FINAL REPORT
for a
STUDY OF CLOUD PATTERNS
as seen by
METEOROLOGICAL SATELLITES

PHASE 2

JANUARY 31, 1966

CONTRACT NO. NAS 5-9551

Prepared by

THE BUNKER-RAMO COMPANY

Information Sciences Center

Westgate Research Park • McLean, Virginia

For

GODDARD SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GREENBELT, MARYLAND

Final Report

on Contract NAS 5-9551

for a Study of Cloud Patterns

as Seen by Meteorological Satellites

Phase 2

Submitted to

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland

by

The Budd Company
Information Sciences Center
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McLean, Virginia

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Foreword

This Final Report for a Study of Cloud Patterns as Seen by Meteorological Satellites, Phase 2 was prepared by The Budd Company Information Sciences Center, McLean, Virginia for the Goddard Space Flight Center, Greenbelt, Maryland, under NASA Contract NAS 5-9551. The contract period covers February 1, 1965 through January 31, 1966.

The principal investigator on the study was Mr. James N. Orton, electronic data processing system analyst, assisted by Mr. Joseph Jordan, digital computer programmer. Other contributors to the study were Dr. Azriel Rosenfeld, Research Associate Professor, Computer Science Center, University of Maryland, consultant in image processing and pattern recognition; Dr. Charles Fried, research experimental psychologist; and Mr. Robert Ryan, electronics technician. The computer time used was supported by NASA grant NSG 398 to the Computer Science Center, University of Maryland.

The cooperation of the Goddard Space Flight Center is gratefully acknowledged for providing TIROS cloud picture film strips and for preparing digital magnetic tapes of selected frames for input to the computer programs developed in the study.

A General Introduction and Summary of Results

This Final Report describes the accomplishments of the second phase of a study of cloud patterns as seen by meteorological satellites. Under the first phase (Contract NAS 5-3461) initiated in July 1963 and completed in October 1964, the groundwork was laid and initial steps taken toward the development of automatic techniques for meteorological cloud picture analysis. A cloud pattern classification and discrimination system was developed based on geometric cloud properties, according to which human observers subdivided a meteorological picture into solid cloud, solid noncloud, and partially overcast or "broken" regions. This scheme was found to be comparable in scope and consistency with schemes employing meteorological terminology. Psychological experiments were conducted to verify this fact. The task of picture subdivision was next automated; a computer program, named SORD (Solid Region Delineator), was developed to subdivide a two-brightness-level meteorological picture into solid cloud, solid noncloud, and broken regions. Two other pictorial data processing programs were developed for general utility purposes:

RAMP (Region Area Measurement Program), for identifying and measuring connected shapes, and REST (Region Enclosed Square Tabulator) for measuring and compiling the frequencies of squares within closed curves (cloud shapes) in a binary-encoded digital picture. Complete descriptions of these programs were included in the Final Report for the first phase of the study.

The first task of the second phase of the study (under the present Contract NAS 5-9551) was to determine if SORD program meteorological picture subdivision is comparable to picture subdivision by human subjects. Part I of this Report describes a psychological study conducted to compare human and computer cloud picture annotations. It was concluded that the SORD program produces annotations which correlate highly with human annotations, particularly in the case of humans with an analytic background. An important first step toward automation of nephanalyses was therefore accomplished.

One of the primary objectives of the second phase of the study was the extension of the SORD program concept to the further analysis of broken regions according to relative brokenness. The articulation of this technique and a program to perform this analysis (designated SB-2) is described in Part II. In Part III there is presented the results of SB-2 processing of a set of TIROS VI pictures exhibiting a variety of meteorological patterns. Key parameter interrelationships affecting these results are first determined, and optimum or near-optimum values selected for pattern processing. Results are presented in both pictorial and statistical form.

An important extension of the SB-2 concept is made in Part IV, which describes a computer program (designated SB-3) developed to perform the solid/broken subdivision process on a digital picture of from three to fifteen brightness levels rather than the two to which SB-2 is restricted. In Part V, the results of its application to TIROS meteorological picture processing are described, these investigations being analogous to those described in Part III for program SB-2. These applications of SB-2 and SB-3 verify the capability of these programs to prepare meteorological pictures for further processing to identify or distinguish meteorological patterns. Suggested steps for further investigations in this direction are described at the conclusion of Parts III and V.

In addition to picture subdivision, another important prerequisite to meteorological pattern recognition is the ability to "extract" or delineate pattern structures within a picture. A program to do this is described in Part VI. Designated PAX (Pattern Extractor), it was developed as a new application of the SB-2 brokenness analysis technique. In Part VII, parameter investigations for PAX are described, followed by a graphic and verbal description of results of PAX meteorological picture processing involving the same variety of TIROS picture patterns used in the SB-2 and SB-3 analyses.

In the concluding Part VIII other computer programs for meteorological picture processing developed under phase two of the study are described in brief. These include a gradient plotting program (possibly also applicable to pattern extraction), a program to print out the brightness values of selected elements within a digital picture, and a set of executive or "driver" programs to supply selected sets of input parameters to programs SB-2 and SB-3. Applications for these programs are suggested.

In summary, this second phase of the study has resulted in significant advances toward meteorological pattern recognition and identification. Computer programs SB-2 and SB-3 have now been developed and tested which isolate parts of a picture likely to contain patterns of interest; the PAX program extracts a pattern structure directly. From each of these two base points further processing steps to be taken in the direction of pattern recognition are suggested. Further investigation may prove that only one of these techniques excluding the other, or possibly some combination of the two incorporating still newer concepts, is best able to achieve this goal.

PART I

A Comparison of Human and Computer Annotation of TIROS Cloud Pictures

ABSTRACT

This Part describes a study conducted to compare the capabilities of a digital computer program and human subjects in annotating TIROS cloud pictures. The computer program, designated SORD-2, was developed during phase one of this study; it is described in Volume IV of the Contract NAS 5-3461 Final Report, "Steps Toward Automatic Cloud Pattern Discrimination." The conclusion of this study is that the program is able to provide an annotation closely resembling a human annotation. This is interpreted as a strong validation of SORD techniques as initial steps toward automated cloud picture analysis.

1.1 Introduction and Summary

The use of TIROS satellite photography for weather prediction currently requires extensive human examination and annotation of the photographs. TIROS photographs are transmitted to Weather Bureau personnel who delineate on them cloud formations which have potential meteorological significance. The cloud outlining is followed by the classification of these clouds according to the presence of significant cloud features.

A long term objective of the present research effort is to circumvent the delay in weather prediction that is imposed by the requirement for human processing. This is to be accomplished by a program for a general purpose computer that will scan the photographs, perform an annotation that resembles the original human annotation, and decide whether any areas of potential meteorological significance are present. Those photographs on which nothing of significance has been detected are then screened out, leaving a small subset of photographs for final analysis by the professional meteorologist. The screening function alone should reduce very significantly the processing time required to extract from the photographs conclusions useful for weather prediction. Beyond this, the more that the computer can assist in the cloud pattern identification and classification functions, the further it can enhance the meteorologist's weather prediction activity.

The first step of the automated annotation process is thus the delineation of areas on the cloud picture of potential meteorological significance. An IBM 7094 computer program which performs an initial step in this direction was developed under NASA Contract NAS 5-3461, preceding the present contract. Designated SORD-2 (where SORD stands for "Solid Region Delineator"), the program assigns the elements of a cloud picture to one of three categories of regions -- solid cloud, solid noncloud, or broken cloud (i.e. partially overcast) -- using a "window" scanning technique. This technique and the program are fully described in Volume IV of the Contract NAS 5-3461 Final Report, entitled "Steps Toward Automatic Cloud Pattern Discrimination." The purpose of the present study was to test the ability of this program to annotate cloud pictures as compared with human ability to do so.

The pictures annotated in the study by both the computer and human subjects were "black-and-white" extractions from the original TIROS photographs which contain up to sixty-four brightness levels varying from pure white to pure black. All elements brighter than a selected threshold brightness value are classified as "cloud" elements; all other elements are classified as "noncloud" elements. On these black and white pictures, which are produced by the computer from a digital representation of the original photograph, noncloud elements are represented by dots and cloud elements by spaces.

In general, areas or regions of a picture which are predominantly occupied by dots are designated by the annotator as "solid noncloud"; regions which are predominantly blank are designated "solid cloud"; and regions which contain dots interspersed with spaces are designated "broken cloud." The human subject was instructed to indicate these regions by drawing lines around them, according to a detailed set of rules included in Appendix 1-A. Region boundaries are likely to be drawn where there occurs a sudden transition from one region type to another. The computer, on the other hand, lacks a line-drawing ability and instead indicates the region to which it assigns an element by appropriate overprinting: an overprinted "X" designates "solid noncloud," an overprinted "slash" symbol (/) designates "broken cloud," and no overprinting designates "solid cloud."

Figure 1 in Section 1.4 below illustrates the three types of pictures that have been described. Figure 1, Picture 1(A) shows a typical unannotated picture used in the study, as produced by the computer and supplied to the human subject. Picture 1(B) of this Figure shows the computer annotation of this picture (hand-drawn lines enclose the regions for ease of comparison with the human annotation).

Pictures 1(C) and 1(D) illustrate two subjects' annotations of the picture, the regions "solid cloud," "solid noncloud," and "broken cloud" being designated by the letter "C", "N", and "B" respectively.

For the study, a set of ten TIROS pictures was selected for annotation by each of six subjects. The pictures were all taken approximately normal to the earth's surface and over oceans, so that the noncloud category includes open sea but not land masses. Various meteorological patterns are represented in the pictures, but no attempt at this stage was made to include all patterns of significance likely to be examined in the future. Some comments are made, however, on the observed relationship between the degree of similarity of the computer and human annotations and the meteorological pattern types represented in the pictures.

The degree of similarity between the two types of annotations of a given picture can be conveniently measured by the well-known product-moment correlation coefficient. Its possible values range from 0, indicating essentially no correspondence (or only "random" correspondence) to 1, indicating exact correspondence; further details on its present application are presented in Section 1.4.

The correlation between the computer and human annotations was determined for each picture by subject, a total of sixty comparisons in all. Many correlations were very high; twenty-four of the sixty coefficients equaled or exceeded .80. All correlations were statistically significant, the lowest being .30.

These results, plus others noted below, support the conclusion that the SORD-2 program efficiently simulates a human in annotating a black-and-white cloud picture, and thus provides a sound basis for the next phase of research, its extension to multi-brightness-level pictures. The further result that the highest correlations were observed for the subjects with greater analytical background and experience indicates that the program would even more efficiently simulate the annotation of a professional meteorologist.

No conclusion is drawn at this stage, however, concerning the similarity of the logical process employed by the computer and the thought process employed by the human in arriving at their separate results. The scope of the present study does not extend beyond duplication of the human result by a computer.

1.2 Cloud Pictures Used in the Study

Ten TIROS VI photographs selected to represent several types of meteorologically significant cloud patterns were employed as the stimulus material for this study. In selecting the photographs three criteria were used: (1) each photograph was of a reasonably good quality and contained a high percentage of usable content, (2) each photograph contained one or more cloud formations of meteorological significance (e.g. cloud cells, streets, bands), and (3) the pictures were taken over oceans (principally the Pacific and North Atlantic) to avoid the problem (irrelevant to the present study) of distinguishing clouds from land masses.

Orbit film-strip numbers for the photographs were selected from the U. S. Department of Commerce publication, <u>Catalogue of Meteorological Satellite Data - TIROS VI Television Cloud Photography</u> (Reference 1.2) on the basis of (1) the geographical area covered and (2) the accompanying indication of the presence of patterns of meteorological significance. The film strips were examined on a microfilm reader for selection of specific frames for the study. The frame numbers were then submitted to the NASA Goddard Space Flight Center, Greenbelt, Maryland, for digitizing of the specified set of frames on magnetic tape. (The cooperation of the Center in this effort is gratefully acknowledged.) This magnetic tape was then copied with minor format changes onto another magnetic tape which was then input to the SORD-2 computer program.

Two sets of pictures, one with and the other without the

SORD-2 annotation, were produced by the computer. These were reduced photographically to 8-1/2" by 11" size, and Xerox copies made for distribution to the subjects.

On the magnetic tape the ten TIROS frames each consisted of 234 picture elements per line and about 240 lines per picture, or about 56,000 picture elements per picture. Each element consisted of six binary digits (bits) with a brightness value in the range 0 (the darkest) to 63 (the brightest). The brightness threshold value used by SORD-2 in reducing the picture to black and white was 32; all elements with a value greater than this were classified as "cloud," and all with a value equal or less, as "noncloud." The pictures produced by the computer were 118 x 118 elements in size, selected from the central portion of the TIROS frame.

The complete set of unannotated pictures and computer-annotated pictures, together with a representative set of human-annotated pictures, is shown in Section 1.4, Figure 1, Pictures 1 through 10. Table 1-1 below lists these pictures according to their TIROS orbit and frame and representative meteorological pattern.

1.3 Experimental Procedure

The subjects were read the instructions which appear in

Table 1-1

Characteristics of TIROS VI Pictures Used

in Human/Computer Annotation Study

Picture Number	TIROS Designation Orbit Number	TIROS Designation Frame Number	Meteorological Pattern Represented
1	004	16	Streaks
2	492	22	Bands
3	508	29	Curved streets
4	520	26	Bands
5	524	03	Noncloud streaks
6	524	24	Sharp region boundaries: Cells/solid cloud
7	538	04	Curving bands
8	538	28	Sharp region boundaries: Small cells/solid cloud/ solid noncloud
9	566	22	Sharp region boundaries: Cells/solid cloud
10	583	21	Cells

Appendix 1-A. They were told that their annotations would be compared with a similar annotation to be performed by a computer. They were instructed to examine the photographs and outline regions which they felt could be properly classified as solid cloud, solid noncloud or broken cloud, as these concepts have been defined above.

The experimenter did not further define these categories but allowed the subject to define them for himself by examining several examples of a previously annotated photograph. The sample annotations are shown in Appendix 1-B. They are annotations that do not appear in the test series.

The only major restriction in the subject's annotation was that a boundary could not be drawn between cloud classes of the same type; all boundaries had to be used to separate dissimilar cloud types. They were also told to ignore the occurrence of small random groupings of dots or spaces in larger formations in their assignment of a picture region to a particular class.

The subjects had to outline carefully every region that belonged to one of three categories within the boundary of the picture, to insure that the pictures would be completely annotated.

Following the reading of the instructions one of the pictures in the test series was selected at random as a training picture. Each subject annotated this picture first, and the resultant annotation was then reviewed by the experimenter in the presence of the subject. They were permitted to ask questions on the annotation procedure during this practice trial and then the experimenter went over any parts of their annotation which he felt indicated a lack of understanding of the instructions. The test trials were begun only after the experimenter felt the subject understood the instructions.

The subjects were then given the ten test pictures in a sequence that was separately randomized for each subject. Each subject worked at a speed of his own choosing and each one decided for himself when an annotation was complete.

After annotating a picture the subject passed it to the experimenter. He then proceeded to the next picture in the series. Approximately two to three minutes elapsed for each annotation. The room illumination was the usual office fluorescent lighting and each subject worked in a separate room of moderate noise level.

Figure 1, Pictures 1(A) through 10(A) in the Section 1.4 below show the ten pictures annotated by the subjects.

The six subjects used in the study were selected at random from the roster of available company employees. Two were engineering and four were administrative/secretarial personnel.

They had no previous experience in cloud annotation or in meteorology. Their sources of knowledge of the TIROS program consisted principally of newspaper and magazine accounts.

The subjects had no apparent visual defects. They were permitted to examine the photographs at a distance which was most convenient to them.

1.4 Study Results

The SORD-2 program classified each point in a picture into one of the three possible categories: (1) white or solid cloud (represented in the picture by a space), black or solid noncloud (represented in the picture by an "X"), and broken cloud (represented in the picture by a slash mark (/). The region outlines in the computer-annotated pictures were added to facilitate visual comparison with the human-annotated pictures.

