LARS Contract Report 122879

Computer-aided Analysis of Land Cover Types Using Landsat-1 Data Over the District of Diema in Mali

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I want to thank the Agency for International Development, which granted the funds for this limited research under contract AID/it-C-6089.

ABSTRACT

Landsat multispectral scanner data 1262-10290 acquired on April 11, 1973, over the Distract of Diema in the economic region of Kayes, in Mali was analyzed using LARSYS software to evaluate the utility of satellite data for land cover classification. The primary purpose was the training of the author in pattern recognition techniques by use of a computer.

Thirteen different classes of land cover types were found and grouped into four different categories. Comparison of the final classification to available land cover maps or aerial photographs was not possible therefore the classification accuracy was not checked.

The data was not geometrically corrected. The geometric correction, when applied, rotates the frame to the true north, eliminates the distortion (skew) due to the earth's rotation during data collection, rescales the data for line printer output at scales of either 1:24,000 or 1:25,000 and eliminates altitude and attitude variations.

INTRODUCTION

During the last decade, remarkable progress has been made in remote sensing technology, especially in the development of computer implemented pattern recognition techniques for analysis of multispectral scanner data. It was the purpose of this study to examine the applicability of pattern recognition in remote sensing technology to an area in Mali.

The Republic of Mali is an interminable plain traversed by only a few mountain ranges, none over 1000 m high. The country is completely landlocked between the Saharian desert vastness of Algeria and Mauritania to the northeast and northwest, the Sahelian savanna lands of Niger and Upper Volta to the east and southeast , and the alluvial valley of the Senegal river and the outskirts of Guincan-Tvorian forest in the west and southwest.

Because of the severe conditions of drought in the Sahel, the encroachment of the desert, and the precarious living conditions of man, animals and plants, it is urgent that a solution be found for regional surveys and inventories to assist in land management.

The planning for land use is necessary for the development of the country for which agriculture and livestock occupy 90 percent of the population. Because of the demand for production in this area, the conservation of the environment is necessary. To meet this goal, there is a need for monitoring the land cover condition in order to manage it properly and maintain high productivity for crops, livestock and wildlife.

The prediction and estimation of agricultural production and the range capacities of the country, the estimation of the potential development of new agricultural programs to offset the trend toward long term losses in range carrying capacities, necessitate knowledge of the availability of natural vegetation, the distribution of soil textures, and the relative moisture available for plant growth. With respect to the size of the country, the information available up to the present time, the small number of technicians involved in the process, the ground observations required, cannot adequately provide the information necessary to evaluate these elements. Regional surveys and inventories using remote sensing techniques supplemented with ground surveys need to be developed.

Landsat MSS provides information on the relative water balance by vegetative density comparisons of several observations over the same area. The synoptic view of Landsat improves the knowledge of distribution of soils, movement of wind driven sands, and the distribution and vigor of the existing natural vegetation as related to precipitation, evaporation and transpiration.

LANDSAT

Landsat I was launched on July 23, 1972 and failed on January 6, 1978. Since that date, Landsat II (January 22, 1975) and Landsat III (March 5, 1978) have been launched.

The satellite has a circular sun-synchronous, rear polar orbit with a 9:30 A.M. crossing of the Equator on a descending node. They circle the Earth every 103 minutes and view the entire Earth in 18 days. A complete coverage of the Earth's surface between 81 degrees north and 81 degrees south latitude is obtained. The satellite makes 14 revolutions of the Earth per day. The multispectral scanner (MSS) is a sensor system that collects data of the Earth in various spectral bands from an altitude of 920 Km.

The multispectral scanner (MSS) scans the Earth from west to east in a 185.2 swath perpendicular to the satellite track. Landsat I and II respond to the Earth reflected sunlight in four spectral bands and Landsat III carries an additional band for the thermal infrared radiation. The spectral bands are:

band 4	0.5-0.6 μm	(the green)
band 5	0.6-0.7 μm	(the red)
band 6	0.7-0.8 μm	(the reflective IR)
band 7	0.8-1.1 μm	(the 2nd reflective IR)
Landsat III-band 8	10.4-12.6 μm	(the emissive IR)

Each multispectral scanner utilizes six detectors per 1 band plus two for band 8. The instantaneous field of view (IFOV) of each detector is 79 m square except that band 8 is 237 m square.

In the image processing facility, data is transformed into framed imagery with a 10 percent overlap between frames. The "effective" IFOV is therefore 79 m by 56 m.

The ground resolution element of Landsat is approximately less than half a hectare (79 x 56 m or 0.4424 ha). Any field equal or larger than this resolution element is recorded by Landsat (Fig. 2 & 3).

The electrical outputs of the sensors in Landsat are transformed at ground stations into photographic images or are recorded on digital magnetic tapes for use with a computer. The Laboratory for Applications of Remote Sensing has developed a remote sensing analysis software system (LARSYS) which was used in this research project.

ANALYSIS PROCEDURES

Examination of Data Quality

One of the first things to a remote sensing data analysis is to examine the quality of the data to be analyzed, that is to examine whether the data is good enough for the analysis. The gray scale printouts or the video displays developed from the computer tape are good tools for this step. Two main effects degrade the quality of multispectral scanner data:

1. Geometric distortion. The geometric distortion is also called skew. It arises on Landsat imagery due to the rotation of the earth and its effect is that a rectangular image on the ground appears as a non-rectangular parallelogram, the top edge of the image being shifted with respect to the bottom edge by about five percent of the height of the image.

2. Noise. The noise arises as the result of a noisy detector, a noisy channel, a telemetry problem or a combination of effects. The noise found on the data to be analyzed was a minor one so the analysis was possible.

Pictorial Display of the Raw Data

The data in pictorial format is used for visual inspection to analyze image quality, the distribution and amount of clouds, to delineate areas of interest for detailed study and to choose the training areas needed to train the classifier. The area displayed was chosen because of the overlapping of this frame and the scene number 8153310304501 obtained on January 7, 1974 and the scene number 8606909524500 obtained December 26, 1977. These Landsat images were analyzed visually in an attempt to classify land cover types and land forms.

The GDATA processor was used to display the data in gray tone format. The GDATA displays the image in sixteen gray tone levels for each channel used. For this analysis, channel 2 (band 5) and channel 4 (band 7) were used. The representation is matched in dots and the image is at a scale of 1:125,000 (Fig. 4).

The PICTUREPRINT function was used to display the image in 10 alphanumerique forms from the less reflective to the very bright reflective features (Fig. 5).

Selection of Training Areas

Selecting the candidate training area involved the identification in the available reference data of general areas that contain relative uniform information classes for analysis of the pattern by the computer.

Five unique training areas were chosen on the gray scale printout. The areas were chosen in such a way that one contained a maximum number of 10,000 pixels and every information class was represented in at least one of the areas. This increases the likelihood that training data will be representative of all the variations in cover types in the scene being analyzed.

The IMAGEDISPLAY function was used to match in color composity form the ground features. Channels 1 (band 4), 2 (band 5), and 4 (band 7) were used to produce thirteen different pictures (Fig. 6).

Scale of Data in Digital Display System

The main display consists of a high resolution TV monitor. The monitor is a 53 cm (21 inches) rectangular TV screen. The viewing area of the screen is 30 x 40 cm (12 x 16 inches). The TV displays a 577 line by 768 column matrix, each element of which is one of the sixteen possible gray levels. The columns are called samples. Scale is equal to pixels/data point (Fig. 7). Each pixel is enlarged four times on the TV screen. The column width of any rectangular area chosen for analysis should not exceed 9.9 cm to enlarge the image at 4/1 scale. The number of lines does not determine the scale at which the data is displayed.

HISTOGRAM CONCEPT

The standard gray level assignment consists of 16 equal probability data ranges. The area from which the histograms are to be calculated is chosen by the analyst. The histograms are usually computed for every tenth data sample and line for each channel. For a small area, such as less than 50,000 points, the histogram is computed for all data points.

The histogram is very useful when the data has few variations or a small range in spectral response. It assists in evaluating the loss of detail from a large area to a small segment. It helps to enhance the data. The histogram is, in fact, a plot of a normal probability distribution of a set of data (Fig. 8).

CLUSTER

Clustering is a computer-aided data analysis method which determines the natural structure in a set of data. CLUSTER is used for the unsupervised classification of reflective data. This classification is a method in which the classes are determined on the basis of inherent properties within the data. Opposed to the unsupervised method is the supervised method in which the classes are determined from the known identification of a representative sample of data.

CLUSTER uses information from more than one channel or wavelength band to produce a single image. The algorithm is based upon distance relationships between each point and the centers of groups of points (clusters). It requires that the user defines the number of clusters (or classes) that are to be produced. For the present study, four channels and ten to twelve cluster-classes were assigned to each of the five train-areas, based upon the reflectance characteristics of soil, water, and green vegetation. The classes were selected on the basis of the variation seen on the color print enlargment of the whole training area produced from the video presentation.

From the cluster output the calibrated means curves of the different classes was derived for each channel (Fig. 9 to 13). The calibration value used were 2.48 for band 1, 2.00 for band 2, 1.76 for band 3 and 4.60 for band 4. These values are the values of radiance emitted by the lamp inside the satellite to calibrate the data. The curves help to identify the cover types or classes (Fig. 14). Unfortunately, it was not the case for this study region. No standard curve was found (Fig. 15). April was one of the driest months in Mali and particularly in the Sahel where the District of Diema is located, there was a lack of living green vegetation and a lack of running water. Also, the vegetation at this time of year is very sparse and mostly composed of bushes.

STATISTICS

The next step after the CLUSTER analysis was the use of CMERGES statistics funtion which calculates the statistics of subsets of data from the multispectral image. The maximum number of training classes allowed is sixty. From this function, the coincident spectral plot for all channels was obtained using the CMERGES function. Also, the bispectral plot was obtained (Fig. 16 & 17).

The coincident spectral plot shows for each channel a data value for each class and training area. This output obviously shows the similarity of the reflectance from each of the training areas and for all four channels. The result was that there was only one major cover type in the area to be analyzed.

The bispectral plot was also an output on the analysis. It confirms that there was only dormant vegetation (or bare soil) as a major cover type in the area analyzed. The bispectral plot was a scatter diagram of the spectral characteristics of the cluster classes by plotting the average of the means of the visible bands versus the average of the means of the infrared bands.

The mean, the standard deviation and the correlation matrix for each class were printed.

Groups of clusters were selected so as to maximize separability from one class to another.

Fifty-six classes from five different training areas were involved in the process.

After the first run, thirteen groups were chosen to do the next iteration. The best separability is obtained after a certain number of iterations and by altering statistics and separability functions. The output of this iteration shows eleven groups on the basis of minimum separability value of 1750. But for soil divergence, the value of 1500 can be used. Therefore, the previous thirteen classes found were adopted as the appropriate classes for this region of Mali.

SEPARABILITY

The separability function helps to select the set of channels that will produce the most accurate classification. It uses the statistics deck to calculate measurement of how well the individual classes may be distinguished from one another. The function uses the means and covariances matrices for classes to calculate the divergence which is a measure of distance between class densities of all class pairs for each set of channels (Fig. 18).

All class pairs used have a default weight of 10.0. If one does not want to use some data then assign them the weight zero.

The output of separability show the transformed divergence ranking of channels by average with respect to the greatest transformed divergence value. In other words, the best will be the class pairs having the largest average transformed divergence. The ranking is done with respect to the minimum transformed divergence, depending on the choice of the analyst. The transformed divergence is a measure of probability of successfully distinguishing between pairs of classes. (Fig. 19)

The separability function used a maximum divergence value of 30,000 and minimum of 0. For this study the minimum separability value of 1750 was requested using the separability function. The class pairs having a transformed divergence value less than 1750 were identified on the bispectral plot.

Minimum Distance Classification

The minimum distance classification is the next step after the separability. The program is done using the CLASSIFY-POINTS function. It assumes that each training class is characterized by a multivariate Gaussian distribution, or equivalently, by class mean vector and covariance matrix. Thus, the program uses the class mean and covariance matrices computed by the statistics, and the data from each point to be classified to calculate the probability that the point belongs to each of the training classes. It then assigns the point to the most probable class and writes the classification on an output file for later use (Fig. 20).

The classification is done by a point by point basis.

The output is stored on tape.

PRINTRESULTS

This function reads the data stored on tape during the CLASSIFYPOINTS process. The function allows the analyst to have a flexible capability to display the results of classifications in the forms of maps or tabular output. The map output is similar to the PICTUREPRINT output. The only difference is that the PICTUREPRINT was implemented with default symbols while during the PRINTRESULT process, specific symbols were assigned to the final thirteen classes with respect to their bispectral plot and their calibrated means curves.

This function computes, in addition to the standard deviation, the covariance and correlation matrices, the percentage of each sample classified into the whole area and the total number of samples.

The total area was computed using the total number of samples as below:

79 X 56 X 361,201 = 159,795.32 ha, or approximately,

1,600 km^2, in which 79m X 56m is the area of one sample (or pixel) and 361,201 was the total number of samples.

The function was iterated a few times to obtain a good contrast in the map. In this case, some classes were grouped into one symbol. For example, two or more different types of soils were considered as a single class. This grouping of classes was done three times to identify the wetlands, light-soil and very dark soil, the farmland and the dormant vegetation.

