SOIL ANALYSIS BY TRISTIMULUS COLOR AND STATISTICAL EVALUATIONS FOR FORENSIC PURPOSES

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ABSTRACT OF THE THESIS

Soil Analysis by Tristimulus Color
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A spectrophotometric procedure is suggested for the routine measurement of dry soil color. An objective procedure is described for recording the tristimulus values. A quantitative color population study has been carried out to establish what type of variations can be expected in several geological provenances and to test whether or not a continuum does exist within sample locations. Continua were found to exist in sample areas and statistical analysis of the tristimulus values allowed assigning confidence to the soils derivation. Statistical soil color data obtained through the spectrophotometric procedure have been used to numerically evaluate a suspect area's level of color homogeneity.

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INTRODUCTION

The first analysis of most forensic scientists, after obtaining soils for examination, is to dry the sample and compare colors of the suspect and control samples directly. If in the initial examination the colors are indistinguishable, then more elaborate techniques are utilized. These involve among other procedures, recording wet and dry colors (Pendleton and Nickerson, 1951) and wet, dry and ashed colors (Dudley, 1975). These color procedures use Munsell Soil Color Charts to record color values. These procedures for color analysis are not truely quantitative as the derived data are not produced using objective techniques. Samples can not be reconstituted because of either sample preparation or sample destruction during analysis. If, on the other hand, the soils do not compare on the first examination, no further testing is pursued even though the possibility exists that the soil came from within the suspect area.

Soil color would be a more valuable piece of evidence if after objectively recording the necessary parameters, a technique were available to assign a soil to a given area and place a level of confidence on the selection. If, in fact, soil colors vary continuously as suggested by Dudley (1975), and if a quantitative analysis can be made, then the data obtained can be statistically analyzed using non-probabilistic (Thornton, 1975) and probabilistic (Parker, 1967) approaches.

METHODOLOGY

Though there are many instruments available for the evaluation of color, a spectrophotometer with an integrating sphere was selected as standards are available either commercially or through the National Bureau of Standards which allow checking the instrument on a day to day basis for reproducibility. The data obtained from the spectrophotometer then are absolute and can be converted mathematically into any standard color coordinate system. The data obtained during this study are recorded as tristimulus values, or X, Y and Z as defined by the International Commission on Illumination (C.I.E., 1931; Judd, 1950).

Samples were obtained from twenty-three areas taking the top six millimeters of a 625 centimeter square area. Sample coring was eliminated as a method as there was excessive variation of color with depth. The samples were dried in sealed kraft sacks at room temperature in a forced air environment. Oven drying at 105°C in forensic investigations should be avoided as some minerals irreversibly dehydrate at temperatures in excess of 60°C (Jackson, 1969) thereby altering the light scattering properties of the minerals.

Sample homogeneity was obtained by using the fraction that passed through a 325 mesh screen. A 200 milligram fraction was slurried in 15 milliliters of water and vacuum filtered through a glass fiber filter. The filter cake thus obtained was dried in a forced draft oven at 30°C and stored in sealed glassine envelopes. The samples prepared in this fashion are sufficiently stable so that ten to twenty replicate analyses can be made without disrupting the surface and yet, if necessary, the total fraction could be removed simply by back washing the filter paper.

Samples were compared to Eastman(R) White Reflectance Standard #6091 (refined barium sulfate) after calibration with NBS Color Chip B-36. The reflectance curves were recorded and the tristimulus values were calculated using the selected 30 ordinate method.

GEOLOGY

Six geological provenances were selected to establish what variations existed in soil colors among provenances and especially between provenances that have similar mineralogy.

Two provenances were selected because they represent slaty shale members. One was the Brunswick Formation (Triassic). The soils developing over the sample locations were shallow and the organic matter was low. In general, they are composed mainly of quartz, both sodic and potastic feldspars and clay minerals. The major clay mineral is illite (Sturm, 1956) and the prime pigmenting material is hematite. Other minerals normally associated with the Brunswick are barite, calcite, gypsum and a family of clay minerals such as kaolinite, montmorillonite and chlorite (Van Houten, 1969). All soils collected over the Brunswick Formation contained fragments of shale aggregates.

The other slaty shale member investigated was the Martinsburg Formation (Ordivician). The areas investigated in general had less than 0.5 meter of soil development. Once again the major mineral is quartz. Here the feldspars are primarily potastic. The major clay minerals are 2M muscovite and chlorite. Though energy dispersive x-ray analysis showed that iron was present in approximately the same ratios as the Brunswick, hematite is noticeably absent. The major color and staining materials in the Martinsburg are organic in nature.

Two limestone areas (dolomitic) namely the Jacksonburg and the Kittatinny Formations were sampled. The soils developing here were once again shallow. In addition to quartz and feldspars, dolomite was present in varying amounts. Grains of garnet, epidote and pyroxenes were found. These were present due to either mechanical or glacial transport.

The last areas examined represent soils developing over glacial till and quaternary alluvium. These soils in general are sandy in nature and low in clay minerals. Area U soils are made up of quaternary alluvium deposits. The samples were obtained from a wild life preserve at Little Neck Point, Virginia Beach, Virginia. Figure 1 shows the location of sample areas in New Jersey.

Sample areas can be classified into three categories namely altered homogenized, altered and unaltered. The areas considered altered homogenized were those that had been used strictly for farming purposes over the past ten years and were currently being tilled twice a year. Those that had been mechanically disturbed or had material mechanically transported into an area are considered to be altered. All other areas are considered unaltered.

Several different sized grids were used in an attempt to establish the number of samples required to describe an area and to ascertain the amount of variation one can expect in small areas. Table 1 summarizes sampling procedures and types of soil sampled.

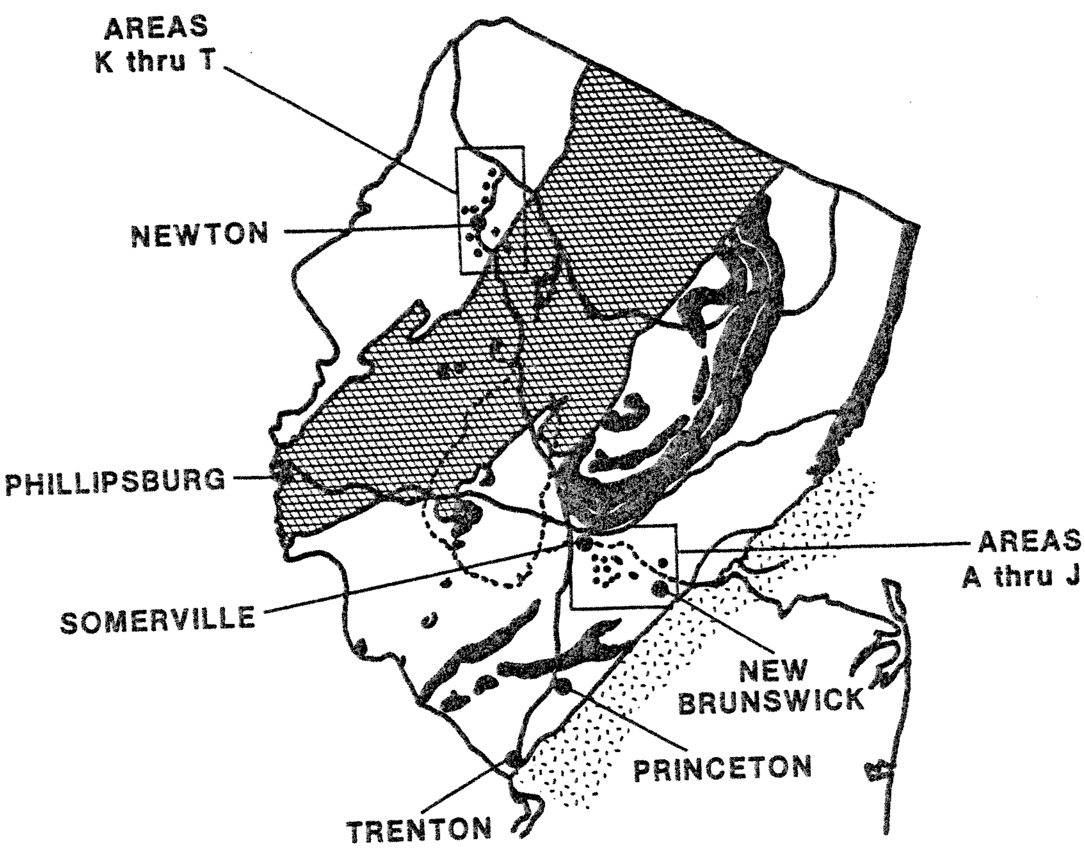


FIGURE I
SAMPLE AREAS
of
NEW JERSEY

TABLE I

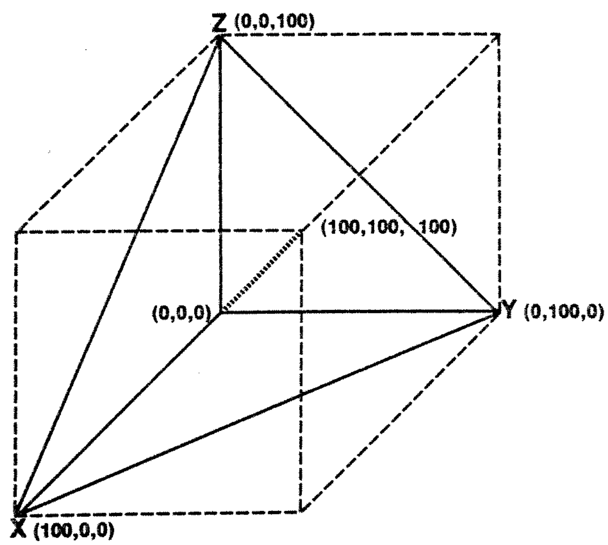
SAMPLING CONDITIONS AND SOIL TYPES

AREA	FORMATION	NO. OF SAMPLES	PATTERN OF SAMPLING	SPACING	AREA TYPE
A	BRUNSWICK	9	SQUARE	1 METER	UNALTERED
B	BRUNSWICK	9	SQUARE	1 METER	HOMO
C	BRUNSWICK	9	SQUARE	1 METER	ALTERED
D	BRUNSWICK	9	SQUARE	1 METER	ALTERED
E	BRUNSWICK	9	SQUARE	1 METER	UNALTERED
F	BRUNSWICK	9	SQUARE	1 METER	ALTERED
G	BRUNSWICK	9	SQUARE	1 METER	HOMO
H	BRUNSWICK	9	SQUARE	1 METER	HOMO
I	BRUNSWICK	100	SQUARE	3 METERS	ALTERED
J_1	BRUNSWICK	6	LINEAR	30 METERS	HOMO
J_2	BRUNSWICK	12	LINEAR	3 METERS	UNALTERED
J_3	BRUNSWICK	6	LINEAR	30 METERS	ALTERED
K	MARTINSBURG	5	SQUARE	1 METER	ALTERED
L	MARTINSBURG	5	SQUARE	1 METER	UNALTERED
M	MARTINSBURG	5	SQUARE	1 METER	HOMO
N	KITTATINNY	5	SQUARE	1 METER	ALTERED
O	MARTINSBURG	5	SQUARE	1 METER	ALTERED
P	JACKSONBURG	5	SQUARE	1 METER	ALTERED
Q	KITTATINNY	5	SQUARE	1 METER	ALTERED
R	GLACIAL DRIFT	5	SQUARE	1 METER	HOMO
S	GLACIAL DRIFT	5	SQUARE	1 METER	ALTERED
T	JACKSONBURG	100	SQUARE	3 METERS	HOMO
U	QUAT. ALLUVIUM	17	LINEAR	3 METERS	ALTERED

TRISTIMULUS COLOR SPACE

The Tristimulus Coordinate System (30 selected ordinate computation method) was used in this investigation. This coordinate system can be visualized as a cube with the origin or black being in one corner (0,0,0) and white (100,100,100) being in the diagonally opposite corner. See Figure 2. The diagonal derived by drawing a line between the above coordinates represents a gray scale which would be equivalent to Munsell Value. The X, Y and Z axes represent respectively, color saturation of the primary colors in this system namely red, yellow, and blue. These axes relate to Munsell Chroma.

FIGURE 2
TRISTIMULUS COLOR SPACE



A plane made by connecting the points (100,0,0), (0,100,0) and (0,0,100) contains all the values of Munsell Hue. The model presented here is for use with instruments utilizing tungsten lamps as a light source. Correcting this model to a standard light source, Illuminant C (C.I.E., 1931) changes the cube to a rectangular solid with the white coordinates being (99.06,100.00,118.14). The new solid contains all of the possible colors both real and imaginary. If only real colors are considered then the rectangular solid model becomes an ellipsoidal model.

REPRODUCIBILITY STUDIES

NBS Color Chip B-36 was used to check the instruments day to day drift. The long term drift was found to be ± 0.1 reflectance units for each of the tristimulus values. Variations in sample preparation were determined by running ten replications of sample I-1 and it was determined that errors caused by sample preparation were so small as to be within the instruments limitations, that is ± 0.1 reflectance units. The data are summarized in Table 2.

