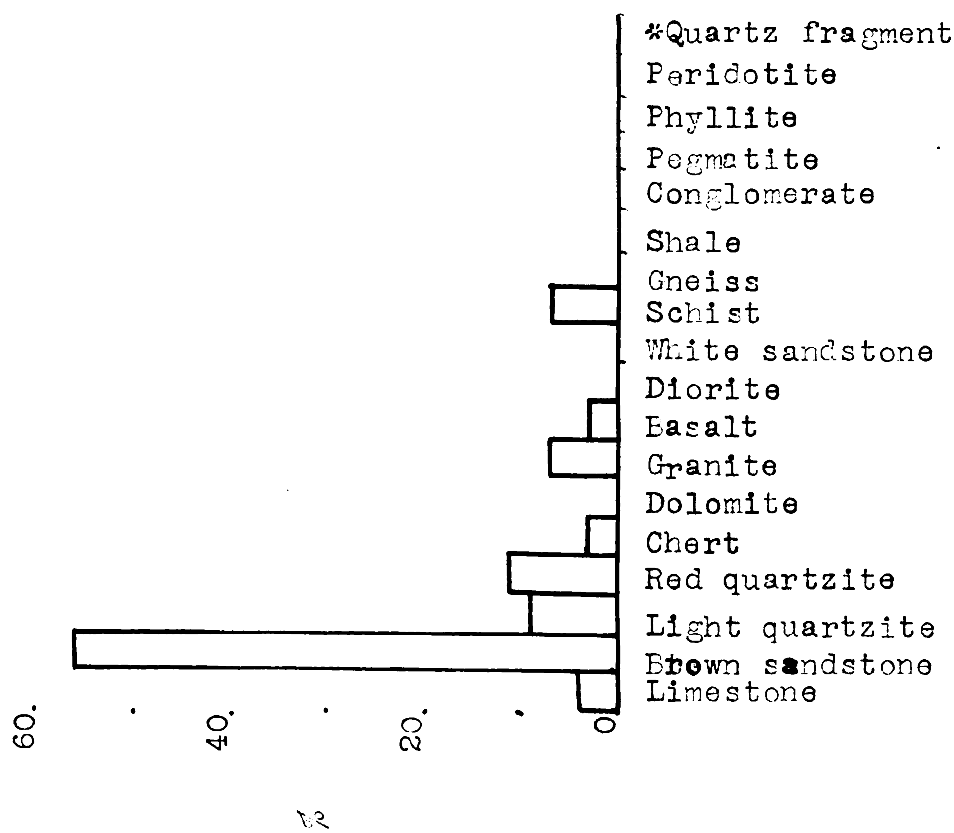


Sample #23

% by weight

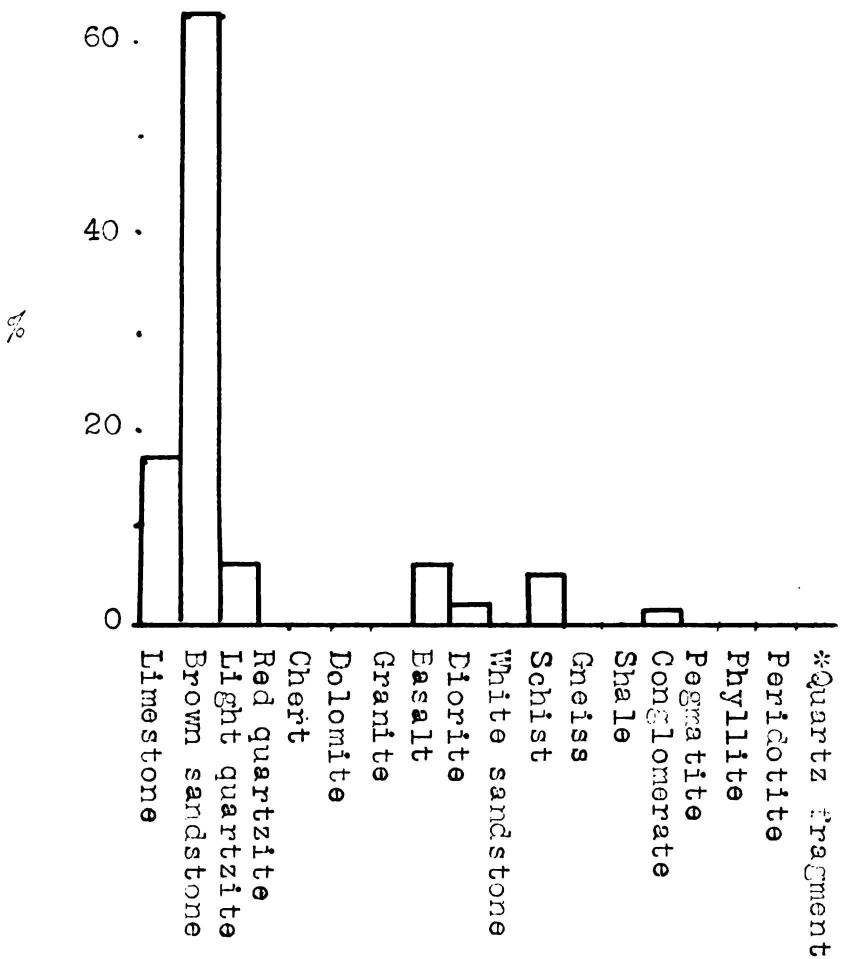


% by number

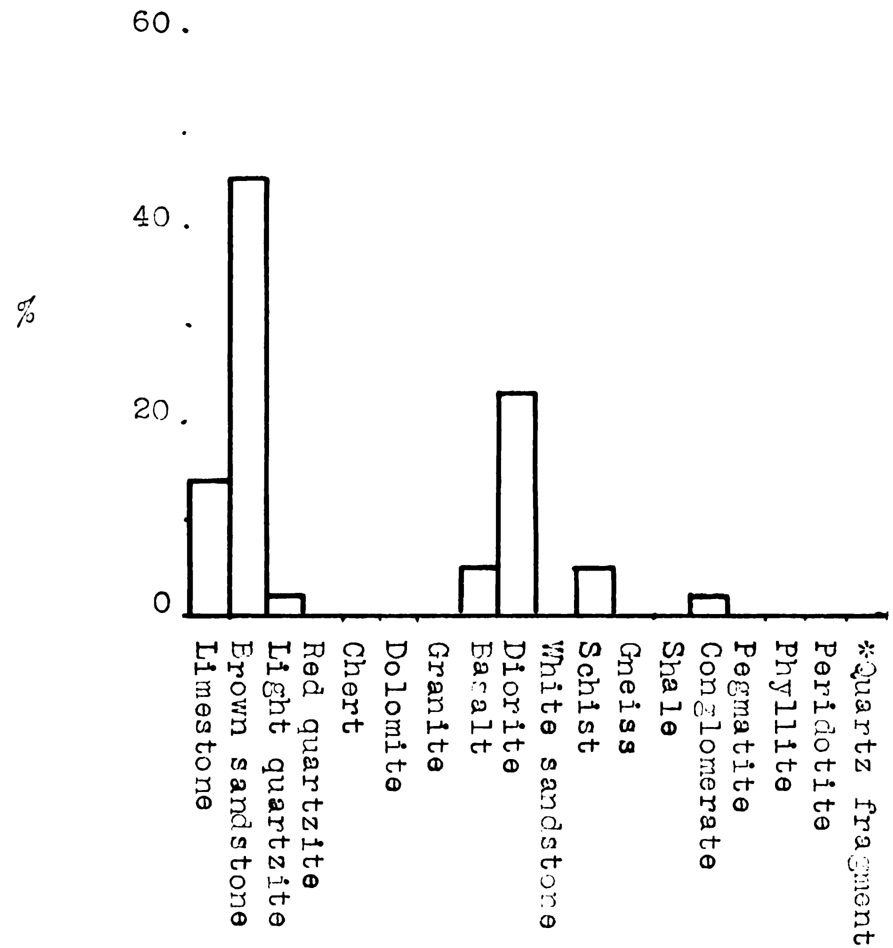


Sample #24

% by number

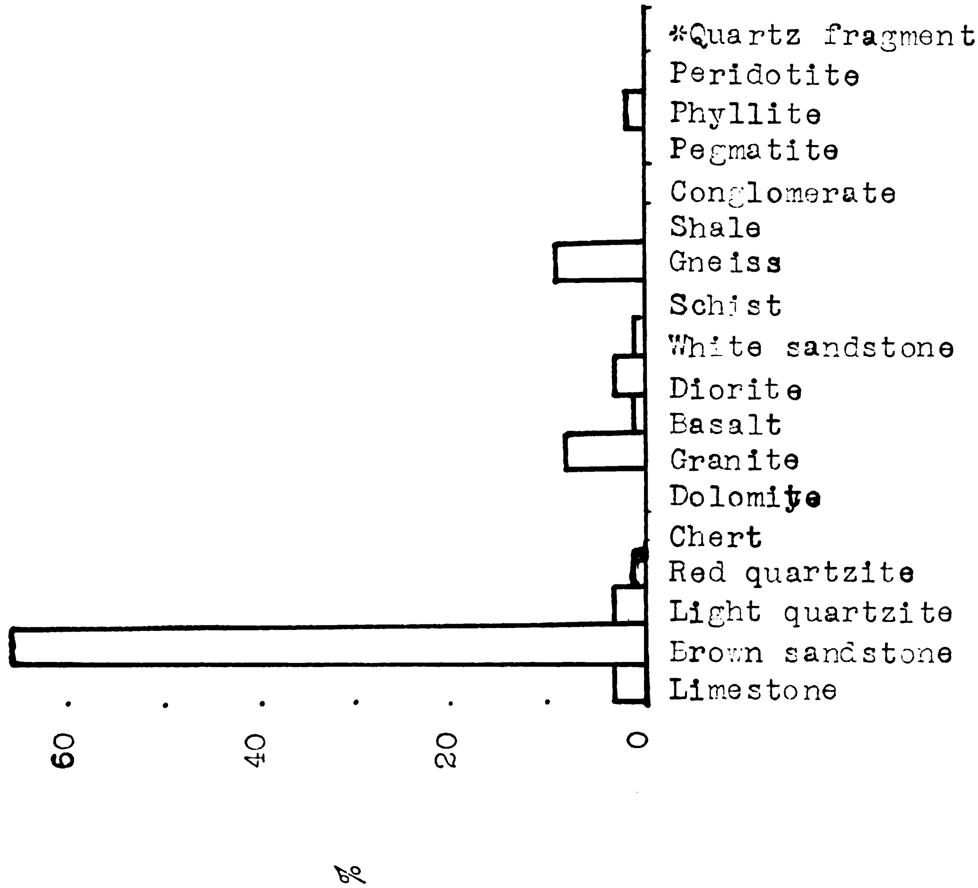


% by weight

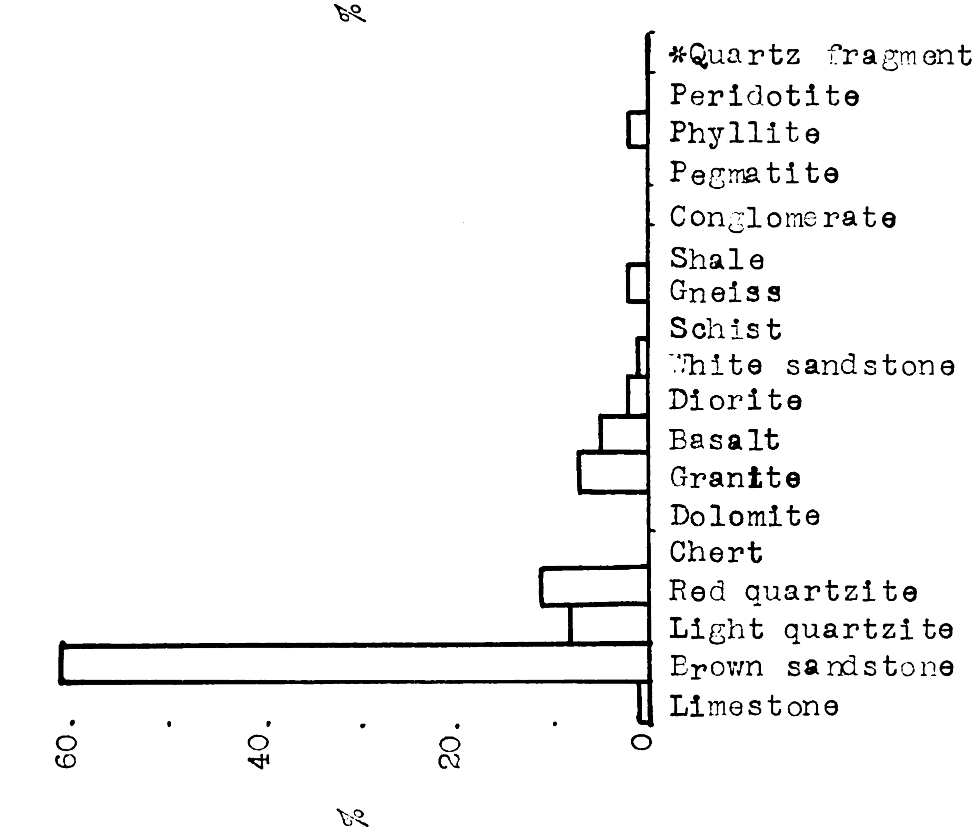