The human annotations consisted of outlines or boundaries drawn around a uniform region and appropriate labeling of the region: "N" for "solid noncloud," "C" for "solid cloud" and "B" for "broken cloud." The categories for labeling a region were identical to those employed by the computer. Though the human probably considered groups of points rather than individual points in selecting regions, he effectively classified each point in the picture, since all parts of the picture were considered and since all points within a drawn region belong to one category.

A measure of the similarity of a picture annotation between the computer and a human subject can be achieved by comparing, point by point, the assignment of each of the points to categories. A numerical value was associated with each category. A point classified as "solid cloud" was assigned a value of +1, as "broken cloud," a value of 0 and as "solid noncloud," a value of -1. The measure used to state the degree of similarity between the human and computer annotation of a picture was the Pearson product moment correlation, whose raw score formula is:

$$r = \frac{N_T \ \Sigma XY - \Sigma X \ \Sigma Y}{\sqrt{\left[N_T \ \Sigma X^2 - (\Sigma X)^2\right] \left[N_T \ \Sigma Y^2 - (\Sigma Y)^2\right]}}$$

where

N_T = total number of points in the picture

X = value of a point in a picture annotated by SORD-2

Y = value of a similar point in a picture annotated by a human subject

With this restricted set of values for X and Y the Pearson r simplifies to

$$r = \frac{N_T \left[N_{BB} + N_{WW} - (N_{BW} + N_{WB}) \right] - (N_{B.} - N_{W.})\,(N_{\cdot B} - N_{\cdot W})}{\sqrt{\left[N_T(N_{B.} + N_{W.}) - (N_{B.} - N_{W.})^2 \right] \left[N_T(N_{\cdot B} + N_{\cdot W}) - (N_{\cdot B} - N_{\cdot W})^2 \right]}}$$

where

N_T = total number of points in the picture.

N_{BB} = number of points in the picture classified as "solid-noncloud" or "black" by both the SORD-2 and human annotations.

N_{WW} = number of points in the picture classified as "solid cloud" or "white" by both the SORD-2 and human annotations.

N_{BW} = number of points in the picture classified as black by the SORD-2 program and white by the human annotation.

N_{WB} = number of points in the picture classified as white by the SORD-2 program and as black by the human annotation.

$N_{B.}$ = number of points in the picture classified as black by the SORD-2 program.

$N_{W.}$ = number of points in the picture classified as white by the SORD-2 program.

$N_{\cdot B}$ = number of points in the picture classified as black by the human annotation.

$N_{\cdot W}$ = number of points in the picture classified as white by the human annotation.

The analysis of the picture consisted of comparing, for each point in a TIROS picture, the classification for that point made by the SORD-2 program and the human annotator. For each picture nine point totals, representing the nine possible paired category combinations, were tallied, as follows:

(1) N_{BB}, N_{WW}, N_{BW}, and N_{WB}, as defined above

(2) N_{BO} = number of points in the picture classified as black by the SORD-2 program and "broken cloud" by the human anotation

N_{WO} = number of points in the picture classified as white by the SORD-2 program and broken by the human annotation

N_{OB} = number of points in the picture classified as broken by the SORD-2 program and black by the human annotation

N_{OW} = number of points in the picture classified as broken by the SORD-2 program and white by the human annotation

N_{OO} = number of points in the picture classified as broken by both annotations

By appropriate summing of the entries in these categories, the values needed for the Pearson r computation may be obtained. It is noted that N_T is the sum of entries in all nine categories and that:

$$N_{B.} = N_{BB} + N_{BO} + N_{BW}$$

$$N_{W.} = N_{WW} + N_{WO} + N_{WB}$$

$$N_{.W} = N_{BB} + N_{OB} + N_{WB}$$

$$N_{.W} = N_{WW} + N_{OW} + N_{BW}$$

Since each picture consisted of 118 lines and each line contained 118 points, computation of the correlation coefficient for a single picture would have required an examination of 13,924 points. In a pilot study using techniques identical to those employed in this study on a different TIROS picture[1], the effect of computing the coefficient based on a sampling of points in the picture was investigated. Three sampling levels were selected: the first randomly picking 1 point in 10 in the picture; the second, 2 points in 10, and the third, 5 points in 10. The four correlation coefficients attained were:

for 10% sampling	.85
for 20% sampling	.81
for 50% sampling	.85

---

1. This picture appears as Figure 4 in the Final Report for a Study of Cloud Patterns as seen by Meteorological Satellites, Volume 4, Steps Toward Automatic Cloud Pattern Discrimination, Page 13.

for 100% sampling .83

These were then compared using a chi-square test for homogeneity. The correlations were practically identical, indicating that for these samplings there was no appreciable change in the obtained correlations. These results are shown in Appendix 1-C.

As a result of this finding it was decided that for the present study the manual comparison of the two annotations could be made by comparing one point in ten with a very low probability of any substantial error in the correlations. The sampling scheme adopted was a systematic sampling of every tenth point, beginning with the first, from each line in the picture.

After the tallies were completed the sums in each category were found and the correlation coefficient computed for the human/computer annotation of each picture. These correlations are shown in Table 1-2. In all cases they proved to be significantly different from zero at the .01 probability level. The high general level of the correlations has been mentioned in Section 1.1.

In Table 1-3 the mean, minimum and maximum correlation are listed for each picture. The mean was obtained by applying to each correlation $\underline{r}$ the log normal transformation

$$Z' = 1/2 \left[\log_e (1+r) - \log_e (1-r)\right] = f(r),$$

Table 1-2

Human/Computer Picture Annotation Correlations

Picture	Subject 1	2	3	4	5	6
1	.93	.78	.82	.89	.92	.85
2	.93	.93	.85	.93	.92	.80
3	.53	.41	.40	.61	.71	.30
4	.36	.35	.54	.83	.84	.57
5	.68	.65	.58	.87	.93	.59
6	.81	.85	.67	.89	.92	.79
7	.58	.38	.36	.49	.56	.37
8	.67	.77	.67	.81	.82	.60
9	.66	.87	.62	.85	.91	.57
10	.64	.64	.53	.73	.74	.53

Table 1-3

Mean, Minimum and Maximum Human/Computer Picture Annotation Correlation

Picture	Correlations: Mean	Minimum	Maximum
1	.88	.78	.93
2	.90	.80	.93
3	.51	.30	.71
4	.63	.35	.84
5	.76	.58	.93
6	.84	.67	.92
7	.46	.36	.58
8	.73	.60	.82
9	.78	.57	.91
10	.64	.53	.74

converting the arithmetic mean $\bar{Z}'$ to the corresponding $\bar{r}$ - value

$$\bar{r} = f^{-1}(\bar{Z}').$$

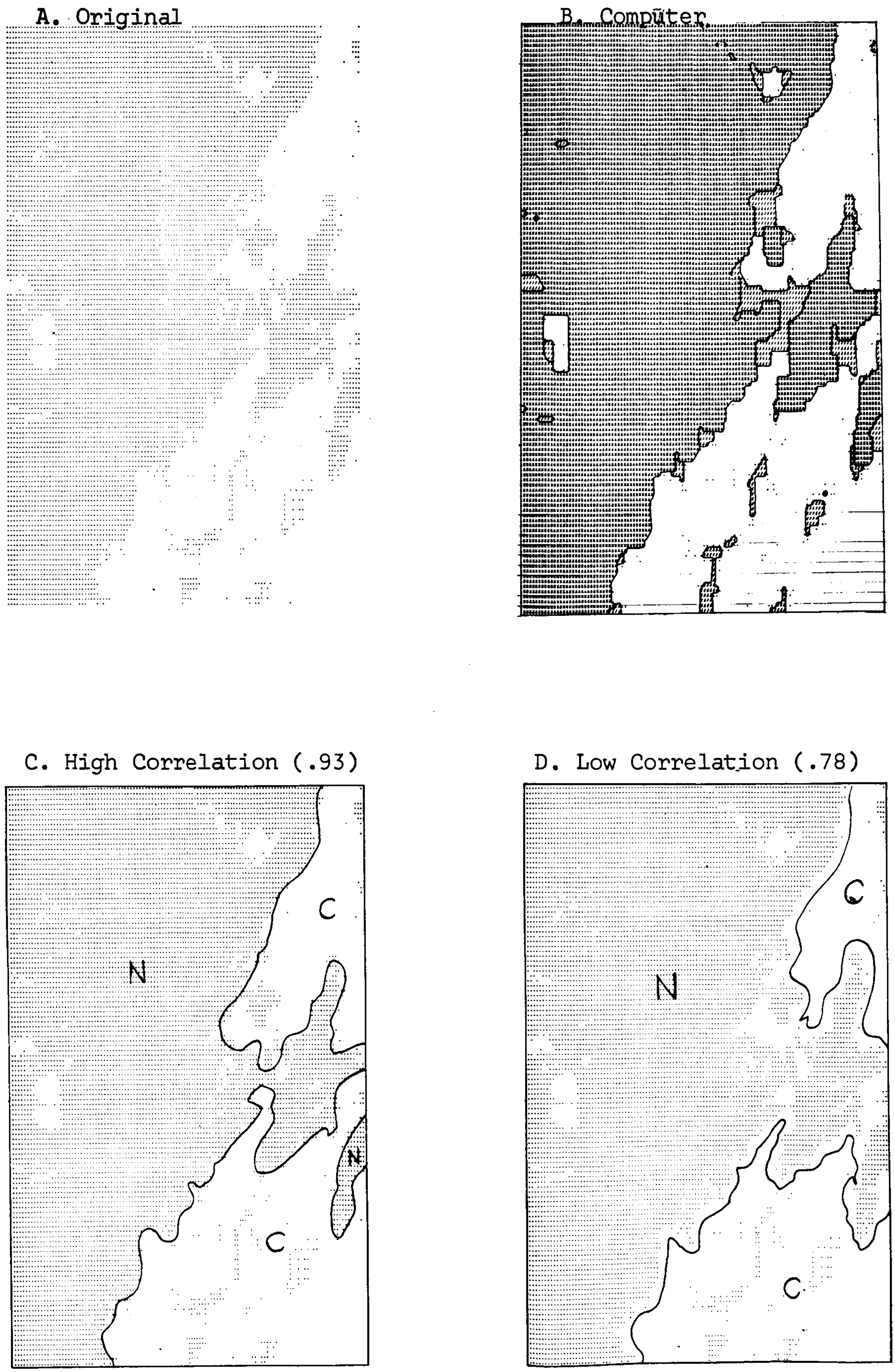
The transformation serves to reduce the disproportionately high weights given to higher r-values due to the non-normality of the distribution of r.

It should be noted that some caution should be exercised in using the mean r value to serve as a "representative value" for all possible human/computer annotations of the given picture. An examination of the individual subject correlations does reveal appreciable differences separating groups of values for some pictures, indicating the possibility of a bimodal population (this is further discussed in the next section). The mean value considered in conjunction with the range, however, affords a reasonable interval estimate which may be considered as representative of the likely range of values to be encountered over a wide variety of subjects.

The results of the ten individual picture annotations are shown in Figure 1, Pictures 1 through 10. Each figure shows four pictures labeled A through D. Picture A is the unannotated picture showing only the original elements. Picture B is the computer-annotated picture, with hand-drawn region outlines added to facilitate comparison with Pictures C and D, the subject-annotated pictures showing the highest and lowest correlation with Picture B.

Figure 1

Annotations for Pictures 1-10


A. Original
B. Computer
C. High Correlation (.93)
N
C
N
C
D. Low Correlation (.78)
C
N
C

PICTURE 1

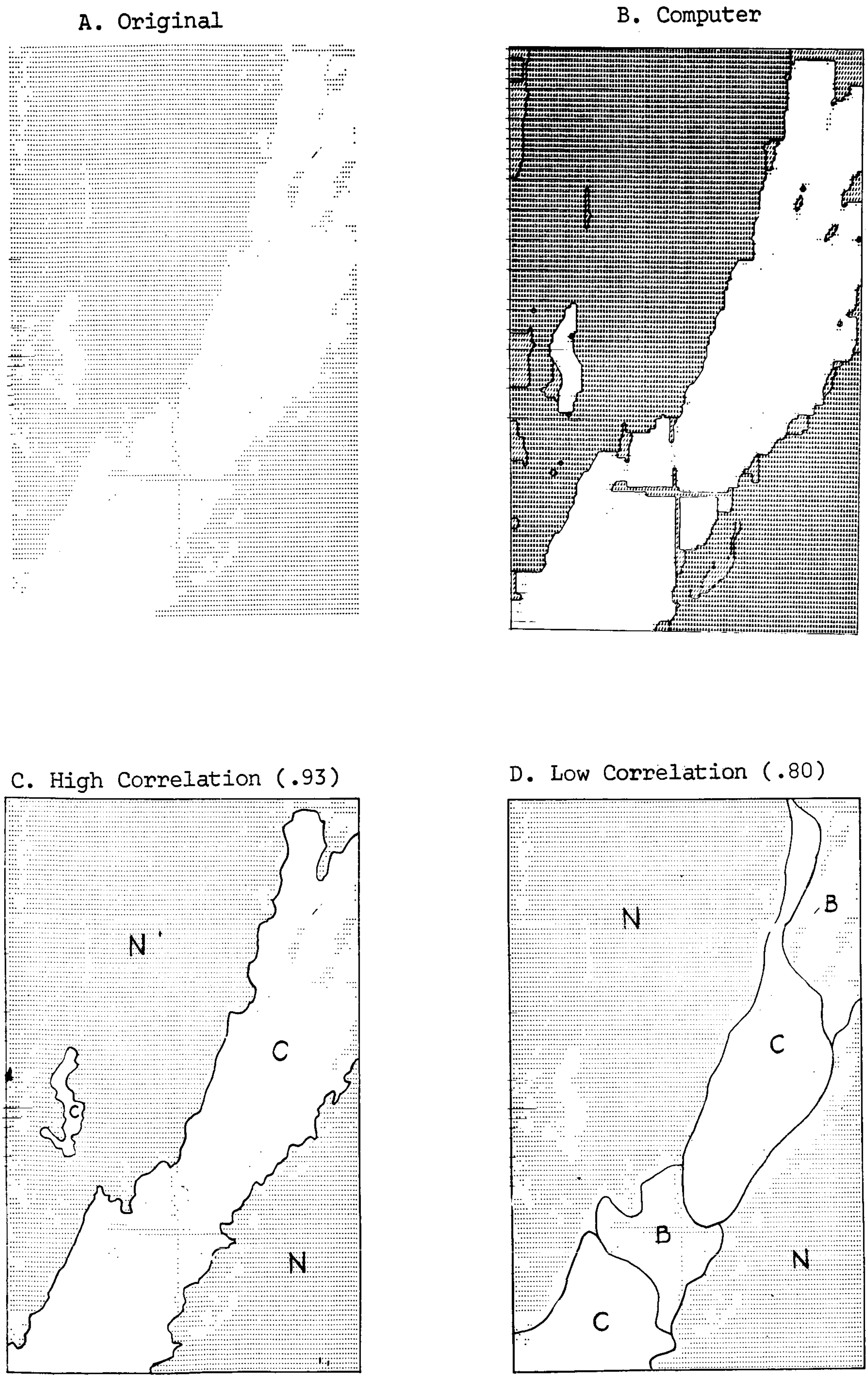
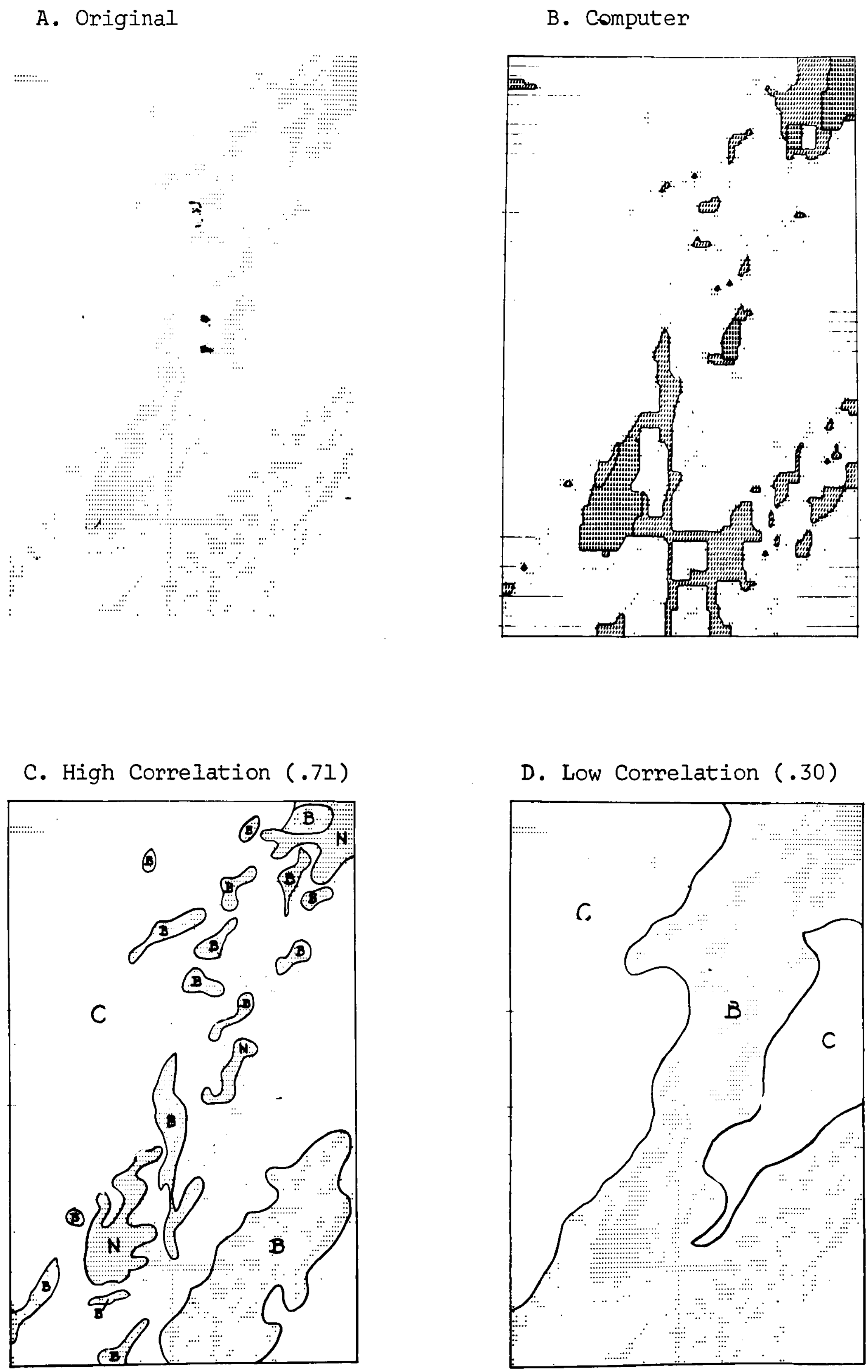