GRESULTS

The GRESULTS has the same functions as the PRINTRESULTS such as the GDATA has the same function as the PICTUREPRINT; except that the GRESULTS is performed on a Varian printer-plotter (Fig. 23).

ANALYSIS OF RESULTS

Wetland

The wetlands were easy to classify because of their spectral response (red on the color composite) and their location (along river or stream beds). Only one class of wetland was identified. (Fig. 21-a).

Farmland

The farmlands were easy to identify because of their very light spectral response. Five different classes were identified as farmland. Each of them was spectrally different some way. April was a very dry month, no rainfall occured, so the farms were bare (Fig. 21-b) and the reflectance contrasted with the surrounding cover types.

Villages

The villages were relatively easy to classify because of their location within the farmland. There was no special class for villages because their spectral response was similar to the surrounding area. The housing was made with mud and dry grass so the spectral response of any village was a combination of those of clay soil and dormant vegetation.

Soils

Four different types of soil area were identified, from light to very dark soil. Three light soil classes were identified mostly in rivers and stream beds. In April, all streams in the Diema District were relatively dry; therefore, the rivers and streams show a dry clay soil. It was difficult to make an assumption for the very dark soil (Fig. 21-a). A field check is required.

Dormant Vegetation

Three different classes of dormant vegetation were identified. These classes were different combinations of soil, sparse dry grass and sparse bushes (Fig. 21-c).

Burned Land

Some very broad dark areas that contrasted distinctly with very dark soils were seen in the area analyzed. The analysis of the imagery obtained in January 4, 1974 and December 26, 1977 over the same area show that the dark areas disappeared on these scenes. Therefore these areas were assumed to be fire burned (Fig. 22).

CONCLUSION

There was a lack of reference information to check the accuracy of the classification developed by the use of MSS data storage and computer analysis; therefore, the general classification must be checked in the field.

The study shows that for a dry land area, the analysis was economical using the computer system as a large area of about 160,000 ha was examined for about 2.5 cents per hectare, once the formatted computer tape was available. The spectral response of the land cover was matched pixel by pixel.

The area of a pixel was approximately one-half hectare. The amount of information from the computer-aided analysis was judged to be adequate for regional inventory and general country. Besides this pixel by pixel information, Landsat II and III would provide information about an area at 9-day intervals throughout the year. An analysis of repetitive imagery from one season to another within a year and from one year to another would be of value in detecting the change of the land cover condition and would provide information necessary for the development planning.

References

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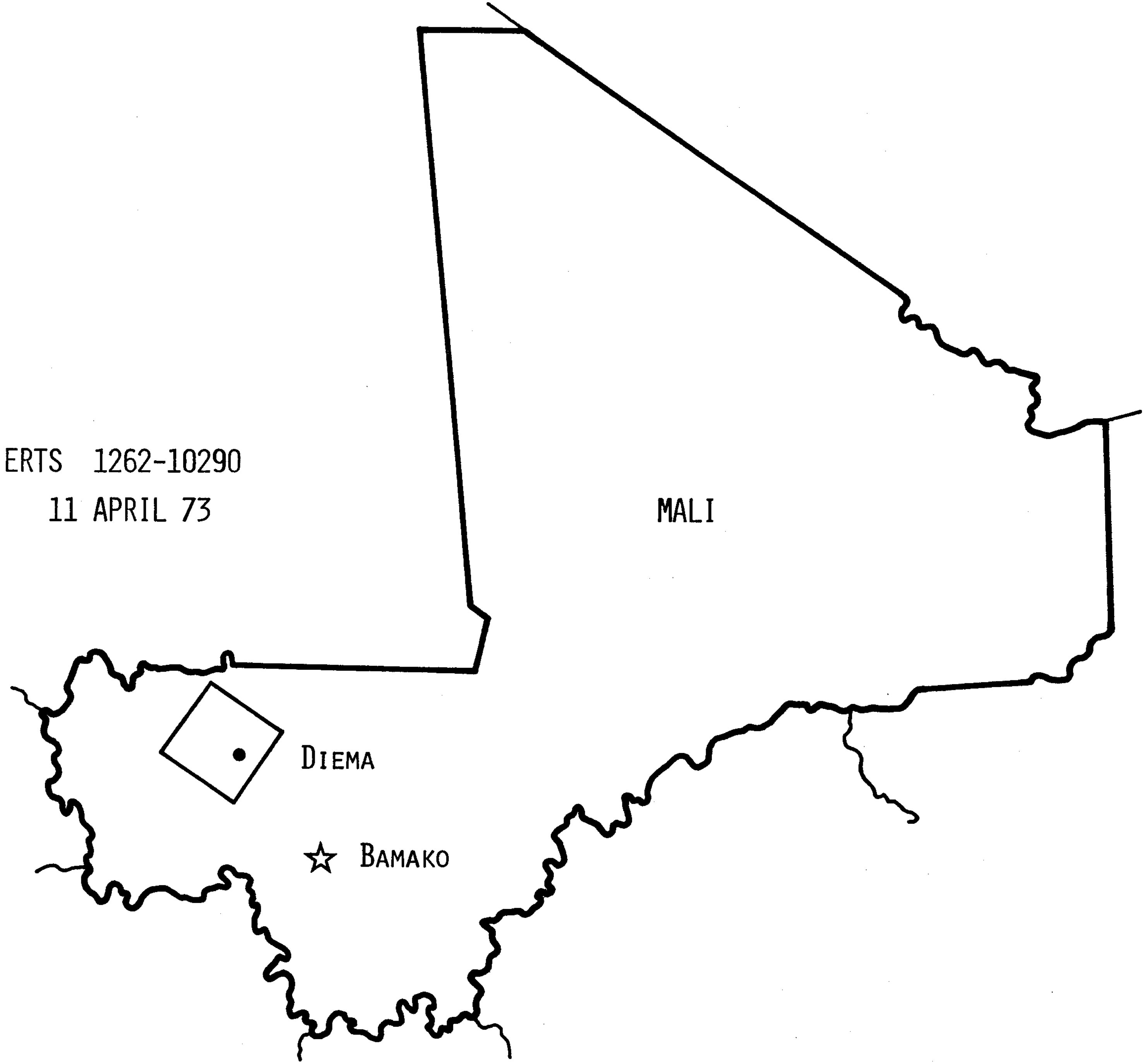
6 Anuta, Paul E.; Geometric Correction of ERTS-1 Digital Multispectral Scanner Data. LARS Publication 103073. LARS, Purdue University.



Location of Diema.

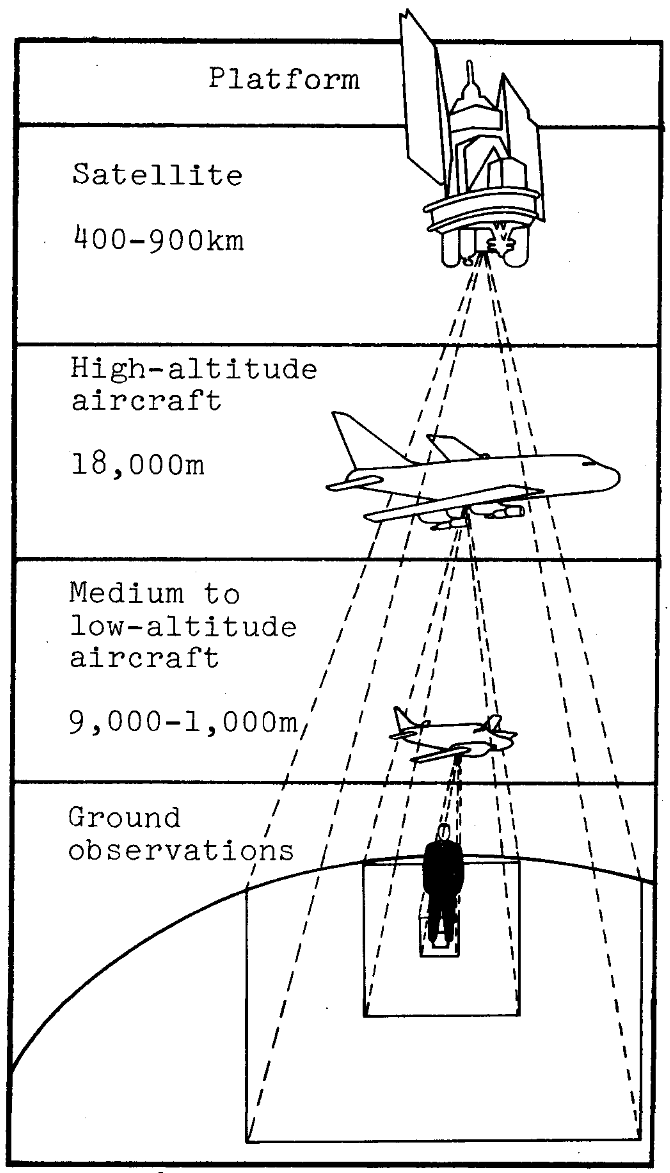


Figure 1. Typical sensors used to acquire remote sensing information. (After R.M. Hoffer and S.M. Davis)

Orbital Path for One Day

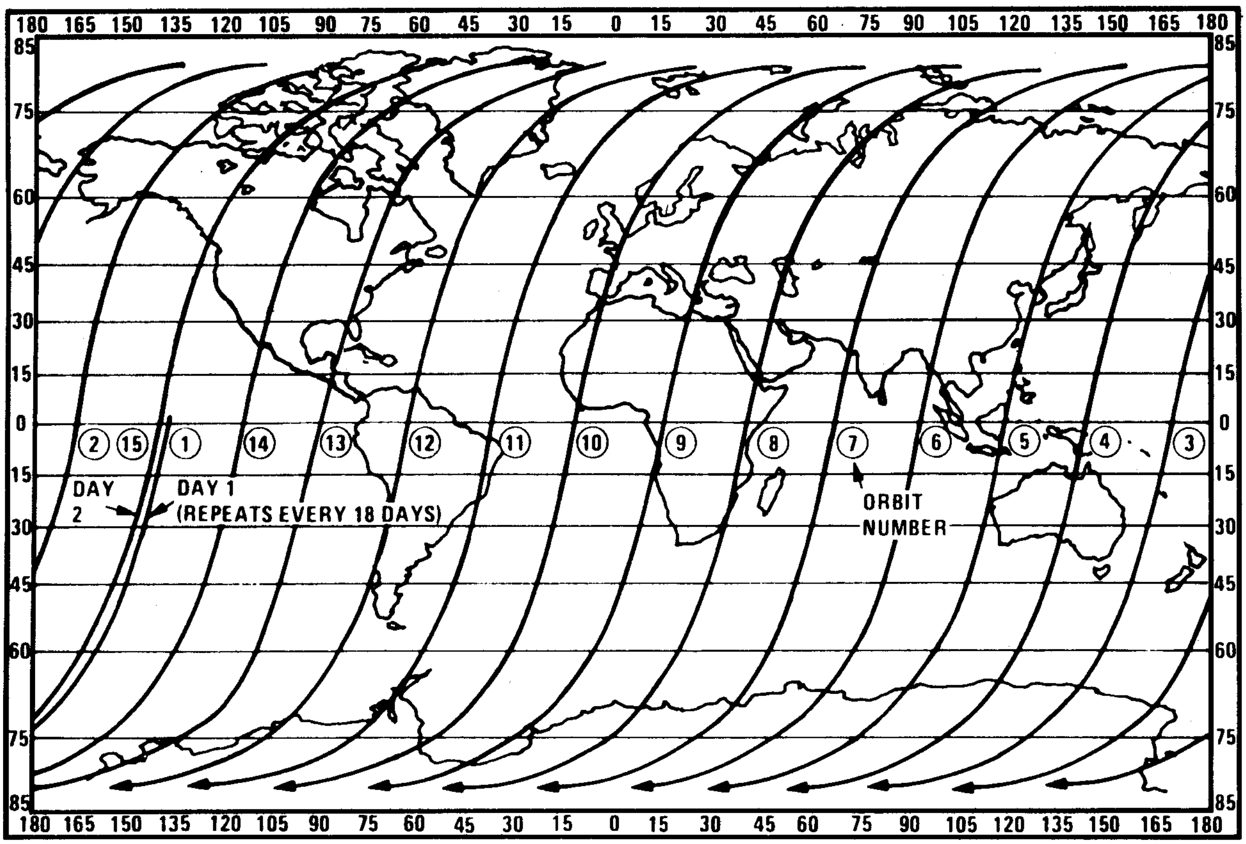


Figure 2 . Landsat Ground Trace for one day.

