SOIL VARIABILITY OVER SHORT DISTANCES

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ABSTRACT

The purpose of this study was to determine the degree of which geologically uniform soil samples can be discriminated using color and mineral composition alone. The intent was to identify a degree of sample uniqueness sufficient for the data to be useful as courtroom evidence.

Eighty samples were taken from the surface of the Wisconsin terminal moraine that crosses the Triassic Newark basin in North Central New Jersey. Individual samples were collected from 12" x 12" x ½" plots in a preselected pattern over a 400' x 160' test area.

Soil color was found to change rapidly over the area. Each sample was visually compared with all others. Dissimilar color pairs were recorded. Over 92% of the samples could be discriminated in this way.

To increase discrimination, the mineralogy of the similar color pairs was studied. Sixteen mineral variables were used for classifying a minimum of 300 grains per sample. A cluster analysis processed the results so that samples of a similar mineral assemblage grouped into clusters.

The similar color pairs were then examined with the criterion that they were different unless both samples were in the same mineral cluster. By increasing the number of clusters, all the sample pairs can eventually be discriminated. The significant number of mineral clusters is between four and ten and can eliminate up to 34% of the pairs that could not be told apart by color. Mineralogy in combination with color discriminated over 95% of the samples.

A heavy mineral count was made to explore the usefulness of this technique for discrimination of seven samples with a high degree of similarity in both color and mineralogy. As before, similar samples were clustered. Of fourteen color similarities found when examined as a color pair with the test samples, eight were considered different because both samples in the pair did not fall into the same heavy mineral cluster.

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INTRODUCTION

Acknowlegements

The writer is grateful to Dr. R.C. Murray for suggestions, guidance and frank advice throughout the study. Dr. R.K. Olsson and Dr. P.E. Wolfe provided helpful information. I am greatly indebted to M.A. Gara and Sam Kingsley of the psychology department for their extensive assistance with computer operations. Thanks also goes to John Rehm for helping with the field work and to Al Bliss and Robert Holzer for making diagnostic mineral identifications. Much appreciation is felt for the writer's family for their support and unselfish help. And finally, I want to thank my Christian colleagues for their attempt to make my education at Rutgers more meaningful.

Statement of the Problem

Soil characteristics have value as physical evidence. This evidential value is the result of, and dependent upon the large number of soil kinds that exist on this earth (Murray and Tedrow, 1975). In forensic geology only the general aspects of soil variability are known. There is little statistical information on the rates of change in soils over short distances or estimates on the total number of identifiable types per unit area, thus limiting the value of soil examination as evidence in court.

Color and mineral proportions are the most useful forensic properties (Frenkel, 1968). Frenkel defines "forensically useful" as "a soil property with limited variation over small areas while showing relatively large variations over 10 yards or more." This study evaluates the discriminatory powers of color and mineral composition in the examination of geologic samples with the same origin.

Color is the more obvious property and the easier to evaluate. There can be marked color changes over linear distances as short as a few feet, but the actual degree of such changes has not been determined for specific areas. Further, there is little quantitative information on the number of soil samples that can be collected without seeing similar colors.

Individual differences in mineralogy are harder to show because statistical methods, which have been developed, are directed towards enhancing similarities, rather than emphasizing differences. Accordingly, a combination of comparison methods were used which promoted identification of mineral differences.

Previous Work

A series of investigations by O.J. Frenkel (1965, 1968) are the only statistical studies of soil variability in forensic geology. Frenkel's work was directed at setting standards for procedures to uniformly handle soil samples, and determine the best sampling plan for study of soil variability in Southern Ontario. Color, mineralogy and modal values of grain size were used. A classification scheme of thirty light and heavy minerals was developed. Frenkel reports 120 mineral assemblages in his study area. Color was measured by trichromatic coefficients and luminous reflectance, and 400 significant soil colors found.

A sampling hierarchy was developed throughout the province using seven sites 10 x 10 yards (designated as "scenes") all within an area one mile in diameter. Within a site, areas 4 x 10 inches designated as "footprints" were sampled for uniformity in properties. This study showed that in an area of about 50,000 square miles, "the probability is smaller than 1/50 of finding two soils which are indistinguishable in both color and mineral composition...in two different areas separated by a distance of 1000 feet or more." Further Frenkel indicated that more extensive sampling along with trace element or organic particle analysis may lower this probability to 1/500 or even 1/5000.

Sampling Plan

In selecting the site for this study it was decided that the area should be geologically simple and contain soil that should, as a first approximation, be geologically homogeneous. The choice of Wisconsin glacial till appeared to meet these criteria, and is of recent enough origin, so that weathering would not make grain identification difficult. A suitable collecting site was found in Roosevelt Park (Figure 1), Menlo Park, New Jersey, on the Bangor terminal moraine as it crosses the Triassic Newark basin. The top of the moraine is a broad, flat, but irregular surface. Relief at the site is less than ten feet. A tall stand of mature maple and oak trees prevent much of the sunlight from reaching the ground. As a consequence, some of the ground is bare, making sampling easier.