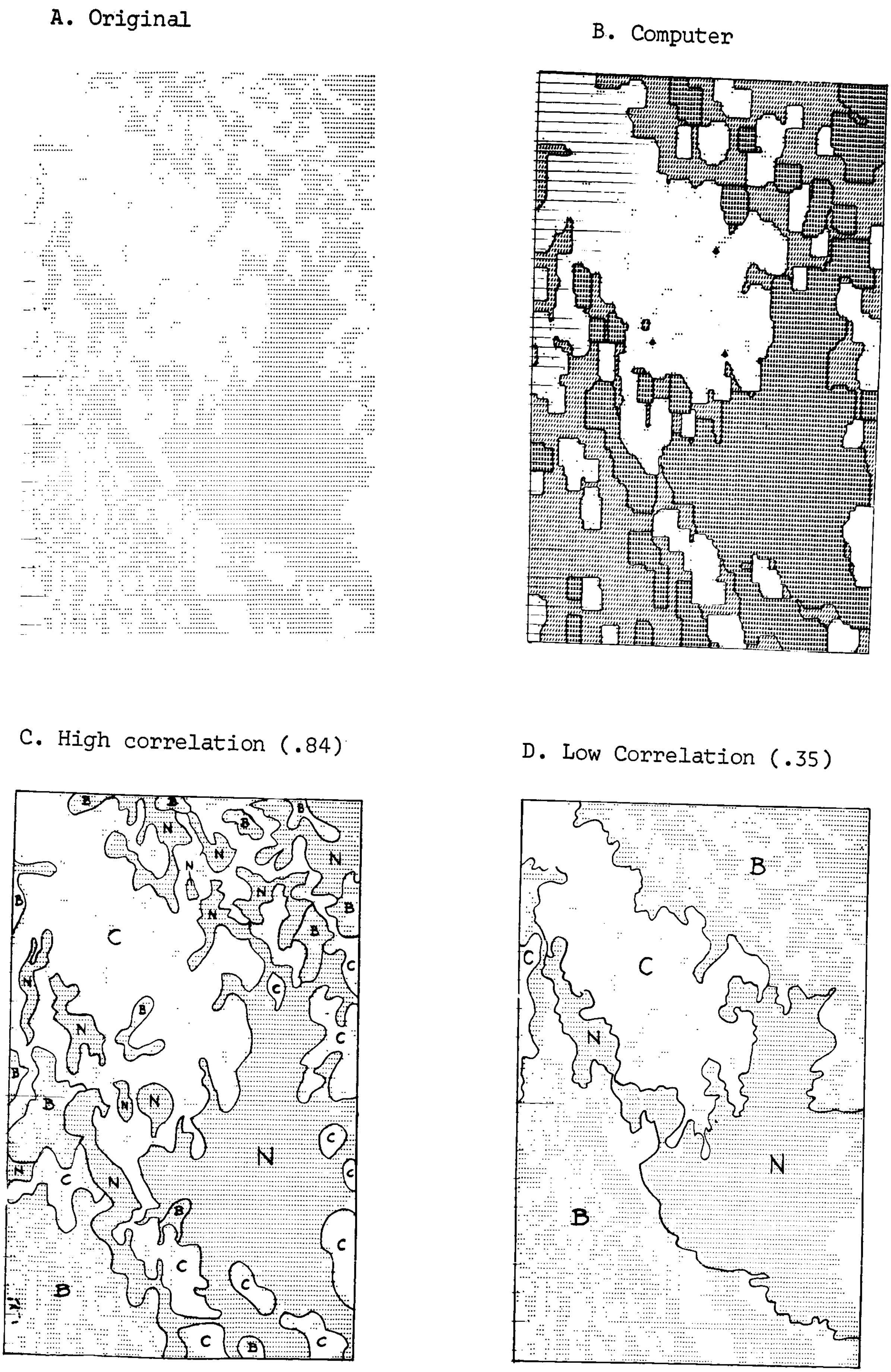
Figure 1/Page 2

PICTURE 2



PICTURE 3

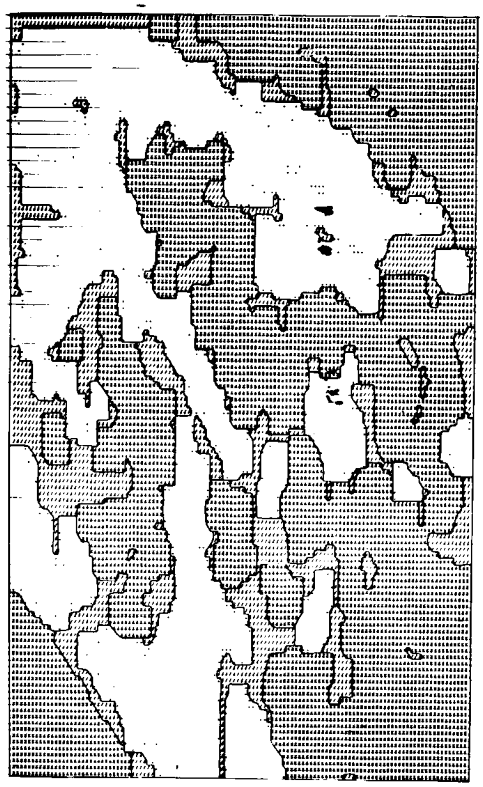
Figure 1/Page 3


A. Original
B. Computer
C. High correlation (.84)
C
N
B
D. Low Correlation (.35)
B
C
N
B

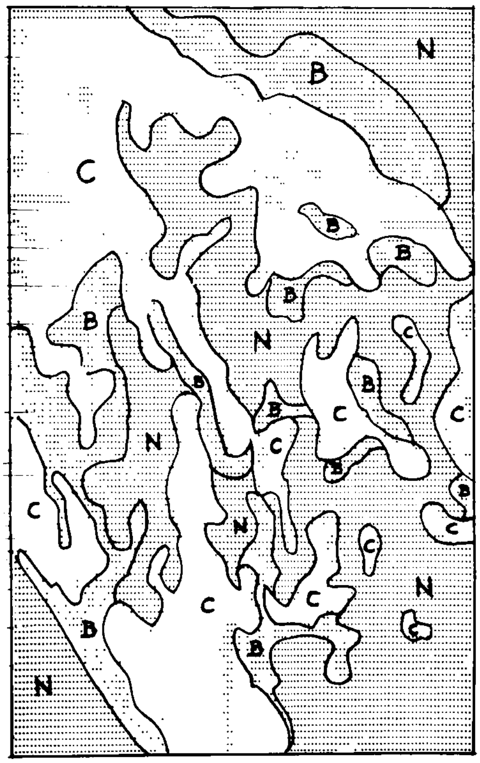
PICTURE 4

A. Original

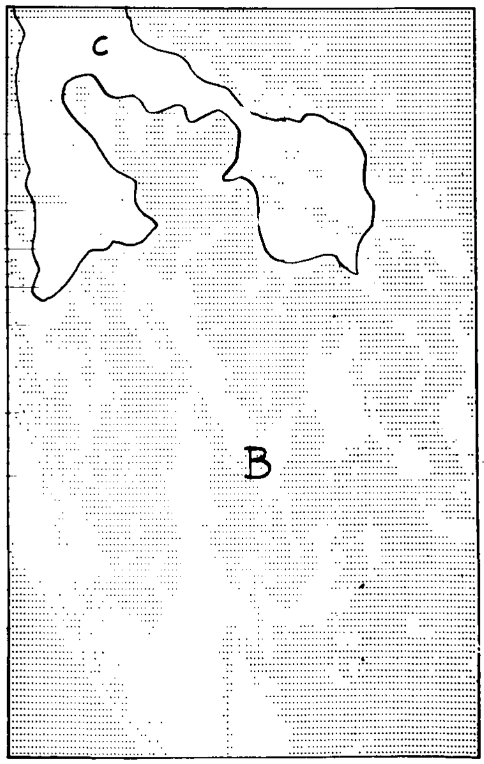
B. Computer



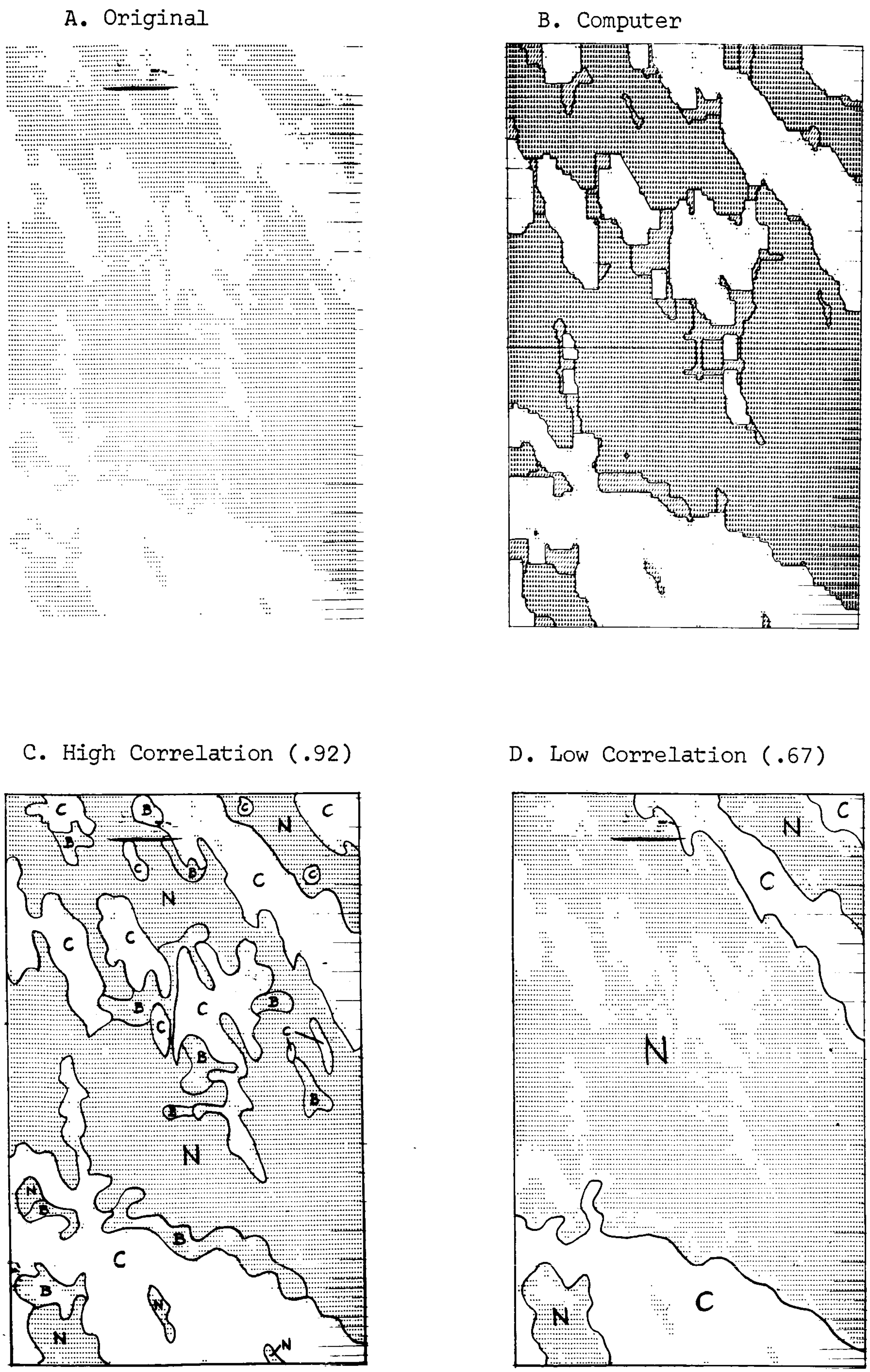
C. High Correlation (.93)



D. Low Correlation (.58)



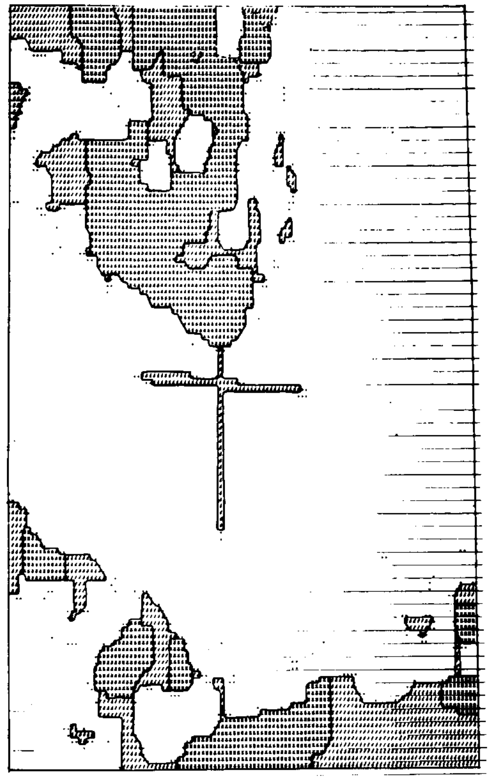
PICTURE 5


A. Original
B. Computer
C. High Correlation (.92)
C
B
C
B
B
N
C
C
C
N
C
C
B
C
B
C
C
B
B
B
N
N
B
B
C
B
N
N
N
D. Low Correlation (.67)
C
N
C
N
N
C