TABLE II

EXPERIMENTAL ACCURACY

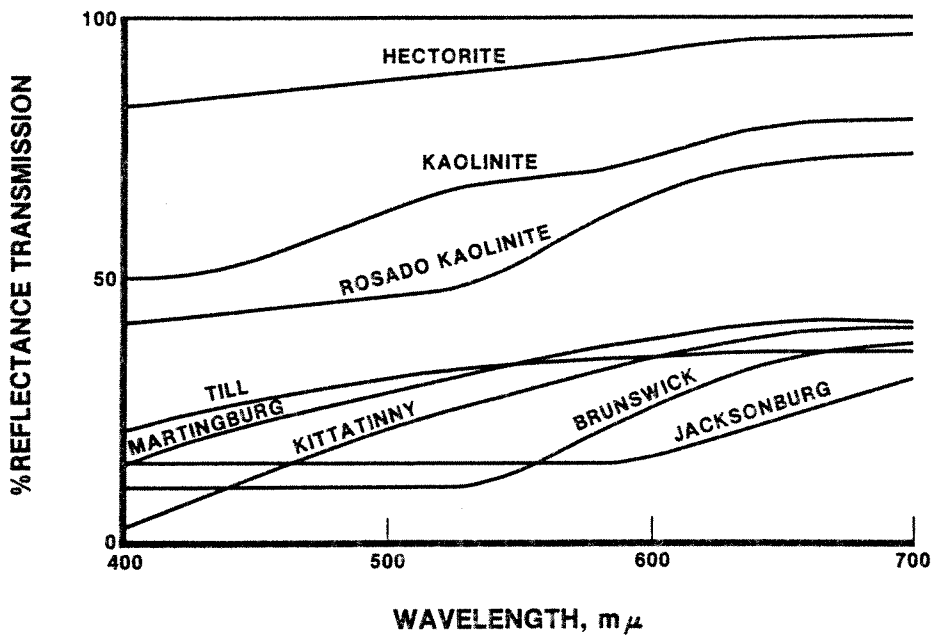
SAMPLE	*TRISTIMULUS COORDINATES* X	Y	Z	*ANALYZED BY*
B-36	26.52	20.02	10.04	NBS
B-36	26.57±.1	20.09±.1	10.08±.1	SPECTRONIC 505
I-1	20.23±.1	17.99±.1	11.78±.1	SPECTRONIC 505

The small differences in the NBS values and the spectrophotometers values are due to differences in instrumentation. The spectrophotometer used in this investigation was a pen recording instrument and calculations were made manually. The values determined by the NBS for Chip B-36 were derived from computer based instruments where 300 points are sampled for computation thereby avoiding any errors by slow pen response.

SPECTRAL RESPONSE OF SOILS

Typical soil reflectance curves for the various provenances are shown in Figure 3. The reflectance curve at the top of Figure 3 (100% reflectance transmission) represents the curve for the white reflectance standard (barium sulfate). The darkest soils, in general, were those taken from the Brunswick Formation. They contain many fines which in turn increase the light scattering capabilities of the sample. The red hemitite staining found in these samples is indicated by the abrupt change in slope near 540 millimicrons. The various

FIGURE 3
SOIL SPECTRAL RESPONSE



shades of brown are indicated by changes in slope of the reflectance curves. It should be noted that the soils developing over the Jacksonburg tend to be grayer than the other soils. This is shown as a nearly horizontal curve over the range of 400 to 640 millimicrons.

The soils derived from glacial till and quaternary alluvium tend to be lighter than the other soils due to the small amounts of organic and mineral staining. Reflectance curves of two kaolinites and an unprocessed hectorite have been added to the figure as a point of reference to show the wide range of soil colors,

TRISTIMULUS DATA AND HOMOGENEITY FACTORS

Means of the tristimulus values along with their standard deviations were determined for all areas. The data are summarized in Table 3. The tabulated data for all samples are shown in Appendix A. The means of an areas tristimulus values can be considered to be the coordinates of the center of a statistical hypervolume that exists in tristimulus color space and the standard deviations then define the specific volume of the hypervolume. If one standard deviation is used to describe the hypervolume, then the majority of the areas can be considered unique. The data show that the samples from the Brunswick Formation are contained in one super hypervolume and that they are isolated from all other provenances. The other provenances can be considered to exist in another supervolume in tristimulus space as there is some overlapping of the Kittatinny area Q, the glacial drift area R and the Jacksonburg area T. In using one sigma to define the volume, the volumes are limited in that only 65% of all the data points are contained within some volume. It is then reasonable to increase the statistical hypervolume to two sigma, thereby enclosing 95% of all the data points in some volume.

In general, it was found that those areas with large standard deviations were those areas that were previously classified as altered and those with small standard deviations were those that were considered altered homogenized. Normalizing the statistical hypervolume for the number of samples examined gives a "homogeneity factor" that can be used to determine what type of area the soil came from. In this classification, homogeneity factors ranging from .000 to .025 would

TABLE III

MEAN & STANDARD DEVIATIONS OF TRISTIMULUS VALUES

AREA	MEAN			STANDARD DEVIATION					
	X	Y	Z	XX	XY	XZ	YY	YZ	ZZ
A	19.41	16.87	10.87	.56	.51	.28	.50	.16	.82
B	21.58	20.07	13.25	.68	.51	.44	.46	.39	.38
C	21.67	20.45	13.67	1.51	1.47	1.21	1.44	1.19	1.01
D	22.30	20.35	13.19	1.42	1.38	.98	1.37	.97	.74
E	22.21	19.48	12.94	.79	.80	.43	.92	.38	.37
F	20.57	18.43	12.14	1.02	.87	.68	.80	.64	.76
G	25.64	23.97	17.03	.66	.61	.59	.59	.57	.57
H	18.74	16.62	11.35	.62	.52	.53	.50	.52	.65
I	15.21	14.00	8.65	2.01	1.92	1.66	1.85	1.60	1.44
J_1	19.66	17.63	12.29	.40	.40	.33	.45	.44	.52
J_2	23.87	21.94	14.50	.81	.81	.75	.82	.73	.92
J_3	21.85	19.90	14.17	1.37	1.38	1.00	1.40	1.08	1.20
K	31.17	31.23	22.86	2.47	2.49	.50	2.51	.50	1.42
L	27.07	26.93	19.98	.74	.75	.67	.75	.68	.63
M	29.81	29.34	20.26	.46	.41	.54	.40	.47	.67
N	31.89	32.66	31.62	1.24	1.27	1.58	1.30	1.63	2.32
O	17.70	17.50	11.96	.94	.93	.81	.92	.81	.85
P	24.58	24.70	20.32	2.07	2.06	1.16	2.06	1.15	.75
Q	27.68	27.40	19.16	1.08	1.15	1.28	1.23	1.36	1.52
R	28.43	28.01	18.91	.47	.48	.30	.50	.34	.45
S	33.20	32.95	23.23	1.44	1.48	1.49	1.52	1.55	1.60
T	25.02	24.50	16.11	1.21	1.19	.96	1.19	.97	1.09
U	26.58	26.54	21.72	3.99	3.99	3.11	4.00	3.11	3.72

be considered altered homogenized. Factors between .025 and .052 would be considered unaltered whereas factors greater than .053 are considered altered. Using this procedure and applying it to the 23 areas investigated, only one area was misclassified, namely, Martinsburg area L. The data indicating area soil type, type of sample area and homogeneity factor are summarized in Table 4.

TABLE IV
HOMOGENEITY FACTORS

AREA	AREA TYPE	AREA DESCRIPTION	FACTOR
A	UNALTERED	FALLOW FIELD	.026
B	HOMO	FARM	.013
C	ALTERED	ROADSIDE	.244
D	ALTERED	RESEEDED LAND	.160
E	UNALTERED	FALLOW FIELD	.030
F	ALTERED	ROADSIDE	.069
G	HOMO	FARM	.025
H	HOMO	FARM	.022
I	ALTERED	RAZED LAND	.054
J_1	HOMO	PLOWED AREA	.016
J_2	UNALTERED	FALLOW FIELD	.051
J_3	ALTERED	ROADSIDE	.384
K	ALTERED	DRIVEWAY	1.761
L	UNALTERED	FALLOW FIELD	.065
M	HOMO	FARM	.022
N	ALTERED	EXCAVATION	.748
O	ALTERED	EXCAVATION	.147
P	ALTERED	ROADSIDE	.640
Q	ALTERED	DRIVEWAY	.404
R	HOMO	FARM	.021
S	ALTERED	ROADSIDE	.700
T	HOMO	FARM	.016
U	ALTERED	ROADSIDE	3.49

VARIATIONS IN SOIL COLOR

Color variation in various locations was determined by contouring. Several procedures are available for value contouring (I.B.M., 1965; Walters, 1969), but a simplified grid program (Davis, 1973) was used in this investigation. The total tristimulus value of each grid point was used to value contour each area. The number of colors in each area was estimated from the contour intervals and the instruments precision. Table 5 summarizes the computer estimates for each area.

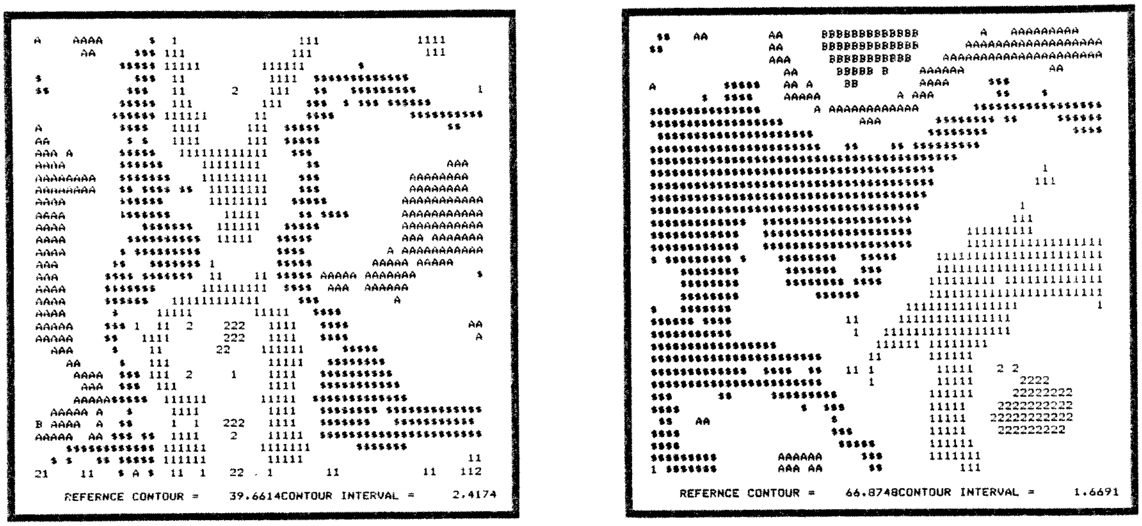
TABLE V
COMPUTER ESTIMATES

AREA	NO. OF SAMPLES TAKEN	COMPUTER ESTIMATE OF THE NO. OF COLORS
A	9	5
B	9	6
C	9	18
D	9	17
E	9	9
F	9	12
G	9	8
H	9	8
I	100	36
J_1	6	5
J_2	12	11
J_3	6	15
K	5	27
L	5	7
M	5	6
N	5	19
O	5	9
P	5	23
Q	5	14
R	5	5
S	5	15
T	100	19
U	17	72

As can be seen from the data, as many as 27 colors can be expected to be found even in areas as small as four square meters. This data indicates that only five samples can be taken in very homogeneous areas. Nine samples can be taken from both altered homogeneous and unaltered areas. In general, a minimum of 30 samples should be evaluated when analyzing an area for color to insure proper definition of the statistical hypervolume. This is further emphasized by value contouring, as the maps generated only using five data points appeared to be random in nature. Value contour maps for all areas are shown in Appendix B. Order increases with nine samples though randomness still appears in areas with large homogeneity factors. When the number of data points used in value contouring are increased to 30 or more, the maps appear to have increased order. If a color continuum does exist as suggested by Dudley (1975), then the value contours should be able to be related to some natural phenomena such as topography. It is reasonable to assume that a color continuum can exist as other continua do exist in nature such as the down stream sorting and rounding of grains. Value contours for areas I and T are shown in Figure 4. The $ contour represents the reference contour. The alphamerics represent areas of decreasing or lightening of color and the numerics represent areas of increasing or darkening of color.

Area I was an area in the Brunswick where buildings had been razed and the top soil had been lightly scoured to remove accumulated debris. The aplhameric areas were once covered by homes and the numeric contours represent areas of heavy vegetation such as garden plots. In the case of area T, the soil is very homogeneous and the contours follow

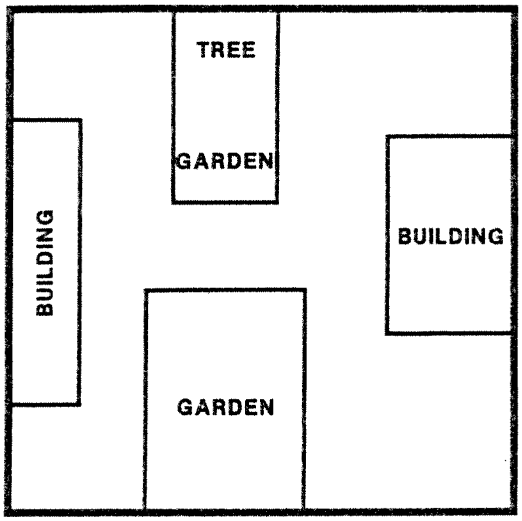
FIGURE 4
VALUE CONTOURS



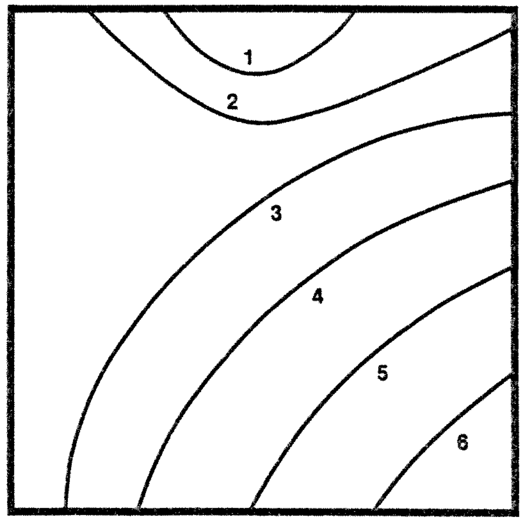
AREA I ***AREA T***

changes in elevation. Here the alphamerics indicate areas of lower elevation and a concentrating of clay minerals. Figure 5 shows landscape and topographic maps of areas I and T respectively. As the value contour maps can be related to recent geological history or topography, it may be assumed that a color contimuum does exist.

FIGURE 5
AREA MAPS



AREA I
PREVIOUS LANDSCAPING



AREA T
RELATIVE TOPOGRAPHY

CLUSTER ANALYSIS

As color continua do exist in the sample areas under investigation, then it is possible to assign an unknown sample to a statistical hypervolume even though a perfect match for the unknow does not exist. Using only three variables, a dual statistical approach must be used if a single sample soil color is to be assigned to one of several suspect areas. In this case, the total assemblage of twenty-three areas will be used. The first attempt will be to rank the suspect unknowns with other areas that have similar color coordinates. This can be accomplished using a non-probabilistic approach suggested by Thornton (1975). This approach of cluster analysis is not new and has been extensively discussed by Tryon and Bailey (1970) and Sokal and Sneath (1963). The essential features of the cluster analysis used in this analysis are:

1. The correlation coefficient is used as a similarity measure.
2. Highest similarities are clustered or linked first.
3. Two objects can be connected only if they have mutually highest correlations with each other.
4. After two objects are clustered, their correlations with all other objects are averaged.