The source materials for this moraine are mainly the Watchung and Palisades basalts, a thin veneer of Pensauken sands and gravels, and the underlying Brunswick shale (Figure 2). The Pre-Cambrian Highlands of the Reading Prong in New York contributed gneiss and quartzite. The serpentinite body in Staten Island and possibly the

Figure 1

Roosevelt Park

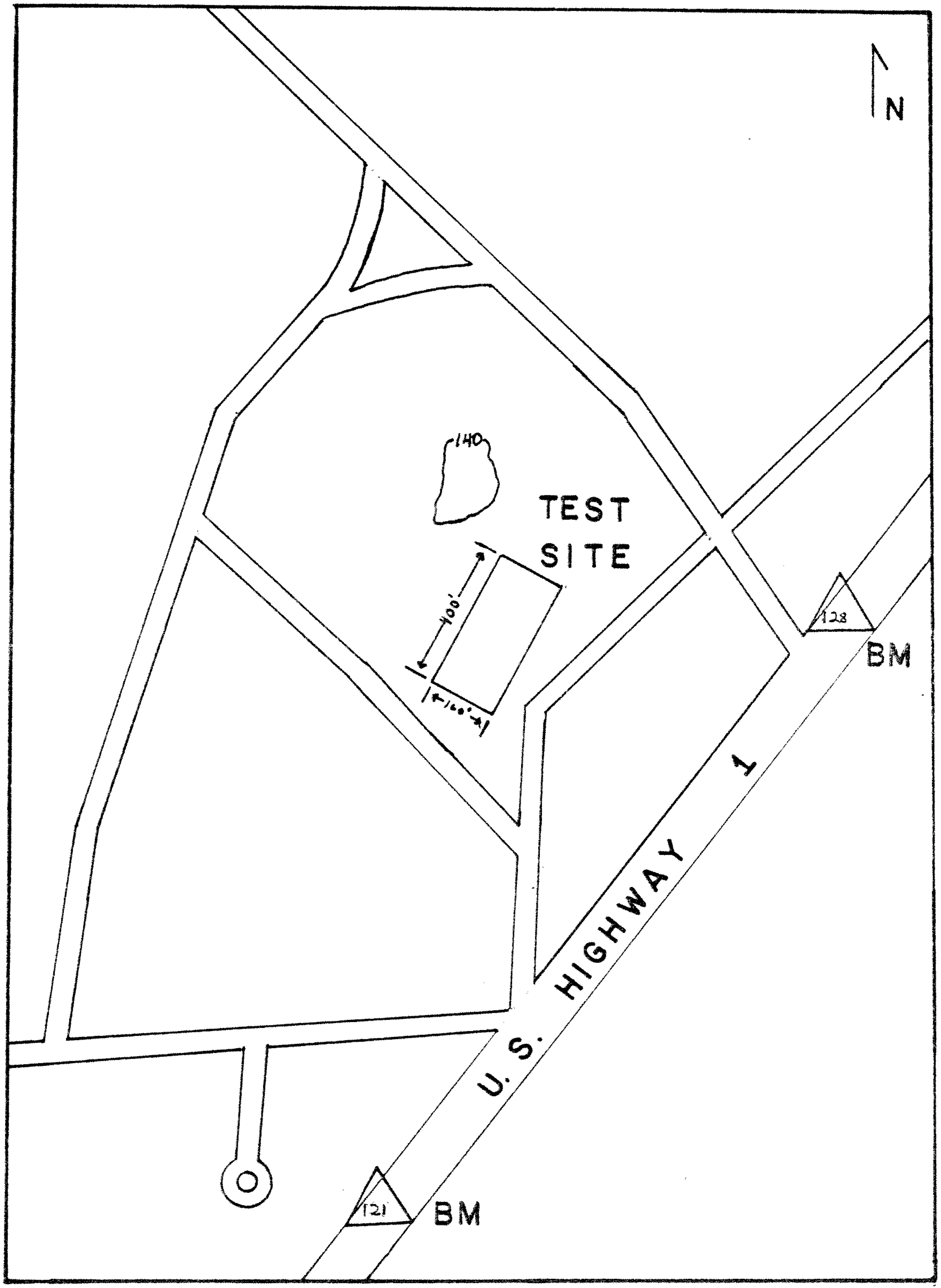
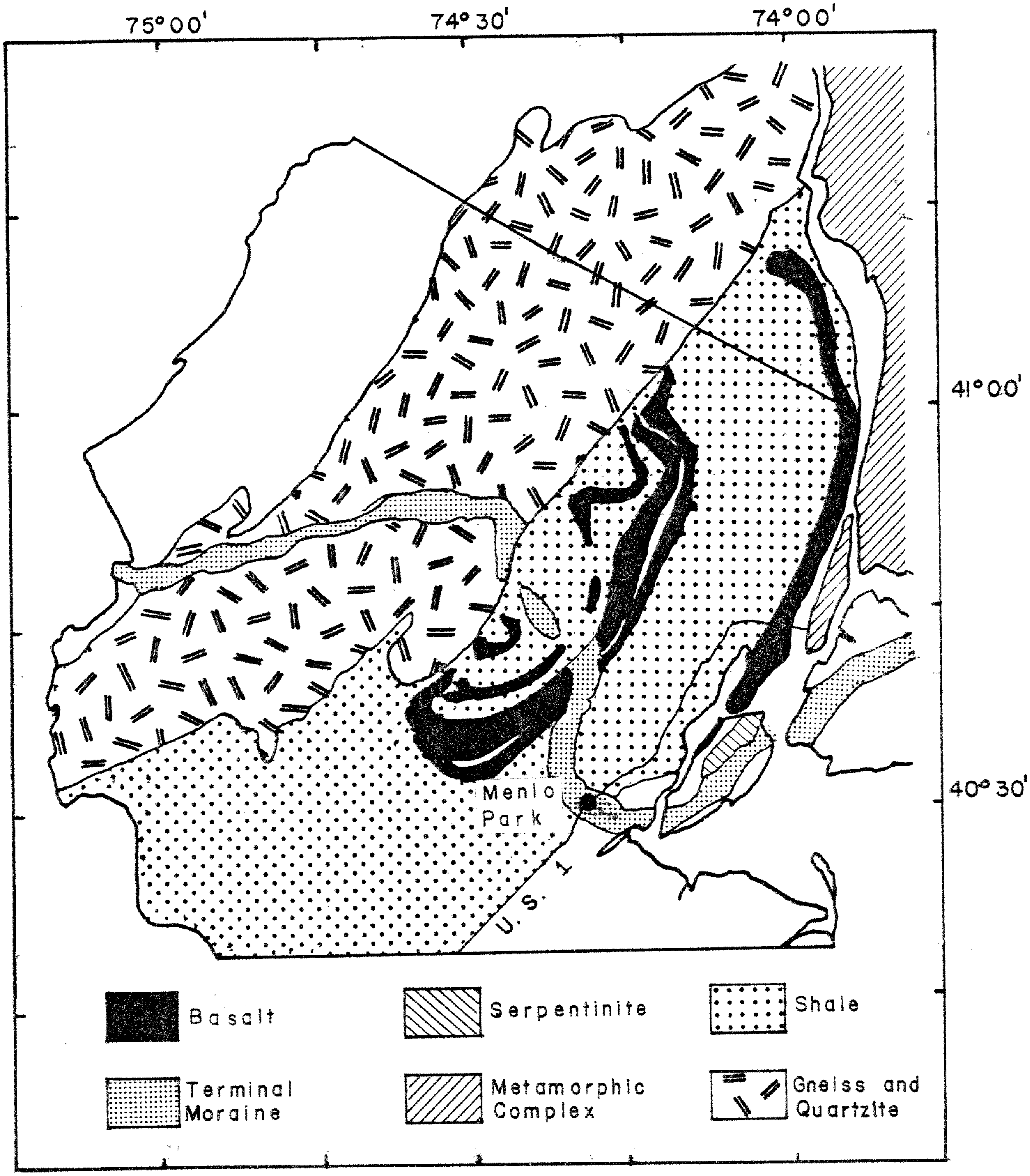