Sample #25

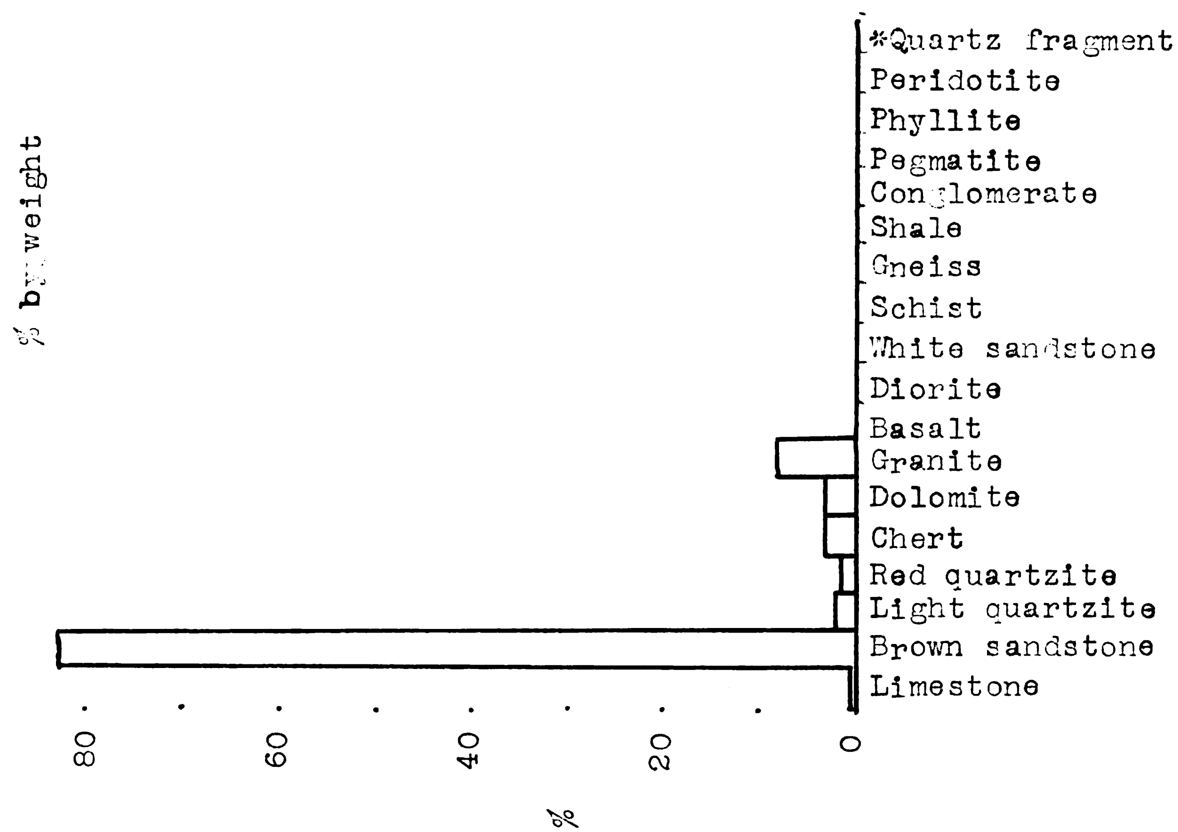
% by weight

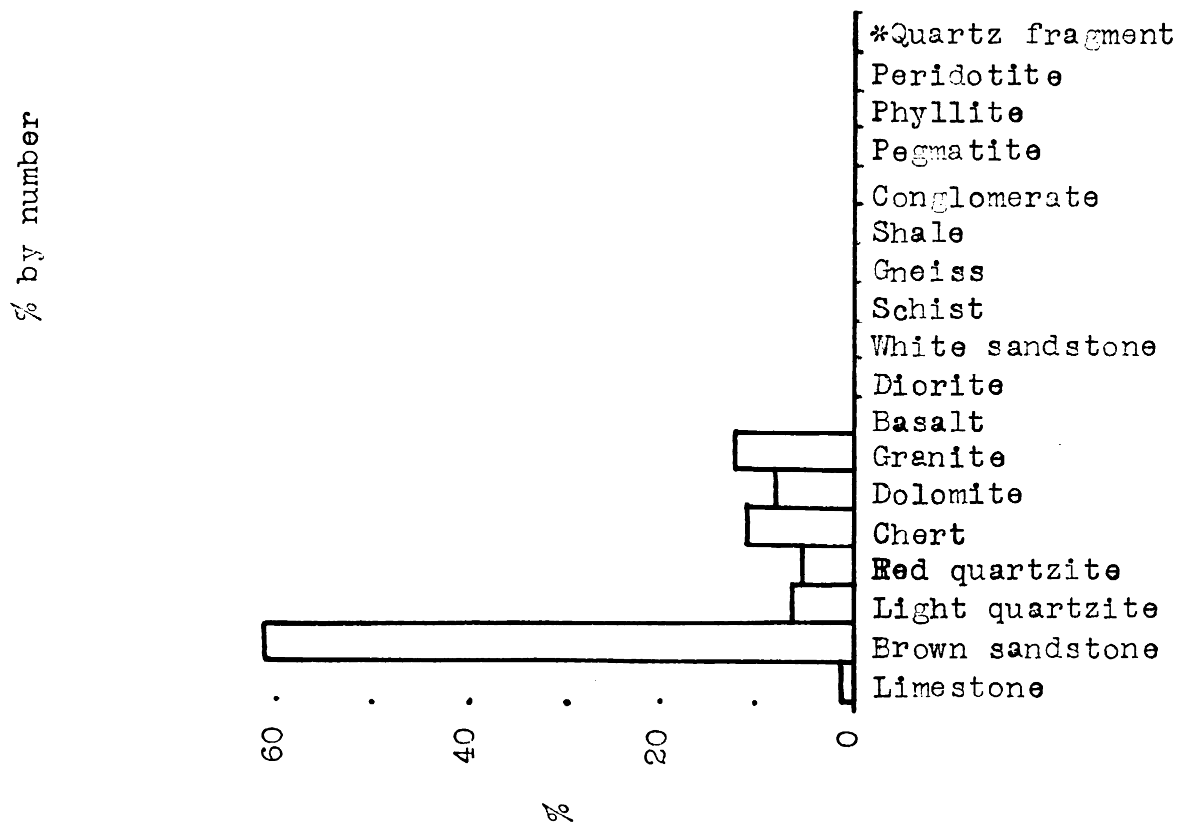


% by number



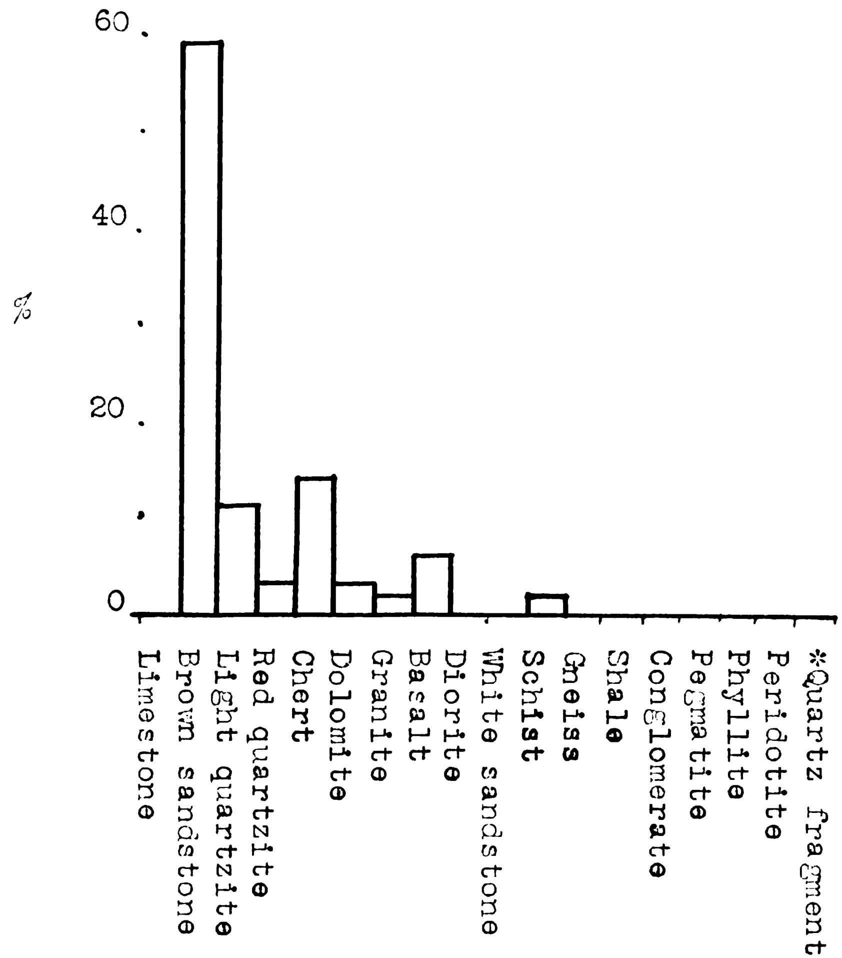
Sample #26


% by weight
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
80
60
40
20
0
%