The computer software used in this analysis was written by Davis (1973). Though many similarity measures have been proposed, only the correlation coefficient was used in ranking the suspect samples with one or more of the areas. The variables are the tristimulus values X, Y and Z and the data are entered as the means of these values. The three suspect samples were selected such that the sample X_1 was within the one sigma hypervolume of area B, sample X_2 at the surface of the one sigma hypervolume and sample X_3 at the surface of the two sigma hypervolume. Cluster analysis data are summarized in Figure 6.

FIGURE 6
CLUSTER ANALYSIS

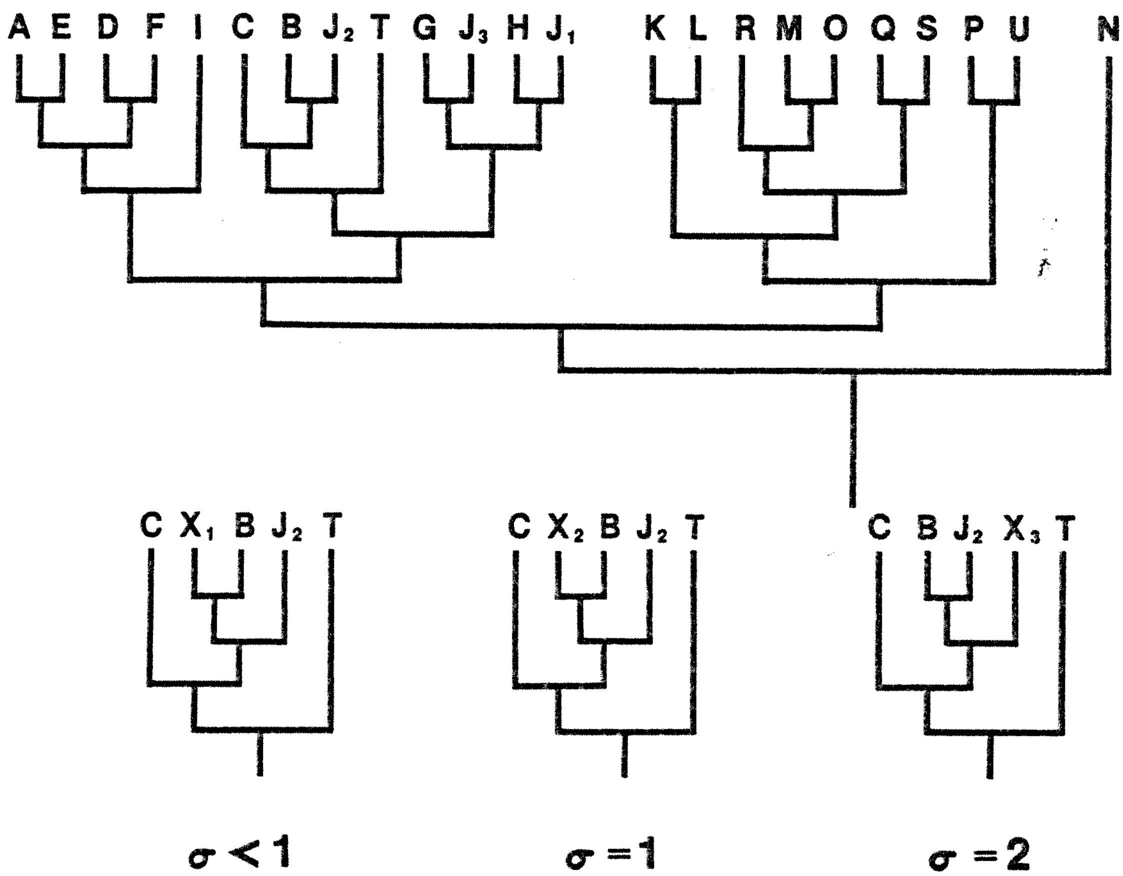


Figure 6 shows that the unknown samples are ranked in the proper area until two sigma values are reached. At this point X_3 can possibly exist in either areas B or J_2. As the mean values for each of the areas were used to obtain the ranking, a probability should not be assigned at this time. If the standard deviations were identical then similarity assignments could be made.

DISCRIMINANT ANALYSIS

The next procedure used, once a multiple ranking has been established, is discriminant analysis. Parker (1967) proposed a model from discriminant analysis for use in forensic investigations. The simplified model was extremely limited as it assumed the standard deviations for all areas was identical and that the statistical hypervolume was spherical rather than ellipsoidal. Kendall (1961) developed the theory of discriminant analysis for when more than two populations exist. The computerized discriminant analysis used in this investigation was written by Aharonian and Little (1973) and was modeled after Kendall's theory.

Using discriminant analysis, areas A and B and area K and P were analyzed to establish if data points from one area would be associated with the other. In both cases the analysis ranked each area unique. When areas B, C and J_2 were tested, areas B and C were linked as were areas B and J_2 by one data point. The single test data points used in the above cluster analysis were used in the discriminant analysis. The data showed that the associated probability of point X_1 existing in area B was 0.719. Test sample X_2 gave the same ranking but the associated probability dropped to 0.630. A joint ranking between areas B and J_2 was found when test sample X_3 was evaluated. The data are summarized in Table 6. A test point midway between the mean tristimulus values for areas A and B was evaluated. The associated probability was zero as anticipated.

TABLE VI

ASSOCIATED PROBABILITY AS DETERMINED BY DISCRIMINANT ANALYSIS

SAMPLE	AREA B	AREA C	AREA J_2
X_1	.719	.000	.000
X_2	.630	.000	.000
X_3	.492	.000	.592

Using the two statistical approaches, a soil sample may be linked to an area and its probability of existance within that area can now be assigned. As shown above, a ranking may be in error if two hypervolumes overlap, but errors of this nature can normally be eliminated with additional anlayses. In the above case, the error would have been eliminated by the use of optical microscopy as there was a significant difference in the particle size distribution. See Appendix C.

To date, statistical models have not been developed to place a single suspect soil into only one investigated area. Remembering that other statistical hypervolumes may exist that are identical to the one under investigation, there are two approaches that may be used with caution. The first approach would be to divide the area under investigation in half if sufficient data points have been accumulated and use discriminant analysis. The second approach would be to make an assignment of probability based on the nearness of the suspect data point to the investigated area's mean tristimulus values. In the above case the probability of the sample X_1, X_2 and X_3 being assigned to area B would be 0.89, 0.33 and 0.11 respectively.

As the sample preparation forms a homogeneous surface, several other methods of analysis can be performed using the same sample. Some of these are x-ray diffraction, bulk x-ray analysis, and scanning electron microscopy. If conclusive data is not derived from the above non-destructive analyses, then back washing the sample is justified. Optical microscopy should be the first investigative tool used after back washing, as this analysis is non-destructive and the sample can still be reconstituted for referee analysis.

CONCLUSION

In conclusion, an objective, non-destructive procedure has been developed for the evaluation of soil color. The statistical data derived from the tristimulus values have been used to:

1. Evaluate color differences between geological provenances.
2. Check on sample area's color variability.
3. Assign values to sample area's homogeneity.
4. Establish that color continua do exist in nature.

The color data substantiates the existance of color continua so that one can use a dual statistical approach to place an unmatched suspect sample into an investigated area and to assign a level of confidence on the selection.

As color continua do exist and the basic soil color is derived from the bedrock, it is conceivable that discontinuities hidden below the soil horizons could be detected by value contouring in homogeneous areas.

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Appendix A

Mean Tristimulus Values

for All Areas

LEGEND

X VALUE	MEAN TRISTIMULUS
Y VALUE	VALUES FØR
Z VALUE	INDIVIDUAL SAMPLES

AREA

18.7	19.1	19.0		22.0	21.2	21.6
16.4	16.7	16.7		20.2	19.8	20.1
10.5	10.3	12.9		13.3	13.2	13.5
19.5	19.9	19.1		22.2	20.4	20.7
17.0	17.3	16.7		20.4	19.9	19.1
10.3	11.0	10.7		13.3	12.9	12.6
20.3	20.0	19.1		21.9	21.9	22.5
17.7	17.4	16.7		20.2	20.1	20.8
10.4	11.1	10.7		13.5	13.0	13.9
	A				B	

21.7	20.9	22.9		20.8	22.0	22.2
20.4	19.7	21.7		18.9	19.9	20.2
13.5	13.5	14.6		12.5	13.1	13.3
21.6	21.9	23.9		22.7	25.1	23.3
20.4	20.6	22.6		20.6	22.0	22.0
14.0	13.3	15.0		13.6	14.0	14.0
19.2	19.9	23.0		20.3	23.0	21.4
18.3	18.6	21.8		18.5	21.0	19.4
12.1	12.4	14.8		12.0	14.0	12.4
	C				D	

22.5	21.3	22.0
19.7	19.0	19.2
13.0	12.6	13.0
22.5	23.5	22.7
17.0	21.2	20.0
13.0	13.0	13.4
22.2	21.0	22.3
20.0	18.0	19.5
13.2	12.2	13.2

E

19.4	20.4	20.4
18.2	18.3	18.1
12.0	12.3	12.3
20.1	20.0	22.0
18.0	17.6	19.4
12.4	12.0	13.0
19.4	22.0	21.6
17.3	19.6	19.1
10.8	13.3	11.3

F

25.7	25.0	24.6
24.0	23.4	23.0
17.0	16.2	16.3
25.7	26.4	25.0
24.0	24.8	23.6
17.0	17.7	16.7
26.2	26.2	25.6
24.5	24.5	23.9
17.6	17.7	16.9

G

19.2	19.8	19.3
17.1	17.4	17.1
11.7	12.0	12.0
18.8	18.0	18.5
16.5	16.6	16.4
11.4	11.4	11.6
18.7	18.1	18.2
16.3	16.0	16.1
11.0	9.9	11.1

H

16.9	17.7	16.7	11.8	13.0	12.5	14.4	14.6	13.6	14.6
15.5	16.4	15.3	10.9	11.7	11.0	13.2	13.2	12.4	13.3
9.9	10.8	10.2	6.9	6.6	6.4	8.2	7.9	7.3	8.2
14.9	16.3	16.1	13.1	11.7	13.7	16.6	16.0	14.4	13.1
13.6	14.9	14.8	11.9	10.7	12.6	15.3	14.4	13.2	12.1
8.4	9.4	8.0	6.9	6.0	7.7	9.5	8.9	7.7	7.8
17.4	15.7	16.4	13.2	12.6	15.5	16.4	16.6	16.6	16.8
16.0	14.4	14.8	12.0	11.6	14.2	14.8	15.3	15.4	16.6
10.3	9.2	9.1	6.9	7.2	8.7	9.5	9.6	9.6	9.8
17.4	18.2	14.6	15.9	12.9	14.2	16.4	16.3	17.2	16.0
16.0	16.7	13.3	14.4	11.7	13.1	15.1	15.0	15.8	14.7
10.2	10.6	7.7	8.1	6.9	8.2	9.6	9.5	10.2	9.7
17.3	15.5	16.1	15.3	12.7	15.9	15.6	15.7	18.0	17.9
15.8	14.2	14.7	14.0	11.4	14.6	14.4	14.5	16.7	16.5
10.2	9.1	9.4	8.8	7.2	8.7	9.2	9.5	11.2	10.8
17.5	16.1	16.1	15.5	14.4	15.2	18.1	17.1	16.7	14.8
15.9	14.8	14.8	14.3	13.3	14.0	16.8	15.9	15.6	13.7
10.6	9.4	9.5	8.9	8.3	8.3	10.8	10.5	9.0	8.8
17.6	16.7	13.2	11.6	10.2	13.4	14.7	16.4	16.6	17.2
16.3	15.4	12.1	10.6	10.4	12.5	13.6	15.1	15.3	16.0
9.3	9.7	7.7	6.7	5.6	6.0	8.4	9.6	9.0	10.6
18.6	17.4	15.6	11.4	13.8	13.5	15.7	15.6	16.4	17.0
17.0	15.8	14.4	10.5	12.7	12.4	14.4	14.4	15.2	15.6
11.0	10.3	8.8	6.5	7.5	7.6	8.8	8.6	9.0	9.3
20.2	19.0	13.8	14.8	10.7	13.7	15.4	16.2	14.9	16.4
18.4	17.4	12.8	13.7	10.0	12.6	14.3	14.9	14.7	15.0
12.0	11.2	7.2	8.7	6.0	7.9	9.3	9.9	8.6	10.0
11.3	12.1	17.2	12.7	11.5	14.6	13.8	15.5	13.7	12.6
10.4	11.2	16.0	12.0	10.6	13.5	13.0	13.8	12.5	11.0
6.3	7.2	10.8	6.7	5.7	8.9	6.8	7.9	7.5	6.4

	31.1	
	31.2	
	24.3	
29.6	28.6	35.0
29.6	28.6	35.1
22.0	21.7	27.3
	31.6	
	31.6	
	24.5	

K

	27.7	
	27.6	
	20.6	
26.0	26.7	27.7
25.8	26.5	27.5
19.2	19.4	20.4
	27.4	
	27.2	
	20.3	

L

	29.1	
	28.9	
	19.0	
29.5	30.3	29.8
29.0	29.9	29.1
20.1	21.0	20.4
	30.4	
	29.9	
	20.8	

M

	32.0	
	32.7	
	30.2	
31.7	32.0	33.6
32.5	32.9	34.4
33.0	32.2	34.4
	30.1	
	30.7	
	28.5	

N

	17.4	
	17.2	
	11.8	
16.8	17.9	19.2
16.6	17.7	19.0
11.5	12.2	12.9
	17.2	
	17.0	
	10.9	

O

	27.7	
	27.8	
	21.6	
22.0	24.4	25.0
22.1	24.6	25.1
18.0	19.9	20.5
	23.9	
	23.9	
	19.8	

P

	28.6	
	28.4	
	20.3	
28.8	27.1	27.8
28.7	26.7	27.5
20.8	18.2	19.3
	26.2	
	25.7	
	17.1	

Q

	34.5	
	34.1	
	24.1	
35.1	32.3	32.3
35.0	31.9	31.9
25.6	23.0	22.3
	32.0	
	31.8	
	22.2	