Figure 2

Geologic Map of Northern New Jersey



New York City metamorphic complex, could also have contributed to the moraine in this area.

Eighty samples were collected on a grid within the test area of 400 by 160 feet. Ten samples were collected on forty foot centers on the 400 foot dimension, and on twenty foot centers along the width (Figure 3). Each sample was recovered from the top one half inch of soil within a square foot.

COMPARISON METHODS

Preparation

Samples were washed with detergent in a low speed blender to minimize the probability of breaking grains and then passed through sieves of mesh sizes 10, 60 and 200. Organic material was removed by floatation. This material and the residue on sieve size 10 were both discarded. The residue from the other two sieves were placed under an infrared lamp until dry.

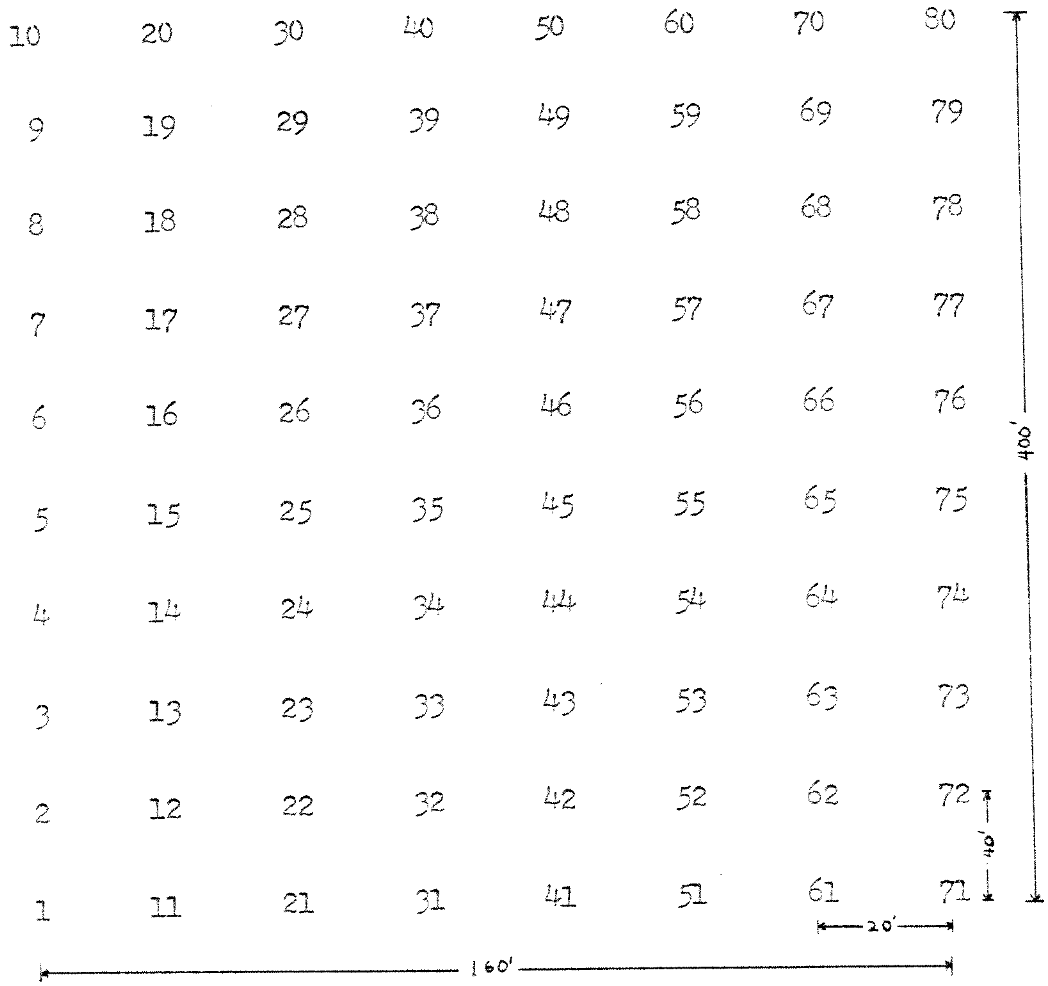
The 60 mesh proportion was the basic working sample. These sand particles were stored in Petri dishes for comparing colors and grain identification. Samples on the 200 mesh were stored in envelopes for future study.