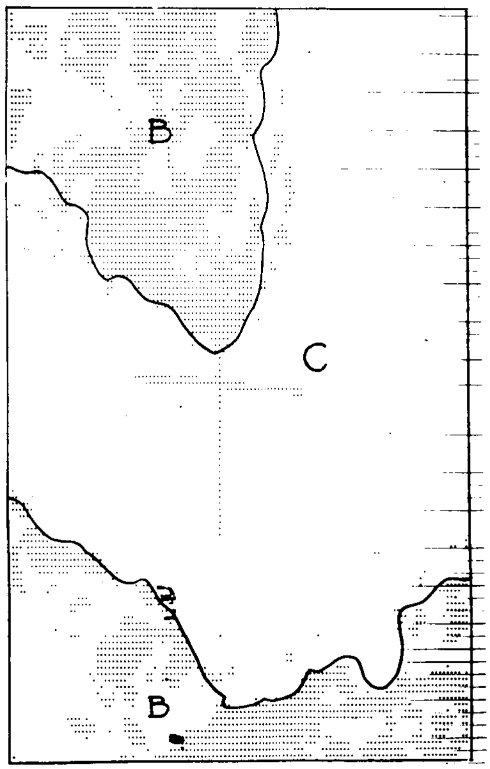
PICTURE 6

A. Original

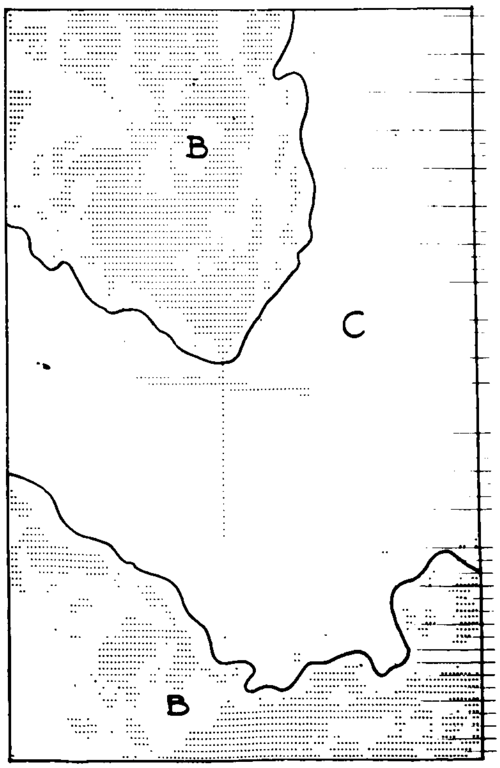
B. Computer



C. High Correlation (.58)

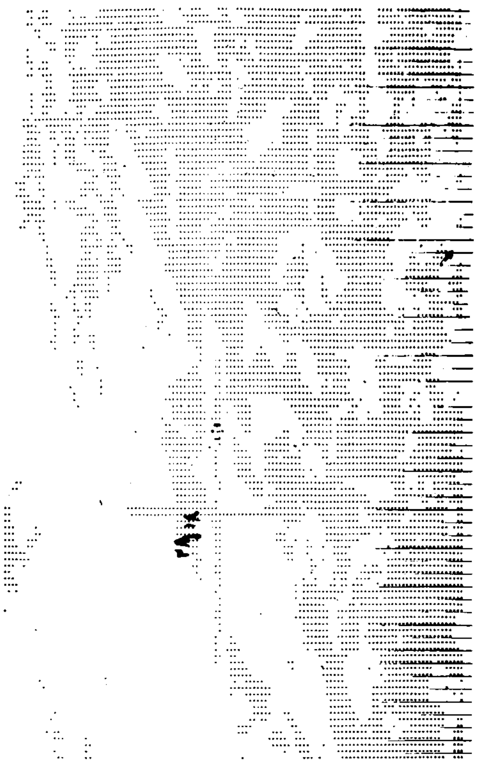


D. Low Correlation (.36)

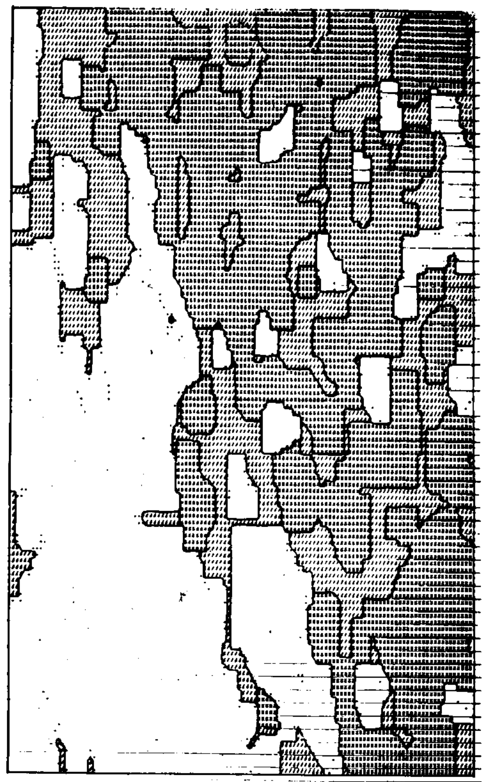


PICTURE 7

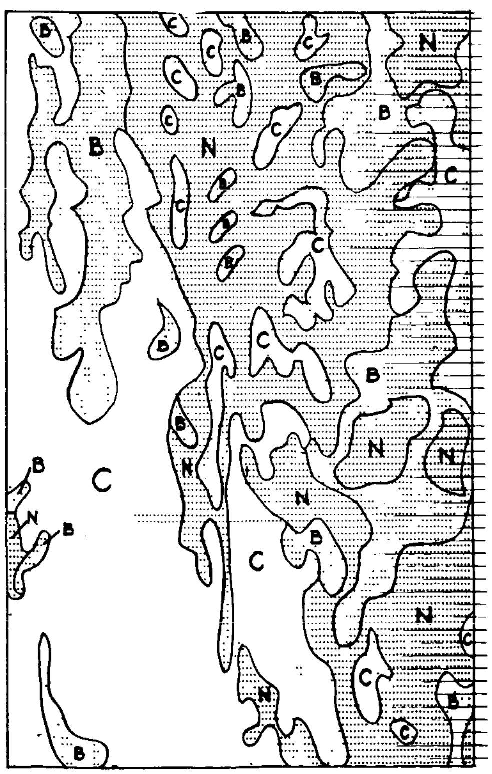
A. Original



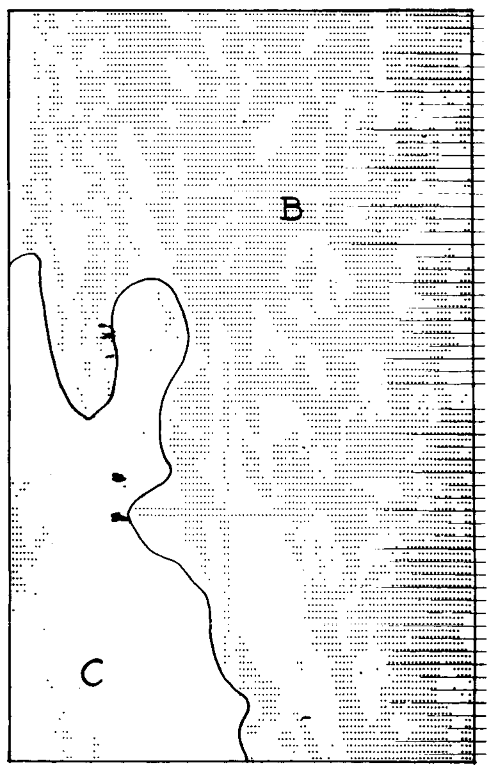
B. Computer



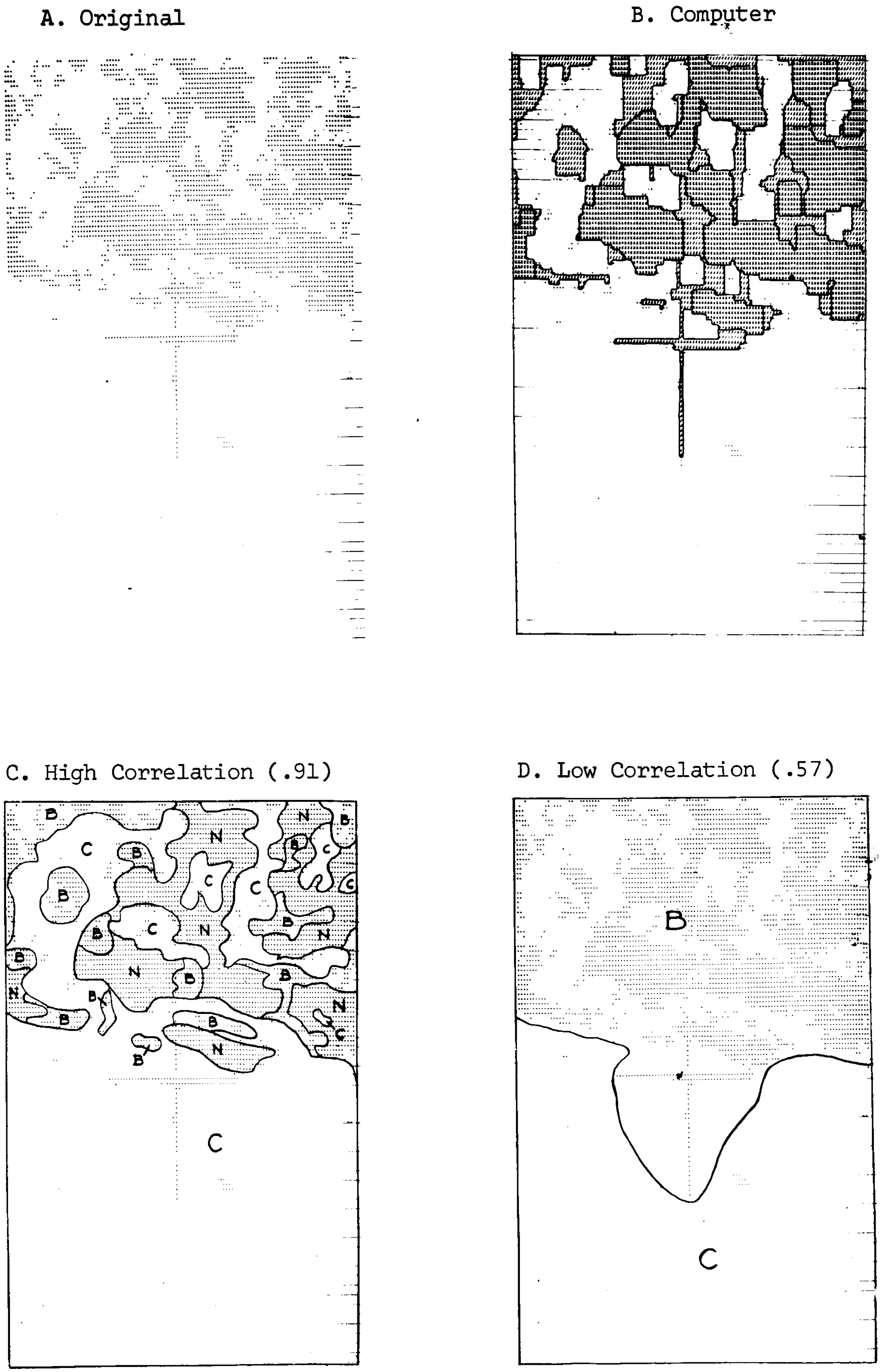
C. High Correlation (.82)



D. Low Correlation (.60)



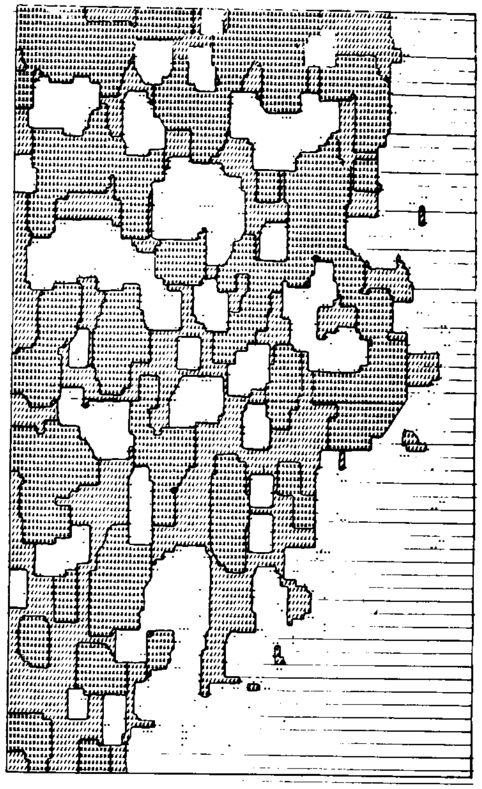
PICTURE 8


A. Original
B. Computer
C. High Correlation (.91)
D. Low Correlation (.57)
B
C

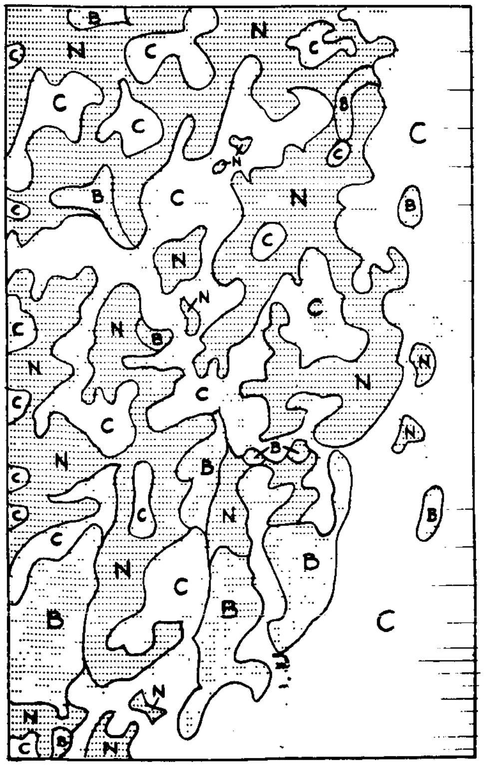
PICTURE 9

A. Original

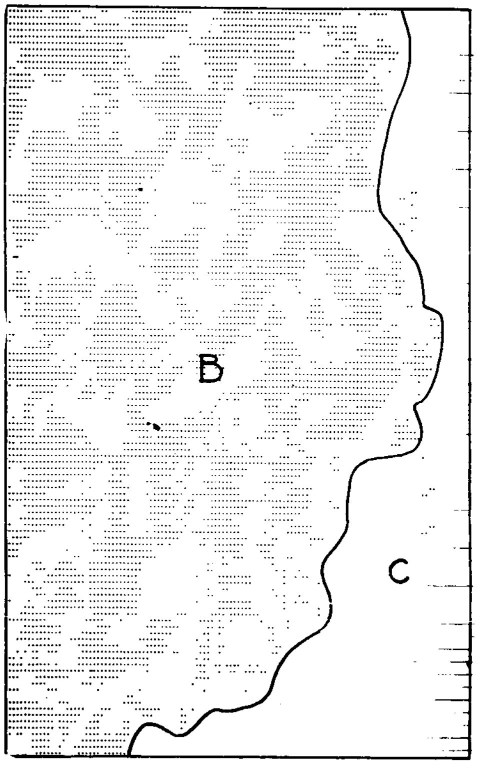
B. Computer



C. High Correlation (.74)



D. Low Correlation (.53)



PICTURE 10

1.5 Discussion of Results

1.5.1 Subject Differences

In this study the human and SORD-2 computer program TIROS picture annotations have been compared as a test of validity of the SORD-2 program and others to follow in the continuance of the research effort.