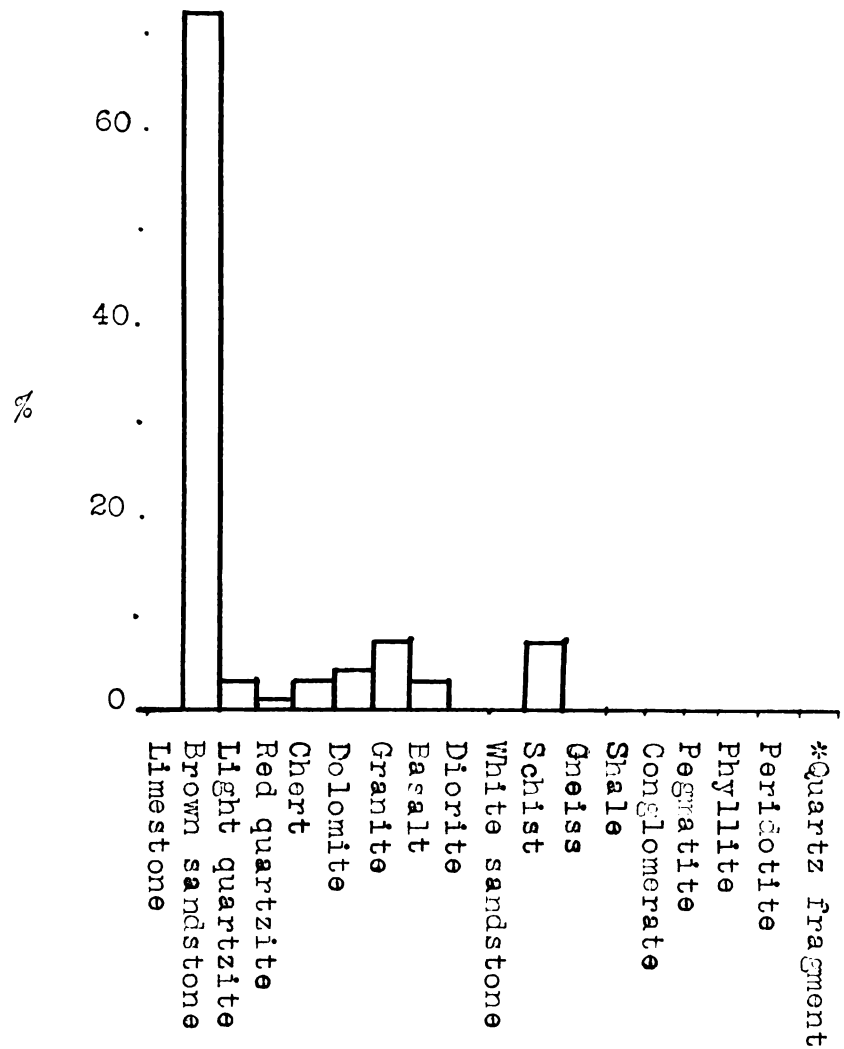

% by number
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
60
40
20
0
%

Sample #27

% by number

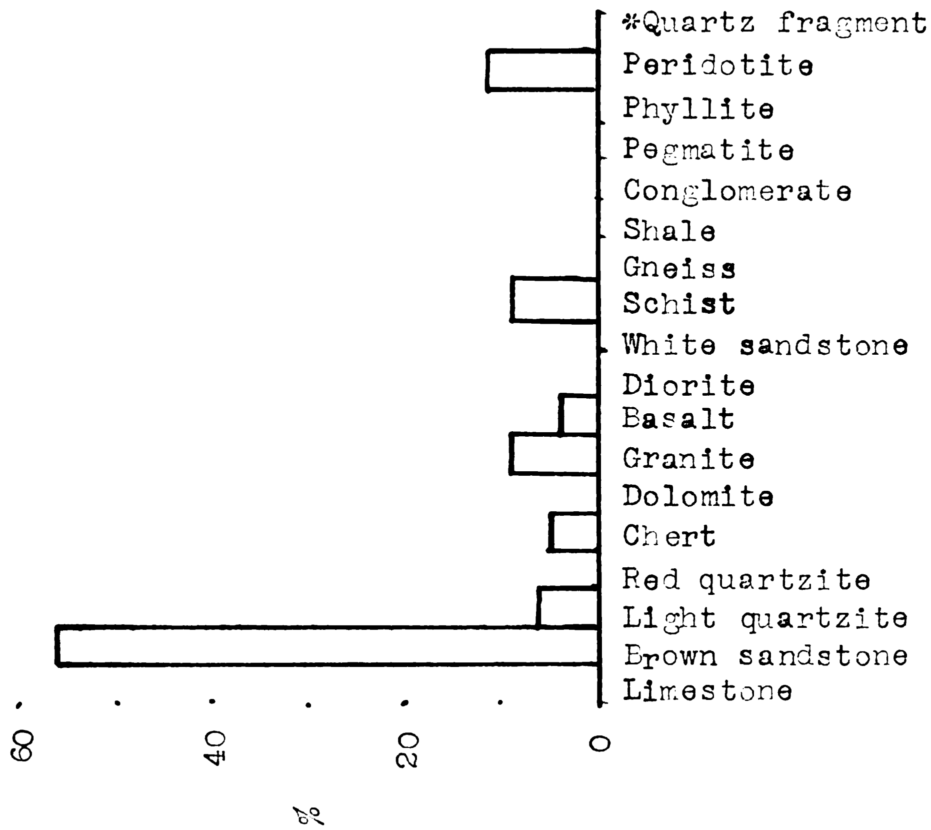


% by weight

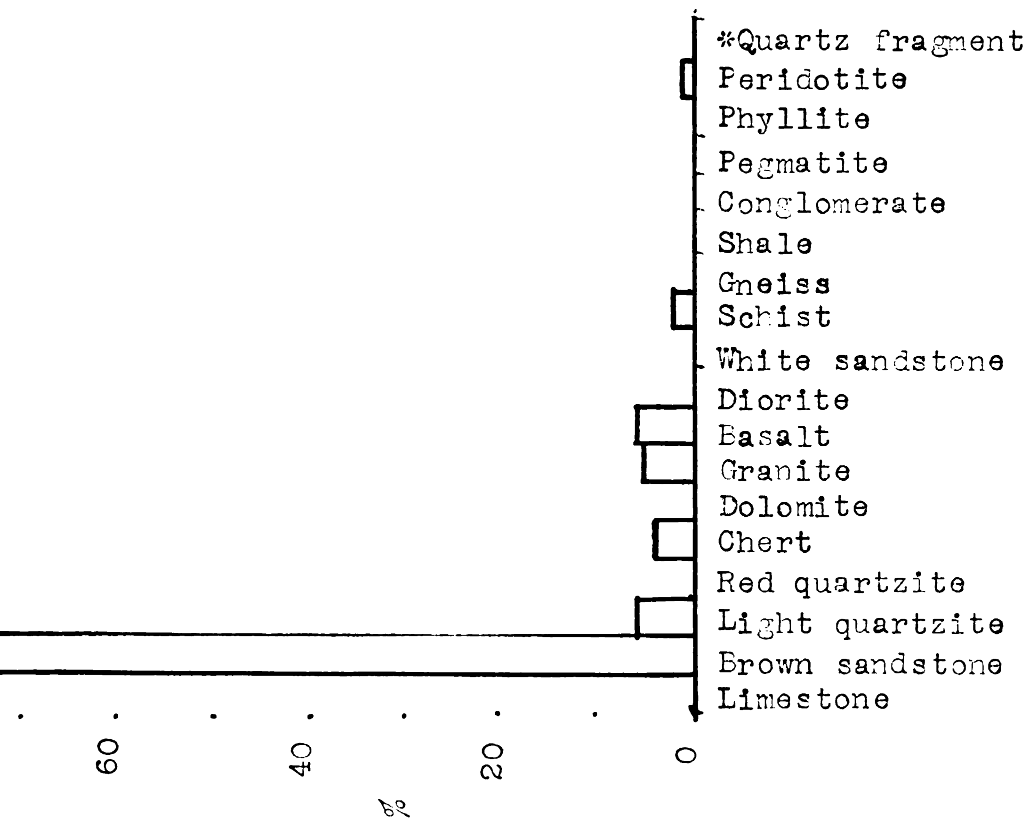


Sample #28

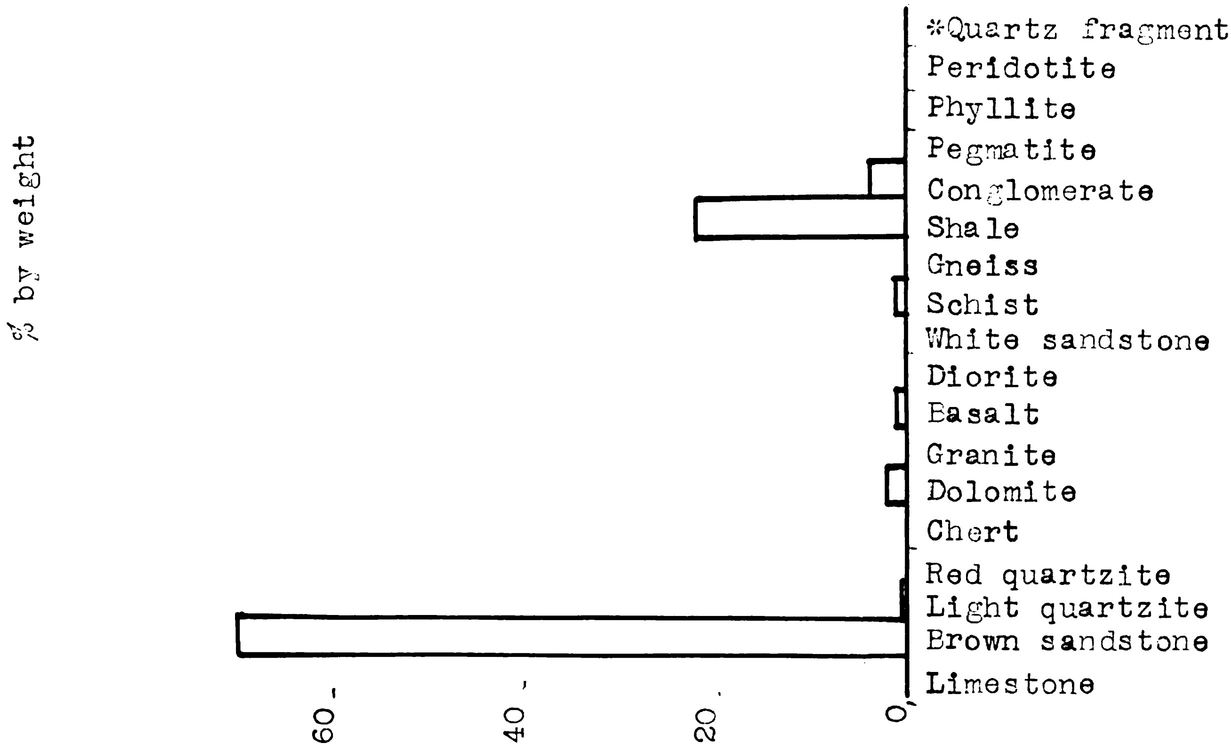
% by weight

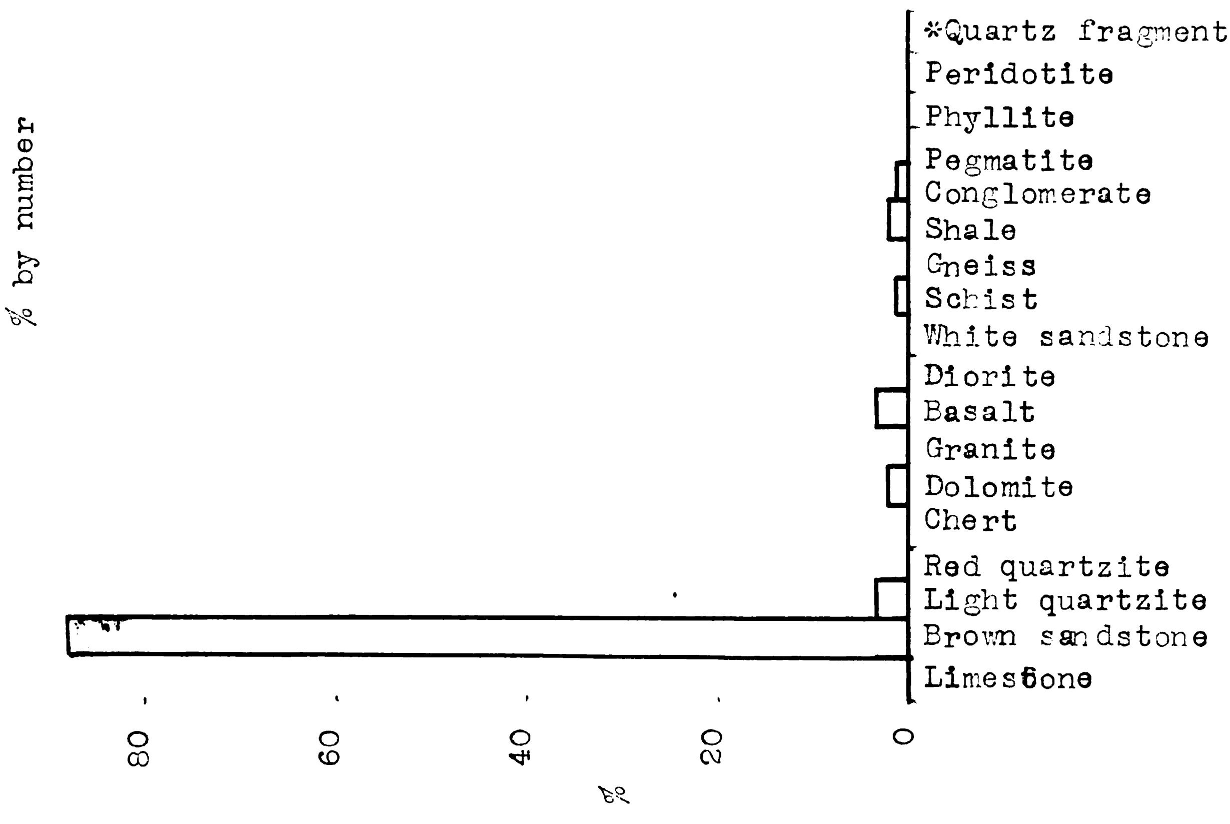


% by number

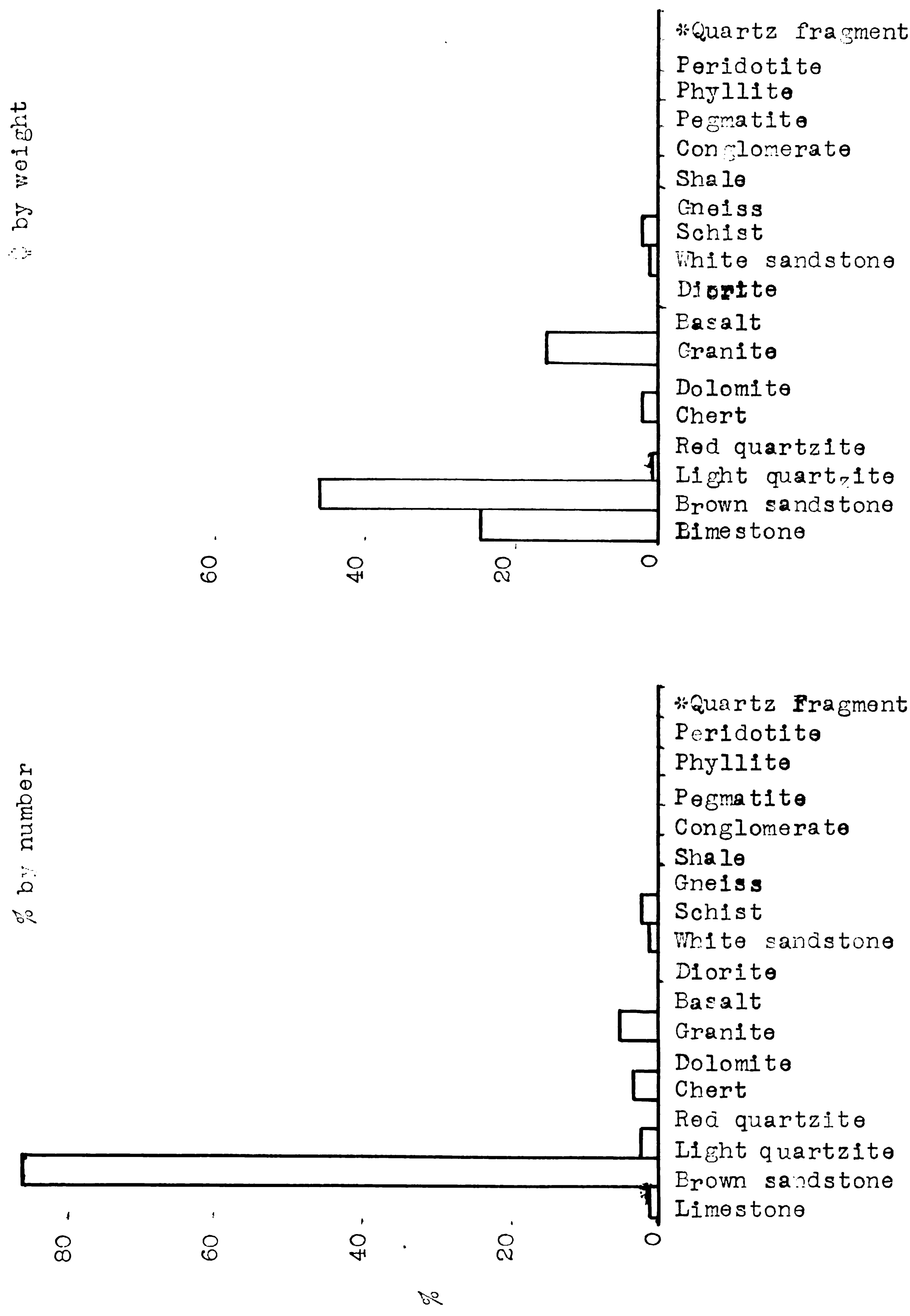


Sample #29

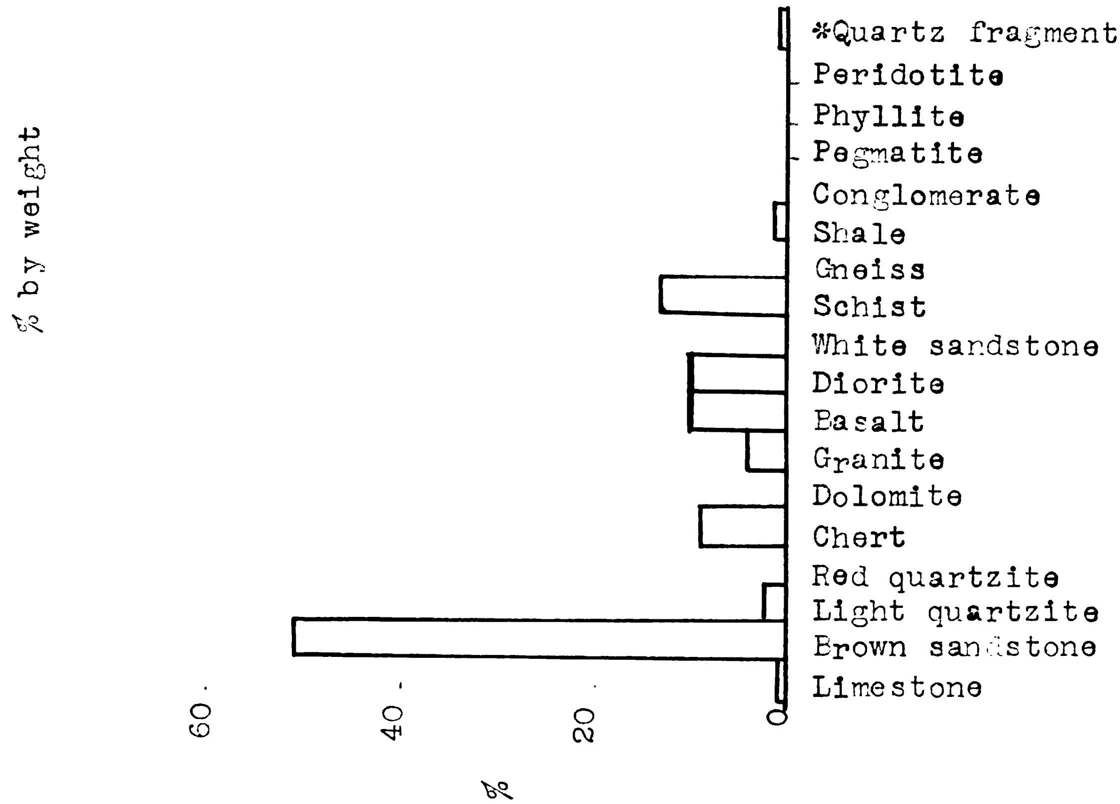