Color Analysis

A great deal of inhomogenity was readily apparent when all the samples in Petri dishes were placed side by side on a tray. However, it became apparent that there was color continuity, ranging from white (mostly quartz), to red (high in Brunswick shale) to orange (iron stained). Experience developed during the course of this study indi-

Figure 3

Sampling Plan



cated that careful discrimination was necessary even under the natural light of a north facing room. Each sample was compared for similarity in color with all of the rest, and a yes-no decision made. For example, Sample 9 was compared with 10 through 80, and Sample 46 was compared with 47 through 80. In this manner each sample was compared with all other samples three times, the second time in reverse. For each run 3160 pairs were examined.

Partial Identification

Sand size particles were identified and counted under a binocular microscope for each sample. Grains were selected at random and lined up in the Petri dish. A classification of sixteen mineral variables was developed to include all the major grain types. The results are presented in Table 1. A minimum of 300 grains were counted from each sample.

The following mineral classifications were used for grain identification: quartz, quartzite, soft sandstone and mudstone, feldspar, Brunswick mudstone, magnetite, glauconite, mica and rock fragments.

Quartz, the most predominant mineral, was broken into four groups and each subdivided by rounded and angular shape.

Although "round" is a small subset, it is some measure of mechanical history, and thus a useful classification. Frosted quartz was classified as "clear" (transparent), whereas opaque non-stained grains such as smokey and white quartz were classified as "milky."

The third quartz category termed "stained quartz" was defined as "clear quartz" colored by impurities. Most particles were iron stained, but transparent yellow and pink quartz were also common.

Table 1. Percent Sand Particles

Sample	1	2	3	4	5	6	7	8	9	10
Quartz										
Clear										
angular	17	27	12	18	22	25	27	31	72	29
round	6	7	1	1	1	3	1	1	1	4
Milky										
angular	8	13	3	4	9	10	22	16	19	20
round	2	1	T	0	0	1	T	T	0	2
Stained										
angular	23	19	59	50	30	29	19	27	7	15
round	7	4	7	6	3	7	1	1	0	2
Milky Stained										
angular	22	13	9	10	22	16	7	9	1	12
round	2	3	0	0	1	T	0	T	0	0
Quartzite	2	3	2	2	2	1	1	1	0	1
Soft Sandstone & Mudstone	2	4	1	2	1	2	16	7	0	2
Feldspar	2	1	T	T	T	1	T	T	0	1
Brunswick	2	1	1	1	3	1	2	1	0	6
Magnetite	2	3	1	2	2	2	1	2	0	1
Glauconite	0	1	T	T	1	T	0	0	0	T
Mica	1	1	T	1	1	T	0	T	0	0
Rock Fragments	4	2	2	3	2	1	3	2	1	3

T = trace, less than 0.05%

Table 1.--Continued

Sample	11	12	13	14	15	16	17	18	19	20
Quartz										
Clear										
angular	33	18	32	26	18	23	37	35	16	31
round	2	2	3	2	T	0	0	T	3	2
Milky										
angular	22	8	8	4	5	28	9	14	5	24
round	1	0	9	0	T	0	T	0	0	2
Stained										
angular	18	41	34	46	48	11	24	28	37	15
round	1	2	3	2	1	T	0	T	5	1
Milky Stained										
angular	6	22	12	5	18	22	8	6	23	7
round	0	1	0	0	T	0	0	0	1	1
Quartzite	3	1	3	2	T	0	1	6	1	2
Soft Sandstone & Mudstone	4	1	1	3	1	2	18	5	1	3
Feldspar	T	0	1	T	0	3	T	1	T	2
Brunswick	6	3	T	1	2	4	1	3	2	9
Magnetite	3	T	1	5	2	3	1	1	1	1
Glauconite	0	1	T	1	0	0	0	0	1	0
Mica	0	T	T	T	1	0	0	0	0	0
Rock fragments	2	1	1	4	3	1	1	2	4	1