Of the six test subjects, the annotations of the two engineers (subjects 4 and 5) were found to compare more closely with that of the computer than those of the remaining four (administrative/secretarial) subjects. Considering all subjects, the rank order of correlations from picture to picture remained generally constant. It can be conjectured that annotations for one type of subject will resemble more closely the annotation made by the computer than for another type of subject. Of some interest is that the subject who usually obtained the highest correlation is an optical engineer, the most technically trained subject in the sample.

The original test material can be described as an unstructured pattern resembling in some ways the Rorschach ink blot. Subjects, in looking for segregated cloud portions of the picture, will reveal distinctive perceptual and motivational tendencies. Thus the subject who makes only a few lines on the picture, grouping large areas into one category, may tend to perceive such material globally and be less motivated to discern smaller aberrations within larger groupings. Another type of subject is more analytical and will expend considerable time and effort in outlining small portions of the picture. These small outlined regions will consequently have little textural variation within their borders.

The results suggest that the analytical subject's annotation will more closely resemble the computer annotation. Trained meteorologists with a strong incentive to perform careful, accurate annotating are likely to be of an analytical temperament. Thus if the subjects are drawn from a population of trained meteorologists the correlations of their annotations with the SORD-2 program would be expected to be more consistent (since one would expect few "global" types in this sample) and therefore the correlations would likely be higher.

1.5.2 Picture Differences

In Table 1-4 the pictures are ranked according to their mean correlation, which may be interpreted as the degree of similarity of the human and computer annotations. The pictures are also labelled by the type of cloud formation that they illustrate. Since in general only one instance of each type of formation is used, on the

Table 1-4

Ranking of Pictures According to Similarity of Human and Computer Annotations

Rank	Picture Number	Mean Correlation	Meteorological Pattern Represented in Picture
1	2	.90	Bands
2	1	.88	Streaks
3	6	.84	Sharp region boundaries: Cells/solid cloud
4	9	.78	Sharp region boundaries: Cells/solid cloud
5	5	.76	Noncloud streaks
6	8	.73	Sharp region boundaries: Small cells/solid cloud/so solid noncloud
7	10	.64	Cells
8	4	.63	Bands
9	3	.51	Curved streaks
10	7	.46	Curving bands

basis of the experimental results it is possible only to indicate, without statistical analysis, which patterns are more likely to yield a computer annotation closely resembling a human annotation, i.e. which might be relatively more susceptible to automated analysis.

The most significant observation that can be made concerns the relationship between curvature in a cloud pattern and the human/computer annotation correlation. The highest correlations are observed in pictures 2 and 1 with straight-line patterns, while the lowest are observed in pictures 3 and 7 with curved streets and curved bands. A tenative explanation for this finding is that the subject is more responsive to curvature of form in his cloud delineation than is the SORD-2 program at this stage.

The remaining cloud patterns have correlations in the range .63 to .84. It is not tenable without further pictorial material to conclude that there is a significant difference in the ability of the program to annotate the different pattern types represented.

1.6 Conclusions

The SORD-2 program can be said to perform an annotation on a variety of TIROS pictures which closely resemble annotations performed by naive human subjects. Although restrictive sampling of pictorial material has been made in that selected meteorological criteria were used in the choice of original pictures used in the study, it is also true that the reasonably high correlations were obtained for significantly representative varieties of picture patterns. Further development of SORD-2 techniques will point the way to automated processing and classification of the entire variety of material transmitted to earth from TIROS satellites.

Appendix 1-A

Instructions to Subjects for Human/Computer Picture Annotation Study

The TIROS Weather Satellite program is designed to provide NASA and the Weather Bureau with photographs (or digitized versions of photographs) of cloud masses covering large portions of the earth's surface. The Information Sciences Center is currently developing a program for a general purpose computer that will enable the computer to scan these photographs and determine the presence or absence of clouds and some of the cloud's properties such as size, shape, location and type.

The validity of this program will be determined eventually by a comparison with annotations made by humans performing the same task. This present study is intended to provide an indication of how humans delineate and classify cloud masses.

I will show you a series of binary quantized TIROS pictures and I want you to carefully outline and label those portions which you feel may be properly classified as (a) Solid Cloud (b) Solid Noncloud, and (c) Broken Cloud.

I will first show you some examples of portions of pictures which have already been annotated. Note the following remarks in making your cloud outlines:

(1) All portions of the picture should be annotated within its borders.

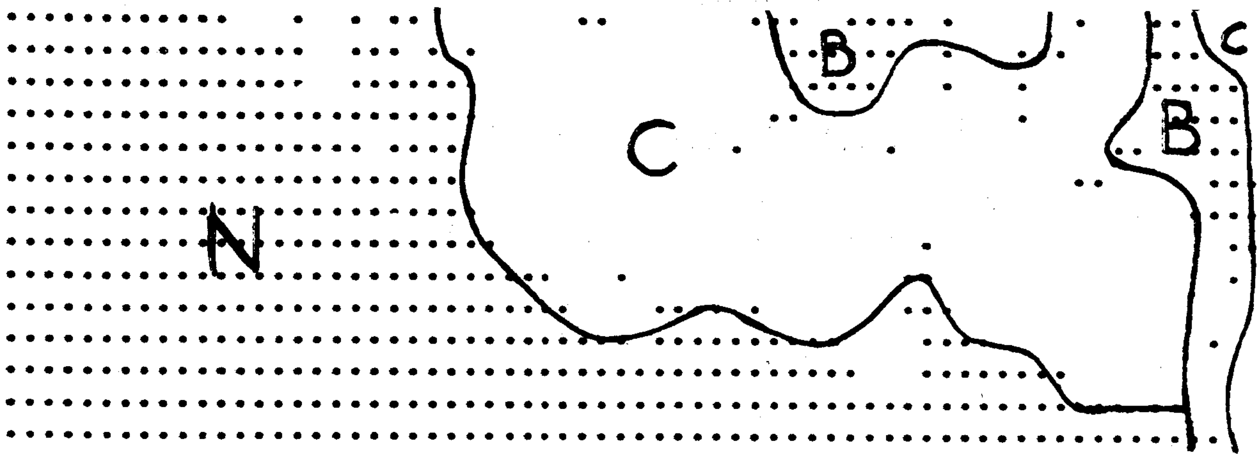
(2) A few stray points or white spaces within a region should not affect your judgment of whether the region is solid cloud or solid noncloud.

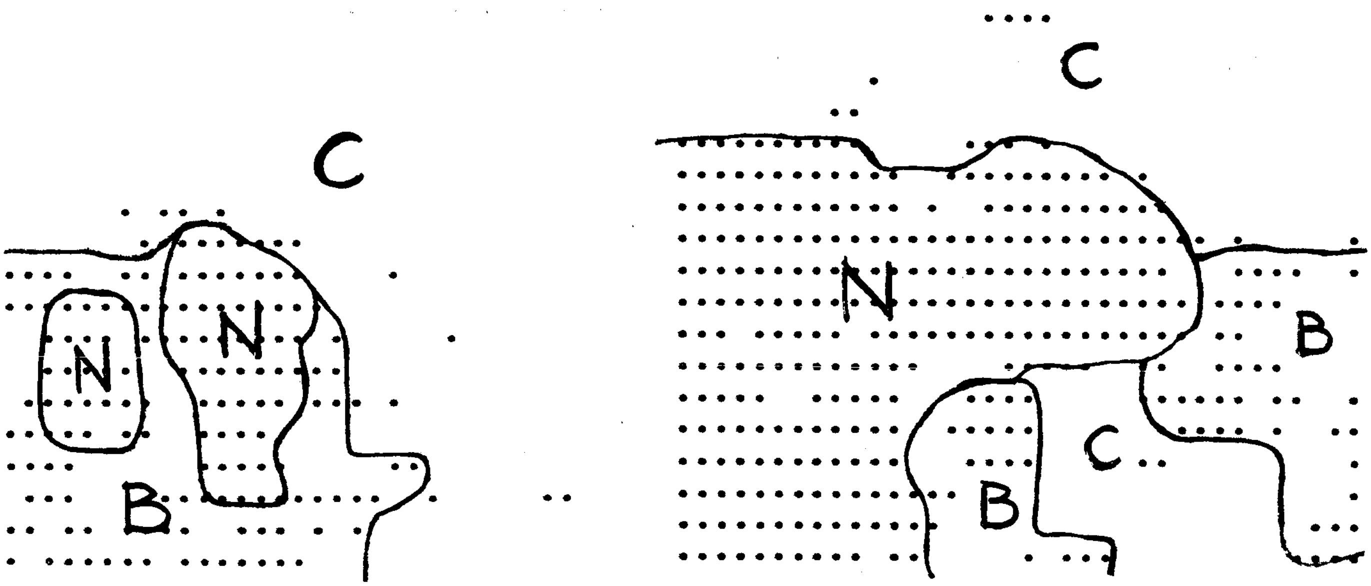
(3) The shape of a region may not resemble cloud formations that you are familiar with. Don't let this influence your judgment of cloud boundaries.

(4) A boundary will occur only between dissimilar cloud masses; it cannot be drawn between clouds of the same type.

You will first perform a training annotation in which you may ask me any questions on the procedure and then you will perform the test annotations.

Appendix 1-B





SAMPLE PICTURE ANNOTATIONS USED AS INSTRUCTION MATERIAL FOR SUBJECTS

Appendix 1-C

Results of Chi-Square Test for Homogeneity of Annotation Correlations Obtained at Various Levels

Test of Homogeneity of Four Values of r

Sample	n_i	r	$n_i - 3$	z_i	$(n_i-3)(z_i)$	$(n_i-3)(z_i^2)$
100%	2178	.829	2175	1.184	2,575.200	3,049,037
50%	1108	.847	1105	1.245	1,375.725	1,712,778
20%	430	.809	427	1.125	480.375	540,422
10%	213	.851	210	1.259	264.390	332,867
Totals	3939	3.336	3917	4.813	4,695.690	5,635,104

$$X^2 = \Sigma(n_i-3)(z_i^2) - \frac{\left[\Sigma(n_i-3)(z_i)\right]^2}{\Sigma(n_i-3)}$$

$$= 5,635,104 - \frac{\left[4,695,690\right]^2}{3,917}$$

$$= 1,227$$

This chi-square value is not significant for three degrees of freedom at confidence level .95. Hence, the hypothesis is accepted that no significant difference exists among the correlation values for a 10%, 20%, 50% and 100% sample.

References

1.1 Final Report for a Study of Cloud Patterns as Seen by Meteorological Satellites, The Budd Company Information Sciences Center, Contract No. NAS 5-3461, for NASA Goddard Space Flight Center, Greenbelt, Maryland.

1.1-I Volume I: Cloud Pattern Classification and Discrimination

1.1-II Volume II: Cloud Pattern Analysis by Interpreters

1.1-III Volume III: Cloud Pattern Analysis Programs

1.1-IV Volume IV: Steps Toward Automatic Cloud Pattern Discrimination

1.2 Catalogue of Meteorological Satellite Data-TIROS VI Television Cloud Photography, Key to Meteorological Records Documentation No. 5.36, U. S. Department of Commerce, Weather Bureau, Washington, D. C., 1964.

PART II

SB-2: A Computer Program for Plotting Solid Regions and Brokenness Contours on a Digital Picture of Two Brightness Levels

ABSTRACT

This Part describes a computer program which first applies program SORD-2 (ref. Part I) to separate a black-and-white digital picture into "solid" and "broken" regions and then applies a program designated BRAND-2 to analyze further the broken regions, assigning to each broken-region element a number which measures the "degree of brokenness" of the picture at that point. The SB-2 program produces a printout of the annotated picture plus a frequency distribution of the numbers measuring the degree of brokenness. The program was developed with the aim of investigating the feasibility of utilizing measured characteristics of brokenness in meteorological pattern recognition.

2.1 Introduction and General Description

After developing in program SORD-2 a technique to subdivide a black-and-white digital picture into solid and broken areas, the next step in the direction of automated meteorological pattern recognition is further analysis of these broken areas. The major purpose of SORD-2 is to locate these broken areas, which are considered most likely to contain any patterns of significance. This Part of the report describes a computer program embodying a technique for further analysis of these broken regions. This technique, termed "brokenness contour" plotting, is felt to be potentially very useful in extracting statistics applicable either to meteorological pattern recognition or to distinguishing between meteorological patterns. Furthermore, it may be possible to analyze geometrically the brokenness contours themselves with either of these ends in view.

The SB-2 program, written for the IBM 7090/94 computer, consists of two parts. The first part is the SORD-2 program (Reference 1.1-IV)[1] which separates the picture into solid noncloud, solid cloud and broken regions. The second part is a program designated BRAND-2, BRAND signifying "Broken Region Analyzer and Delineator". BRAND-2 considers only the broken regions delineated by SORD-2, using a "window" scanning technique analogous to that employed in SORD-2. A number termed the "degree of brokenness" is computed for and attached as a label to each element (point) within a broken region. This number ranges in value from 0 to 9. The higher its value, the more broken is the picture in the neighborhood

1. With minor additions and improvements which will be noted in appropriate sections below.

of the point it labels. "Degree of brokenness" is defined in terms of observed contrasts in brightness between neighboring horizontal or vertical elements. The "neighborhood" is defined in terms of the scanning window, a square whose side length is a program parameter. Over a square n elements on a side, the maximum possible number of contrasts occurs in a pattern of alternating black and white elements in a "checkerboard" pattern. The minimum possible number of contrasts occurs in a square containing all white or all black elements. The degree of brokenness is the ratio of the number of observed contrasts to the maximum possible number of contrasts within the neighborhood (which is either the scanning square or, if all of its elements do not belong to a broken region, a proper subset of it). The number 0 signifies a ratio of 0 to less than 0.1; the number 1, a ratio of 0.1 to less than 0.2, etc., with the number 9 signifying a ratio of 0.9 to 1.0.

The SB-2 program produces, first, the annotated digital picture in the same format as SORD-2 except for the broken regions, where the overprinted slashes of SORD-2 are replaced by the "brokenness numbers" labeling each broken-region element. Connected strings of like numbers appear as "brokenness contours" in the picture analogous to Marggraf's "cloud/no-cloud contours" (Ref. 2.1).

The SB-2 program produces, secondly, a tabular frequency distribution of the number of elements with brokenness value 0, 1, ..., 9 appearing over all the broken regions of the picture. For each value V = 0, 1, ..., 9 is also listed the percentage

$$P(V) = \frac{100\ (\text{Total area of picture with brokenness value } V)}{\text{Total broken-region area of picture}}$$

Also listed are the total number of broken-region elements in the picture, and the percent of total picture area occupied by these elements.

Geometric examination of specific contours, in addition to statistical analysis of the distributions of brokenness percentages and frequencies relating to whole broken regions, is expected to prove useful as a preliminary tool in pattern recognition. In any event, if the conjecture proves to be correct that areas of maximum brokenness are most likely to contain meteorological patterns of significance, the BRAND technique will have proved its usefulness as a pattern detector.

The remaining sections of this Part describe the SB-2 program input, operating parameters, output, and logical structure, followed by a logical flow chart (Figure 2-3) and a symbolic listing of the program (Figure 2-4).