R

	28.9	
	28.0	
	21.6	
28.5	28.2	29.2
28.0	27.8	28.8
18.7	18.8	19.2
	28.3	
	28.0	
	19.5	

S

25.0	26.8	25.5	27.2	28.1	28.5	26.6	26.8	26.4	26.8
24.5	26.2	25.1	26.6	27.5	28.0	26.1	26.4	26.1	26.4
15.3	16.5	16.4	17.7	18.1	17.1	17.8	18.2	17.9	18.3
26.6	25.9	25.4	27.6	27.7	27.3	26.0	25.1	25.9	25.6
25.9	25.2	24.7	26.7	27.2	26.8	25.5	24.6	25.5	25.3
16.7	16.4	16.0	17.3	18.2	18.0	17.1	16.5	17.5	17.4
24.8	25.1	25.3	25.3	25.6	25.7	24.8	24.4	24.1	25.0
24.2	24.5	24.6	24.8	25.1	25.2	24.3	23.9	23.7	24.6
15.0	15.9	16.1	16.5	16.8	17.0	16.2	16.3	16.0	16.7
25.0	25.5	25.2	24.9	25.3	25.2	24.6	24.3	23.8	24.7
24.4	25.0	24.8	24.3	24.7	24.7	24.0	24.0	23.3	24.2
16.1	16.4	16.7	15.9	15.3	15.4	16.2	16.0	15.8	15.3
24.7	25.2	24.7	25.2	25.2	25.4	24.0	24.1	24.3	24.2
24.1	24.7	24.1	24.7	24.8	24.9	23.6	23.7	23.9	23.8
15.9	16.3	15.5	16.4	16.7	16.7	16.3	15.9	16.2	16.2
26.2	25.2	24.6	24.9	26.1	24.2	23.7	23.8	23.9	23.4
25.6	24.6	24.0	24.4	25.7	23.6	23.2	22.8	23.3	23.0
16.9	16.4	15.9	16.2	17.2	16.0	15.6	15.2	15.4	15.7
25.3	25.4	24.5	24.4	24.2	24.1	23.9	23.9	23.1	23.5
24.8	24.8	23.9	23.7	23.7	23.5	23.5	23.4	22.7	23.0
16.7	17.1	15.7	15.7	14.4	15.9	15.7	15.7	15.2	15.3
25.1	24.9	24.9	25.7	23.1	24.7	24.2	23.4	23.0	23.0
24.6	24.4	24.4	25.2	23.0	24.1	23.7	22.9	22.4	22.5
16.5	16.3	15.3	17.4	15.9	15.9	15.7	13.3	15.4	15.2
25.5	26.6	25.6	26.2	25.0	24.9	24.0	23.0	23.0	23.4
24.9	26.3	25.1	24.4	24.4	24.4	23.3	22.5	22.4	22.7
16.6	17.9	16.4	16.8	14.6	14.6	15.1	14.2	14.4	15.0
24.9	25.8	26.0	26.9	26.1	24.4	24.5	23.6	23.4	23.3
24.3	25.3	25.4	26.3	25.4	23.8	23.9	23.1	22.9	22.8
14.3	14.1	16.6	18.0	17.1	15.8	16.4	14.4	15.6	15.4

T

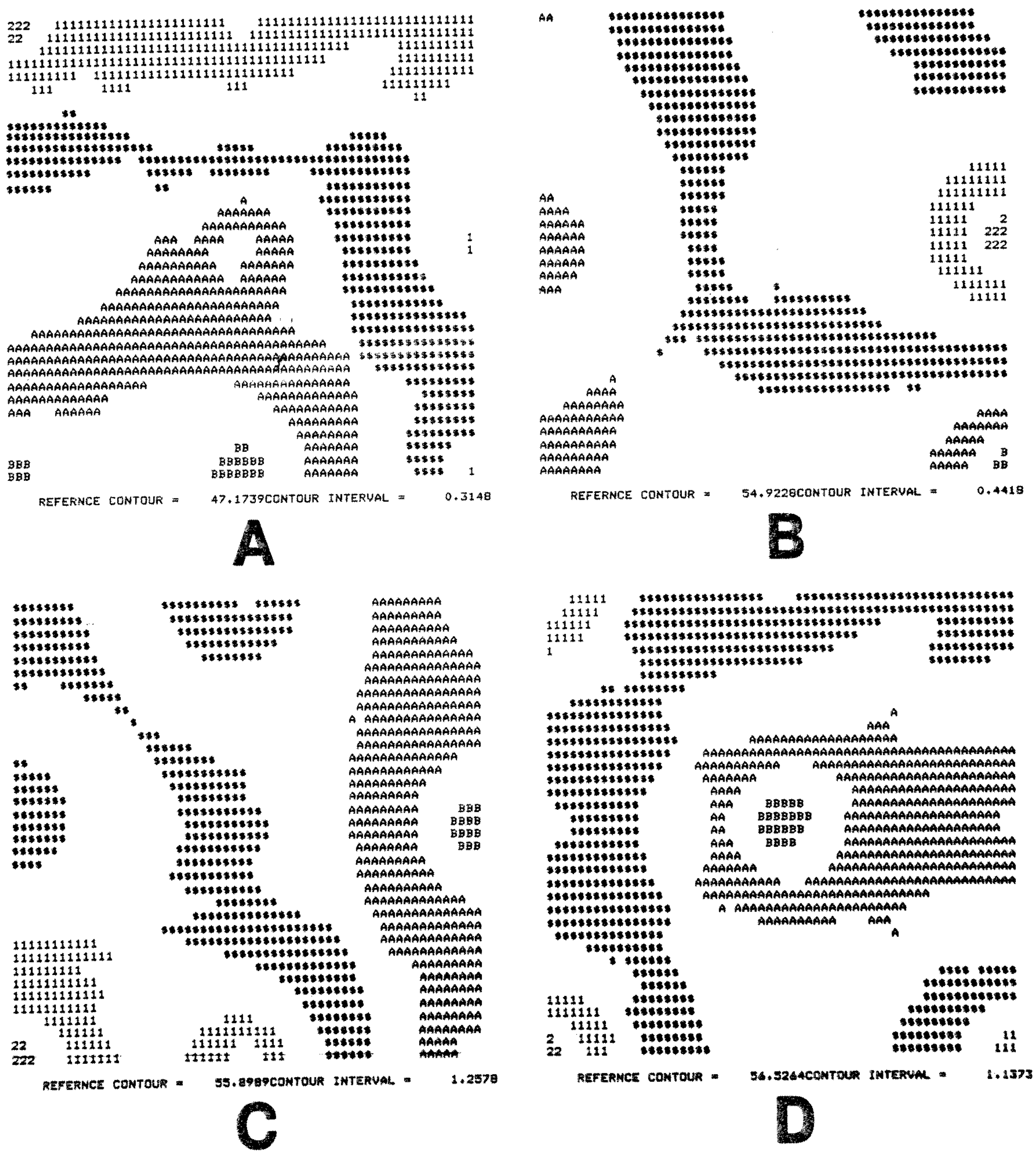
18.6						
18.5						
15.8						
	26.2					
	26.2					
	22.2					
		21.4	24.8	25.3	35.5	31.0
		21.2	24.7	25.1	35.3	30.9
		18.2	20.9	21.8	30.6	22.5
		25.0				
		25.0				
		21.8				
		29.9				
		29.8				
		23.3				
		25.7				
		25.7				
		21.9				
		29.3				
		29.4				
		23.9				
		25.9				
		25.9				
		21.8				
		22.3				
		22.3				
		19.0				
			28.7			
			28.9			
			25.6			
				26.5		
				26.6		
				24.0		
					25.4	
					25.5	
					23.3	
						30.4
						30.3
						22.9

U

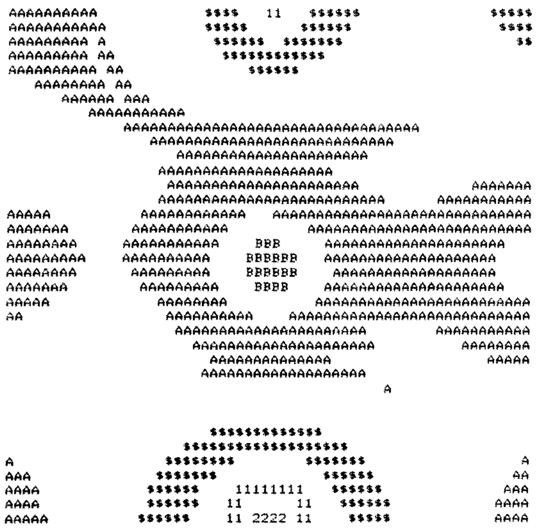
Appendix B

Value Contour Maps

for All Areas



REFERNCE CONTOUR = 47.1739CONTOUR INTERVAL = 0.3148
A
REFERNCE CONTOUR = 54.9228CONTOUR INTERVAL = 0.4418
B
REFERNCE CONTOUR = 55.8989CONTOUR INTERVAL = 1.2578
C
REFERNCE CONTOUR = 56.5264CONTOUR INTERVAL = 1.1373
D

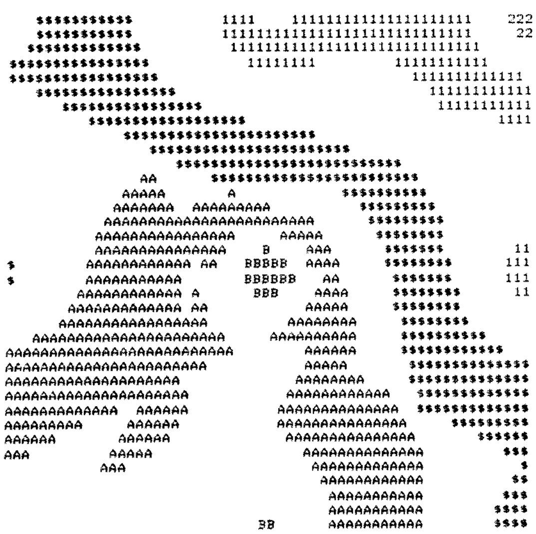


REFERNCE CONTOUR = 54.3730CONTOUR INTERVAL = 0.5817

E

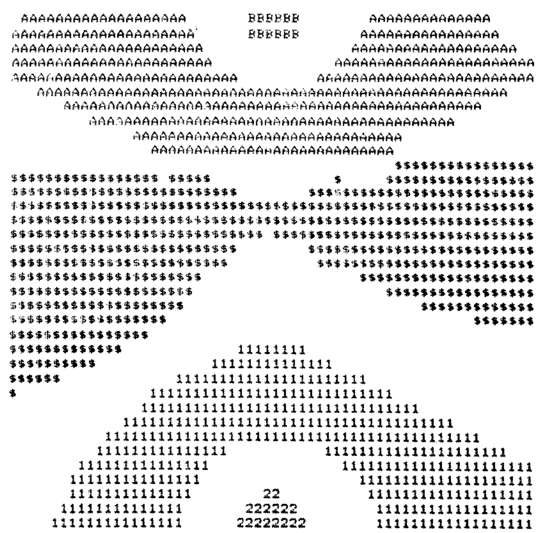
REFERNCE CONTOUR = 51.4900CONTOUR INTERVAL = 0.8000

F



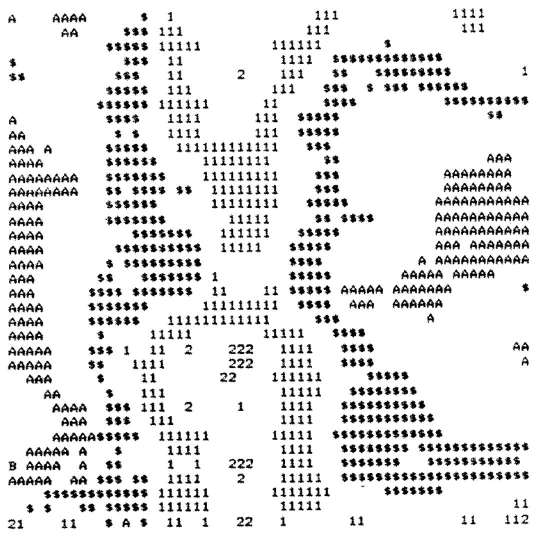
REFERNCE CONTOUR = 66.7164CONTOUR INTERVAL = 0.5413

G



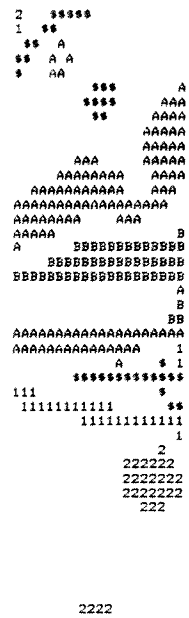
REFERNCE CONTOUR = 46.9570CONTOUR INTERVAL = 0.5521