T = trace, less than 0.5%

Table 1.--Continued

Sample	21	22	23	24	25	26	27	28	29	30
Quartz										
Clear										
angular	24	21	24	10	24	18	34	76	23	22
round	2	2	3	1	2	2	0	T	2	1
Milky										
angular	7	5	9	4	20	5	14	12	17	9
round	0	0	T	2	1	T	0	0	0	1
Stained										
angular	41	42	39	49	29	38	16	9	35	25
round	2	5	1	5	0	4	0	0	1	2
Milky Stained										
angular	11	17	16	20	14	22	14	2	8	26
round	0	T	0	1	0	1	T	0	0	2
Quartzite	3	2	1	T	1	0	1	0	3	3
Soft Sandstone & Mudstone	1	1	1	2	0	2	9	0	T	T
Feldspar	1	T	1	0	T	0	1	0	1	1
Brunswick	1	1	1	1	6	1	2	1	7	2
Magnetite	4	1	2	1	1	2	7	0	0	1
Glauconite	1	1	1	T	T	1	0	0	0	T
Mica	T	T	2	1	0	T	0	0	T	T
Rock fragments	3	2	2	2	3	2	2	0	2	3

T = trace, less than 0.5%

Table 1.--Continued

Sample	31	32	33	34	35	36	37	38	39	40
Quartz										
Clear										
angular	25	20	18	15	16	15	28	67	22	28
round	2	1	2	1	1	0	3	2	2	T
Milky										
angular	25	4	8	6	6	30	19	17	19	14
round	0	0	0	1	0	1	0	T	0	1
Stained										
angular	25	55	43	50	56	6	22	11	27	24
round	T	1	1	1	2	0	T	T	2	1
Milky Stained										
angular	8	8	19	18	10	34	13	1	11	12
round	T	1	0	T	1	0	0	0	T	0
Quartzite	1	3	1	0	2	2	1	T	1	0
Soft Sandstone & Mudstone	2	1	1	2	1	2	0	0	2	4
Feldspar	0	2	0	0	1	4	T	0	1	1
Brunswick	9	2	1	2	1	5	2	0	7	12
Magnetite	0	2	3	1	1	T	5	1	2	0
Glauconite	0	0	1	1	T	0	0	0	0	0
Mica	0	1	0	1	T	0	0	0	0	0
Rock fragments	1	T	2	2	2	1	7	0	4	4

T = trace, less than 0.5%

Table 1.--Continued

Sample	41	42	43	44	45	46	47	48	49	50
Quartz										
Clear										
angular	17	19	18	20	22	46	55	63	26	27
round	1	6	2	3	2	1	2	0	1	1
Milky										
angular	4	4	5	9	7	9	23	15	23	23
round	0	1	1	1	2	1	1	0	T	T
Stained										
angular	60	35	44	44	32	29	11	11	17	28
round	1	5	4	2	6	T	1	T	T	T
Milky Stained										
angular	6	17	4	11	17	6	6	8	14	5
round	T	2	6	0	3	T	T	0	0	0
Quartzite	2	1	4	3	1	2	1	0	1	2
Soft Sandstone & Mudstone	0	2	2	T	3	0	T	0	4	1
Feldspar	1	1	2	T	1	1	0	0	T	T
Brunswick	1	3	2	1	2	3	0	2	10	8
Magnetite	2	2	1	2	1	1	0	1	2	1
Glauconite	0	1	T	1	T	0	0	0	0	0
Mica	1	1	2	0	T	0	0	0	0	0
Rock fragments	4	2	2	2	1	1	T	0	1	3

T = trace, less than 0.5%

Table 1.--Continued

Sample	51	52	53	54	55	56	57	58	59	60
Quartz										
Clear										
angular	11	22	1	18	36	42	55	34	31	18
round	1	1	3	4	1	0	T	0	2	1
Milky										
angular	7	4	3	12	15	22	16	14	16	4
round	T	0	0	2	T	0	T	0	0	0
Stained										
angular	39	51	61	24	30	19	17	31	30	47
round	7	4	3	7	1	0	T	0	0	1
Milky Stained										
angular	26	3	15	17	7	14	9	8	12	14
round	0	T	0	4	0	T	0	T	T	0
Quartzite	1	4	1	1	1	1	T	2	1	2
Soft Sandstone & Mudstone	1	T	4	1	1	T	1	2	T	2
Feldspar	1	1	T	1	0	0	0	T	T	0
Brunswick	2	T	1	4	4	1	1	5	6	4
Magnetite	2	3	1	2	1	0	T	1	T	3
Glauconite	T	T	T	1	T	0	0	0	0	1
Mica	0	1	2	T	0	0	0	0	0	1
Rock fragments	2	4	2	3	2	1	0	3	1	4

T = trace, less than 0.5%

Table 1.--Continued

Sample	61	62	63	64	65	66	67	68	69	70
Quartz										
Clear										
angular	18	30	22	22	28	50	43	28	32	30
round	0	1	T	3	1	7	1	T	T	3
Milky										
angular	14	15	5	8	23	18	15	8	11	13
round	0	T	1	1	T	2	0	T	0	1
Stained										
angular	15	10	45	30	17	10	28	48	37	32
round	T	0	2	2	3	2	T	0	1	0
Milky Stained										
angular	6	26	18	17	16	10	4	9	4	1
round	0	0	1	2	0	0	0	0	T	T
Quartzite	0	3	0	4	0	T	0	1	1	1
Soft Sandstone & Mudstone	T	3	1	1	12	0	1	T	3	7
Feldspar	0	1	0	1	0	0	0	T	1	T
Brunswick	1	5	1	2	T	1	5	4	6	3
Magnetite	18	5	2	2	T	0	T	1	1	1
Glauconite	0	0	0	1	0	0	0	0	0	0
Mica	T	0	0	0	0	0	0	0	0	0
Rock fragments	27	2	2	4	T	0	2	1	3	1