2.2 Input

The data input to the program consists of a digital representation of the picture in exactly the same format as for SORD-2. On input to computer memory from magnetic tape, picture elements are stored six to a 7094 computer word, six bits per element. Element brightness values range from 0 for the darkest to 63 for the brightest. The entire picture (or subpicture) to be processed is stored in computer memory prior to processing. The maximum picture size is 1000 rows by 120 columns of elements. The program may be entered as many times as desired on a single run, each time to process one of a specified set of subpictures drawn from the "file" of pictures on magnetic tape. The parameters required to do this are described in the next section.

2.3 Operating Parameters

SB-2 requires all the parameters required for SORD-2 and one additional. The entire set follows:

Parameter	Definition	Allowable Range Min.	Max.
T	Cloud-noncloud threshold	0	63
L1	First line of tape picture	1	tape limit
L2	Last line of tape picture	1	L1+999
W1	First word of tape picture	1	288
W2	Last word of tape picture	1	W1+19
S	Scanning square side length (in elements) for SORD processing	1	30
S2	Scanning square side length (in elements) for BRAND processing	1	30
WR	Words per line of tape picture	1	288
BW	Max. quantity of noncloud elements allowed in square assigned to "solid cloud" region	1	S^2
BB	Max. quantity of noncloud elements allowed in square assigned to "solid noncloud" region	1	S^2

The cloud/noncloud threshold T is used to classify elements as noncloud or cloud as they are input from tape into computer memory. Elements whose value exceeds T are classified cloud; otherwise, noncloud.

The location on magnetic tape of the subpicture to be processed is specified by the "length" parameters L1 and L2 and the "width" parameters W1 and W2. Picture lines on the tape are numbered sequentially from 1 through the entire picture file. The width is expressed in computer words (of six elements each) rather than single elements. The parameter WR defines the overall width of the picture stored on magnetic tape; W1 and W2 define a segment of this width.

The scanning square size for SORD and BRAND processing is specified by the parameters S and S2, respectively. Specifying these independently of one another provides the opportunity to determine their independent effects on picture annotation.

The definition of "solid" regions is supplied by the parameters BW and BB. Any scanning square of elements containing BW noncloud elements or fewer is assigned to a "solid cloud" region. Any scanning square of elements containing BB noncloud elements or more is assigned to a "solid noncloud" region. If the number of black elements lies between BW and BB no assignment of the square is made to a solid region, and any elements not so assigned after the scan is complete make up the "broken" regions of the picture.

Parameters are supplied to the program on cards included within the "driver" or executive control subroutine. They are identified by the symbols given above, the operation code DEC and the decimal value. For example a value of T = 24 would be specified as

T DEC 24

punched in appropriate card fields. Sample parameter values are included in the symbolic listing of the program (Figure 2-4).

2.4 Sample Output

A sample picture annotated by SB-2 is presented in Figure 2-1, and the output of brokenness frequencies for this picture in Figure 2-2.

Elements of the original picture are represented as dots for noncloud elements and spaces for cloud elements. Solid noncloud regions

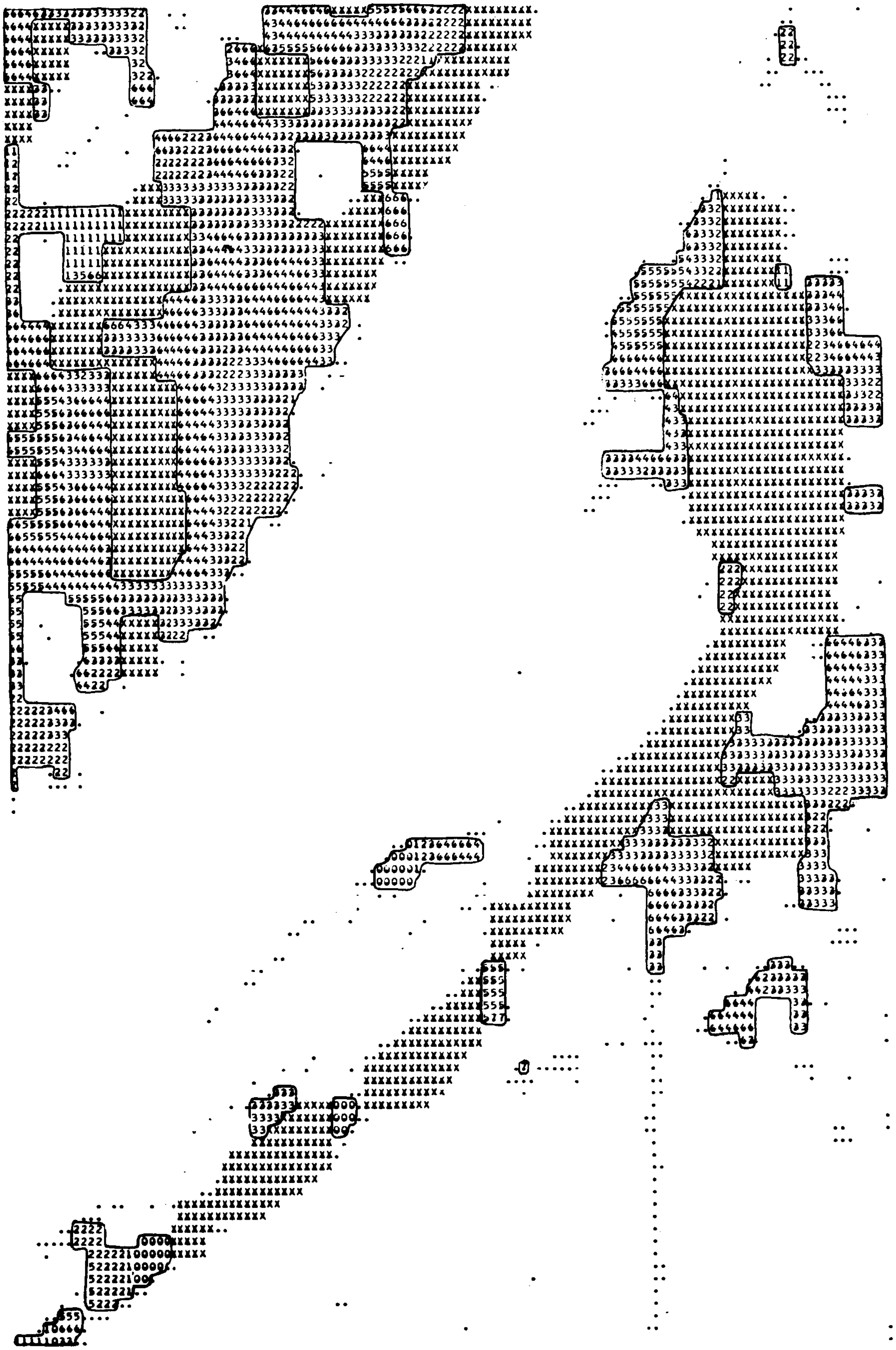


Figure 2-1

Sample Picture Annotated by SB-2 Program

Brokenness Value	Frequency	Percent
0	2	2
1	67	3
2	304	14
3	877	41
4	645	30
5	167	8
6	29	1
7	3	0
8	0	0
9	0	0

2131 Broken Elements

6318 Elements in Picture

34 Percent Broken

Figure 2-2

Output of Brokenness Value Frequencies for Figure 2-1 are overprinted with the character "X", solid cloud regions have no overprint,[2] and broken regions are overprinted as follows:

Overprinted Digit	Signifying this range of local degree of brokenness
0	0 to less than 10%
1	10 to less than 20%
2	20 to less than 30%
3	30 to less than 40%
4	40 to less than 50%
5	50 to less than 60%
6	60 to less than 70%
7	70 to less than 80%
8	80 to less than 90%
9	90 to 100%

The concept of brokenness, introduced in Section 2.1, is further described in Section 2.5. Also printed out are the total number of broken-region elements in the picture, and the percent of total picture area occupied by these elements.

These two outputs are provided for each magnetic tape subpicture specified during a computer run. The parameter values used in producing the sample annotated picture were:

2. This is a slight departure from the SORD-2 output format described in Ref. 1.1-IV, where only border elements between cloud and noncloud solid regions were overprinted by "X". The change was made to improve picture readability.

T	24
S	5
S2	5
BW	2
BB	23

Figure 2-2 also lists the percentage distribution of brokenness values; these represent the percent of the broken area of the picture which is labeled with each of the numbers 0, 1, ..., 9. Below this distribution is listed (1) the total number of broken elements in the picture, (2) the total number of elements in the picture, and (3) the percent of total picture area classified as broken.

2.5 Logical Description

The picture is first processed by the SORD-2 program and then by the BRAND-2 program. A logical description of SORD-2 operation is provided in Ref. 1.1-IV. Following SORD-2 processing the elements of the picture, stored in computer memory, have been classified as belonging to either a solid cloud, solid noncloud or broken region (henceforth the word "solid" will be dropped from the first two designations). The BRAND-2 program processes only the broken-region elements, ignoring the rest.

The two principal results of BRAND-2 processing are:

(1) The local degree of brokenness, or brokenness percentage, as defined in Section 2.1, is determined for each broken-region element of the picture. Each element is labeled with the digit 0, 1, ... or 9 expressing this percentage.

(2) Prior to labeling, <u>isolated</u> broken-region elements are "erased" from the picture in the sense that these elements are reclassified either cloud or noncloud depending upon the surrounding context. An isolated broken-region element is defined as one which is flanked either horizontally or vertically by solid-region elements (which may be both cloud, both noncloud, or one of each). This has the effect of eliminating small patches of broken regions resulting from the fact that the broken-region classification performed by SORD-2 is residual to solid-region classification. For example, a single string of broken-region elements contained within a cloud region would be reclassified as cloud; thin fiducial marks classified as broken on a solid background would be eliminated; etc.

Prior to processing, the value assigned to a broken-region element is changed from the SORD-assigned value as follows:

	Value Assigned By		Bit Pattern	
Element of Broken Region	SORD-2	BRAND-2	SORD-2	BRAND-2
Cloud	0	32	000000	100000
Noncloud	1	48	000001	110000

Thus for BRAND-2, a leftmost bit of 1 signifies a broken-region element; of 0, a solid-region element. For a broken-region element, a next-to-leftmost bit of 1 indicates a noncloud element; of 0, a cloud element. This format change was necessary to provide the four rightmost bits for storage of the brokenness value. Solid-region elements retain the format of SORD-2, i.e.:

Region type	Element	Value	Bit pattern
Cloud	Cloud	2	000010
	Noncloud	3	000011
Noncloud	Cloud	4	000100
	Noncloud	5	000101

Processing consists of placing the scanning square, S2 elements on a side, in all possible positions of the picture, starting from the top and working from left to right for each successively lower line position until the bottom of the picture is reached. If there are no broken region elements within the square in its current position, or even if there are no broken-region elements on the top line or leftmost column of the square, the square is moved to the next position. This test is performed to ensure that prior to computation of the brokenness percentages the square will be positioned to cover a maximum area of the broken region (i.e. to make the covered "neighborhood" as large as possible). Next, any isolated broken-region element within the square which has not previously been assigned a brokenness value is "erased," i.e., reclassified as belonging to a cloud or noncloud region. The technique for performing this is described completely in the flow chart of Figure 2-3 and it will be only generally described here. The four elements horizontally and vertically adjacent to the element in question are assigned a value 0, 1, or 2 according to their regional classification of broken, cloud, and noncloud respectively. A logical operation on a selected combination of these numbers first of all determines whether the element is in fact isolated. If not, processing continues to the next stage; if so, a series of further logical tests determines whether the element should be reclassified cloud or noncloud (e. g. if it is flanked horizontally by cloud-region elements, it is reclassified as a cloud-region element). That is, the "context" of the element is determined in order to decide into which solid region the element should be reclassified. Following "erasure" the next element of the square is considered.

If the element is not isolated, its contribution to the brokenness percentage is determined. If the element above it is a broken-region element, a tally is made to the count A of broken-region-element adjacencies over the square area. If, furthermore, it "contrasts"[3] with the given element (is noncloud when the given element is cloud or vice versa) a tally is made to the count C of contrasts over the square area. The same operations are performed on the left neighboring element of the given element.

This continues until all elements of the square have been considered. If now at least one isolated element has been "erased", the program verifies that there is still at least one broken-region element in the first row and first column of the square (if not, the square is moved to the next position) before performing the brokenness computations.

The value

$$P = \text{Integer}\left[\frac{10C}{A}\right]$$

is computed and assigned as a label (by storage within the rightmost four bit positions of the six-bit element) to all broken-region elements

---

3. Here note that the element itself is being considered, rather than the region to which it is assigned.

within the square which have not previously been assigned a value or which have a preassigned value smaller than P. It will be seen that P represents the degree of brokenness as the ratio of actual contrasts to maximum possible contrasts over the neighborhood of the scanning square, and that the P-value ultimately assigned to an element is the maximum value obtained for varying positions of the element relative to the square.

On completion of the scan, elements of the picture stored in computer memory have now been classified as cloud-region, noncloud-region or broken-region with brokenness value 0, 1, ..., or 9. The picture, consisting of the cloud/noncloud elements and the overprinting indicating their regional assignment, is now printed line by line. During this output a frequency count is made of the number of broken-region elements $n_0, n_1, \ldots n_9$ assigned the value 0, 1, ..., 9 respectively. Following the picture printout for each value $i(i = 0, 1, \ldots, 9)$ the designation i, the frequency n_i, and the percentage of total area

$$\frac{n_i}{n_0 + n_1 + \ldots + n_9}$$

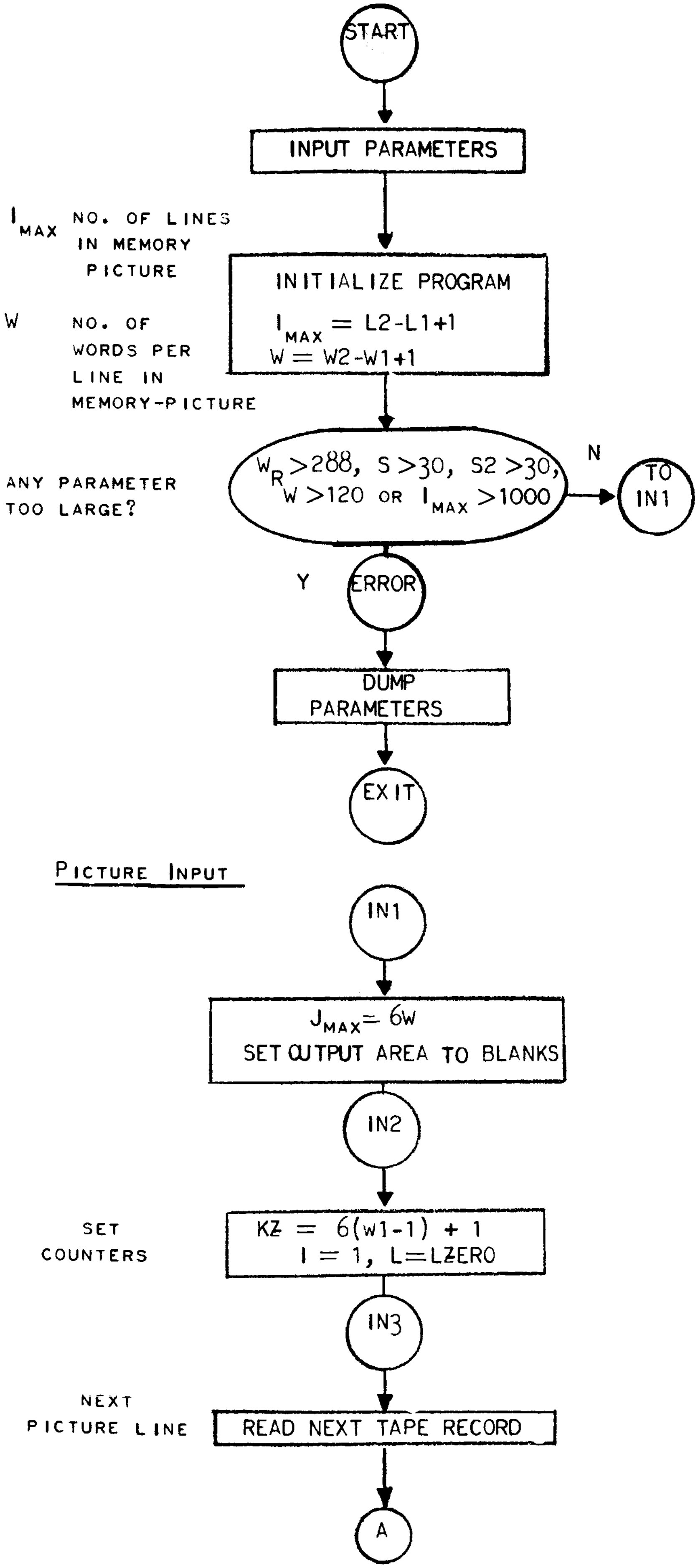
are output as shown in Figure 2-2.