% by weight
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
60
40
20
0

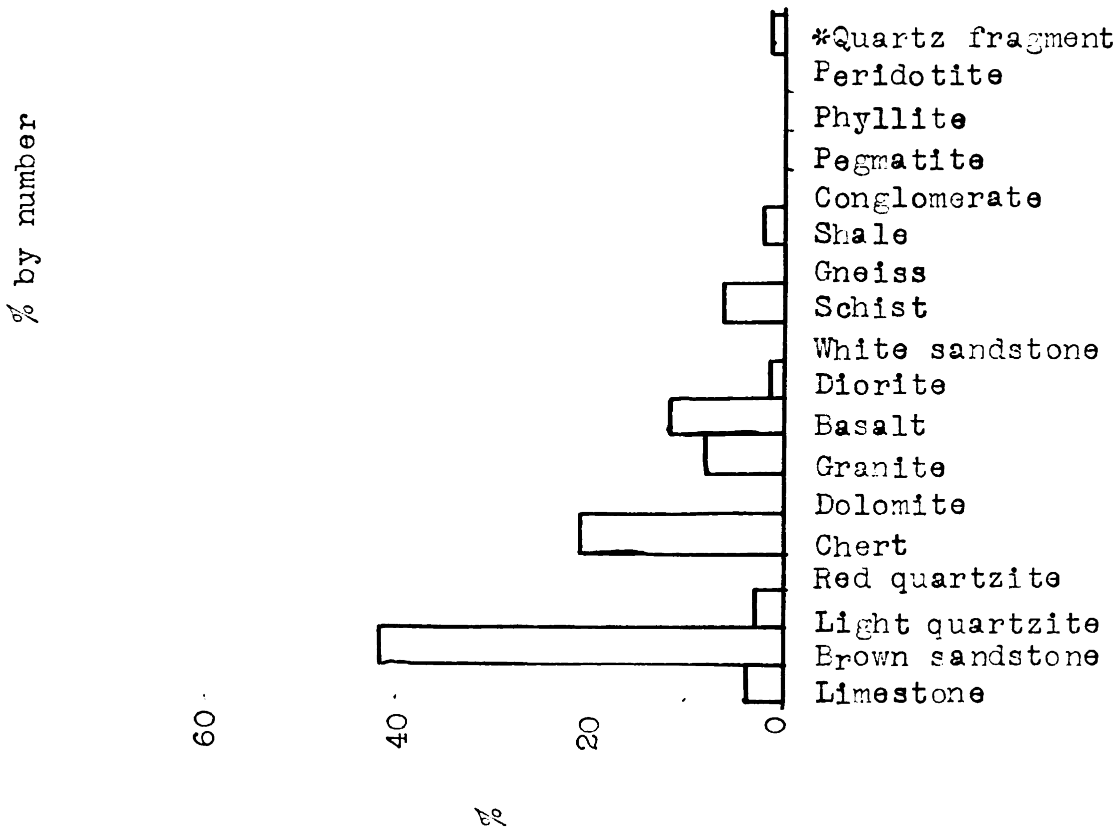

% by number
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
80
60
40
20
0
%

Sample #30

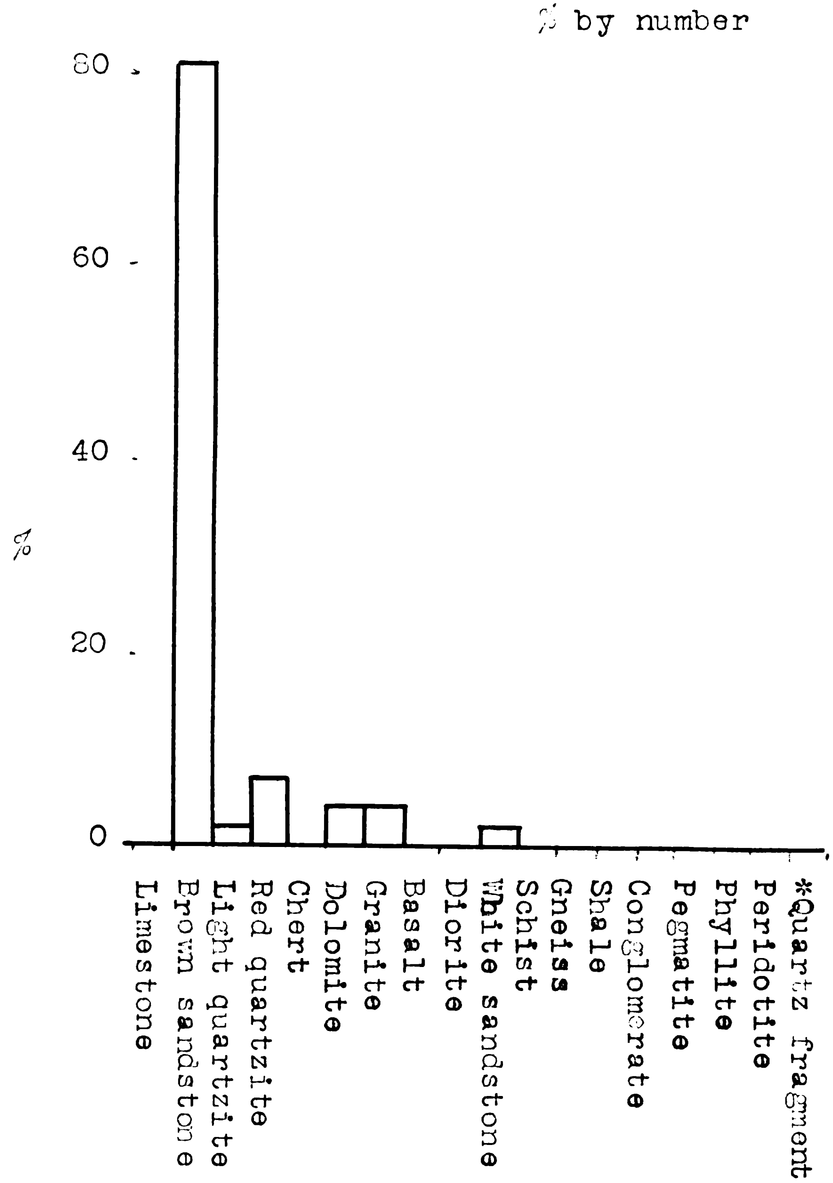

% by weight
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
0
20
40
60
% by number
*Quartz Fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
0
20
40
60
80
%