T = trace, less than 0.5%

might well be expected to remain exposed for longer periods of time than others during the early stages of progradation by continental detritus. While karst development in these areas represents an unconformity in a strict definition of the word the sequence of sediments preserved after burial may not indicate a significant loss of record. Solution of the tide flat carbonates and evaporites by groundwater could also occur during deposition in the continental environments or any time thereafter but this would not indicate an unconformity due to a break in sedimentation. In either case the solution cavities would be filled with the overlying sediment and a distinction between the two processes may be difficult. Dissolution of carbonates occurs above the groundwater table; therefore, there must have been a lowering of sea level prior to either karst development or the subsurface dissolution of the carbonates. Evaporites, however may be dissolved below the groundwater table by either normal marine or fresh waters. There is evidence that many of the solution breccias in the Madison Limestone are the result of the removal of evaporites. Surface exposures of solution breccias have been correlated with evaporite intervals in the subsurface in many areas (Andrichuk, 1955; Roberts, 1966).

Wanless, Belknap and Foster (1955) describe the top of the Madison Limestone as a paleo-karst surface in western Wyoming. The writer found no evidence of karsting on the

Milky stained quartz included pegmatites, rose quartz and highly weathered and pitted grains. No attempt was made to subdivide quartzite.

Standard mineralogical definitions were used for feldspar, magnetite, glauconite and muscovite mica.

"Soft sandstone and mudstone" was a disparate group. Most were poorly cemented and fine grained shales, mud chips, sandstone and stained weathered opaque minerals. Porous weathered orthoclase resisted washing, but broke down with slight pressure from a metal probe.

"Brunswick" mudstone was the common red mudstone of the Triassic Newark group.

The rock fragment group was used for less frequent constituents such as heavy minerals, conglomerates or grains weathered beyond recognition.

This classification was developed for use with the samples to include most of the grains observed. It might have been modified during the course of the study to more accurately represent the true groups present at this level of observation. However, it was not the objective to find the best classification for Roosevelt Park, but to test the method. This scheme accounts for the largest number of variables with a minimum of overlap. It was developed as a rapid and efficient way to survey the samples.

STATISTICAL ANALYSIS

Color Pairs

The color data derived from qualitative yes-no judgements, can be handled quantitatively by representing the sample pairs that appear to be similar as a percentage of the whole. Thirty-one hundred and sixty pairs of eighty samples were examined three times for similarity. A total of 2681 pairs or 84.9% were always found to be different. Another 250 were judged different on two out of three examinations and are also considered significantly different. This increased the number of pairs that could be told apart to 2931 or 92.8%. The remaining 229 sample pairs were considered to be similar in color because they were judged to be similar in at least two out of three runs. This is the portion of pairs that will be further differentiated by mineralogy.

Cluster Analysis

A cluster analysis of the eighty samples was used to place samples of similar mineralogy into groups using the data from Table 1.

This technique calculates the distance between each sample and every other sample on all the variables on which the sample is measured. Pairs of samples are joined which are the least distance apart. Clustering begins with each sample in its own cluster and ends with all the samples in one cluster. The computer output is in the form of a histogram or more commonly, the sample relationships are shown with a dendrogram (Figure 4).

An IBM 360/168 computer, available at Rutgers, performed a hierarchical cluster analysis based on an algorithm by Johnson (1967), using standard SAS76 programs (Barr et al., 1976). The Standard procedure in SAS76 first normalized the data so that the mean of all variables was set to zero, and a standard deviation of 1; a typical Z distribution.