At the end of processing the picture representation in memory remains intact for optional further processing.

The logical flow chart of SB-2 is presented as Figure 2-3. The IBM 7094 symbolic program listing for SB-2 is presented as Figure 2-4.

Figure 2-3

SB-2 Flow Chart



TAPES

INPUT TAPE: PICTURE TAPE

PARAMETERS

T	THRESHOLD
L1	FIRST LINE OF TAPE-PICTURE
L2	LAST LINE OF TAPE-PICTURE
W1	FIRST WORD OF TAPE-PICTURE
W2	LAST WORD OF TAPE-PICTURE
S	SCANNING SQUARE SIZE FOR SORD PROCESSING
W_R	WORDS PER LINE OF TAPE-PICTURE
B_W	MAXIMUM QUANTITY OF NONCLOUD ELEMENTS IN SQUARE FOR ASSIGNMENT TO CLOUD REGION
B_B	MINIMUM QUANTITY OF BLACK ELEMENTS IN SQUARE FOR ASSIGNMENT TO CLOUD REGION
S2	SCANNING SQUARE SIZE FOR BRAND PROCESSING

J_{MAX}	NO. OF ELEMENTS PER LINE IN MEMORY-PICTURE
KZ	NO. OF FIRST ELEMENT OF TAPE-PICTURE
I	MEMORY-PICTURE LINE COUNTER
L	TAPE-PICTURE LINE COUNTER
LZERØ	MASTER TAPE LINE COUNTER

FIGURE 2-3/ PAGE 1

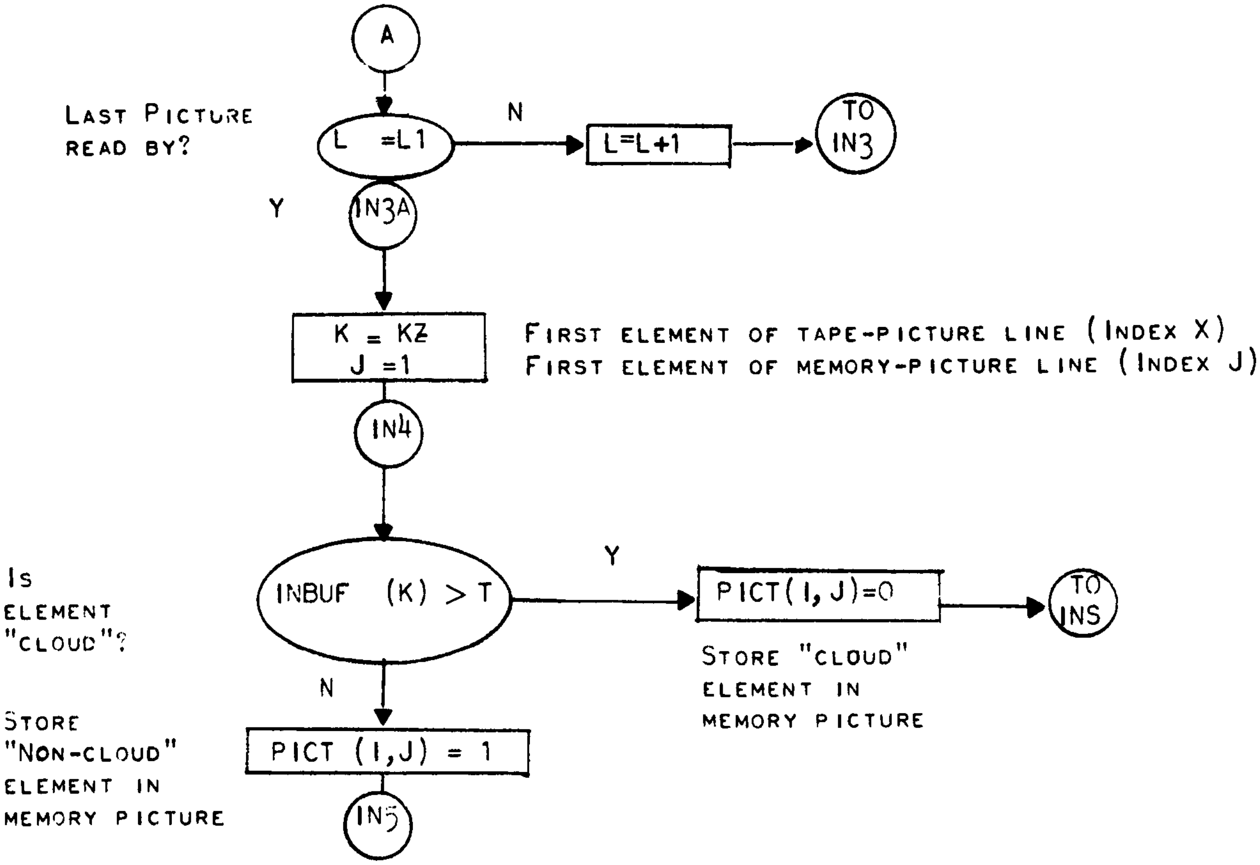


FIGURE 2-3/PAGE 2

SORD-2 PROCESSING

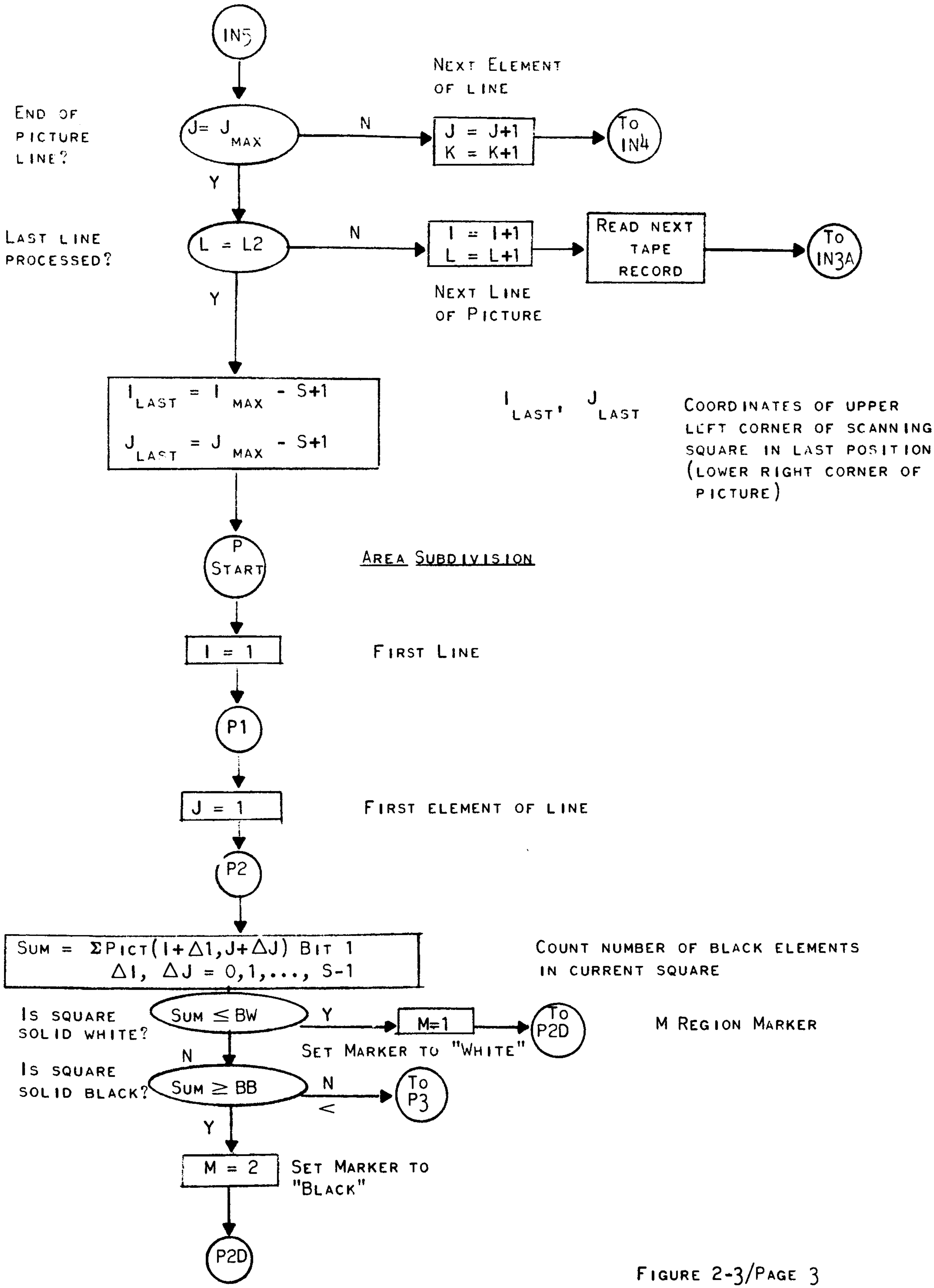


FIGURE 2-3/PAGE 3

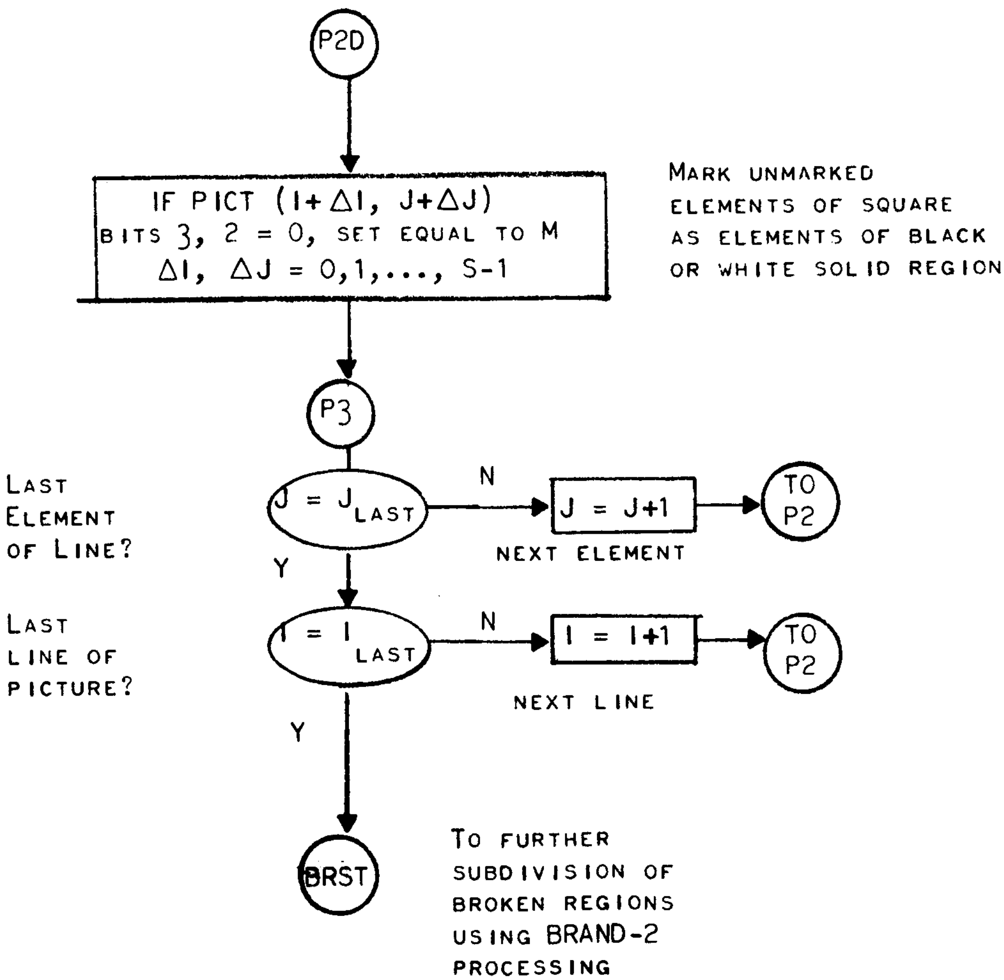
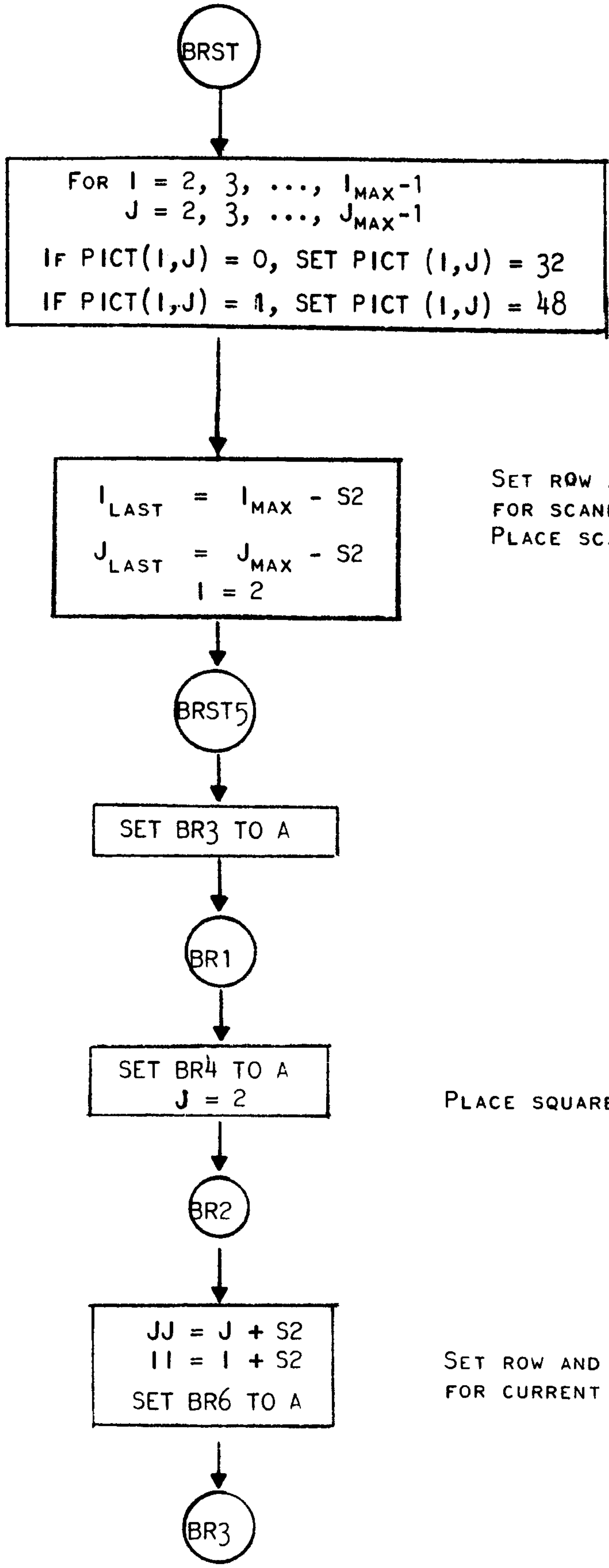