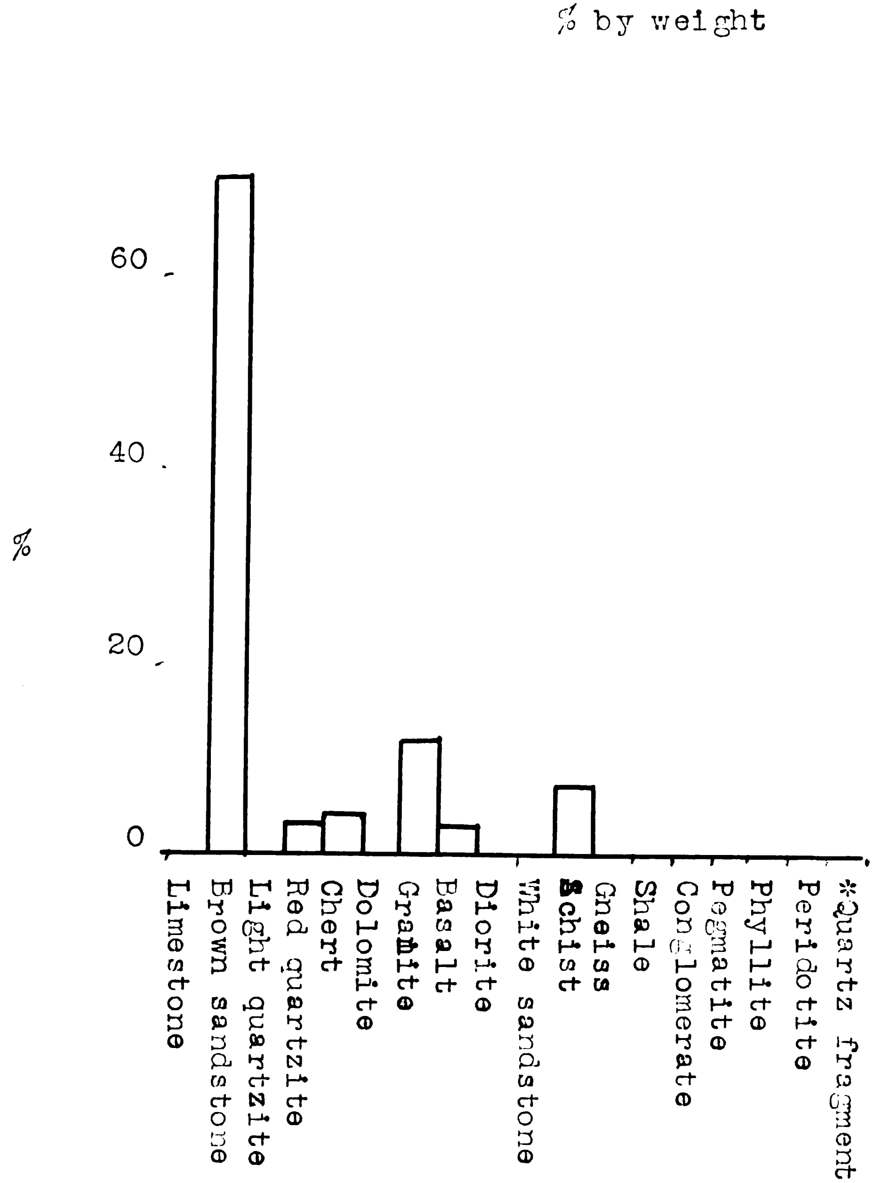
Sample #31


% by weight
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
60
40
20
0
%

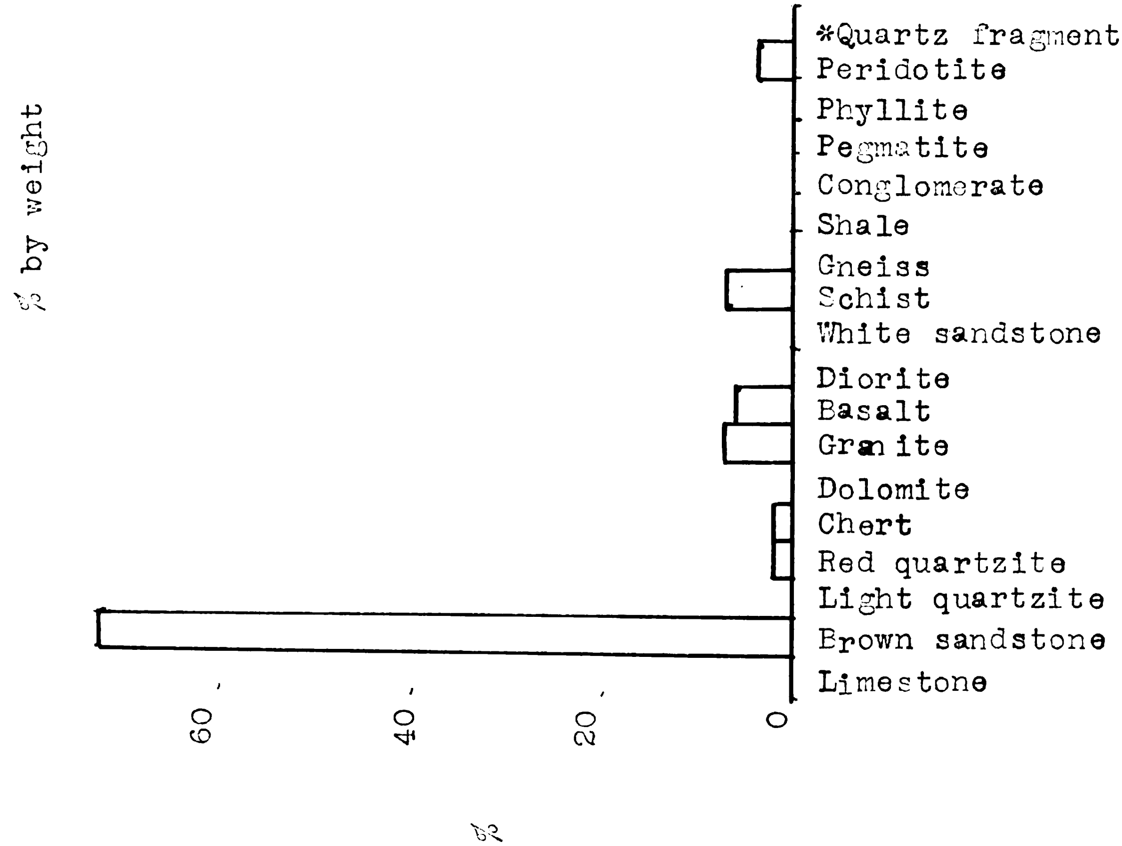

% by number
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
60
40
20
0
%

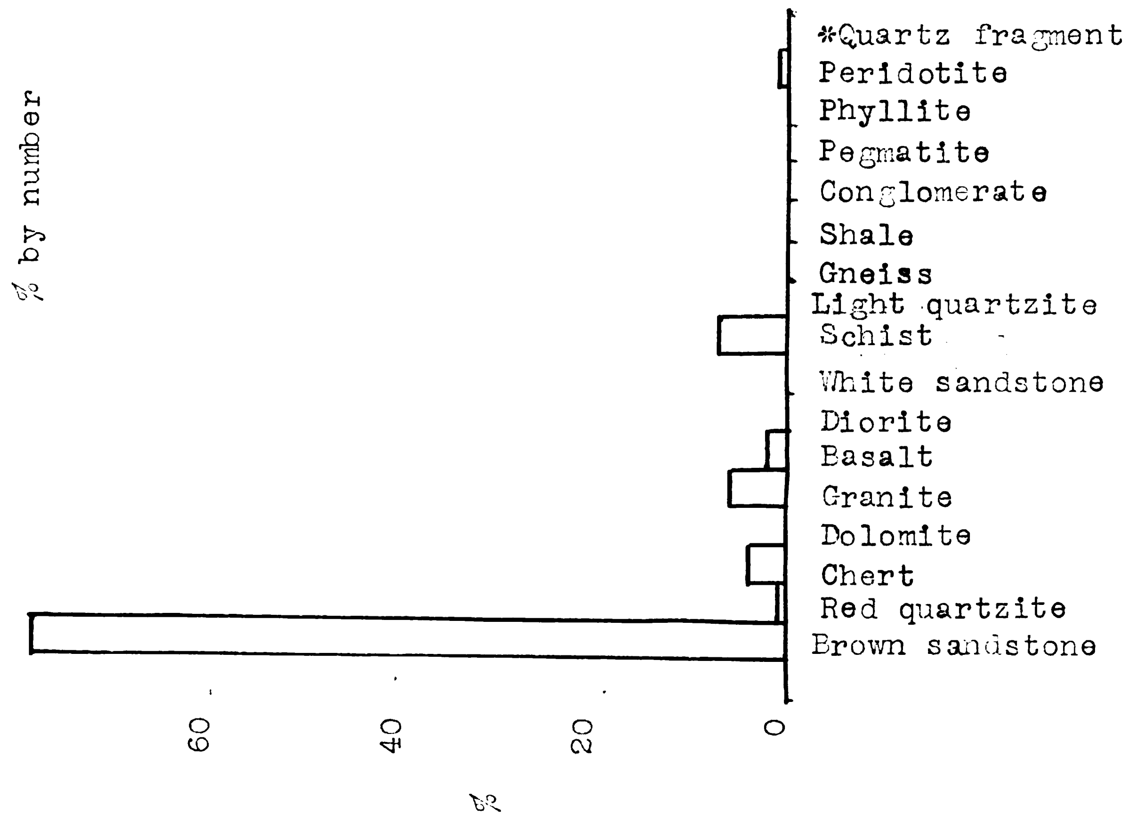
Sample #32


% by number
80
60
40
20
0
%
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