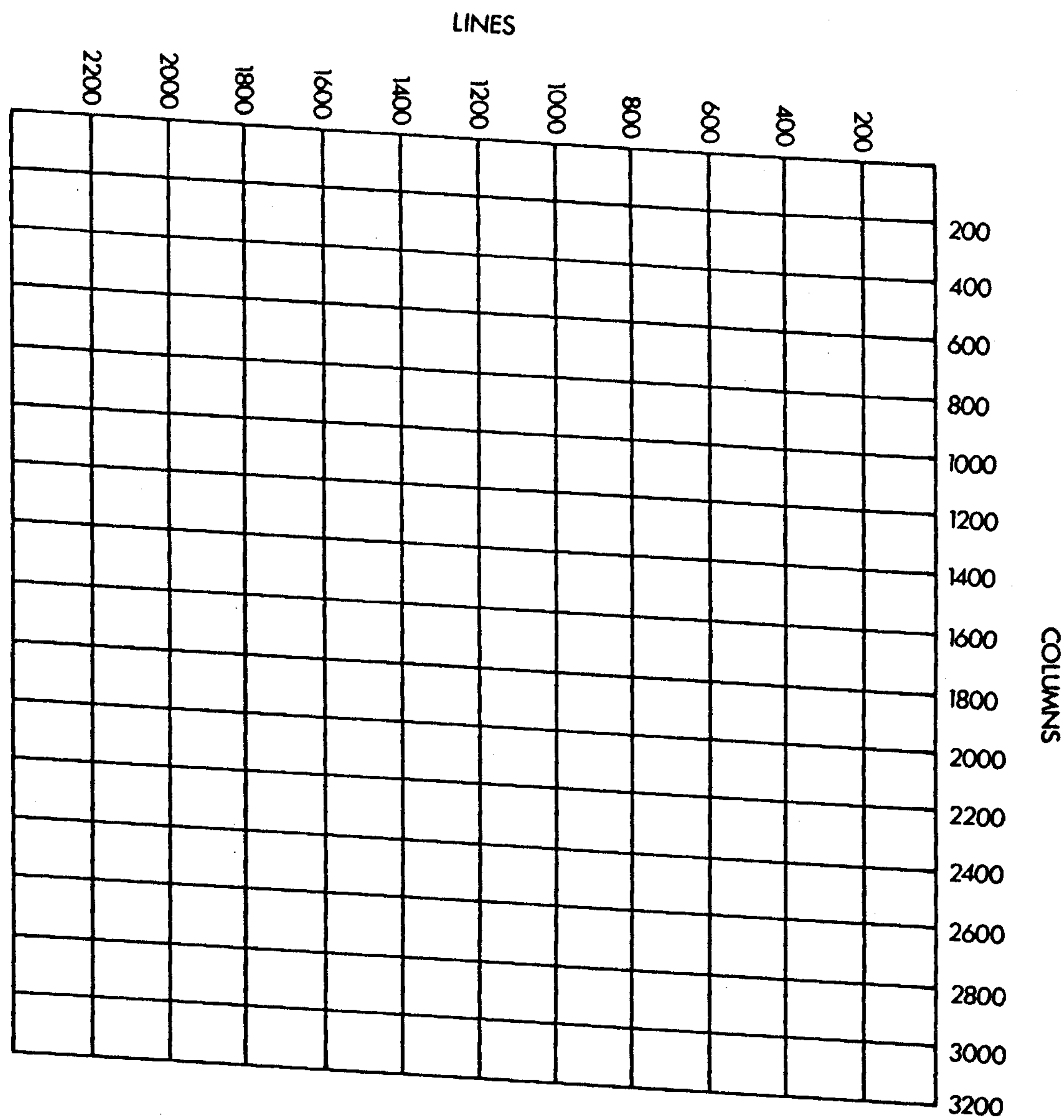


Figure 3. Coordinate grid overlay (2340 X 3232).

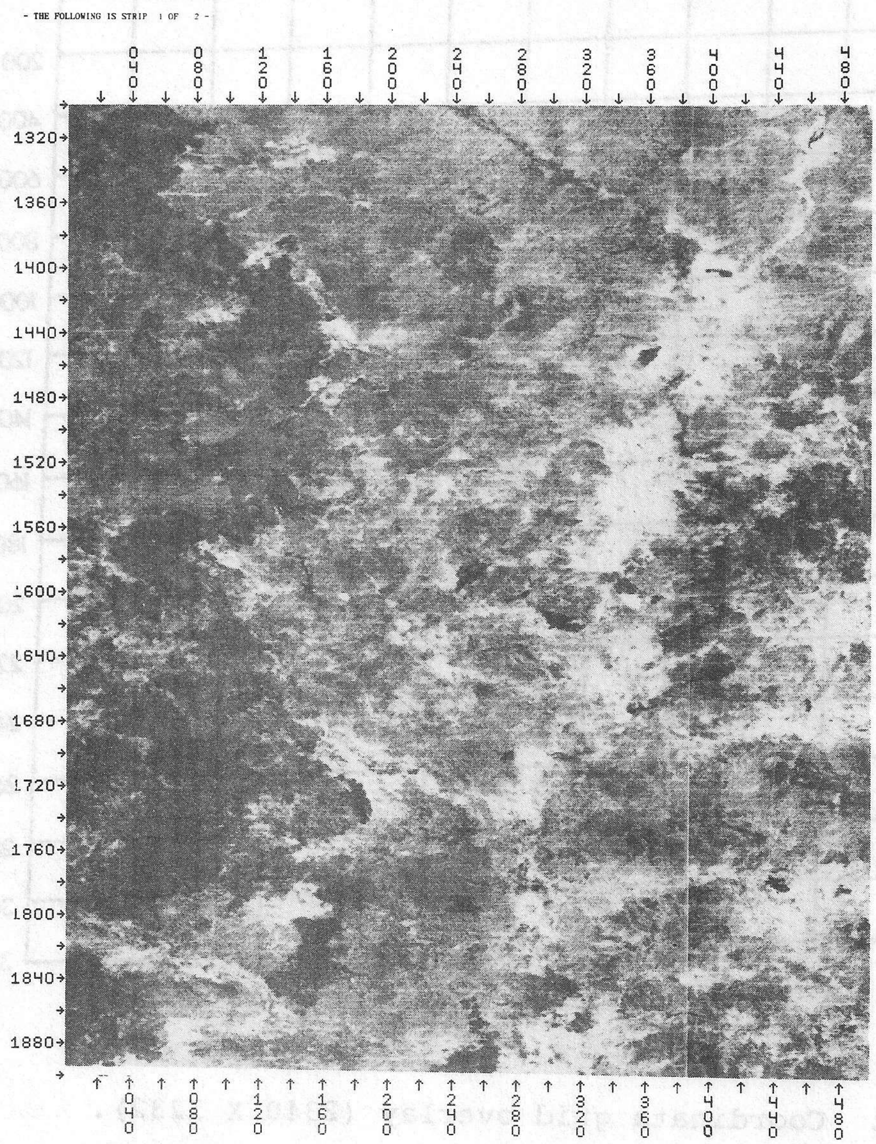

- THE FOLLOWING IS STRIP 1 OF 2 -
040 080 120 160 200 240 280 320 360 400 440 480
1320 1360 1400 1440 1480 1520 1560 1600 1640 1680 1720 1760 1800 1840 1880

Figure 4.

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BATMED                                   LABORATORY FOR APPLICATIONS OF REMOTE SENSING                    OCT   2,1979
DAGAKORO SAMAKE                                      PURDUE UNIVERSITY                                    01 21 57 PM
                                                                                                          LARSYS VERSION 3
DATA FROM MALI AREA 1

          RUN NUMBER............ 73012400                  DATE DATA TAKEN... APR  11,1973
          FLIGHT LINE... 126210290    MALI                 TIME DATA TAKEN..... 1229 HOURS
          DATA TAPE/FILE NUMBER.. 1068/ 3                  PLATFORM ALTITUDE..3062000 FEET
          REFORMATTING DATE. JUNE  1,1973                  GROUND HEADING..... 188 DEGREES

   CHANNEL  2    SPECTRAL BAND  0.60 TO  0.70 MICROMETERS    CALIBRATION CODE= 1    C0 = 0.0


       THE CHARACTER SET USED FOR DISPLAY IS                  HISTOGRAM BLOCK(S)

       BELOW  14.5            DISPLAYED AS M
       FROM   14.5 TO   45.5 DISPLAYED AS M
       FROM   45.5 TO   48.5 DISPLAYED AS $                RUN NUMBER........... 73012400
       FROM   48.5 TO   51.5 DISPLAYED AS X                LINES....... (   600, 2340, 10)
       FROM   51.5 TO   53.5 DISPLAYED AS Z                COLUMNS..... (     1, 1000, 10)
       FROM   53.5 TO   55.5 DISPLAYED AS *                CALIBRATION CODE............ 1
       FROM   55.5 TO   57.5 DISPLAYED AS I
       FROM   57.5 TO   60.5 DISPLAYED AS /
       FROM   60.5 TO   61.5 DISPLAYED AS =
       FROM   61.5 TO   64.5 DISPLAYED AS -
       FROM   64.5 TO   89.5 DISPLAYED AS
       ABOVE             89.5 DISPLAYED AS
```

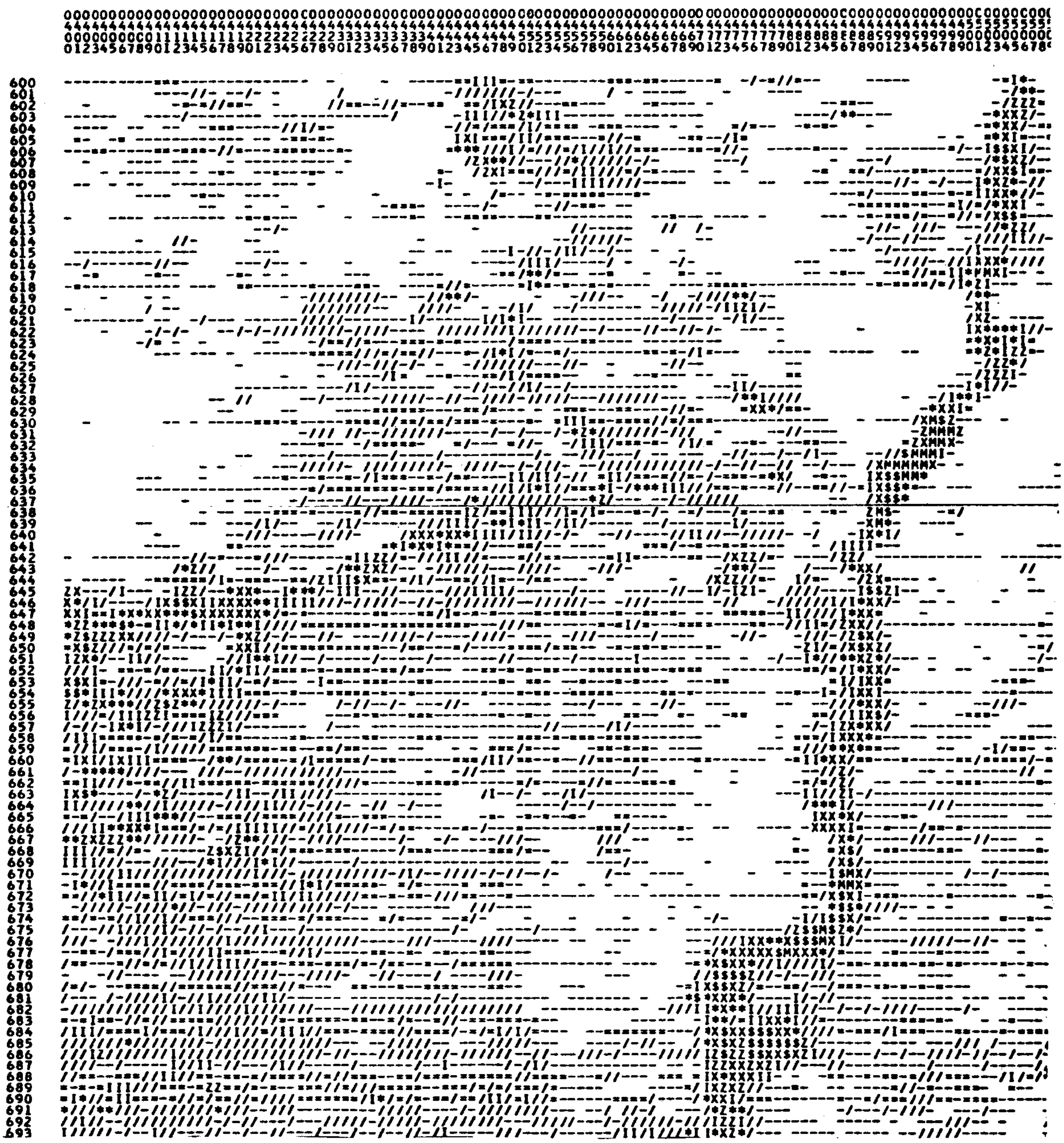

Figure 5.

Figure 6.

TABLE OF SCREEN SIZES

Image Size*	Maximum Number of Lines	Maximum Number of Columns	Maximum Total Area (in data points) Represented
1/5	2880	3840	11,059,200
1/4	2304	3072	7,077,888
1/3	1728	2304	3,981,312
1/2	1152	1536	1,769,472
1/1	576	768	442,368
4/1	288	384	110,592
16/1	144	192	27,648

*Pixels representing each data point/line and column interval.

Figure 7a

A Table of Screen Sizes
For Use With the Digital Display

at scale 1/5
To obtain a full frame display at: column width is:

SCALE	INCHES	CM
1/4	12 1/2	32.0
1/3	9 5/8	24.5
1/2	6 3/8	16.1
1/1	3 1/8	8.1
4/1	1 1/2	4.0
16/1	3/4	2.1

at scale 1/4
To obtain a full frame display at: column width is:

SCALE	INCHES	CM
1/3	11 7/8	30.4
1/2	7 3/4	19.9
1/1	3 7/8	10.0
4/1	1 7/8	4.8
16/1	7/8	2.4

at scale 1/3

SCALE	INCHES	CM
1/2	10 1/2	26.8
1/1	5 1/8	13.2
4/1	2 1/2	6.4
16/1	1 1/8	3.1

at scale 1/2

SCALE	INCHES	CM
1/1	7 7/8	20.0
4/1	3 7/8	9.9
16/1	1 3/4	4.7

at scale 1/1

SCALE	INCHES	CM
4/1	7 7/8	20.1
16/1	3 7/8	10.1

at scale 4/1

SCALE	INCHES	CM
16/1	7 7/8	20.1

Figure 7b

The Display Enlargement Table

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OCT 2,1979
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LARSYS VERSION 3

DATA FROM MALI AREA 1

****** HISTOGRAM GRAPH FOR CHANNEL 2 ******

SPECTRAL BAND 0.60 TO 0.70 MICROMETERS

RUN... 73012400 CALIBRATION CODE... 1 LINES... (600, 2340, 10) COLUMNS... (1, 1COC, 1C)

EACH * REPRESENTS... 74 SAMPLES. TOTAL NUMBER OF SAMPLES... 17500

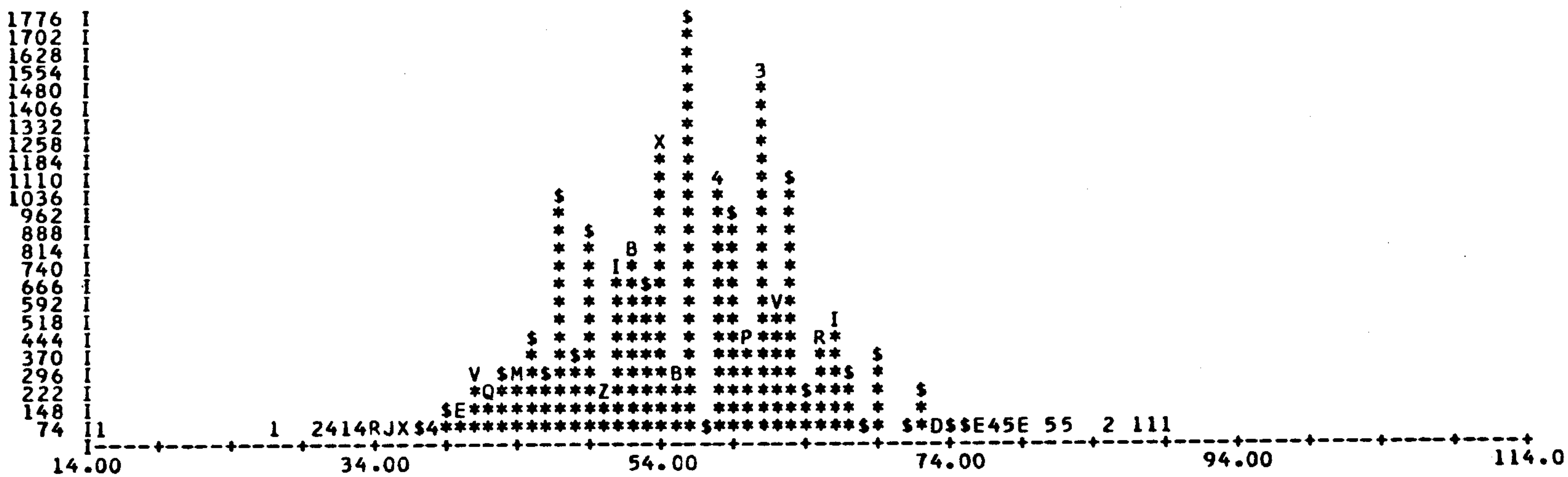

Figure 8a. Histogram from GDATA

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                                                                                         LARSYS VERSION 3
DATA FRCM MALI AREA 1

                        ****** HISTOGRAM GRAPH FOR CHANNEL  4 ******
                           SPECTRAL BAND  0.80 TO  1.10 MICROMETERS
RUN... 73012400    CALIBRATION CODE... 1    LINES... (  600, 2340,   10)    COLUMNS... (   1, 1COC,   10)
    EACH * REPRESENTS...  76  SAMPLES.                                     TOTAL NUMBER OF SAMPLES... 175C0
```