H



REFERNCE CONTOUR = 39.6614CONTOUR INTERVAL = 2.4174

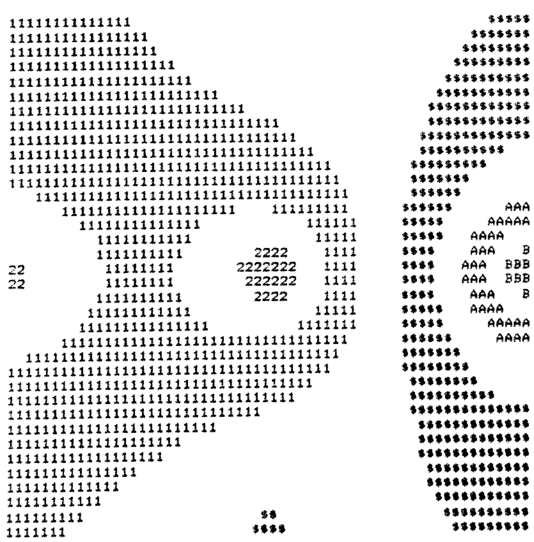
I



REFERNCE CONTOUR = 55.9302

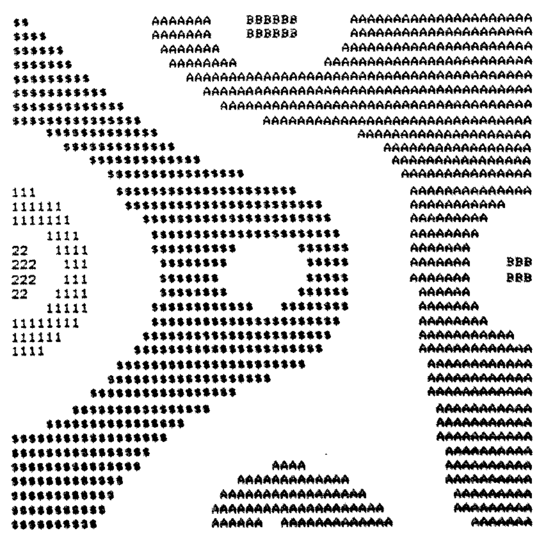
CONTOUR INTERVAL = 1.3662

J



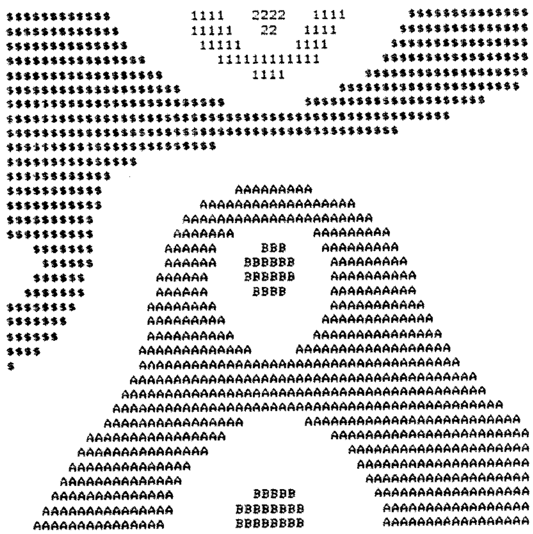
REFERNCE CONTOUR = 89.2614CONTOUR INTERVAL = 1.8697

K



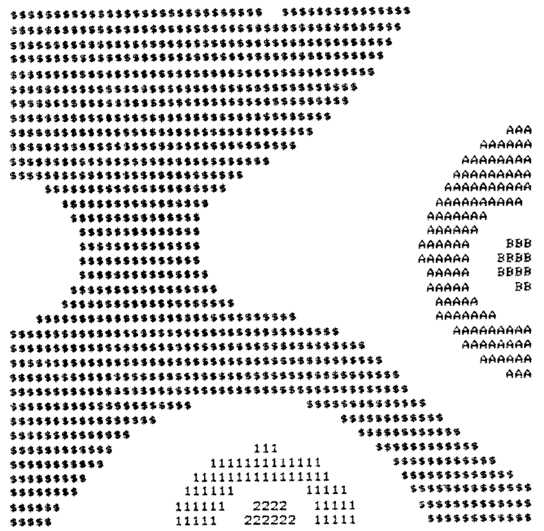
REFERNCE CONTOUR = 73.7397CONTOUR INTERVAL = 0.5004

L



REFERNCE CONTOUR = 79.2630CONTOUR INTERVAL = 0.4294

M

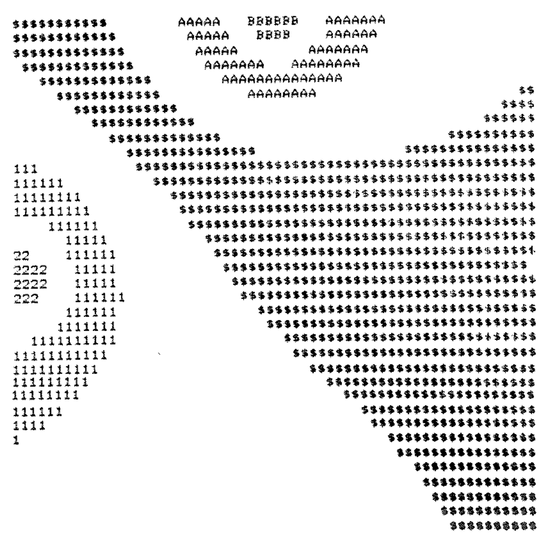


REFERNCE CONTOUR = 96.4375CONTOUR INTERVAL = 1.3361

N

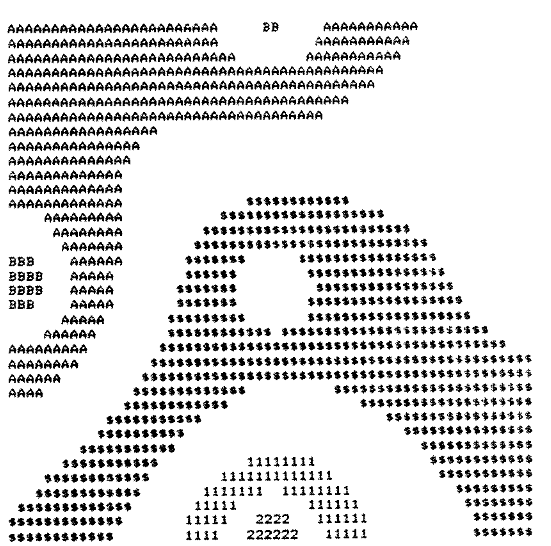
REFERNCE CONTOUR = 48.1973CONTOUR INTERVAL = 0.6411