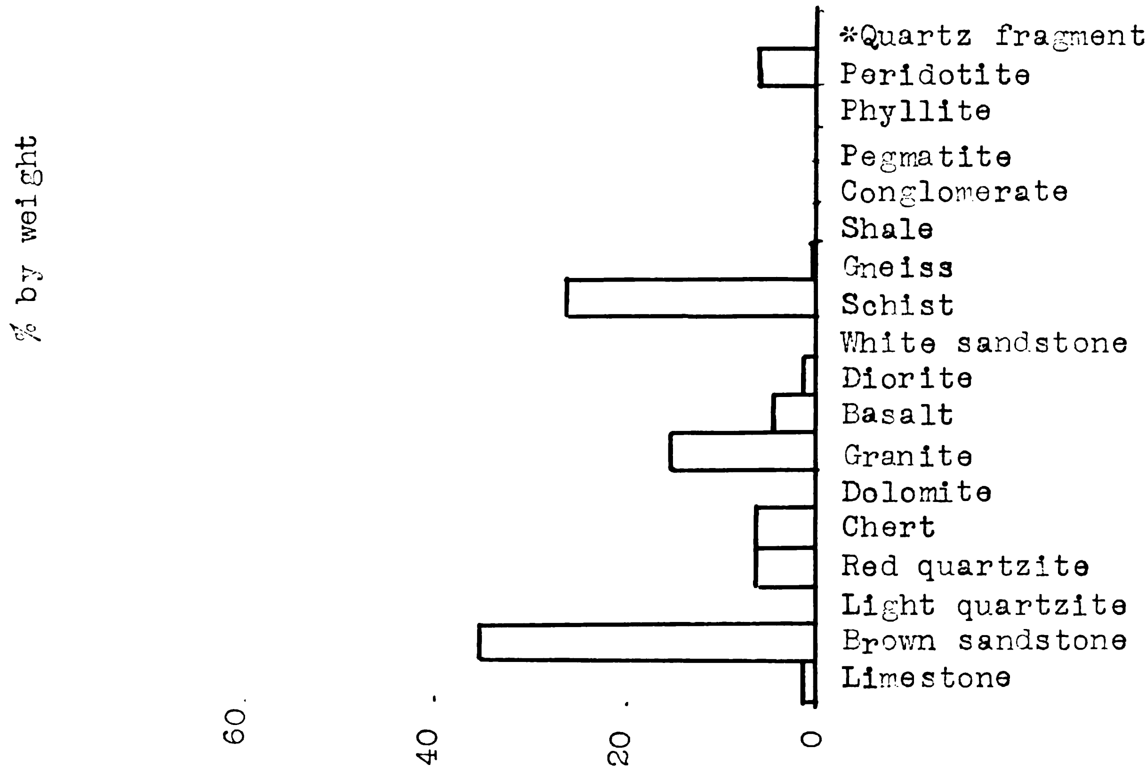

% by weight
60
40
20
0
%
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

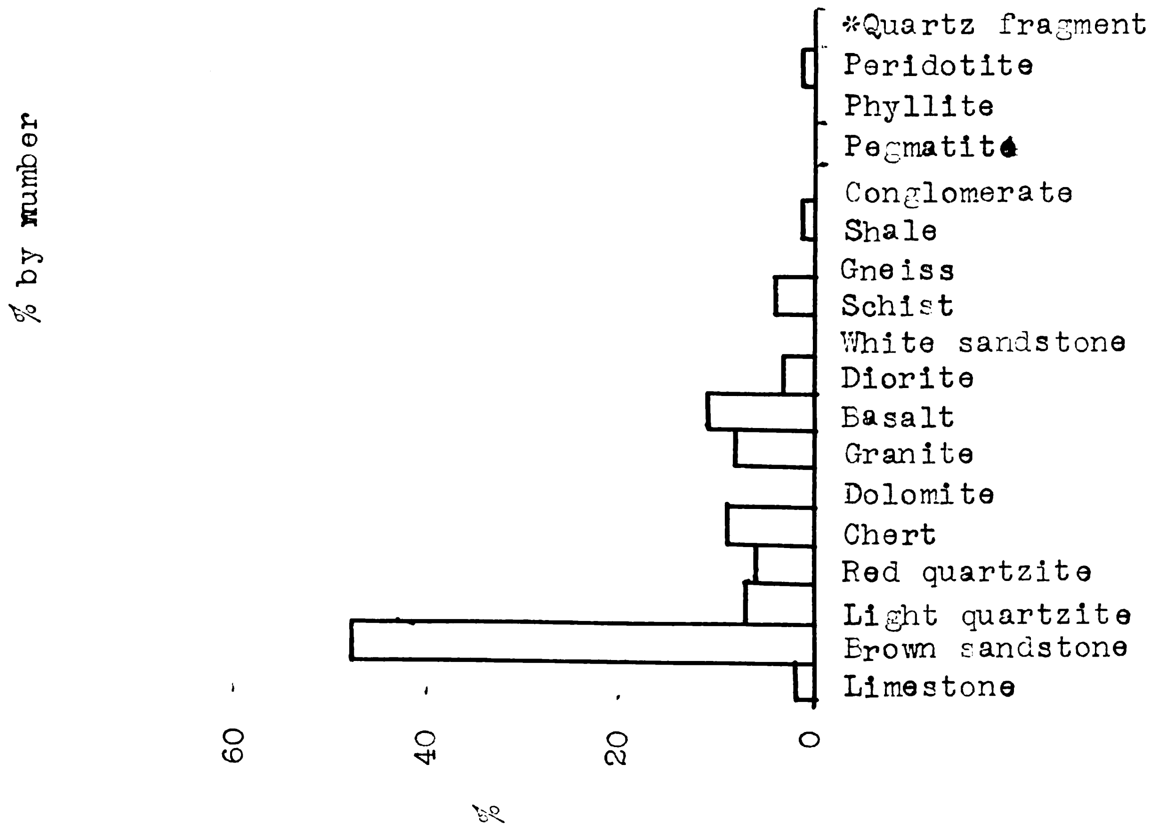
Sample #33


% by weight
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
60
40
20
0
%

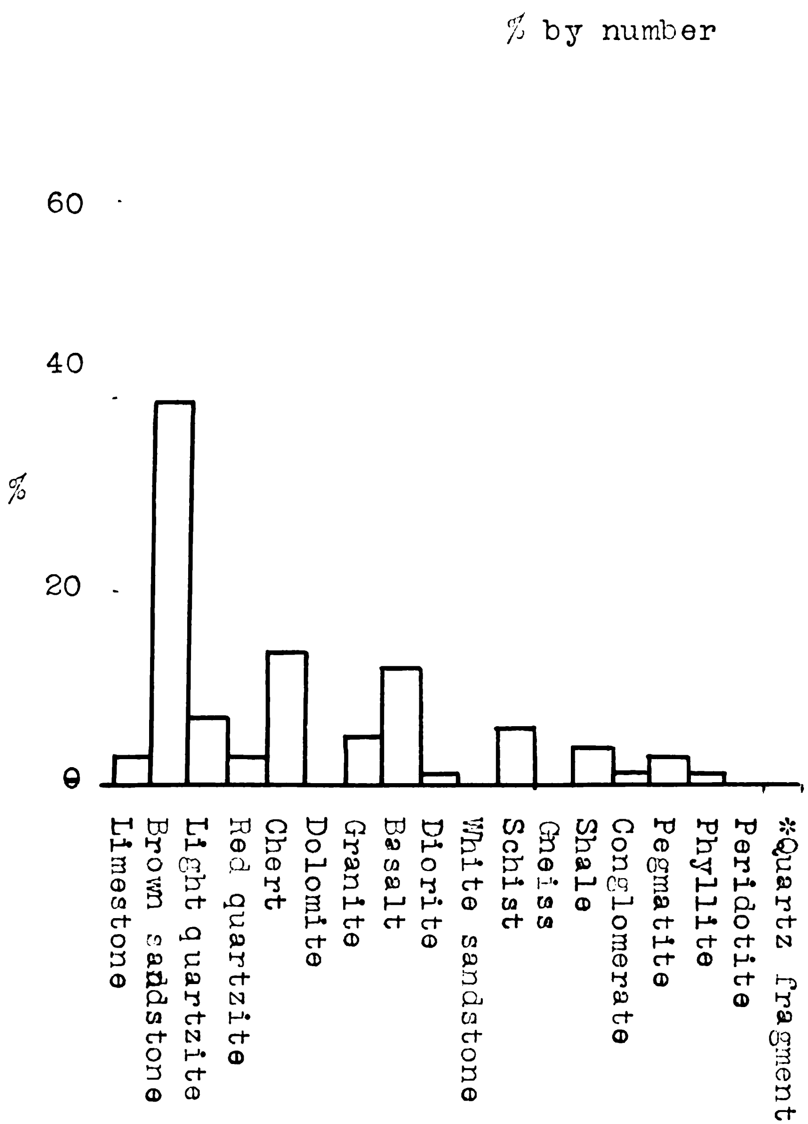

% by number
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Light quartzite
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Brown sandstone