Figure 4

Dendrogram from Cluster Analysis of Eighty Light Mineral Counts

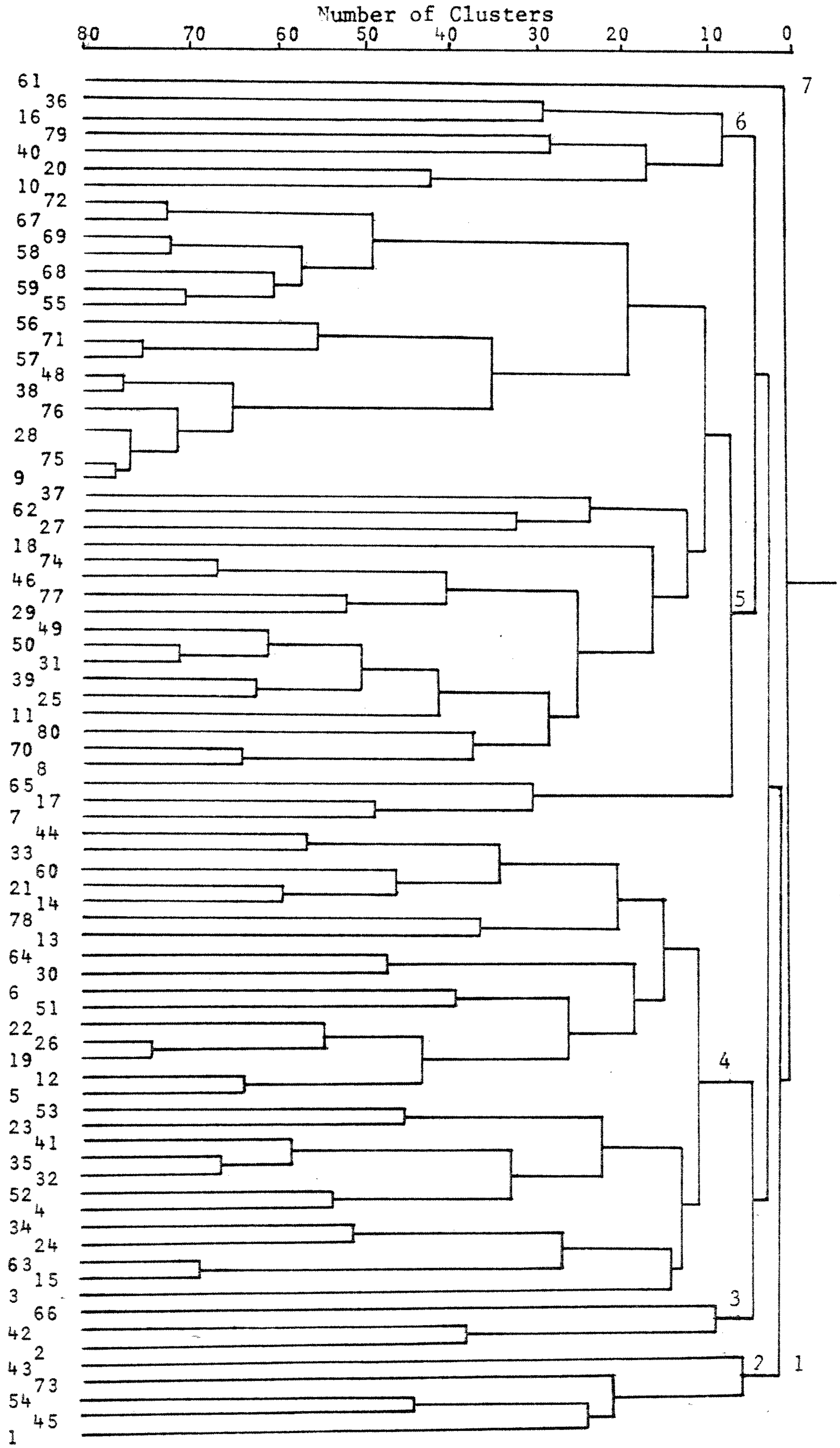


Figure 4 shows how the samples (labled on the left) were joined. Samples 9 and 75 were the least distance apart and are the first to join on the left. The last two samples, 61 and 36 (Sample 36 is part of a cluster of seventy-nine samples), are joined to the far right into one cluster.

Clusters can be chosen for any desired level of similarity or dissimilarity. The last seven clusters are labled from bottom to top. Light Mineral Cluster 6 contains Samples 10, 16, 20, 36, 40 and 79, and Light Mineral Cluster 7 contains only Sample 61. As the number of clusters increases, the number of samples per cluster decreases.

The choice of the number of clusters to use is subjective. The distance ratios: within cluster to between clusters, as part of the computer output, were a guide for choosing the most parsimonious number of clusters. Between four and ten clusters were indicated as being the best number of levels for breaking up the eighty samples. An intermediate level of seven clusters was first studied.

The objective for using clusters was to examine the effect of mineralogy for differentiating the 229 color pairs. Any two samples that were similar in color with a different mineralogy, i.e. in separate clusters, were considered different.

Table 2 contains the samples in Light Mineral Cluster 6. On the right are the respective color similarities (excluding those of Cluster 6) found when examined as a color pair. These eighteen color pairs are considered different because both samples of the pair are not in the same cluster. Similarities among members in the same cluster can not be differentiated this way. At this cluster level 71 of the 229 pairs can be discriminated by mineralogy.

Table 2. Differentiation of Color Pairs in Light Mineral Cluster 6.

Samples in Light Mineral Cluster 6	Samples Not in Light Mineral Cluster 6 Similar in Color
10	29,49,62,78
16	27,46,80
20	29,58,62,67,74,77,78
36	37,58
40	58,67
79	-

This procedure was also done at the level of 4, 10, 15, 20 and 30 clusters (Table 3) to explore the effect of cluster level on discrimination capability. At the level of thirty clusters, 83% of the color pairs could be told apart by mineralogy.

Table 3. Discrimination Capability of Various Cluster Levels

Cluster Level	Pairs Differentiated by Mineralogy	Total Pairs Similar in Color	Percent Discrimination
4	27	229	12
7	71	229	31
10	79	229	34
15	152	229	66
20	183	229	80
30	189	229	83

Cluster ratios indicate there are between four and ten significant mineral assemblages. At this level of similarity, a maximum of 34% of the color pairs can be discerned. This indicates that two out of three times a sample will have a color similar to mineralogy at the test site. The 79 more sample pairs that can be differentiated can be added to the 2931 pairs already differentiated for a total of 3010 or 95.3% of the samples using the methods of color and mineralogy.

Beyond the ten cluster level, cluster groupings are not justifiable according to computer analysis and are probably not geologically significant.

The Problem of Individuality

In order to discriminate all eighty samples and 229 color pairs, seventy-nine cluster levels must be introduced. The reason for this can be found by examining Samples 9 and 75 in Figure 4. These samples are the two most similar mineralogically and cannot be told apart by color. After finding other pairs of samples similar in color that also have very high levels of similarity in their light mineral proportions, an exploratory effort for discrimination with heavy minerals was made.