O



REFERNCE CONTOUR = 70.4126CONTOUR INTERVAL = 1.5437

P

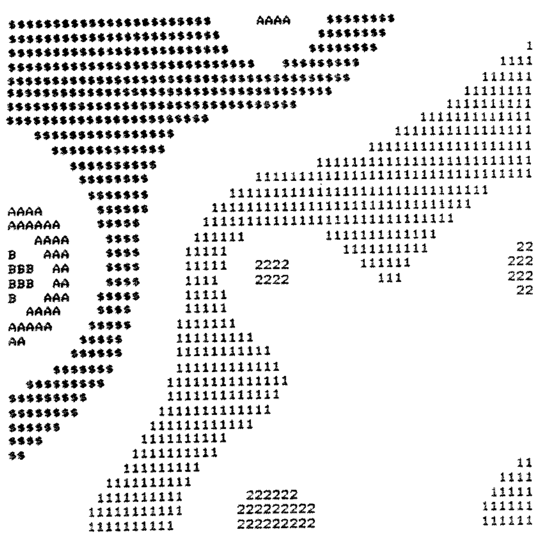


REFERNCE CONTOUR = 74.0446CONTOUR INTERVAL = 0.9631

Q

REFERNCE CONTOUR = 75.6384CONTOUR INTERVAL = 0.3430

R

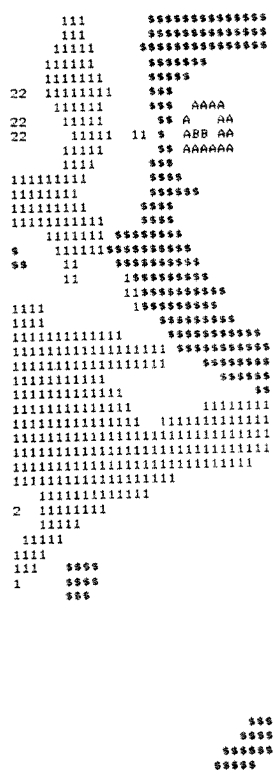


REFERNCE CONTOUR = 91.0988CONTOUR INTERVAL = 1.0045

S

REFERNCE CONTOUR = 66.8748CONTOUR INTERVAL = 1.6691

T



REFERNCE CONTOUR = 81.6960CONTOUR INTERVAL = 3.6727

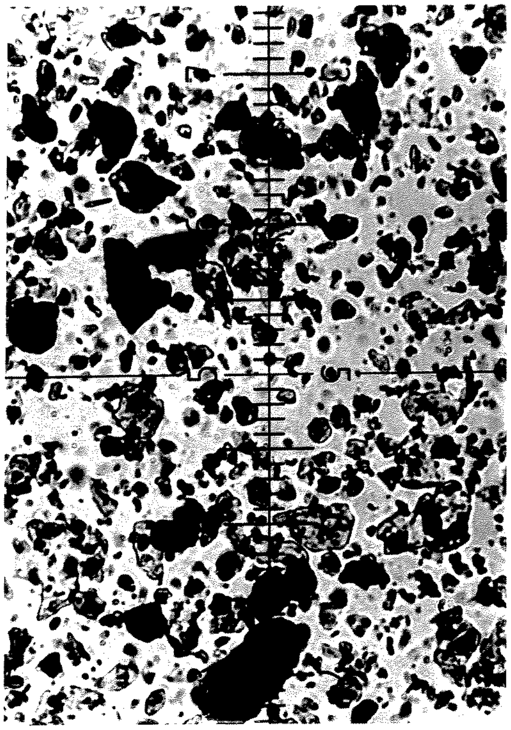
U

Appendix C

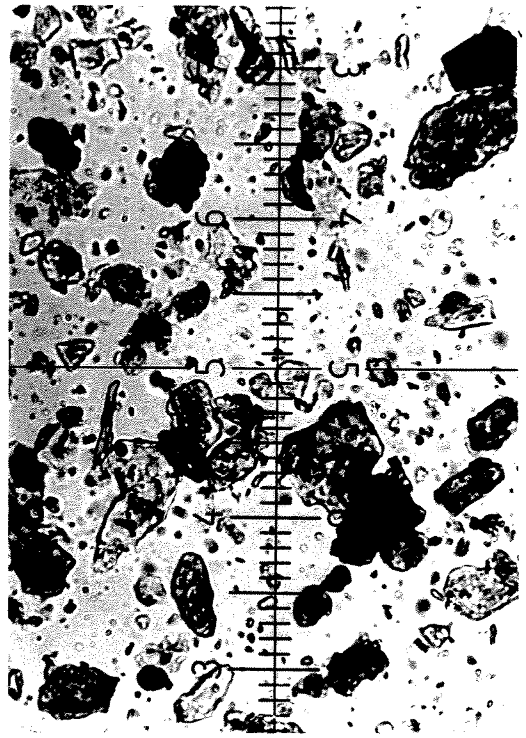
Optical Micrographs

of a Representative

Sample from Each Area

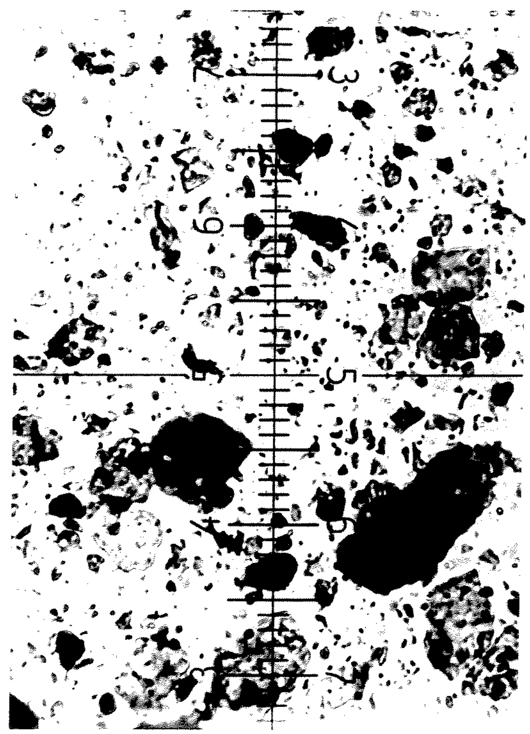


A

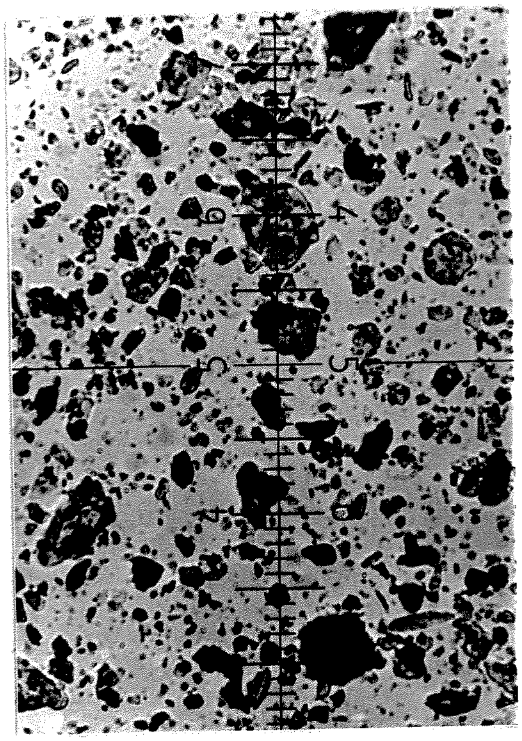


B

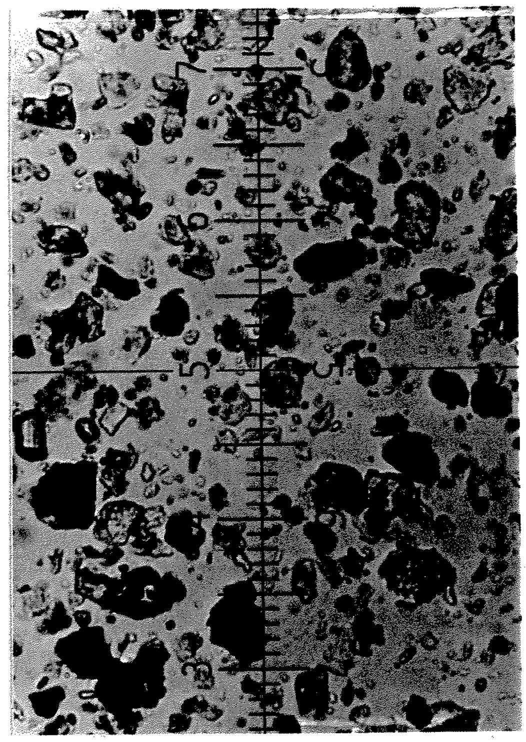
C



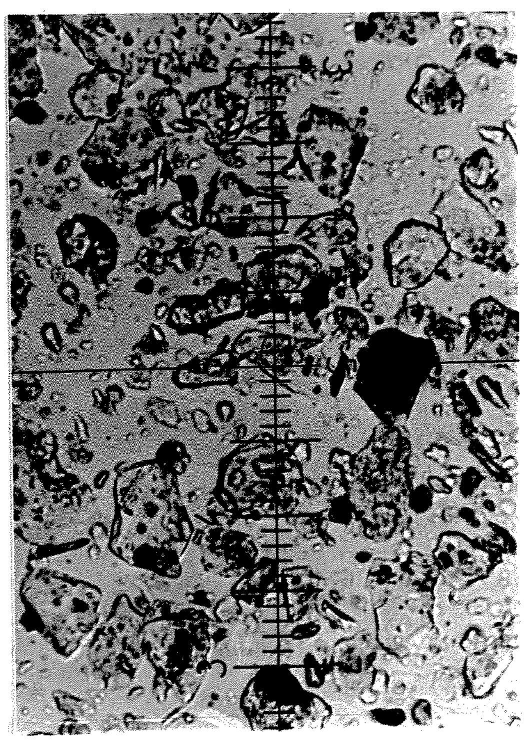
D



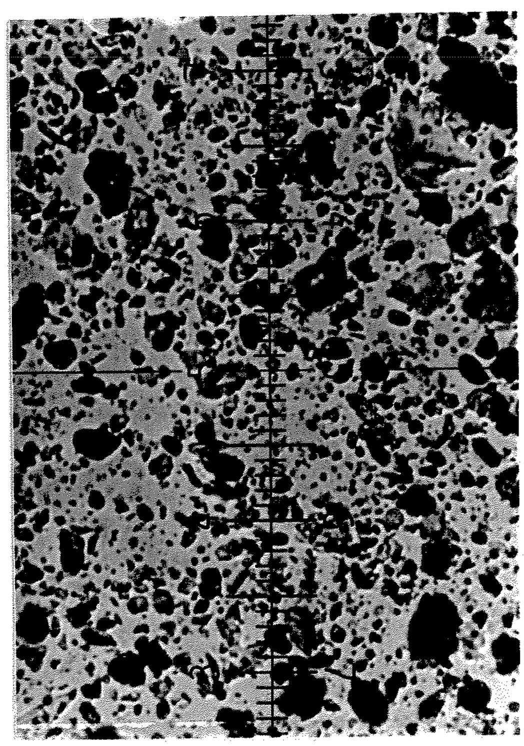
E



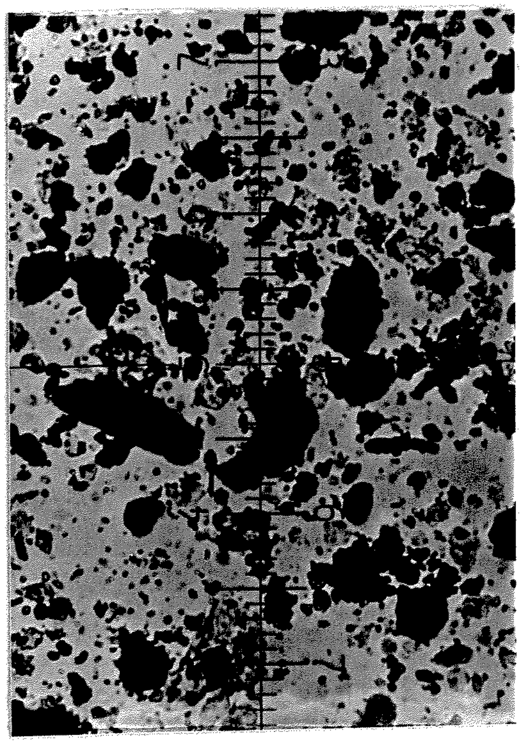
F



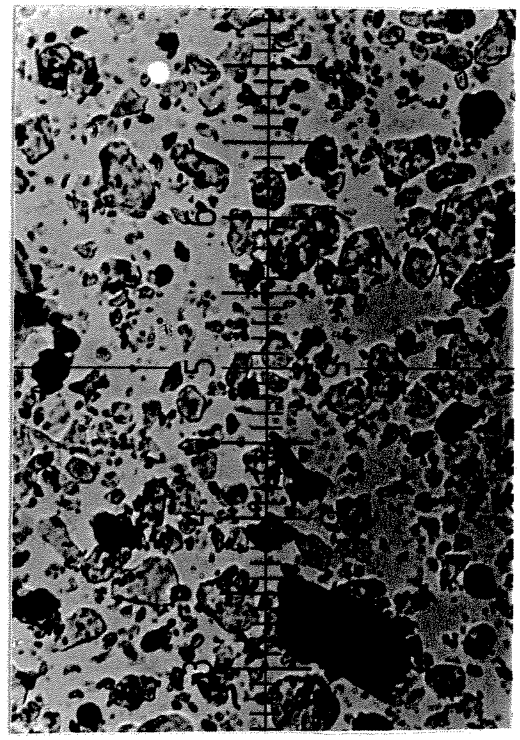
G



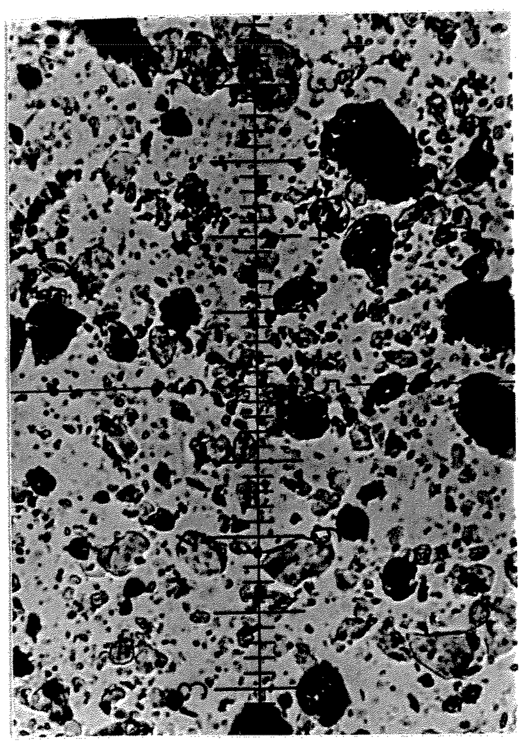
H



I



J



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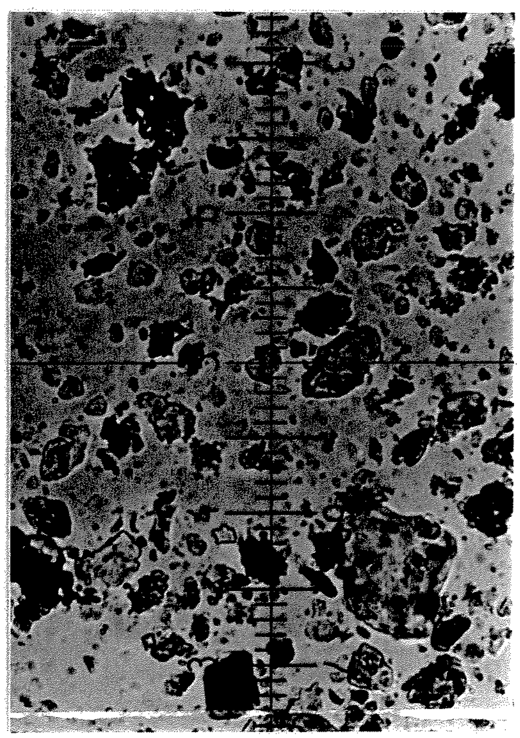

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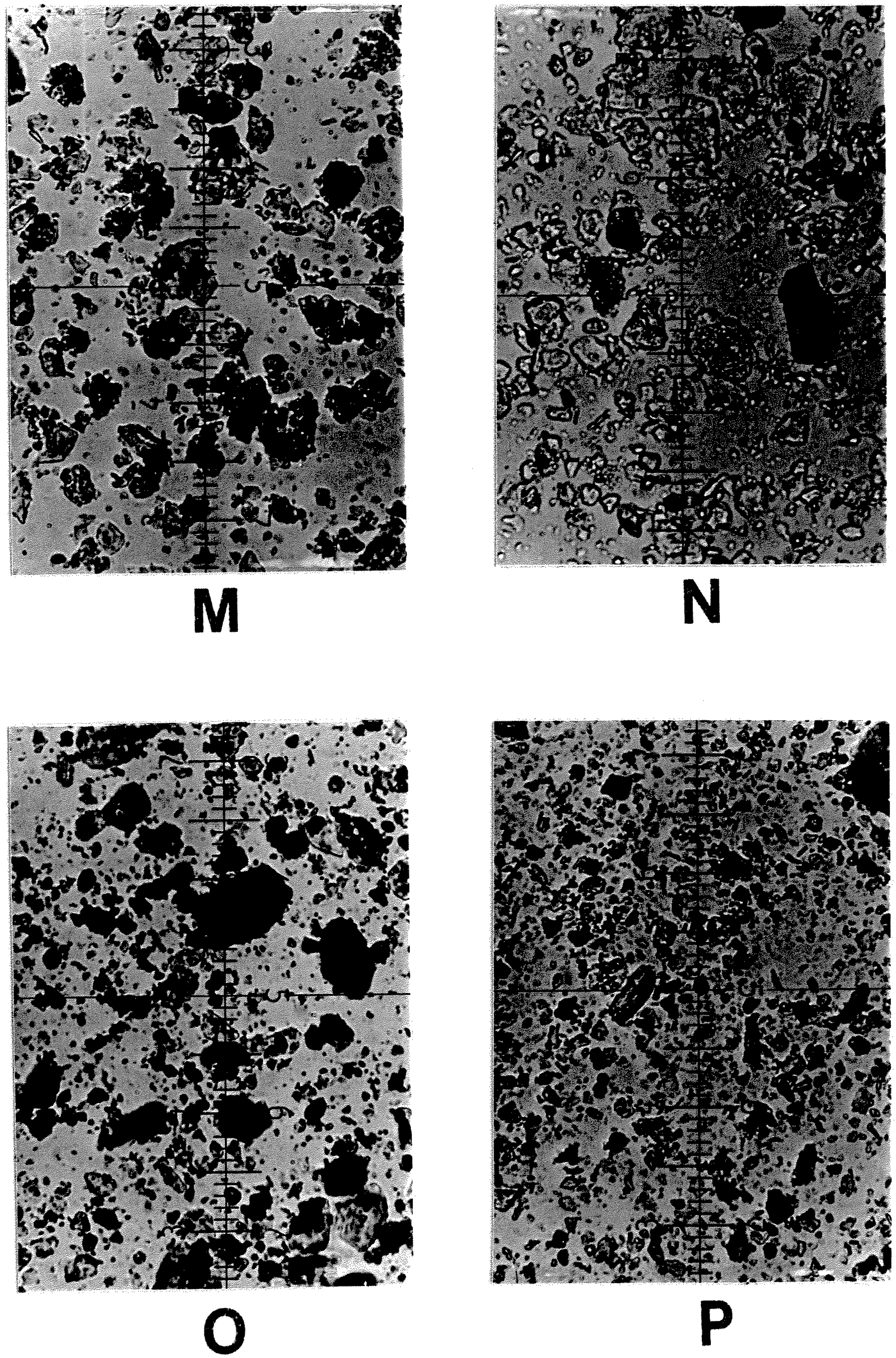

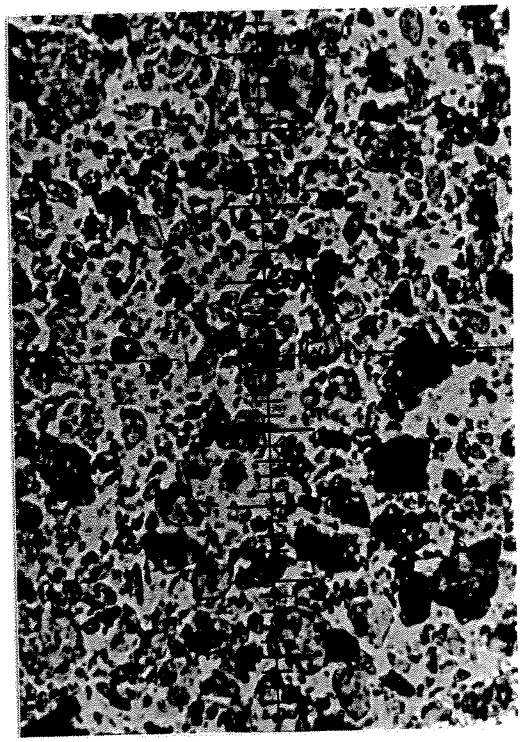

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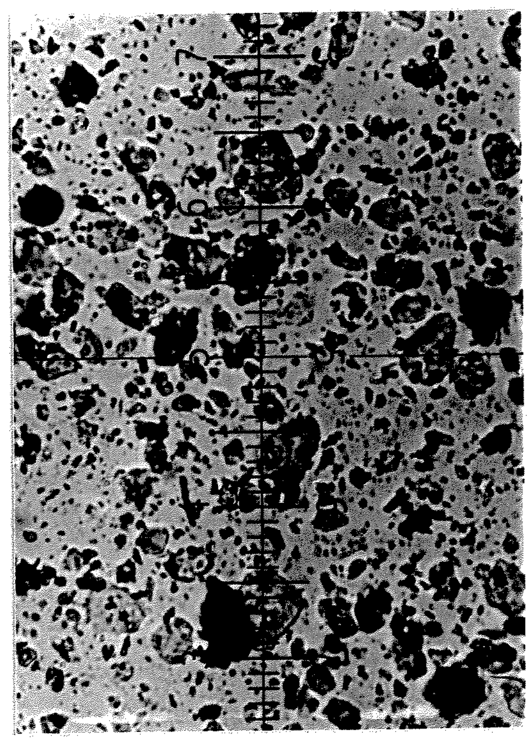

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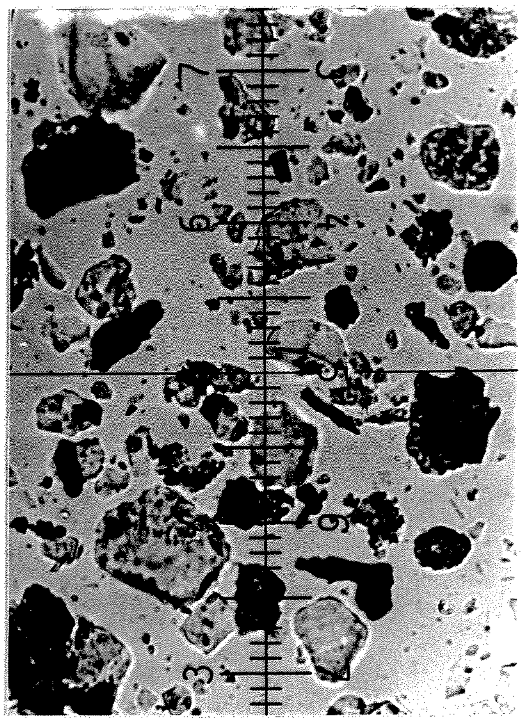