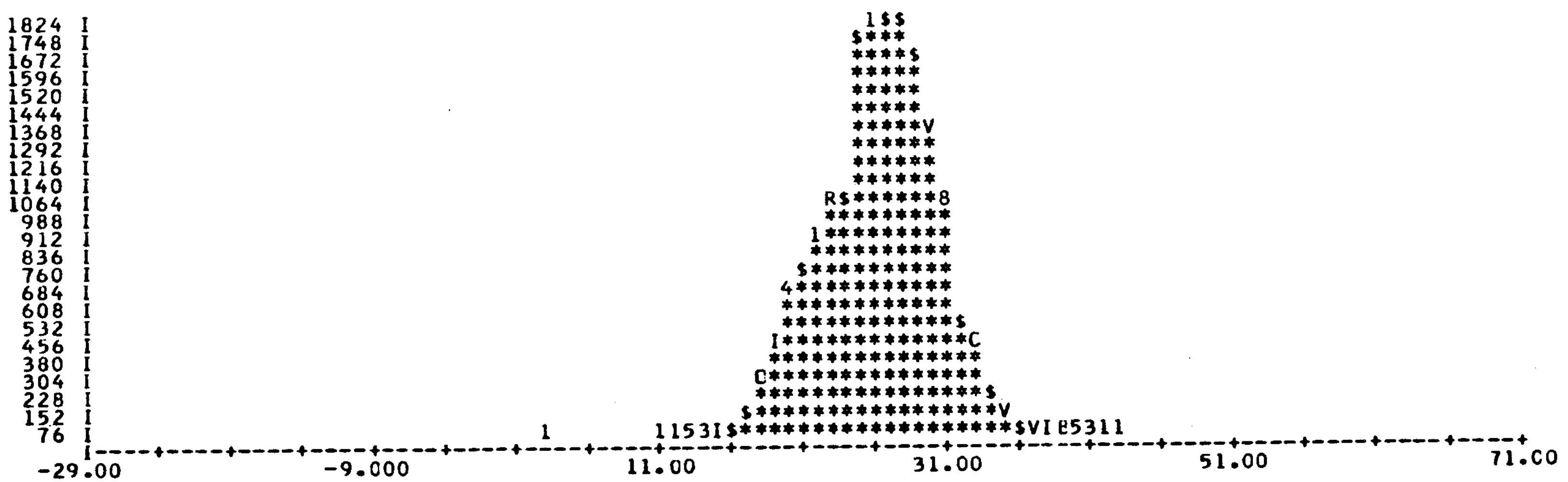

Figure 8b. Histogram from GDATA.

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NOV 6,1979
10 23 13 PM
LARSYS VERSION 3

DATA FROM MALI CLUSTER AREA NE

CLUSTERING INFORMATION

NUMBER OF CLUSTERS = 12 CLUSTERING UNIT SIZE = 9943 CLUSTERING INTERVAL = 1

CHANNEL NUMBER 1 SPECTRAL RANGE 0.50 TO 0.60 MICROMETERS CALIBRATION CODE 1
CHANNEL NUMBER 2 SPECTRAL RANGE 0.60 TO 0.70 MICROMETERS CALIBRATION CODE 1
CHANNEL NUMBER 3 SPECTRAL RANGE 0.70 TO 0.80 MICROMETERS CALIBRATION CODE 1
CHANNEL NUMBER 4 SPECTRAL RANGE 0.80 TO 1.10 MICROMETERS CALIBRATION CODE 1

CLUSTER	POINTS	MEANS CH(1)	CH(2)	CH(3)	CH(4)
1	322	59.60	77.82	77.31	36.85
2	661	56.53	71.87	70.54	33.29
3	1230	55.04	66.97	66.34	31.30
4	1155	52.34	64.67	64.15	30.17
5	1326	51.95	62.69	61.23	29.02
6	877	49.92	61.70	58.62	28.05
7	681	48.88	58.09	59.95	28.77
8	545	47.50	58.12	55.14	26.26
9	[illegible]	45.98	55.53	55.07	26.30
10	988	44.53	52.60	51.12	24.31
11	928	42.43	48.64	46.94	22.19
12	523	40.07	43.52	41.84	19.63

CLUSTER VARIANCES

	CH(1)	CH(2)	CH(3)	CH(4)
1	4.50	8.37	9.05	3.31
2	2.59	3.29	4.52	2.22
3	2.59	3.33	2.60	1.48
4	2.60	2.12	1.80	1.20
5	2.70	2.03	1.64	1.19
6	2.23	1.67	1.48	0.95
7	2.39	3.03	2.74	1.67
8	1.96	2.20	2.27	1.41
9	1.76	3.39	2.95	1.85
10	1.91	3.16	2.26	1.19
11	1.92	2.69	2.94	1.05
12	1.68	6.64	6.44	1.71

Figure 9. A sample of cluster means and variances.