60
40
20
0
%

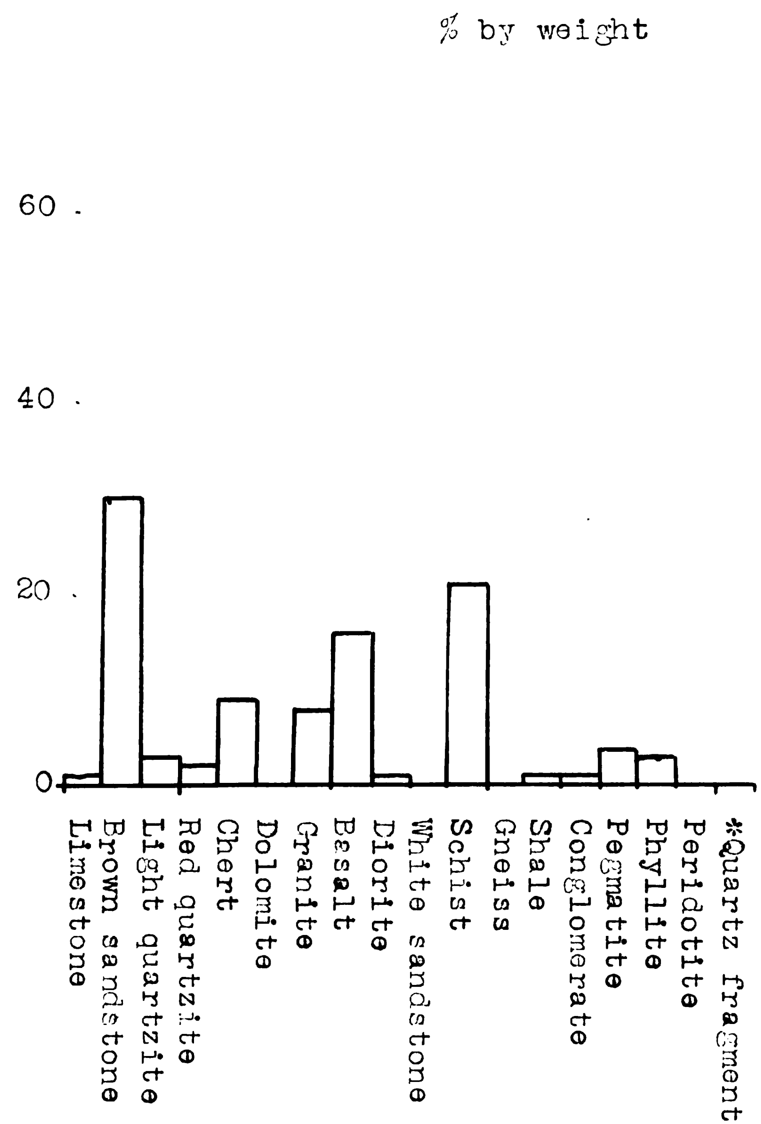
Sample #34


% by weight
60
40
20
0
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone

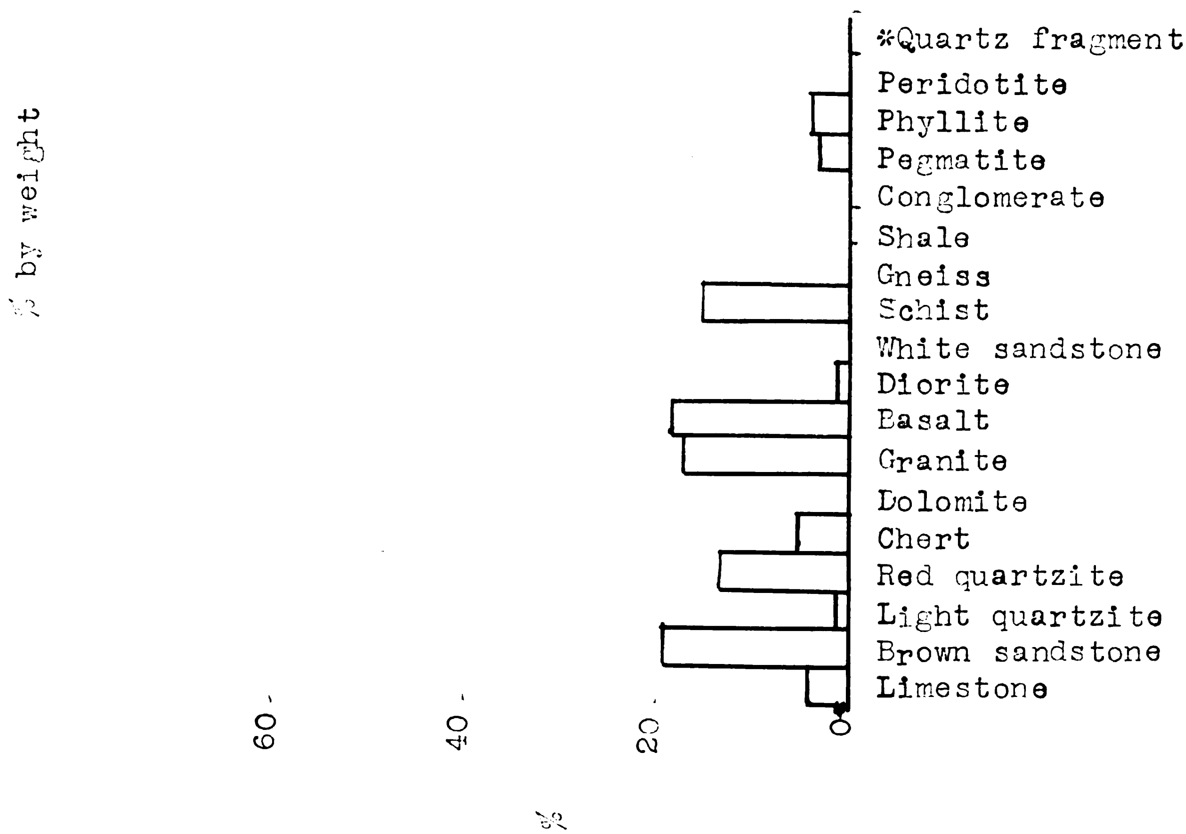

% by number
60
40
20
0
%
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone

Sample #35

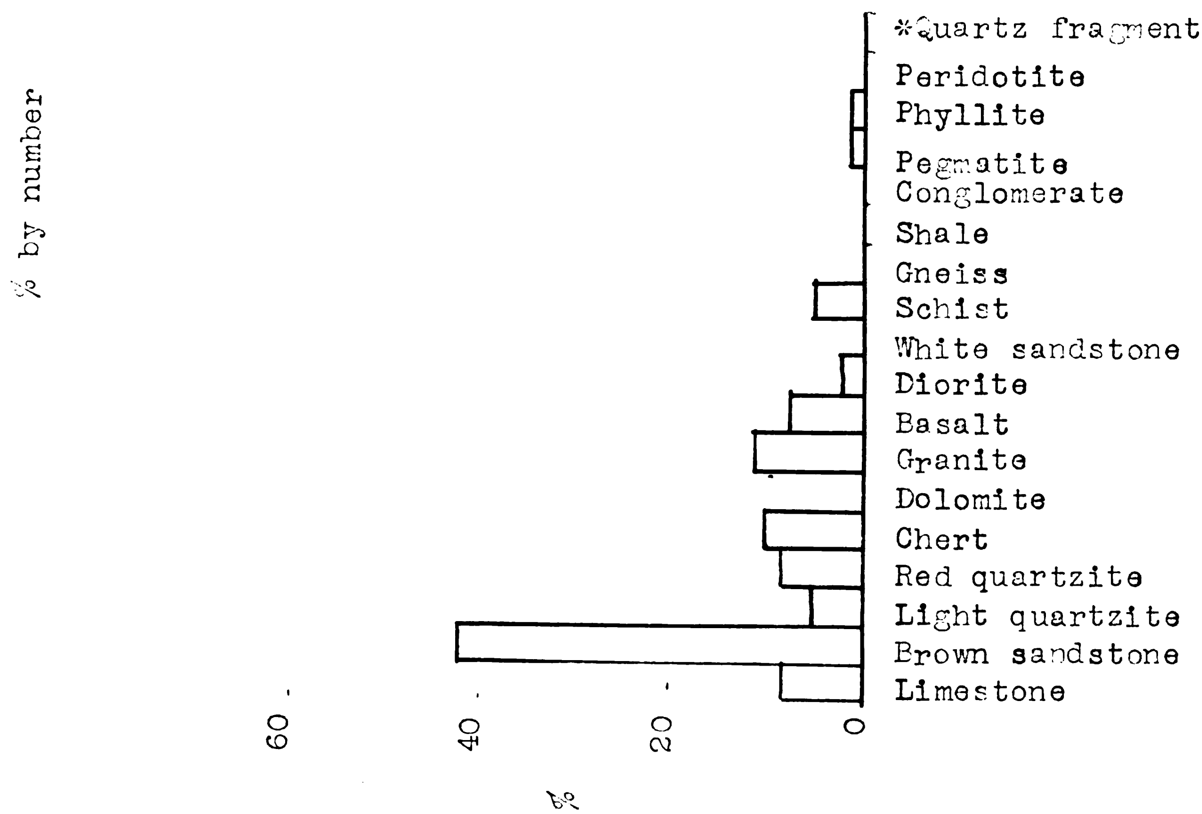

% by number
60
40
%
20
0
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment


% by weight
60
40
20
0
Limestone
Brown sandstone
Light quartzite
Red quartzite
Chert
Dolomite
Granite
Basalt
Diorite
White sandstone
Schist
Gneiss
Shale
Conglomerate
Pegmatite
Phyllite
Peridotite
*Quartz fragment

Sample #36



% by weight
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
60
40
20
0
%



% by number
*Quartz fragment
Peridotite
Phyllite
Pegmatite
Conglomerate
Shale
Gneiss
Schist
White sandstone
Diorite
Basalt
Granite
Dolomite
Chert
Red quartzite
Light quartzite
Brown sandstone
Limestone
60
40
20
0
%

RESULTS

As the pebble counts were conducted all data accrued were recorded in tabular form. When all of the samples had been analysed a composite table was prepared in which 18 major rock units or groups were represented (Table VI).

A check on the accuracy of the pebble count was felt to be an integral part of the study, therefore, Sample #8 was selected at random and by the technique described under "Procedure" three counts were made. The results of these three counts, taken from the same total mass of pebbles, are given below in Table VII. It should be noted that after each test count all pebbles were recombined into the total and thoroughly mixed before beginning the next test.

TABLE VII

Three separate counts of Sample #8

	Count 1		Count 2		Count 3	
Rock Units	No.	Wt.	No.	Wt.	No.	Wt.
Limestone	61	104.55	64	110.25	62	99.85
Brown sandstone						
Light quartzite	3	15.50	2	6.80	5	16.50
Red quartzite	2	.60			1	.30
Chert	11	2.20	9	2.10	10	2.30
Dolomite			1	1.90		
Granite	9	18.40	10	19.30	8	15.75
Basalt	5	1.10	7	1.75	6	1.80
Diorite	2	1.50			1	.70
White sandstone						
Schist	6	14.80	6	15.80	7	15.25
Gneiss						
Shale						
Conglomerate						
Pegmatite						
Phyllite	1	60.00				
Peridotite						
*Quartz fragment			1	.70		
TOTALS	100	218.65	100	158.60	100	152.45

In the test of accuracy preformed on Sample #8 the maximum deviation in the numerical percentage was three. Five of the rock units were entirely absent in at least one of the test counts, and in three cases they were absent in two of the test couhts. The weight deviation reached a maximum of 60 grams, however this was in the case of a single fragment counted only in one of the three tests. A deviation of 10.50 grams was the maximum observed in a rock unit that appeared in each count. It was felt that these variations were within the permissible limits of accuracy.

An inspection of the table of results indicates a definite correlation between the dominance of a certain variety of pebbles and a specific moraine. The samples from the Charlotte moraine contained significant amounts of limestone pebbles; those of the Lake Border moraine contained equally significant amounts of brown sandstone pebbles. To better illustrate this correlation a graphic representation of the tabular data is included.(Figure 2).

CONCLUSIONS

A perusal of the tables and graphs portraying the results of pebble counts will show two prominent differences that exist between the features studied.

The Charlotte moraine contains an abundance of limestone while the Lake Border has only moderate amounts. A composite of the samples of each moraine gave the following results:

TABLE VIII

Table of composites of pebble counts percentage by number, of the Charlotte and Lake Border moraines

Rock Units	Charlotte	Lake Border
Limestone	49.0	3.8
Brown sandstone	.4	59.0
Light quartzite	5.7	5.3
Red quartzite	4.1	2.8
Chert	11.2	7.8
Dolomite	2.6	1.4
Granite	9.9	7.4
Basalt	7.0	5.7
Diorite	2.2	.9
White sandstone	1.3	.7
Schist	4.3	3.2
Gneiss	1.0	.7
Shale	.4	.4
Conglomerate	.2	.1
Pegmatite	.2	.3
Phyllite	.3	.2
Peridotite	.1	.2
*Quartz fragment	.1	.1
TOTAL	100.0	100.0

Most of the limestone observed in the drift of the Charlotte moraine was white, bluish, or grayish in color.

Some of the pebbles appeared to be fossiliferous, however, most of the included fossil remains were so badly weathered as to make positive identification difficult.

The apparent concentration of light colored fossiliferous limestone, dolomite, and chert in the Charlotte composite led the writer to postulate the possible source beds as being the Bayport limestone.

The second prominent difference noted in the composites is the high incidence of brown sandstone in the Lake Border moraine. A study of the geologic map of Michigan and other pertinent references (Leverett and Taylor, 1915; Newcombe, 1933; Terwilliger, 1954), led the write to postulate the Lower Marshall as being the possible source bed.

As noted in Table VIII, the Lake Border moraine is not entirely devoid of limestone pebbles. These differ somewhat in color from those of the Charlotte, being mostly brownish to buff. They have some of the characteristics of the Thunder Bay limestone of the Traverse group, but the identification is not to be considered definite.

Reference to Table VIII reveals a difference exists in the percentages of granite, basalt, and diorite in the Charlotte as compared to the Lake Border moraine. This difference can be explained on the basis of the distance the pebbles traveled from their source beds. The shorter the distance, the greater the percentage, according to R. F. Flint (1947, p. 114-116). The difference can also be controlled by the areal extent of the source beds that were exposed to glacial erosion (Flint, 1947, p. 105-6). Reference to geologic maps of Michigan and Ontario and measurements based on the proposed direction of ice movement (Leverett and Taylor, 1915, p. 62), led the writer to postulate that the source beds of the granite, basalt and diorite pebbles observed in the Charlotte moraine were closer than the source beds of the similar types of pebbles in the Lake Border moraine.

No significant difference is noted in the percentages of light quartzite and schist in the features studied. White sandstone, shale, conglomerate, pegmatite, phyllite, and peridotite were not found in sufficient quantities to be of value in correlation.

The difference in percentages of pebbles of certain rock types and their relationships to specific moraines indicate that this method of study can be used to differentiate between features of different lobes of glacialiation. However, further substantiation by similar studies of other areas should be made to confirm the accuracy of the method.

In any future work on similar problems the author suggests that emphasis should be placed on extensive sampling problems. Also that a definite means of correlation between the pebbles sampled and specific parent formations would be of great value.

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APPENDIX

APPENDIX

TABLE II

MEGASCOPIC CLASSIFICATION OF IGNEOUS ROCKS*

		Light-colored rocks(leuco rocks) -	
		Felsic mineral dominant	
		Quartz present	Quartz absent
Phanerites	Nonporphyritic	Granite Aplite Pegmatite	Syenite
	Porphyritic	Granite porphyry	Syenite porphyry
Aphanites	Porphyritic	Felsite porphyry	
	Nonporphyritic	Felsite	
Glasses	Porphyritic	Vitrophyre Obsidian porphyry Pitchstone porphyry	
	Nonporphyritic	Obsidian,pitchstone,perlite,pumice	
Fragmental igneous rocks		Volcanic ash, tuff, breccia,	

*After Wahlstrom, Igneous Minerals and Rocks, 1947, p. 258.

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←——→ Dark-colored rocks(mela rocks)			
Ferromagnesian minerals abundant		Feldspar absent	
Hornblende conspicuous	Pyroxene conspicuous	Without olivine	With olivine
Diorite	Gabbro Diabase	Pyroxenite Hornblendite	Peridotite
Diorite porphyry	Gabbro porphyry		
Basalt porphyry Melaphyre		Very rare rocks	
Basalt Trap			
Rare			
agglomerate, etc.			

APPENDIX

TABLE V

IDENTIFICATION TABLE OF COMMON ROCK MINERALS*

Nonmetallic light-colored	Hard	Show cleavage	Flesh-colored, stubby	Orthoclase
			Gray-white, lathlike, striated	Plagioclase
			Green columnar	Actinolite
			Gray or red, greasy luster	Nepheline
		Fracture only	Isometric crystals in dark rocks	Leucite
			Green, glassy, granular	Olivine
			Fine grained, yellowish green	Epidote
			Glassy, variously colored	Quartz, chert
	Soft	Cleavage	Cubic, salty taste	Halite
			Rhombohedral cleavage, H - 3	Calcite and dolomite
			Flexible plates, etc., H - 2	Gypsum
			Rectangular cleavage, H - 3.5	Anhydrite
			Soapy feel, H - 1	Talc
			Elastic mica	Muscovite
			Fibrous, brittle, H - 2-4	Zeolites
			Fibrous, flexible, H - 2-4	Asbestos
		Fracture	Yellow, burns with blue flame	Sulphur
			Earthy	Kaolinite
			Waxy look, H - 4	Serpentine
			Soapy feel, H - 1	Talc

APPENDIX

TABLE V (continued)

IDENTIFICATION TABLE OF COMMON ROCK MINERALS

Nonmetallic dark-colored	Hard	Cleavage	Black, cleavage about 90°	Augite
			Black, cleavage about 60°	Hornblende
			Green, poor cleavage	Epidote
		Fracture	Dirty green	Epidote
			Brown, orthorhombic	Staurolite
			Red, isometric, glassy	Garnet
			Black, hexagonal columns fluted	Tourmaline
			Variously colored, waxy	Jasper, quartz
			Black to red, conchoidal	Obsidian
	Soft	Cleavage	Brown to black, elastic mica	Biotite
			Green to dark blue-gray, H - 1	Chlorite
			Brown rhombohedrons	Siderite
		Fracture	Earthy	Clay
			Green to dark blue-gray, H - 1	Chlorite
			Green, waxy, H - 4	Serpentine
			Green, dark, sandy grains	Glauconite

APPENDIX

TABLE V(continued)

IDENTIFICATION TABLE OF COMMON ROCK MINERALS

Metallic-colored	Black	Streak black	Hardness - 6	strongly magnetic	Magnetite
				weakly magnetic	Ilmenite
			Hardness - 1 to 3		Graphite and coal
		Streak red			Hematite
		Streak yellow			Limonite
	Red	Metallic			Copper
		Earthy			Hematite
	Yellow	Metallic, black streak, H - 6			Pyrite
		Earthy, yellow streak			Limonite

*After Lahee, <u>Field Geology</u>, 1941, p. 783.