Heavy minerals from Samples 9, 28, 38, 47, 48, 75 and 76 were extracted by heavy liquid separation with Bromoform, density 2.87 gm/cc, (Carver, 1970, pp. 427-452) and slides were made with Lakeside #70 cement. These samples are a subset of Cluster 5 (Figure 4) and remain grouped together up to the thirty-six cluster level.

Three hundred heavy mineral grains were counted by ribbon method (Carver, p. 391) using a mechanical stage on a polarizing microscope.

The results are tabulated in Table 4. With the exceptions that follow, most of these grains have characteristics that have been documented by Kerr (1959).

Most of the black opaques were either magnetite or ilmenite, and the white opaques were leucoxene, a weathering product of ilmenite. Hematite, limonite and thick grains of rutile were classified as red opaques.

Figure 5 is a cluster analysis of heavy mineral data. Three clusters are probably significant. At this level, Sample 75 in Heavy Mineral Cluster 1, Sample 47 falls into Cluster 2 and the rest are labled Cluster 3.

Table 5 presents the seven test heavy mineral samples in their respective clusters and the color similarities to each sample. As before, where both members of a color pair were not in the same cluster, the samples were considered different. Since Heavy Mineral Clusters 1 and 2 have only one member each, the samples judged to be similar in color, cannot be in the same respective heavy mineral cluster and are automatically different. Also note that Sample 66 was not previously a part of Light Mineral Cluster 5 and is automatically different from the rest. Out of the fourteen color pairs found among these samples, eight of the pairs do not fall into the same cluster and are considered different.

Table 4. Percent Heavy Minerals

Sample	9	28	38	47	48	75	76
Isotropic	1	1	1	1	T	2	T
Tourmaline							
brown	1	1	T	3	1	T	2
blue	1	2	3	3	2	T	2
Andalusite	0	T	0	T	0	T	T
Kyanite	T	0	T	0	T	2	1
Staurolite	0	0	1	T	T	1	T
Epidote	1	1	1	3	1	1	1
Zircon	6	4	3	2	1	1	2
Hypersthene	1	1	1	2	1	3	2
Opaque							
black	51	45	56	46	51	12	33
red-brown	21	22	13	7	20	36	27
white	9	8	12	14	9	15	14
Zoisite	1	1	0	1	1	2	1
Tremolite	0	T	T	0	1	2	1
Hornblende	5	5	4	4	3	9	7
Augite	1	T	3	8	1	2	1
Brookite	0	3	1	2	5	1	3
Unknown	2	5	2	2	4	9	4

T = trace, less than 0.5%

Figure 5

Dendrogram from Cluster Analysis of Seven Heavy Mineral Counts

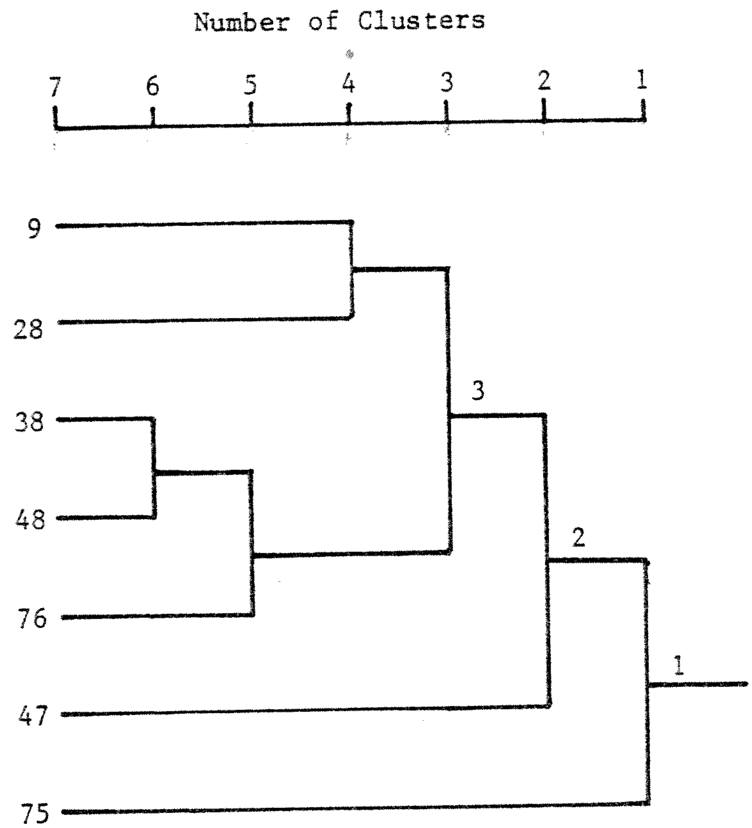


Table 5. Differentiation of Color Pairs by Heavy Minerals

Heavy Mineral Cluster	Sample	Samples Similar in Color
1	75	-
2	47	66,75,76
3	9	28,38,47,76
	28	38,47,66,76
	38	47,75,76
	48	-
	76	-

CONCLUSIONS

1. The color data provided discrimination capability of 92.8% of the samples.
2. The mineralogy data in combination with color, slightly increases discernment to 95.3%.
3. A heavy mineral analysis also appears to be useful for differentiating soil samples that cannot be told apart by color and light mineralogy.
4. The three discrimination methods used here were not sufficient to uniquely identify all eighty samples.

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