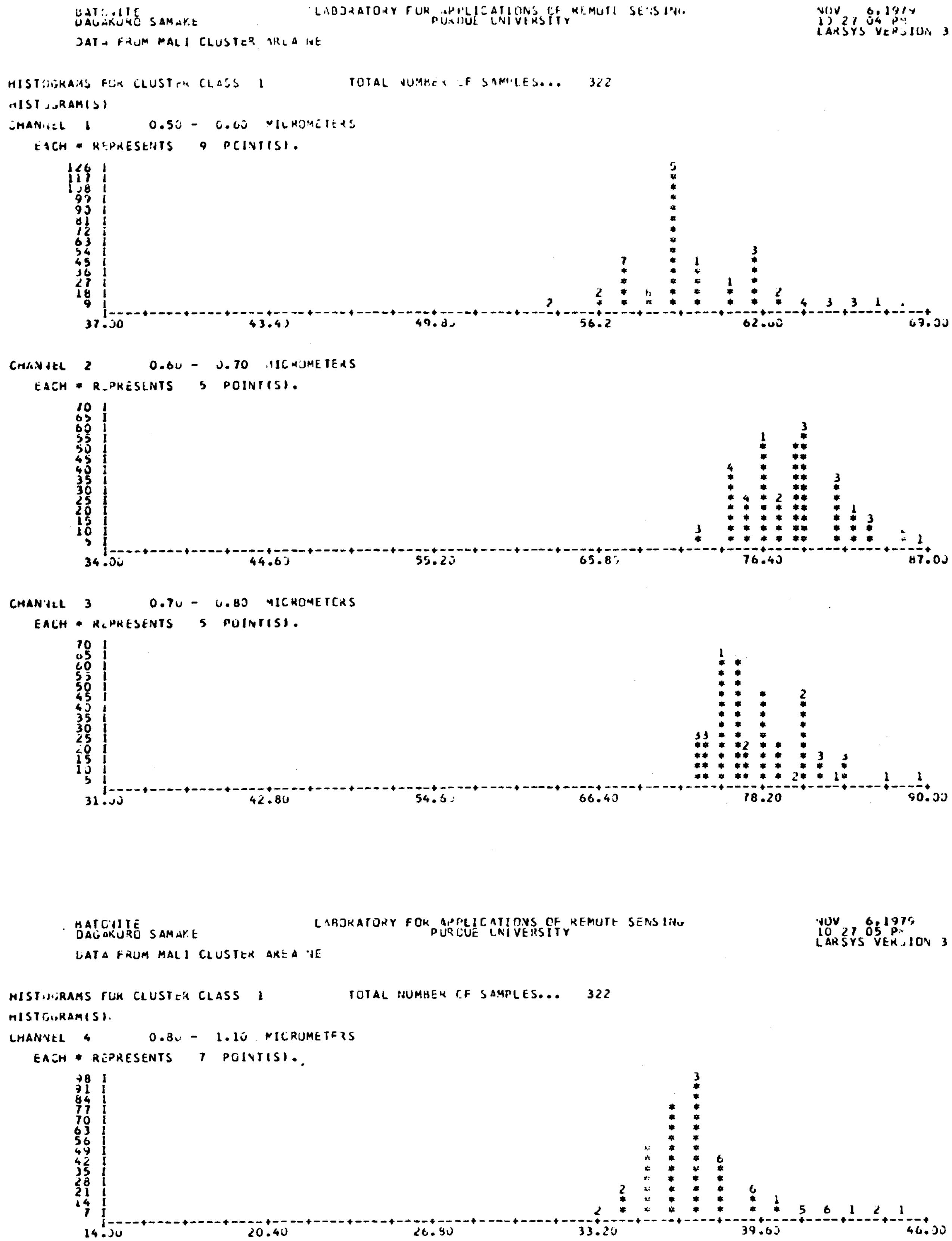

Figure 10. Sample of cluster histogram.

```
BATONITE                         LABORATORY FOR APPLICATIONS OF REMOTE SENSING                    NOV    6,1979
DAGAKORO SAMAKE                                PURDUE UNIVERSITY                                  10 27 02 PM
                                                                                                  LARSYS VERSION 3
DATA FROM MALI CLUSTER AREA NE

                                           FIELD INFORMATION
                                       ---------------------

FIELD                                          TYPE                               LINES    620-   640  (BY    1)
RUN NO.    73012400                            NO. OF SAMPLES  1281               COLUMNS  700-   760  (BY    1)
OTHER INFORMATION

                00000)00C00000000000000000000000000000000000000000000000 00000000
                77777777777777777777777777777777777777777777777777777 77777777
                00000000C011111111112222222222333333333344444444445555 55555556
                01234567890123456789012345678901234567890123456789012 34567890

         620    Y8KYY7).)Y2288KYV2KY2..7KKV77V277777..)77)22))728V28888887..)
         621    8KY27)..Y7)7YVVV22222772227.787)77777777)722VV2V8YY88VV272V22
         622    YKY7.)777.))272222Y277227))))27727))777)72VV82V88V88K2))))7Y2
         623    KY72YYKYY)..777772VVV222VV77)77)))72)772VVV8V))..)7)7).)77V2)
         624    YY28K8YKY277))7V2\2222222277)77)77)77228V22))2))777))))77227
         625    KYVY8VV8K8772777277722V2)777/)))77)7.))2VV2)22)))7222722227V
         626    YYYVV8K8888Y27)777227))7777777))77727VVV822))))72227))))))722
         627    8K8K88YVV22VVV7)722227722727(72227777772822227)2V22Y222228222
         628    2KKKKYY72)))))27)722222227)77777727722 72V888)28822Y2V8228V).)
         629    VNKKYVVV2))..)727772VVV)7222777777777VV2V8828V2V272V272227...
         630    88K8V2)VV2).)...288827)272VV2V2222222V)228V882272V822Y88V7)))
         631    V727VV2)72)72)).)888277)772V2777V72V882)288VVV272V8V2VV72V7))
         632    V77V8V27).227..7288))822VV87)27777 2VV828N8V88K8V882VV77V7772.
         633    Y2VV2VYVV2772222V82)).22V7   )22222722V88V2)7VV).))727222777))
         634    222V2772VYVVV722V272))2V2)))77727)))2KV222))2).))222222))))22
         635    7))72222722277 28KVV2777YY777)77..))8N887)22227V7))772277))))))2
         636    ).)722227772V8882V)2227VV88222)28NNN8222VV8YVKV77772V2V8).)27
         637    7))727V777772V888).)7V77VV88VV22N0N88VV22VVVKKV72V77VVV2).72V
         638    7227222))722))272).2VV7VV888V22NNNN888NNKKNKVVV88VVVVY7)2V882
         639    )72VV27227722227))))77)728888V8NNN8.88VNNK8KV2VKKV22VV7V2VVY7)
         640    ))))2V88Y8K2VV22))))27)88888K888282)V88KYVVVY8827728272 2V82))
```

NUMBER OF POINTS PER CLUSTER

CLUSTER	1	2	3	4	5	6	7	8	9	10
SYMBOL		.	)	7	2	V	Y	8	K	N
POINTS	2	43	186	282	334	182	49	142	40	20

CLUSTER	11	12
SYMBOL	O	W
POINTS	1	0

Figure 11, A sample of a cluster map.

DATA FROM MALI CLUSTER AREA NE

SEPARABILITY INFORMATION

I	J	D(I,J)	D(I)	D(J)	D(I)+D(J)	QUOT
1	2	10.164	9.838	5.609	15.447	0.658
1	3	17.020	9.776	4.112	13.889	1.225
1	4	21.060	9.826	2.818	12.644	1.666
1	5	24.651	9.896	2.731	12.626	1.952
1	6	27.925	9.896	3.187	13.083	2.135
1	7	29.515	9.628	4.269	13.898	2.124
1	8	33.078	9.915	4.058	13.972	2.367
1	9	35.862	9.755	3.688	13.443	2.668
1	10	41.304	9.830	4.345	14.174	2.914
1	11	47.793	9.844	5.165	15.008	3.184
1	12	55.790	9.857	8.088	17.945	3.109
2	3	6.918	5.314	4.171	9.486	0.729
2	4	10.956	5.424	2.833	8.257	1.327
2	5	14.506	5.494	2.735	8.229	1.763
2	6	17.791	5.580	3.182	8.762	2.030
2	7	19.525	5.282	4.262	9.544	2.046
2	8	22.921	5.560	4.061	9.621	2.383
2	9	25.787	5.441	3.658	9.099	2.834
2	10	31.192	5.497	4.337	9.834	3.172
2	11	37.672	5.510	5.167	10.677	3.528
2	12	45.662	5.512	8.013	13.525	3.376
3	4	4.321	3.906	2.937	6.842	0.632
3	5	7.699	4.000	2.712	6.712	1.147
3	6	11.136	3.936	3.121	7.057	1.578
3	7	12.812	4.022	4.218	8.240	1.555
3	8	16.126	4.028	4.036	8.065	2.000
3	9	19.075	3.981	3.603	7.584	2.515
3	10	24.439	4.000	4.309	8.309	2.941
3	11	30.899	4.015	5.176	9.190	3.362
3	12	38.864	4.032	7.724	11.756	3.306
4	5	3.737	2.827	2.722	5.550	0.673
4	6	7.046	2.827	3.107	5.934	1.187
4	7	8.657	2.880	4.273	7.153	1.210
4	8	12.146	2.807	4.087	6.894	1.762
4	9	14.848	2.833	3.647	6.480	2.291
4	10	20.263	2.820	4.323	7.143	2.837
4	11	26.745	2.818	5.174	7.992	3.346
4	12	34.736	2.816	8.070	10.886	3.191
5	6	3.576	2.694	3.027	5.721	0.625
5	7	5.676	3.161	4.162	7.322	0.775
5	8	8.461	2.698	4.062	6.760	1.252
5	9	11.462	2.803	3.550	6.353	1.804
5	10	16.760	2.750	4.310	7.060	2.374
5	11	23.213	2.743	5.169	7.912	2.934
5	12	31.181	2.741	7.775	10.516	2.965
6	7	4.054	2.864	4.131	6.995	0.580
6	8	5.329	3.341	4.105	7.446	0.716
6	9	8.292	3.217	3.574	6.790	1.221
6	10	13.496	3.216	4.360	7.576	1.781
6	11	19.947	3.213	5.134	8.347	2.390
6	12	27.934	3.217	8.063	11.280	2.476
7	8	5.462	4.323	3.932	8.254	0.662
7	9	6.676	4.219	3.765	7.983	0.836
7	10	12.114	4.265	4.287	8.552	1.416
7	11	18.535	4.271	5.127	9.398	1.972
7	12	26.479	4.278	7.898	12.176	2.175
8	9	4.336	3.649	3.352	7.002	0.619
8	10	8.658	3.874	4.213	8.087	1.071
8	11	14.956	3.950	5.094	9.044	1.654
8	12	22.862	3.992	7.394	11.386	2.008
9	10	5.522	3.835	4.317	8.152	0.677
9	11	11.995	3.781	5.110	8.892	1.349
9	12	19.996	3.770	8.373	12.143	1.647
10	11	6.495	4.356	5.136	9.492	0.684
10	12	14.507	4.362	8.390	12.752	1.138
11	12	8.015	5.098	8.496	13.594	0.590

AVERAGE QUOTIENT 1.865

Figure 12. Sample separability information from Cluster.

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LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

DATA FROM MALI CLUSTER AREA NE

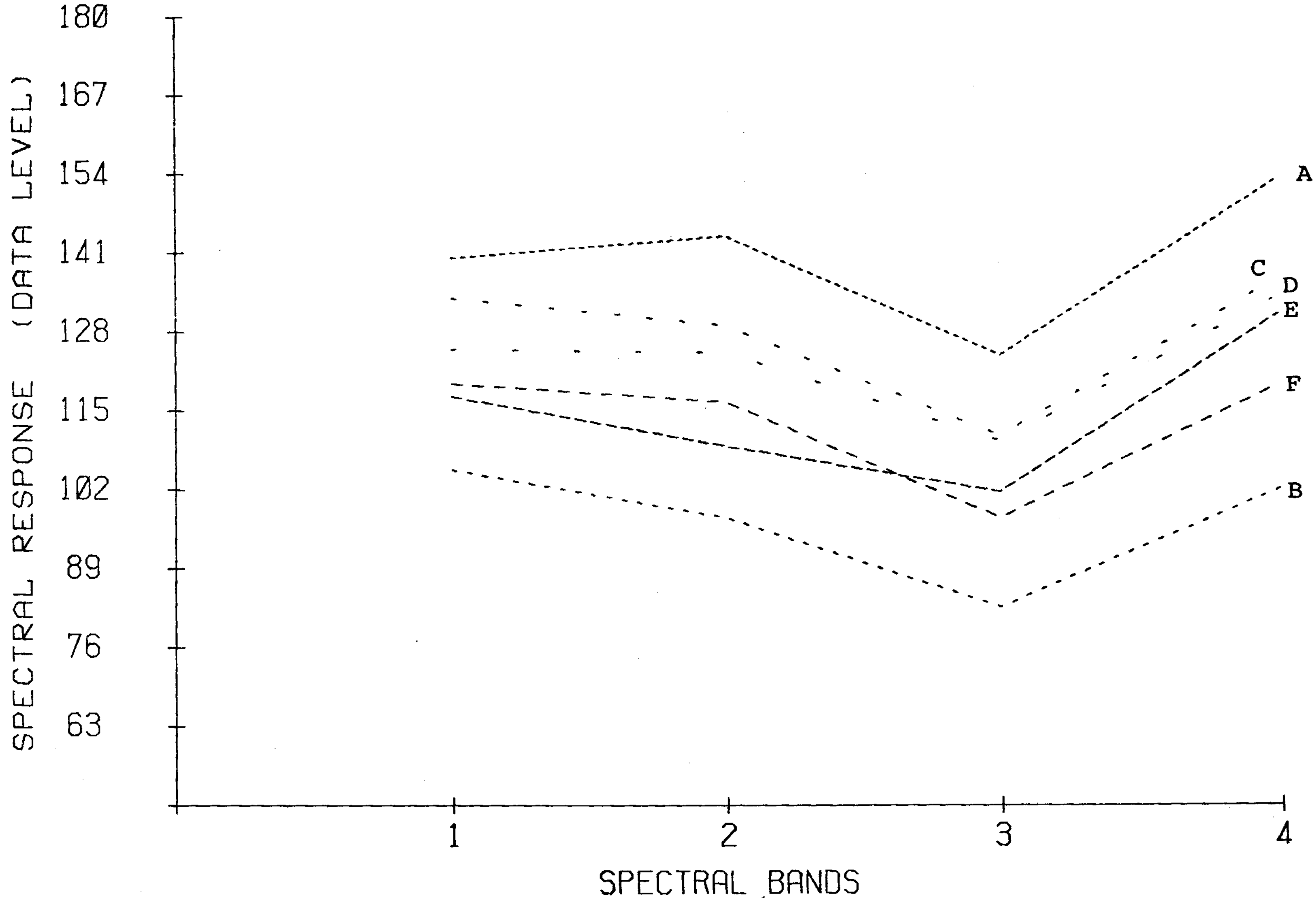
RESULTS OF CLUSTER GROUPING

THRESHOLD = 0.750

GROUP	CLUSTERS	NO. PTS.
1		
	1	322
	2	661
2		
	3	1230
	4	1155
3		
	5	1326
4		
	6	877
	7	681
5		
	8	545
	9	707
6		
	10	988
7		
	11	928
	12	523