U

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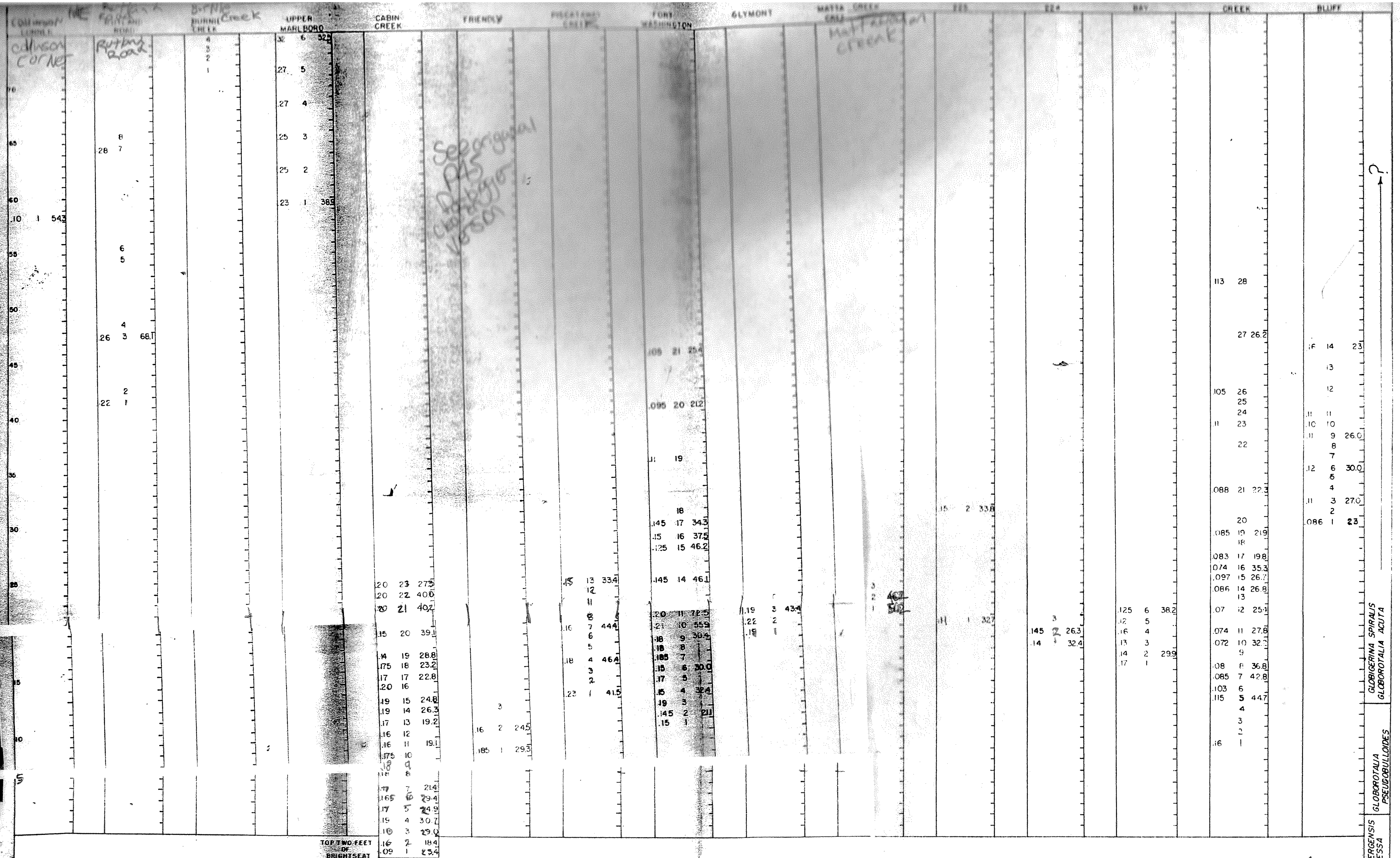
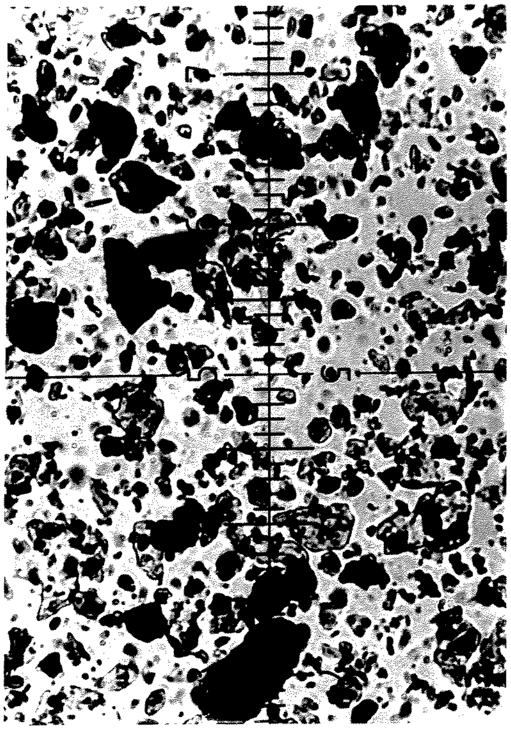


COMPOSITE COLUMNAR SECTION SHOWING LATERAL AND VERTICAL VARIATIONS OF MEDIAN DIAMETER AND GLAUCONITE CONTENT

MEDIAN DIAMETER IN MM
GLAUCONITE IN % VOLUME



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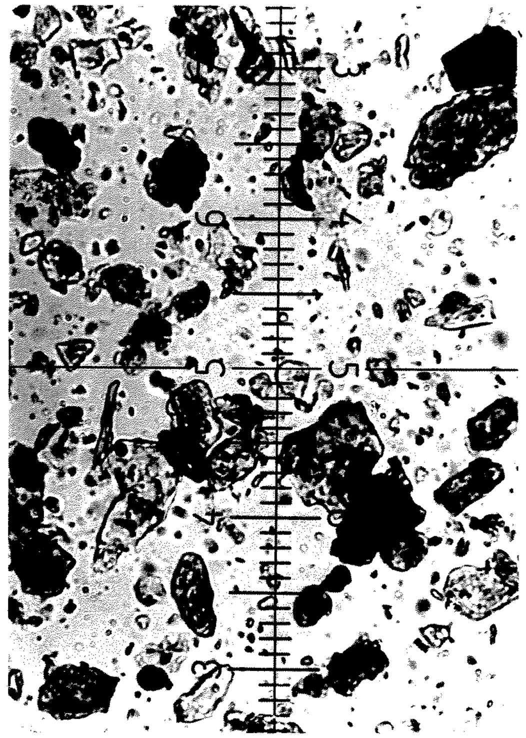

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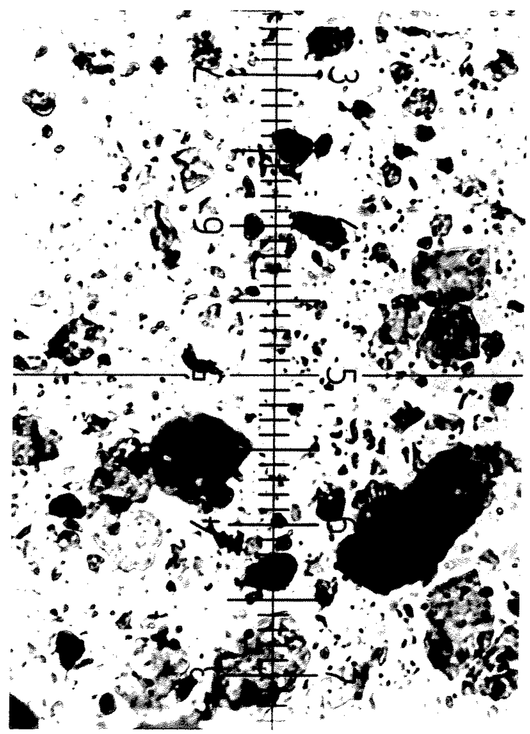

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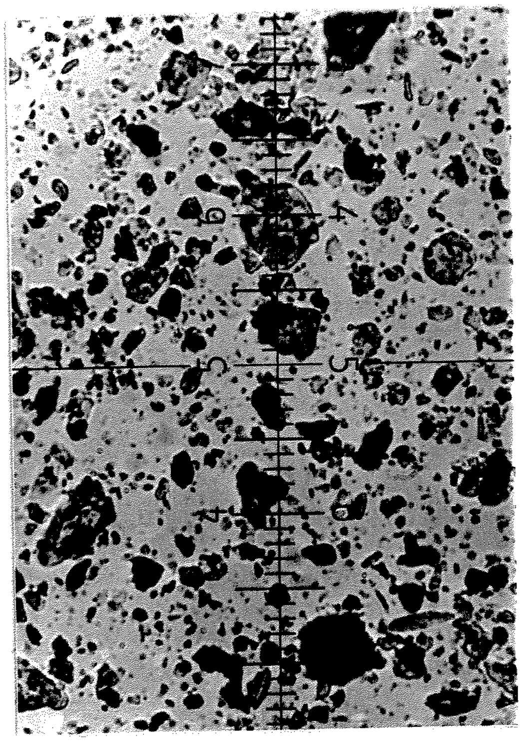

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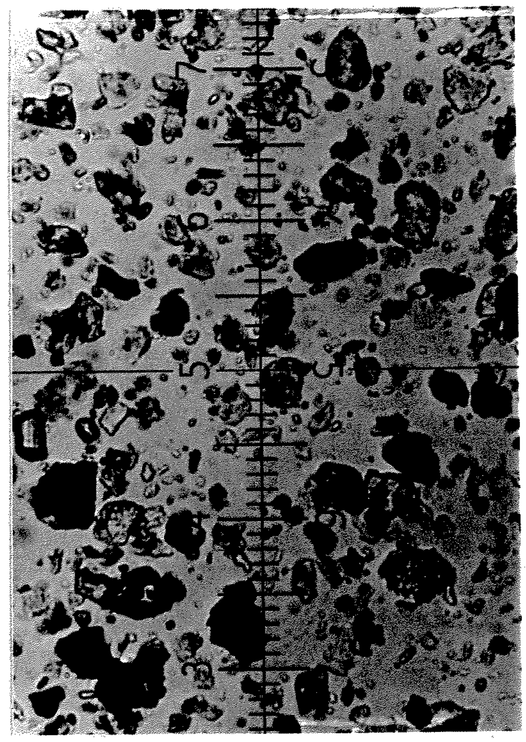

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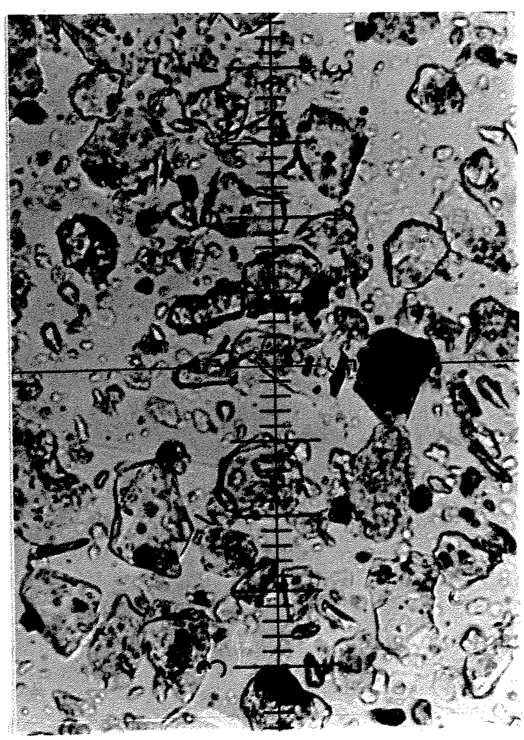

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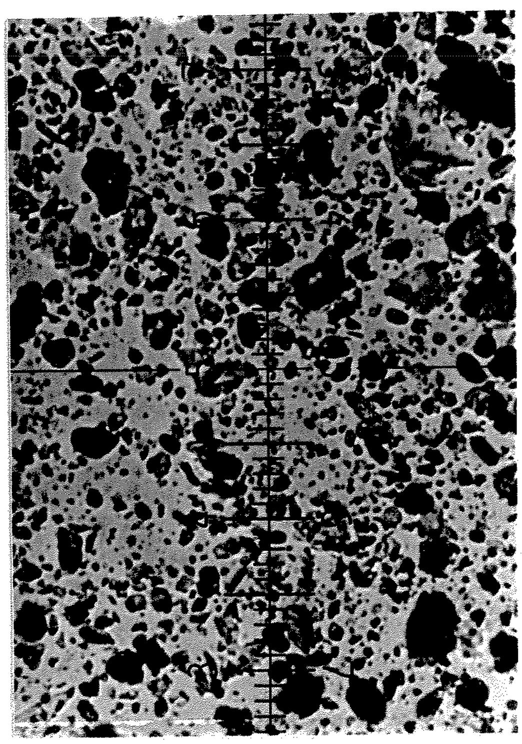

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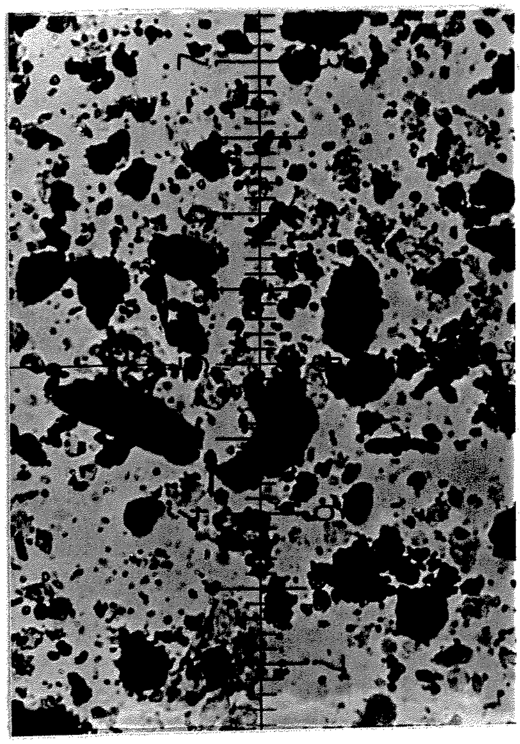