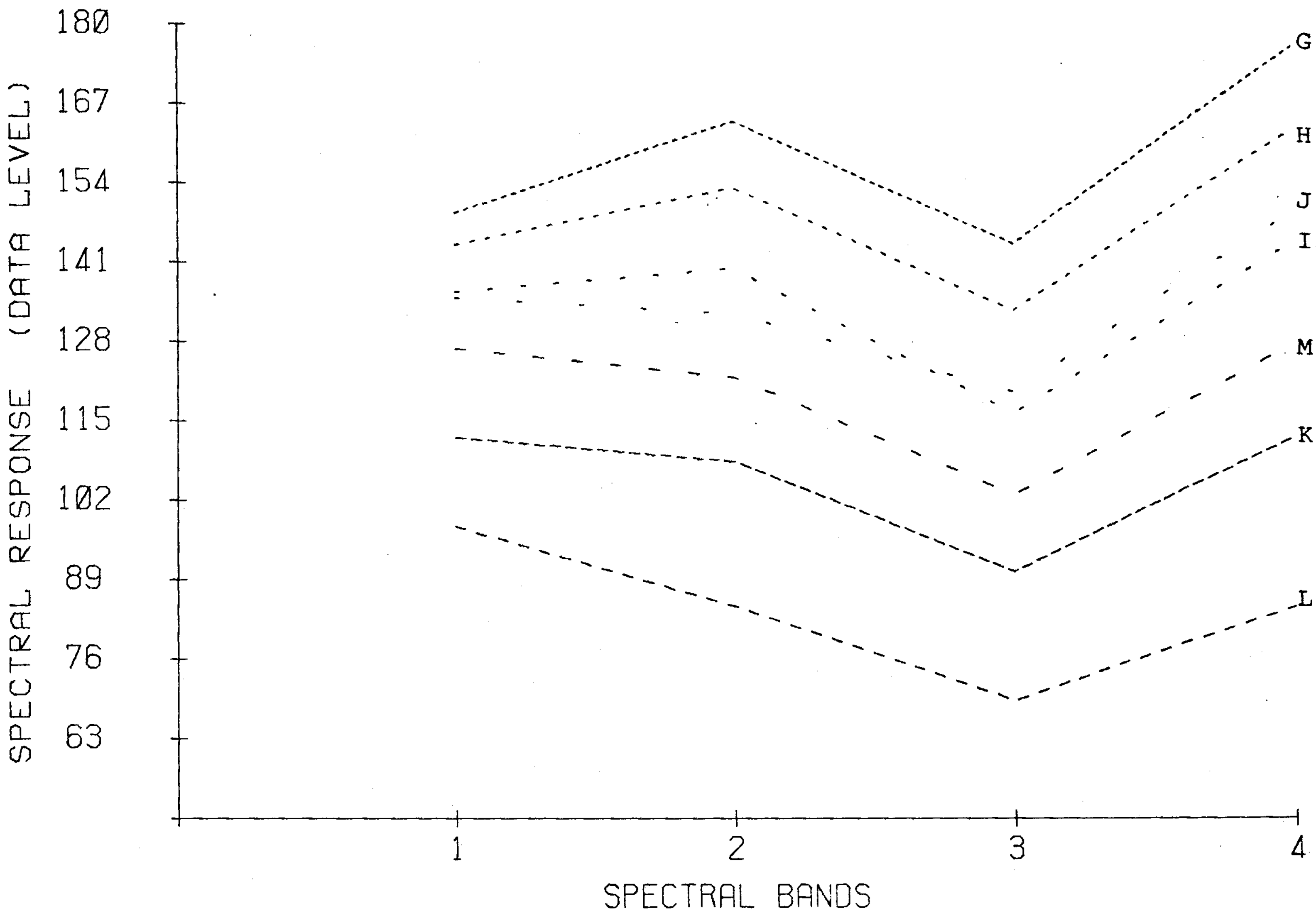
I0103 CPU TIME USED WAS 249.855 SECONDS. (LARSMN)

Figure 13. Sample of Cluster grouping results.



CALIBRATED MEANS OF MALI CLASSIFICATION
CLASSES 1-6

Figure 14a



CALIBRATED MEANS OF MALI CLASSIFICATION
CLASSES 7-13

Figure 14b

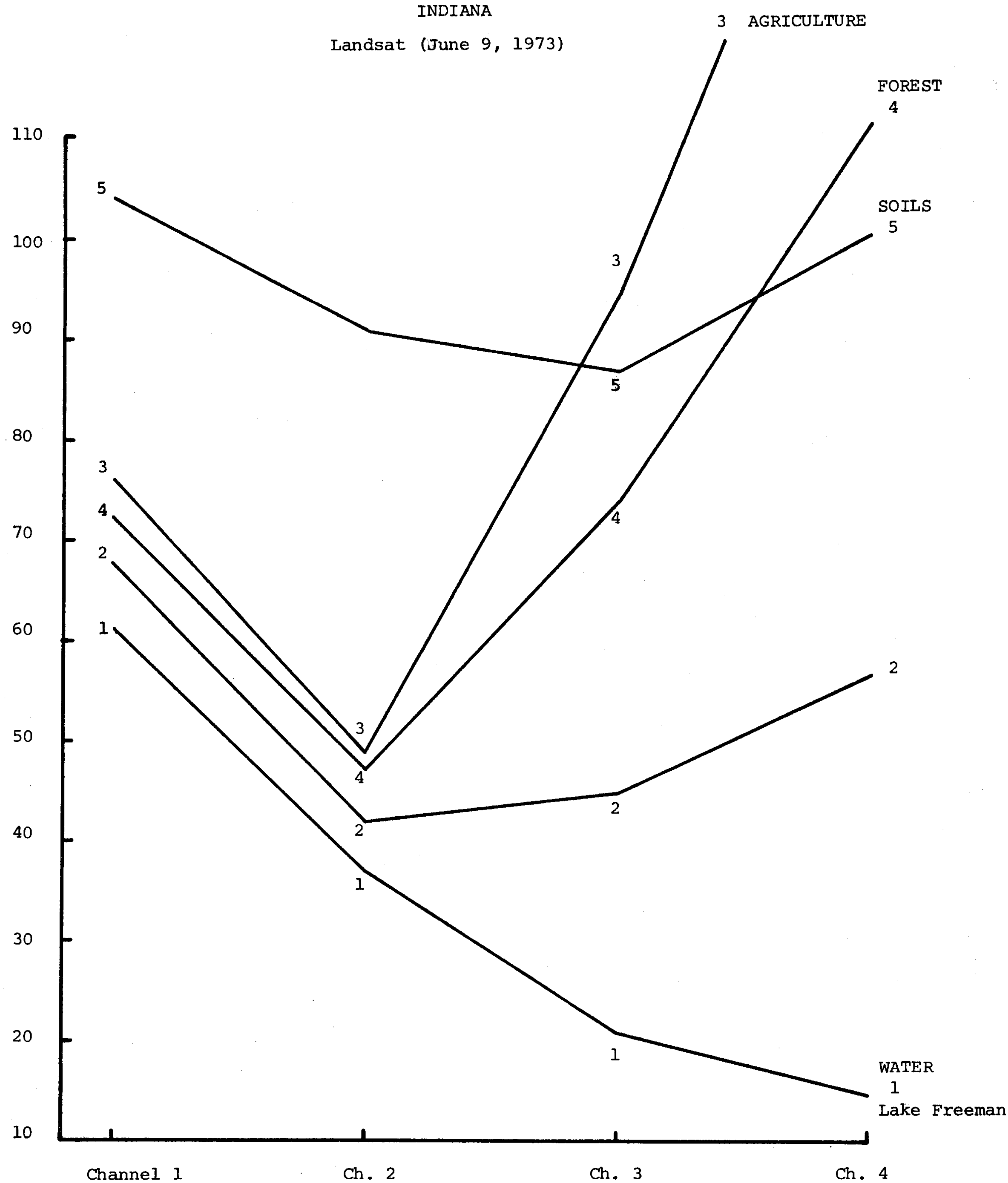

INDIANA
Landsat (June 9, 1973)
3 AGRICULTURE
FOREST
4
SOILS
5
2
WATER
1
Lake Freeman
110
100
90
80
70
60
50
40
30
20
10
5
3
4
2
1
3
4
2
1
3
5
4
2
1
Channel 1
Ch. 2
Ch. 3
Ch. 4

Figure 15a

ILLINOIS

August 9, 1972

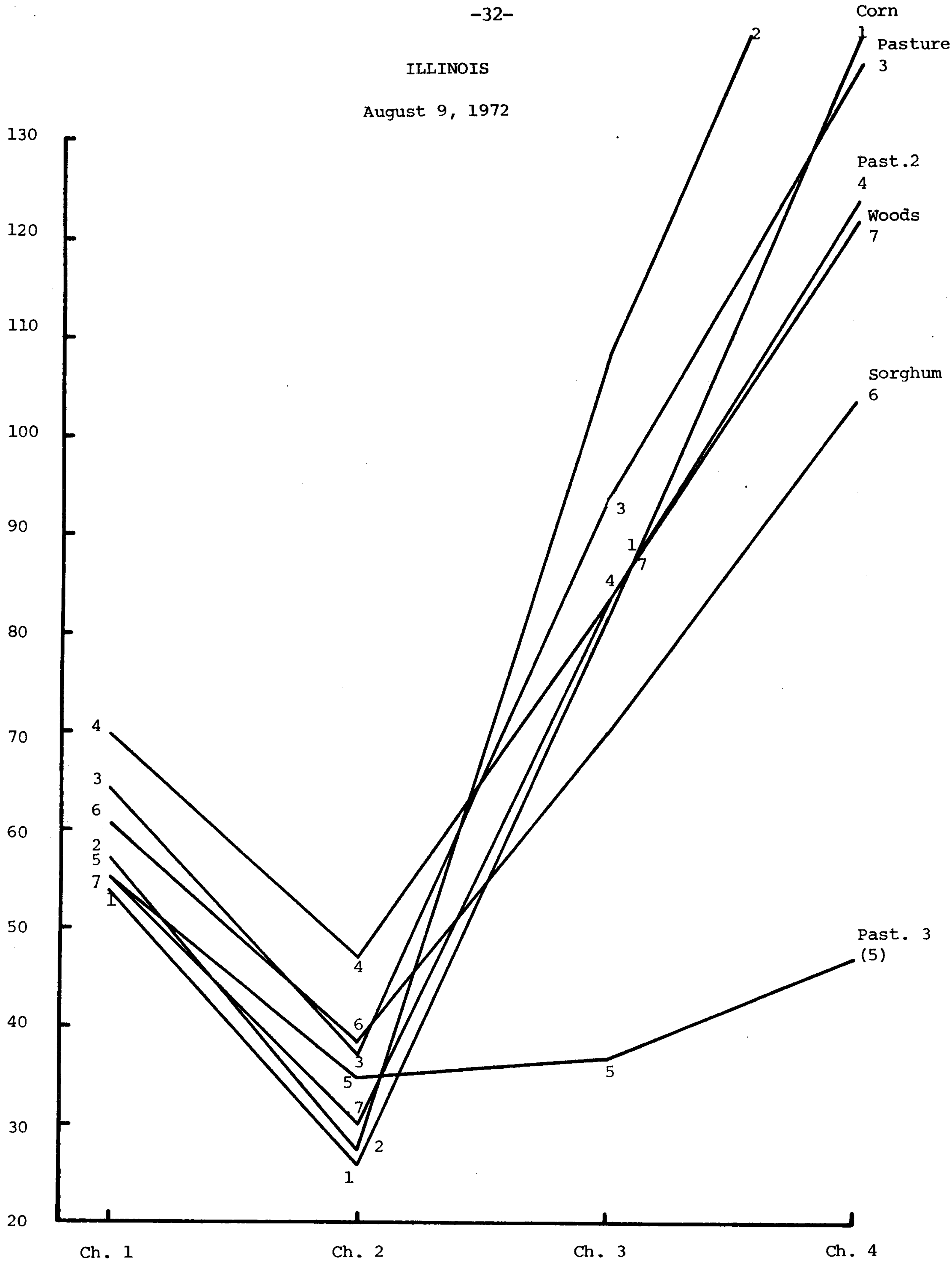


Figure 15b

BOLIVIA

(Andres Ibañez)

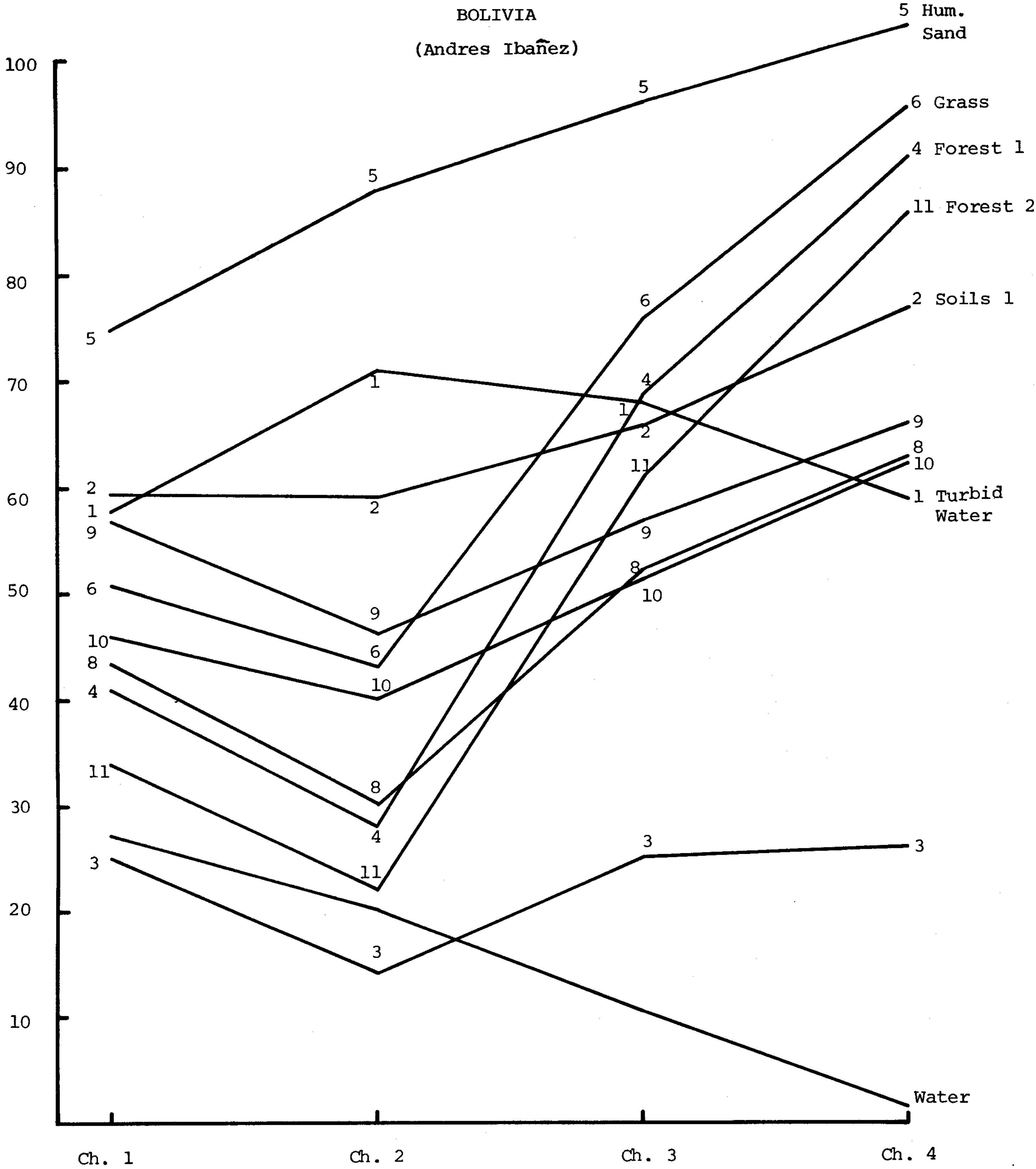


Figure 15c

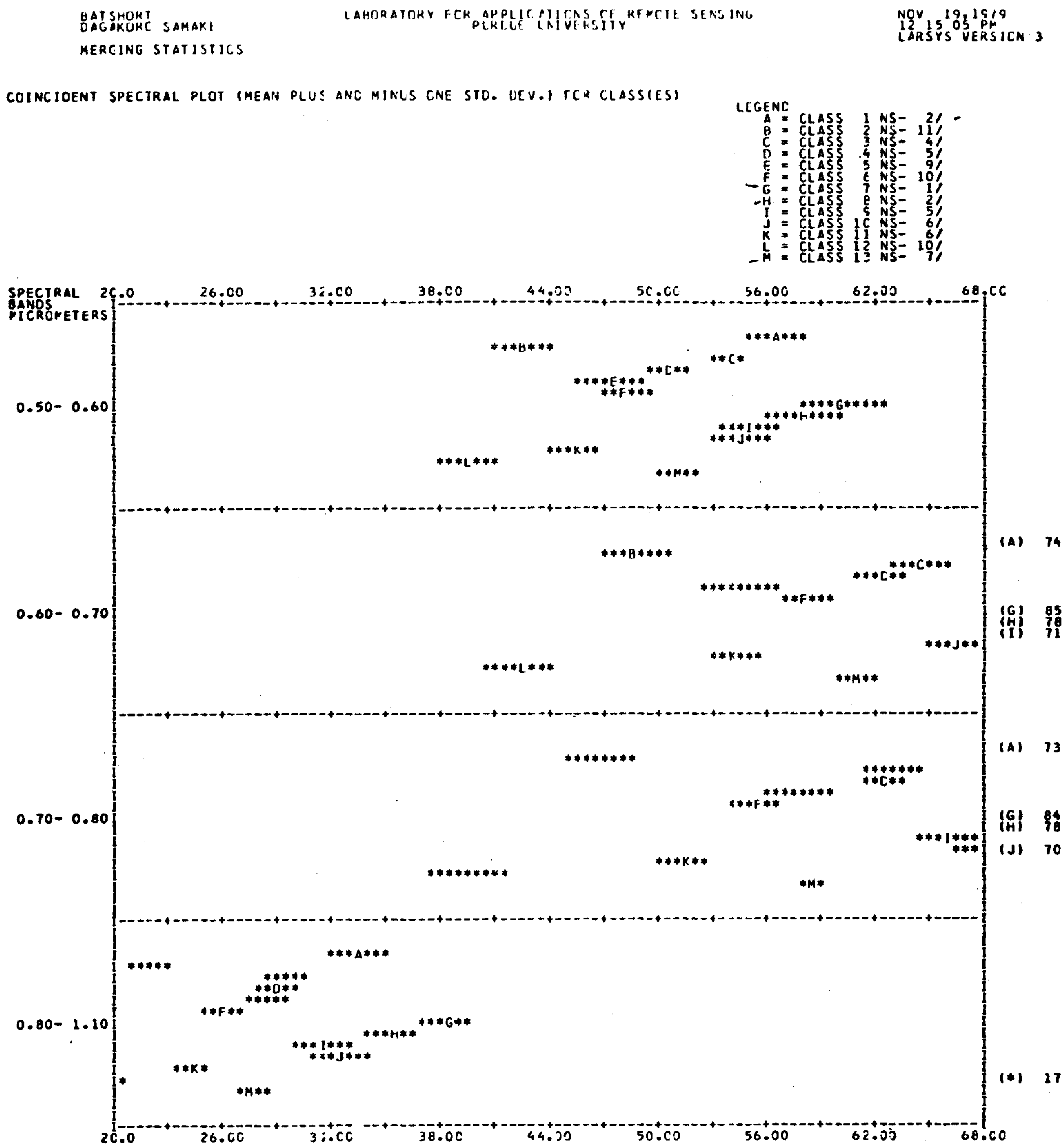


Figure 16. Coincident spectral plot.

MERGING STATISTICS

COINCIDENTAL BI-SPECTRAL PLOT(MEAN) FOR CLASS(ES)

LEGEND
A = CLASS 1 NS- 2/
B = CLASS 2 NS- 11/
C = CLASS 3 NS- 4/
D = CLASS 4 NS- 5/
E = CLASS 5 NS- 9/
F = CLASS 6 NS- 10/
G = CLASS 7 NS- 1/
H = CLASS 8 NS- 2/
I = CLASS 9 NS- 5/
J = CLASS 10 NS- 6/
K = CLASS 11 NS- 6/
L = CLASS 12 NS- 10/
M = CLASS 13 NS- 7/

MEANS PLOT OF CHANNEL 1 & 2 VERSES 3 & 4

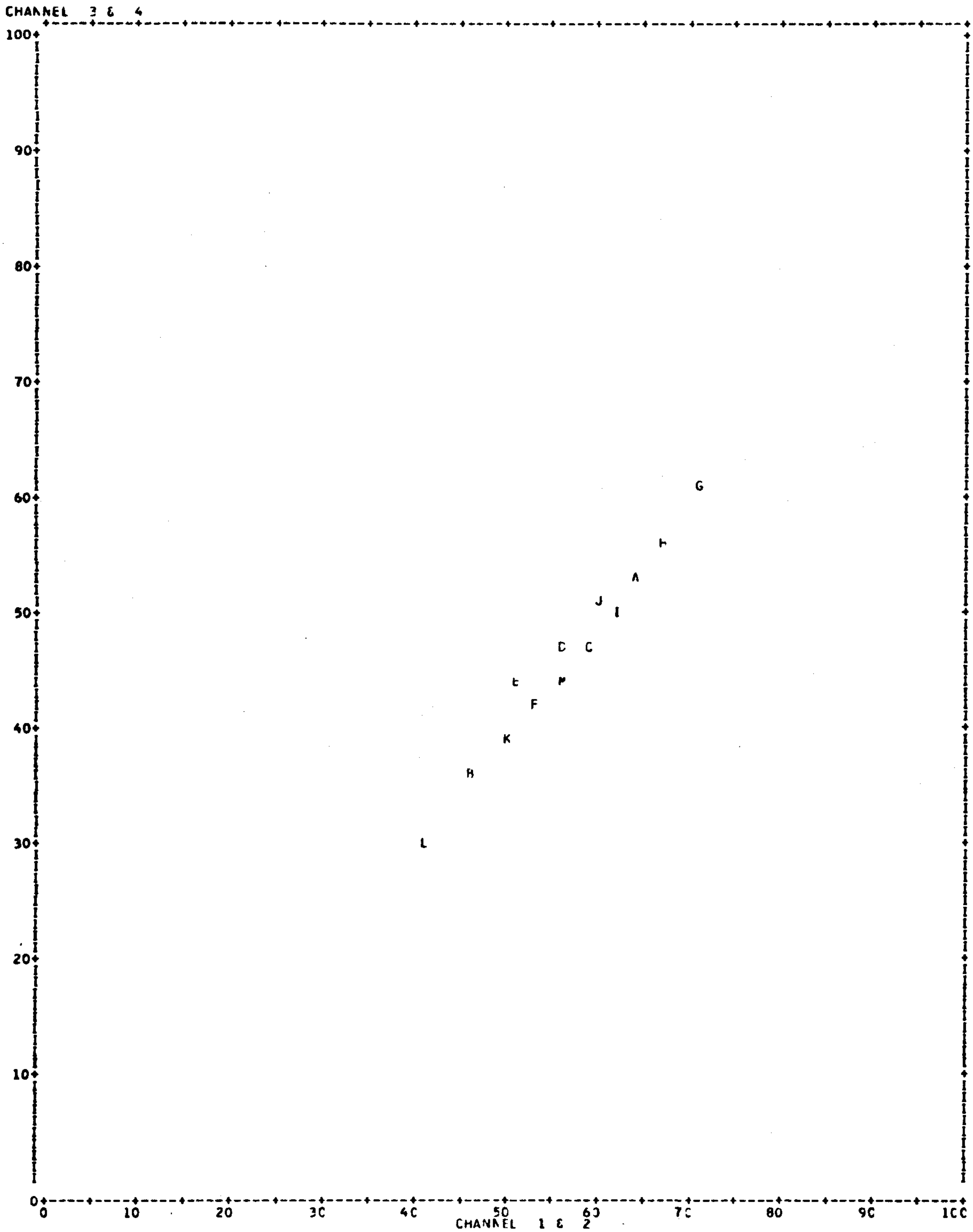


Figure 17.

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PURDUE UNIVERSITY

SEPARABILITY OF ALL CLASSES

SEPARABILITY STUDY

CLASS....NS- 17

CHANNEL	1	2	3	4
SPECTRAL BAND	0.50 - 0.60	0.60 - 0.70	0.70 - 0.80	0.80 - 1.10
MEAN	59.60	77.82	77.31	36.85
STD. DEV.	2.12	2.89	3.01	1.82

CORRELATION MATRIX

SPECTRAL BAND	0.50 - 0.60	0.60 - 0.70	0.70 - 0.80	0.80 - 1.10
0.50- 0.60	1.00			
0.60- 0.70	0.36	1.00		
0.70- 0.80	0.42	0.59	1.00	
0.80- 1.10	0.50	0.37	0.63	1.00

Figure 18. A sample of mean, standard deviation and correlation from separability.

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LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

NOV 13,1979
11 10 08 AM
LARSYS VERSION 3

SEPARABILITY OF ALL CLASSES

RETENTION LEVEL .. 1 MAXIMUM 30000
MINIMUM 0

DIVERGENCE **WITH** SATURATING TRANSFORM

	CHANNELS	DIJ(MIN)	D(AVE)	AB (10)	AC (10)	AD (10)	AE (10)	AF (10)	AG (10)	AH (10)	AI (10)	AJ (10)	AK (10)
1.	1 2 3 4	148.	1837.	1653	1999	2000	2000	2000	2000	2000	2000	2000	2000

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	CHANNELS	AL (10)	AM (10)	AN (10)	AO (10)	AP (10)	AQ (10)	AR (10)	AS (10)	AT (10)	AU (10)	AV (10)	AW (10)	AX (10)	AY (10)	AZ (10)
1.	1 2 3 4	2000	1284	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	625	614

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	CHANNELS	A$ (10)	A+ (10)	A= (10)	A/ (10)	¢A (10)	AB (10)	AC (10)	AD (10)	AE (10)	AF (10)	AG (10)	AH (10)	AI (10)	AJ (10)	AK (10)
1.	1 2 3 4	1946	2000	2000	2000	2000	2000	2000	2000	249	1726	1999	2000	2000	2000	2000

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	CHANNELS	AL (10)	AM (10)	AN (10)	AO (10)	AP (10)	AQ (10)	AR (10)	AS (10)	AT (10)	AU (10)	AV (10)	AW (10)	AX (10)	AY (10)	AZ (10)
1.	1 2 3 4	2000	2000	2000	1768	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	CHANNELS	BC (10)	BD (10)	BE (10)	BF (10)	BG (10)	BH (10)	BI (10)	BJ (10)	BK (10)	BL (10)	BM (10)	BN (10)	BO (10)	BP (10)	BQ (10)
1.	1 2 3 4	1641	1999	2000	2000	2000	2000	2000	2000	2000	2000	259	1664	2000	1998	2000

Figure 19. A sample of transformed divergence from separability.

CLASSES THAT MAY BE COMBINED-MAX DIV. = 1750

AB	1653.
AM	1284.
AY	825.
AZ	614.
AE	249.
AF	1726.
BC	1641.
BM	259.
BN	1664.
BZ	1575.
B$	593.
B+	796.
B=	1597.
BE	1715.
BF	740.
BG	428.
CD	1467.
CM	1733.
CN	153.
CP	1550.
C=	948.
C/	541.
CA	1039.
CF	907.
CG	1430.
CC	891.
CP	667.
CE	1496.
DN	1428.
DC	938.
DF	946.
DG	1464.
D/	1698.
DA	385.
DE	1037.
DG	530.
DP	524.
DC	1385.
DR	891.
DS	1742.
EF	1418.