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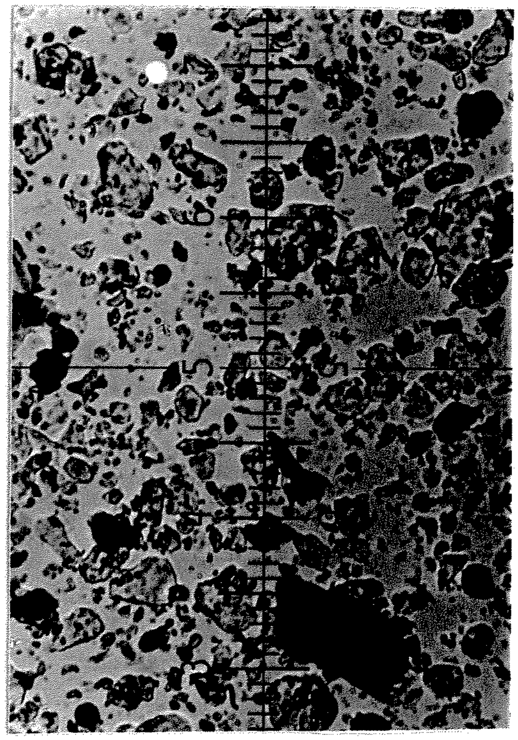

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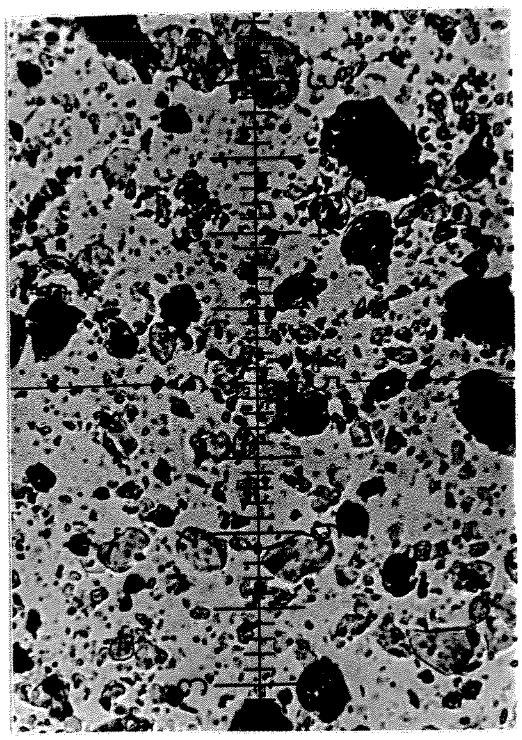

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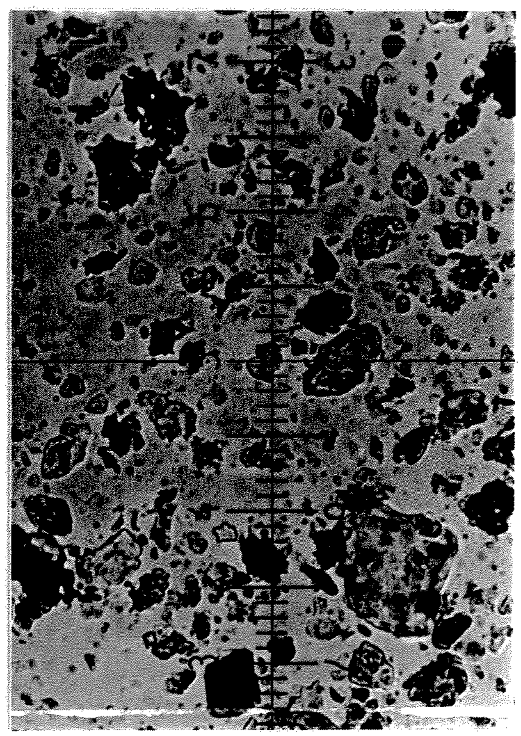

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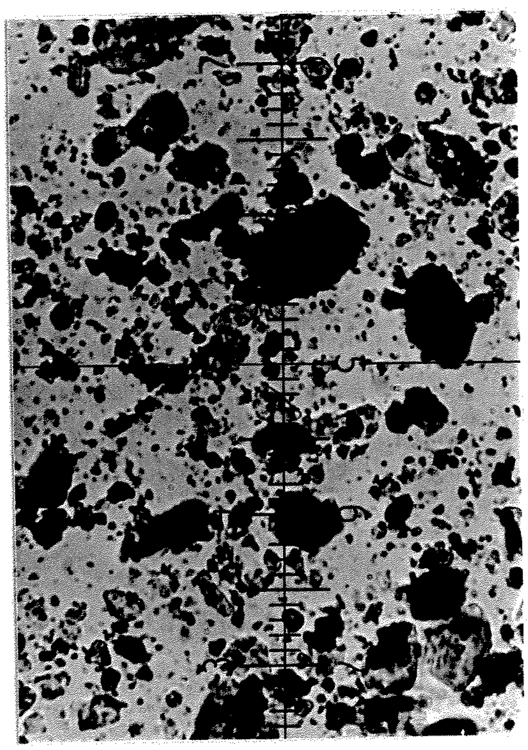

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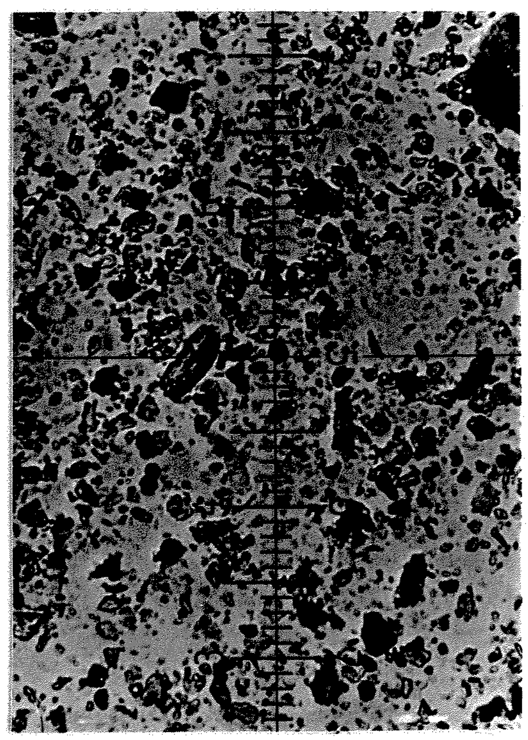

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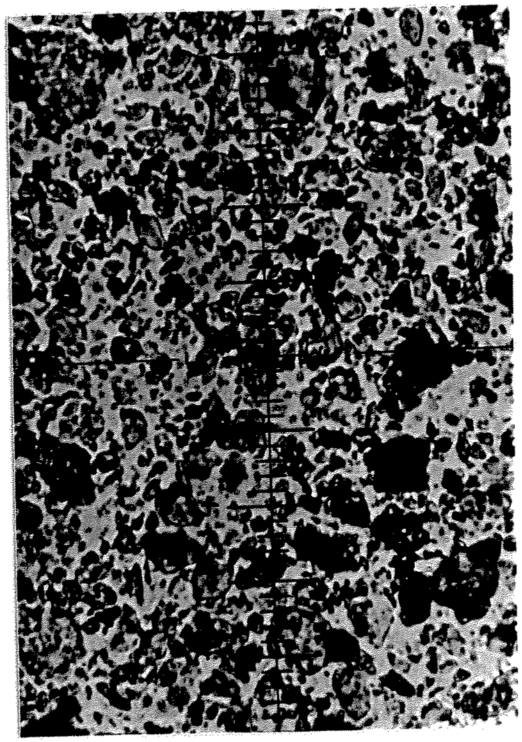

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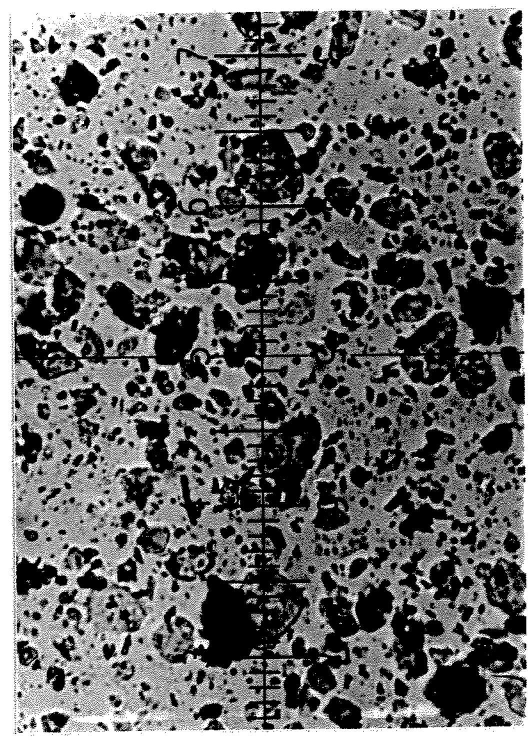

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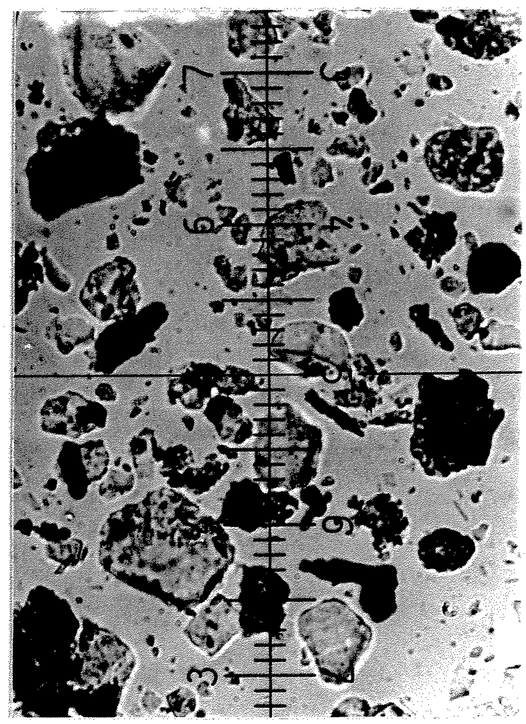

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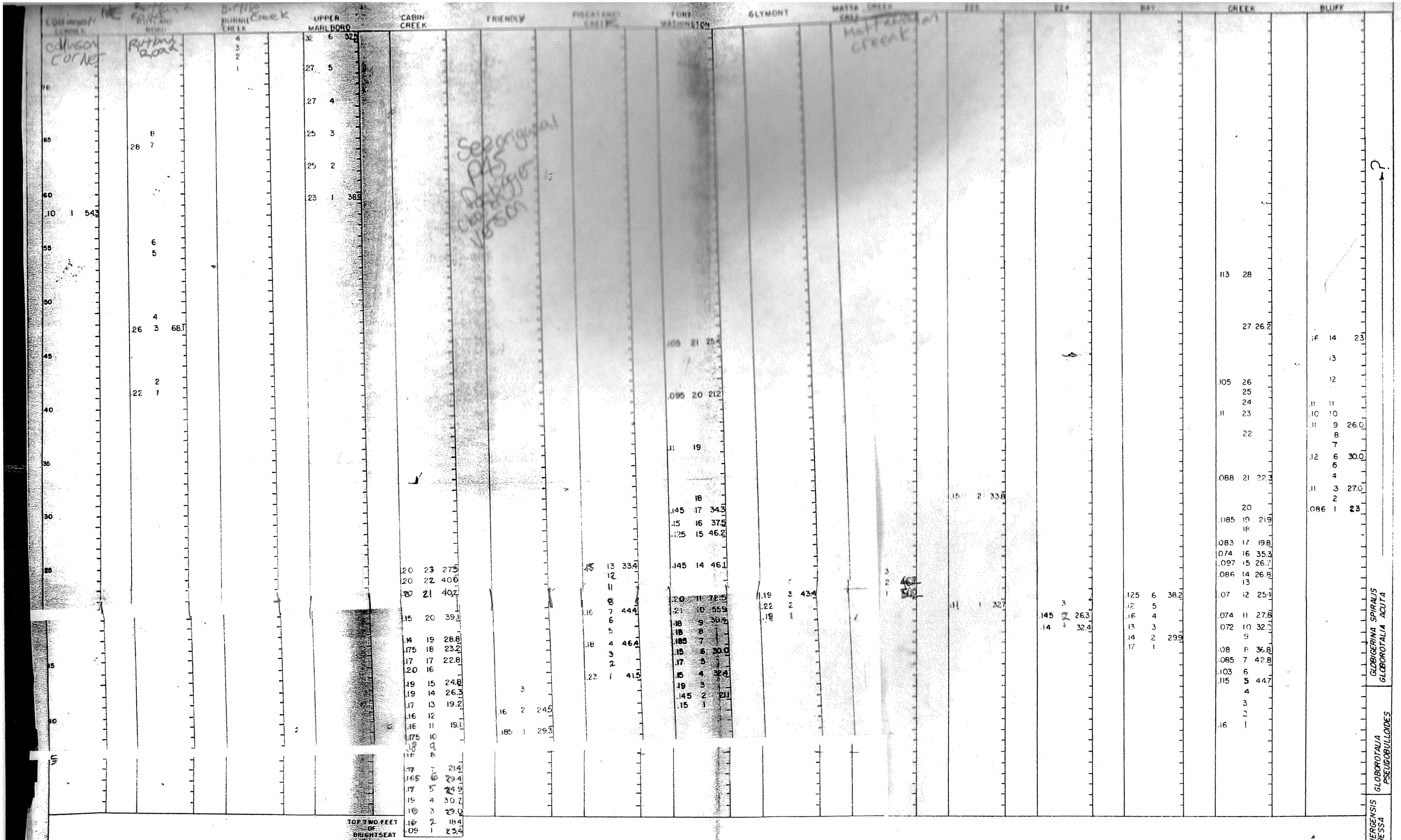

COMPOSITE COLUMNAR SECTION SHOWING LATERAL AND VERTICAL VARIATIONS OF MEDIAN DIAMETER AND GLAU-