Figure 20. A sample of grouping with respect to maximum divergence value of 1750.

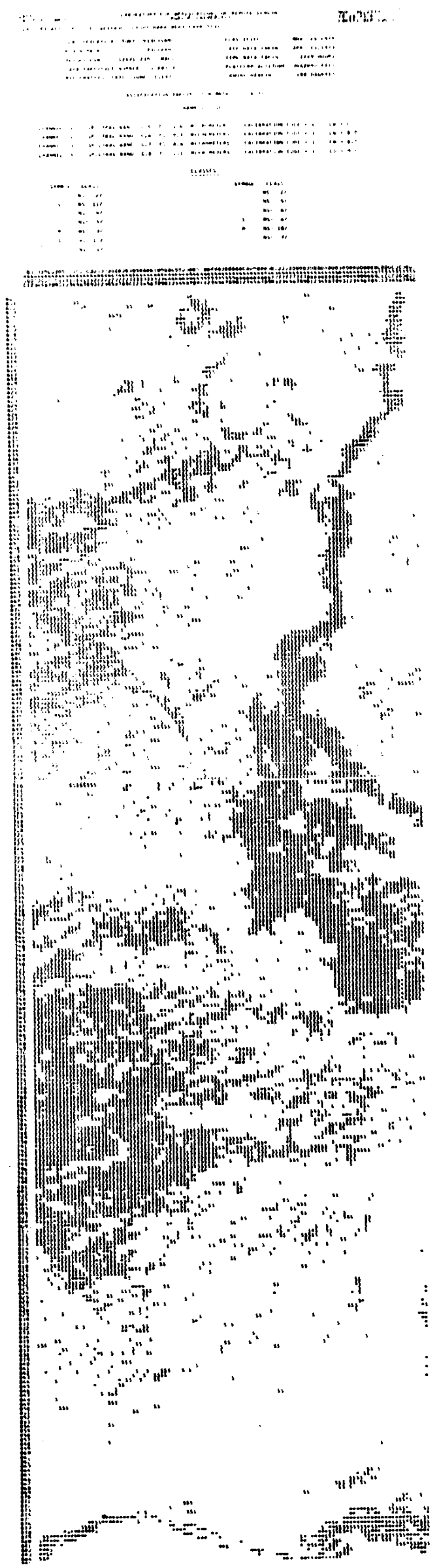

Figure 21a. Soils and Wetland.

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

NOV 30,1979

CLASSIFICATION RESULTS FARM LANDS

CLASSIFICATION STUDY 931035090
RUN NUMBER............ 73012400
FLIGHT LINE... 126210290 MALI
DATA TAPE/FILE NUMBER.. 1068/ 3
REFORMATTING DATE. JUNE 1,1973

CLASSIFIED NOV 26,1979
DATE DATA TAKEN... APR 11,1973
TIME DATA TAKEN..... 1229 HOURS
PLATFORM ALTITUDE..3062000 FEET
GROUND HEADING..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 652/ 1

CHANNELS USED

CHANNEL 1	SPECTRAL BAND 0.50 TO 0.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 2	SPECTRAL BAND 0.60 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 3	SPECTRAL BAND 0.70 TO 0.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND 0.80 TO 1.10 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

CLASSES

SYMBOL	CLASS	SYMBOL	CLASS
	NS- 2/	.	NS- 2/
	NS- 11/	.	NS- 5/
	NS- 4/	.	NS- 6/
	NS- 5/		NS- 6/
	NS- 9/		NS- 10/
	NS- 10/		NS- 7/
	NS- 1/		

Figure 21b. Farmland.

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LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

NOV 30,1979
11 11 01 AM
LARSYS VERSION 3

CLASSIFICATION RESULTS DORMANT VEGETATION

CLASSIFICATION STUDY 933035090	CLASSIFIED NOV 26,1979
RUN NUMBER............ 73012400	DATE DATA TAKEN... APR 11,1973
FLIGHT LINE... 126210290 MALI	TIME DATA TAKEN..... 1229 HOURS
DATA TAPE/FILE NUMBER.. 1068/ 3	PLATFORM ALTITUDE..3062000 FEET
REFORMATTING DATE. JUNE 1,1973	GROUND HEADING..... 188 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 652/ 1

CHANNELS USED

CHANNEL 1	SPECTRAL BAND 0.5C TO 0.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 2	SPECTRAL BAND 0.60 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 3	SPECTRAL BAND 0.70 TO 0.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND 0.80 TO 1.10 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

CLASSES

SYMBOL	CLASS	SYMBOL	CLASS
	NS- 2/		NS- 2/
	NS- 11/		NS- 5/
/	NS- 4/		NS- 6/
/	NS- 5/		NS- 6/
	NS- 9/		NS- 10/
	NS- 10/	/	NS- 7/
	NS- 1/		

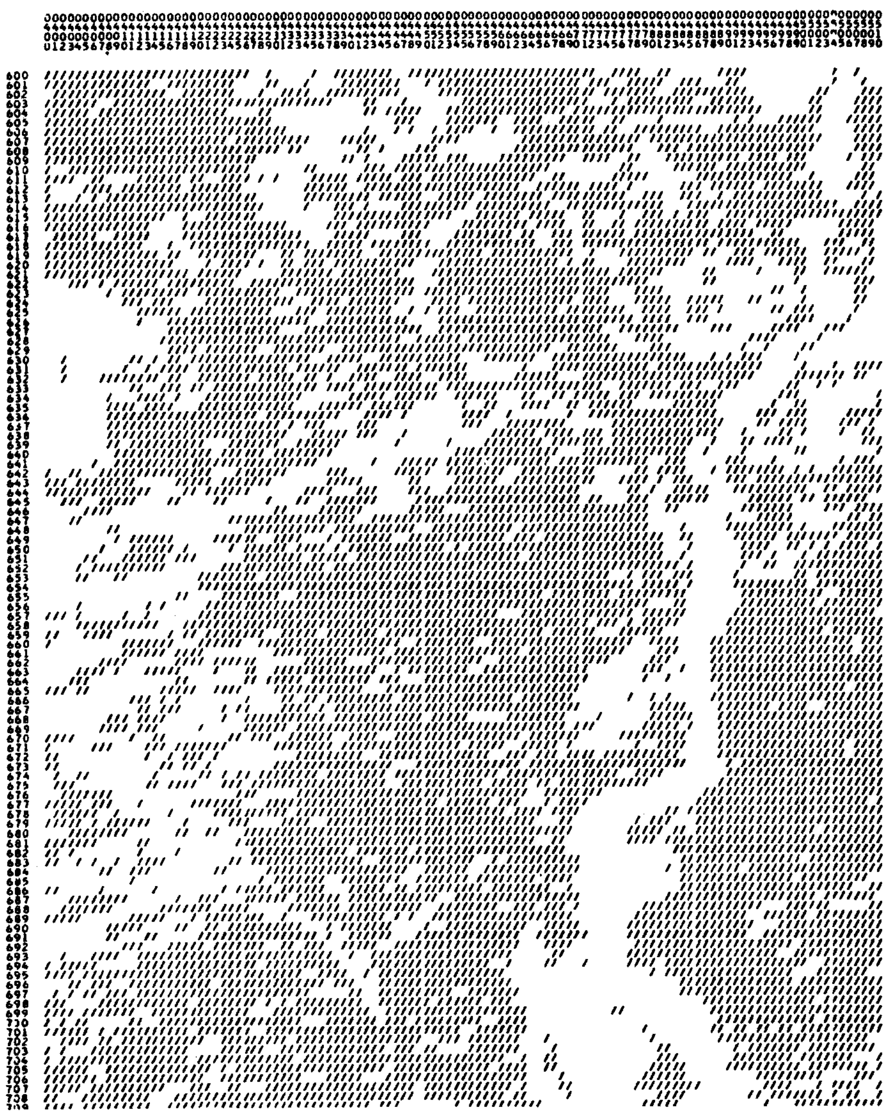

Figure 21c. Dormant vegetation.

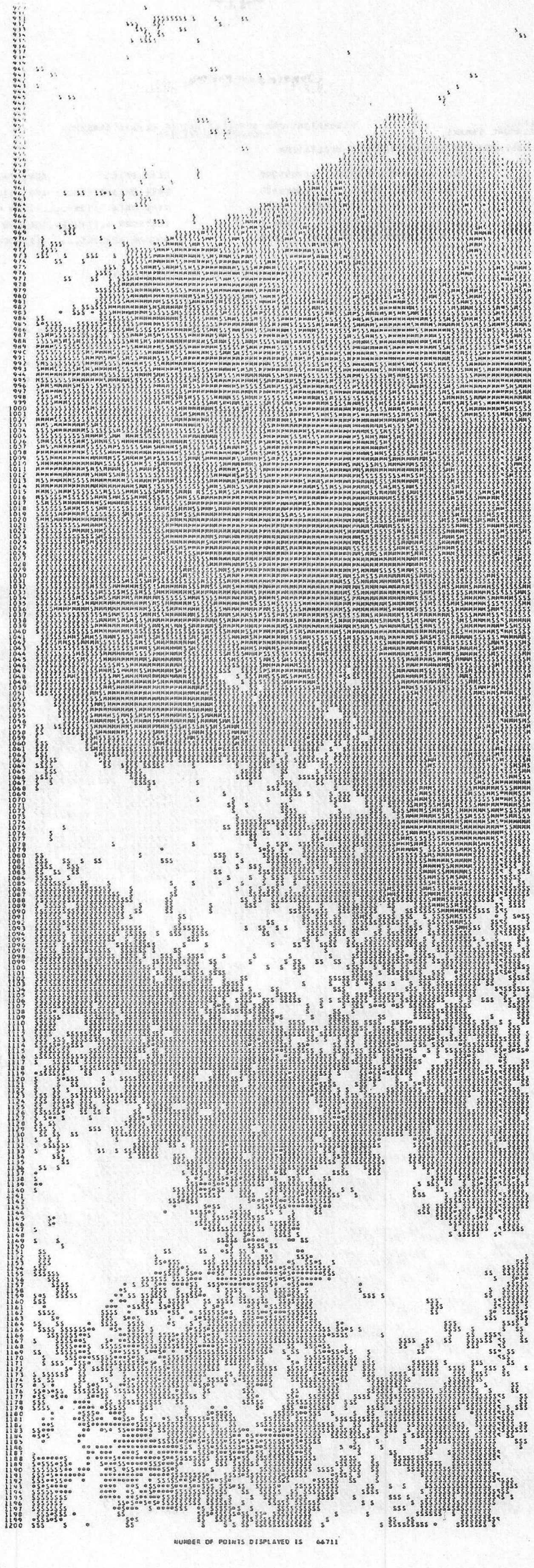

Figure 22. Fire-burned land.

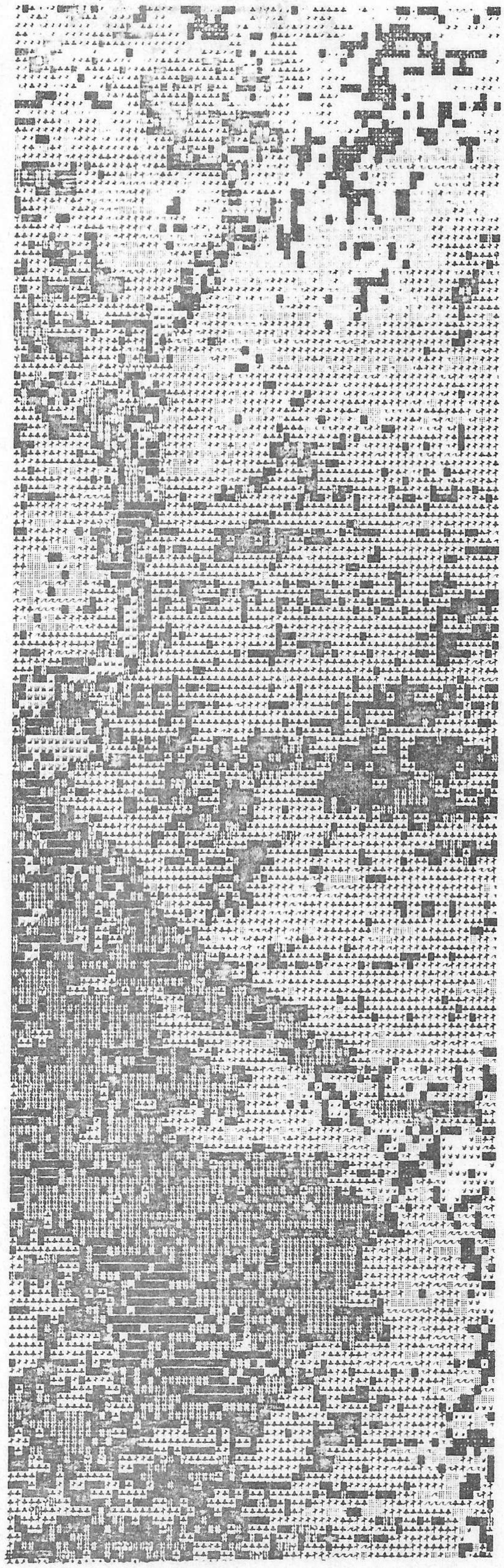

Figure 23