FIGURE 2-3/PAGE 4



CHANGE FORMAT OF BROKEN-REGION ELEMENTS TO ALLOW STORAGE OF BROKENNESS VALUE

BIT 6: 1=BROKEN, 0=SOLID REGION

5: 1=NONCLOUD, 0=CLOUD ELEMENT

4-1: BROKENNESS VALUE

SET ROW AND COLUMN INDEX FLAGS FOR SCANNING SQUARE OVER WHOLE PICTURE. PLACE SCANNING SQUARE AT TOP OF PICTURE

PLACE SQUARE AT LEFT BORDER OF PICTURE

SET ROW AND COLUMN INDEX FLAGS FOR CURRENT SQUARE

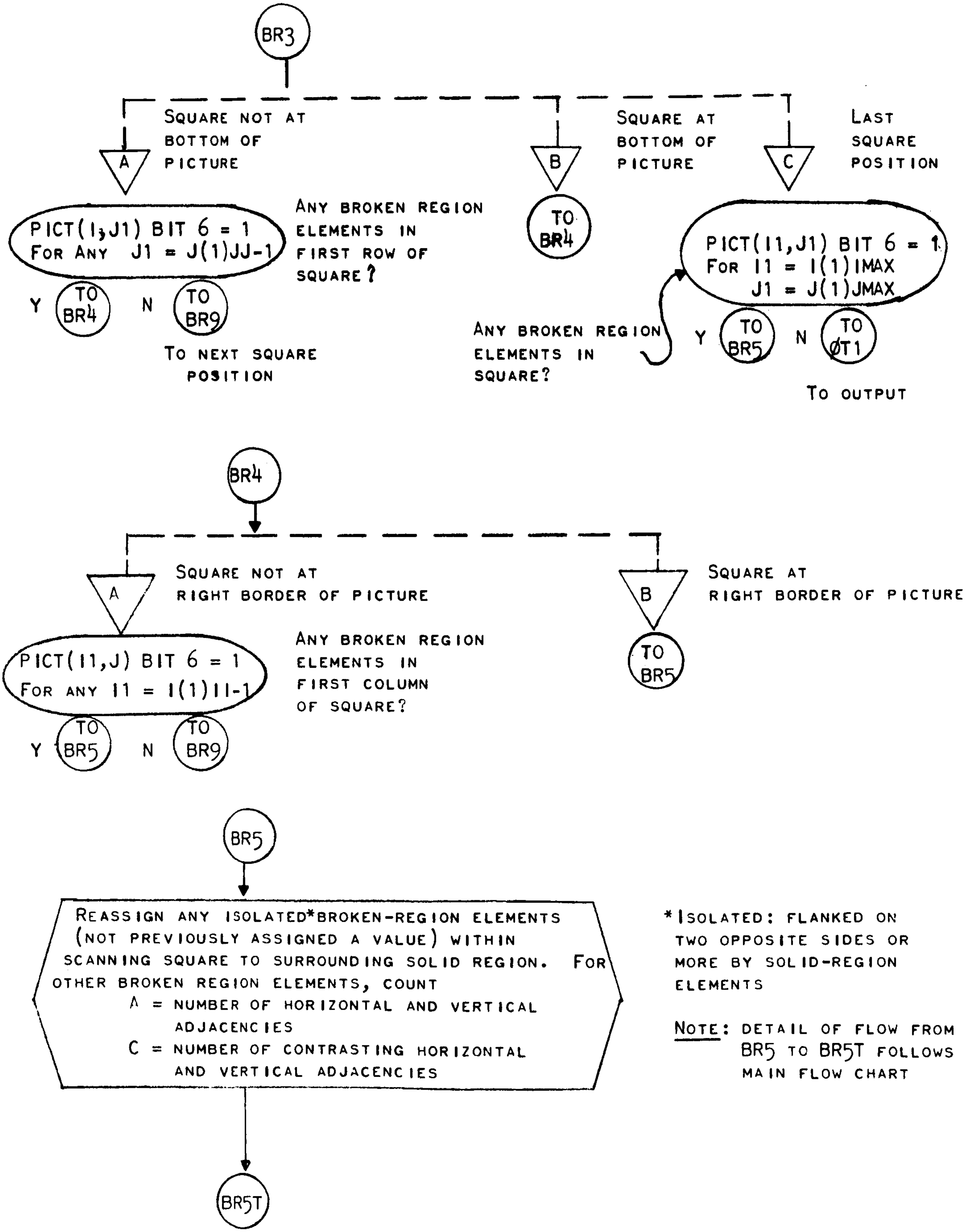


Figure 2-3/Page 6

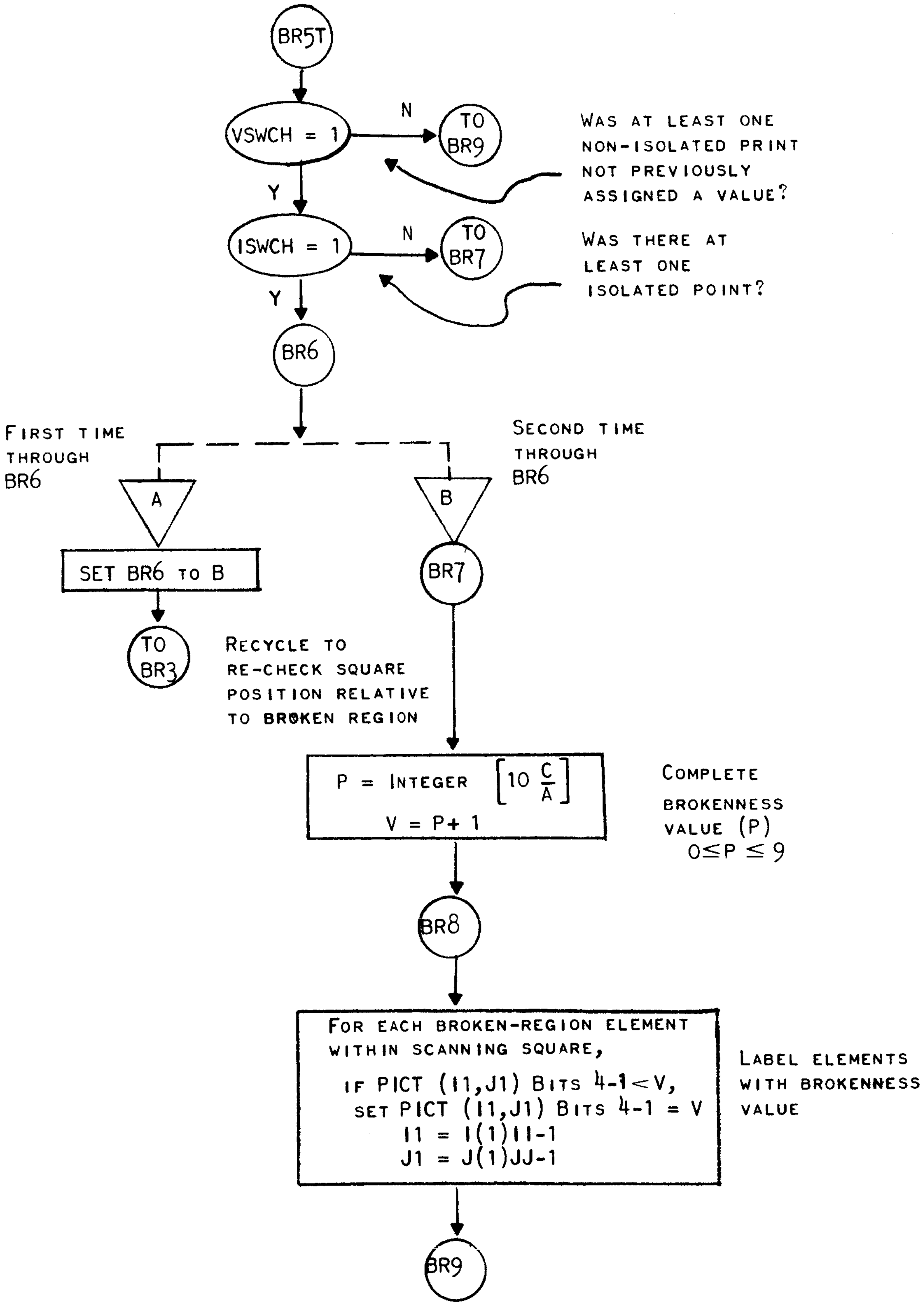
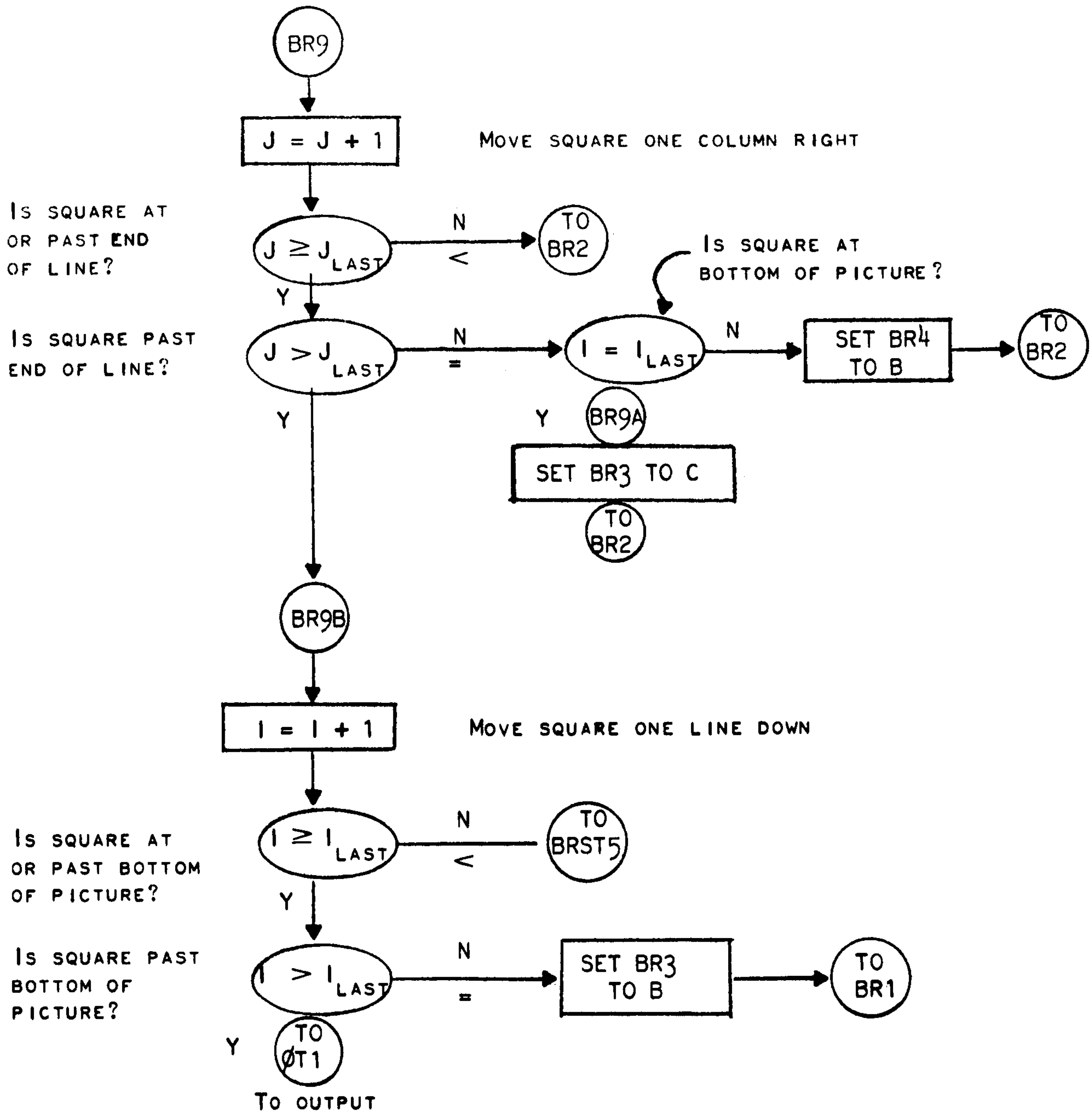
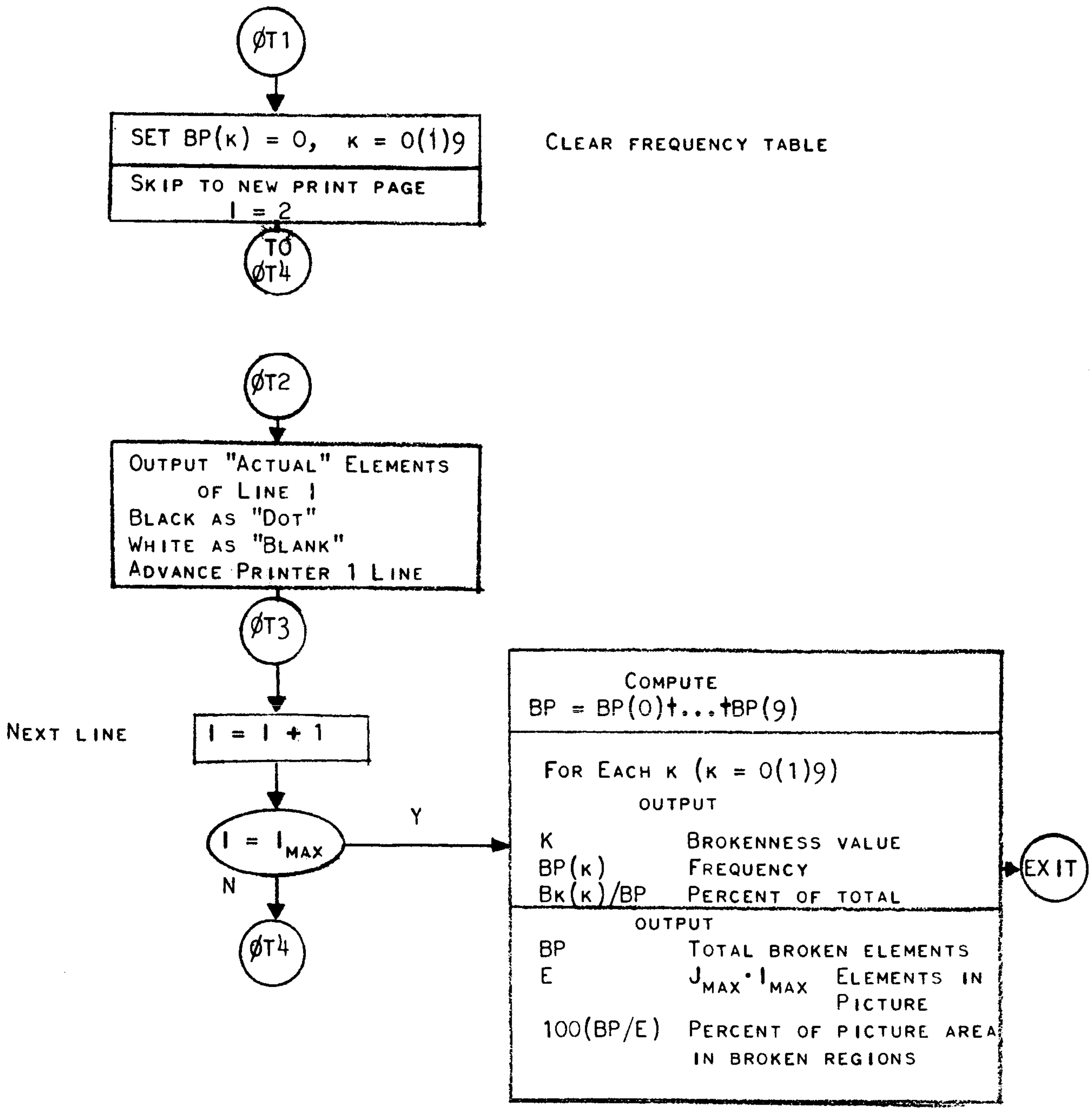


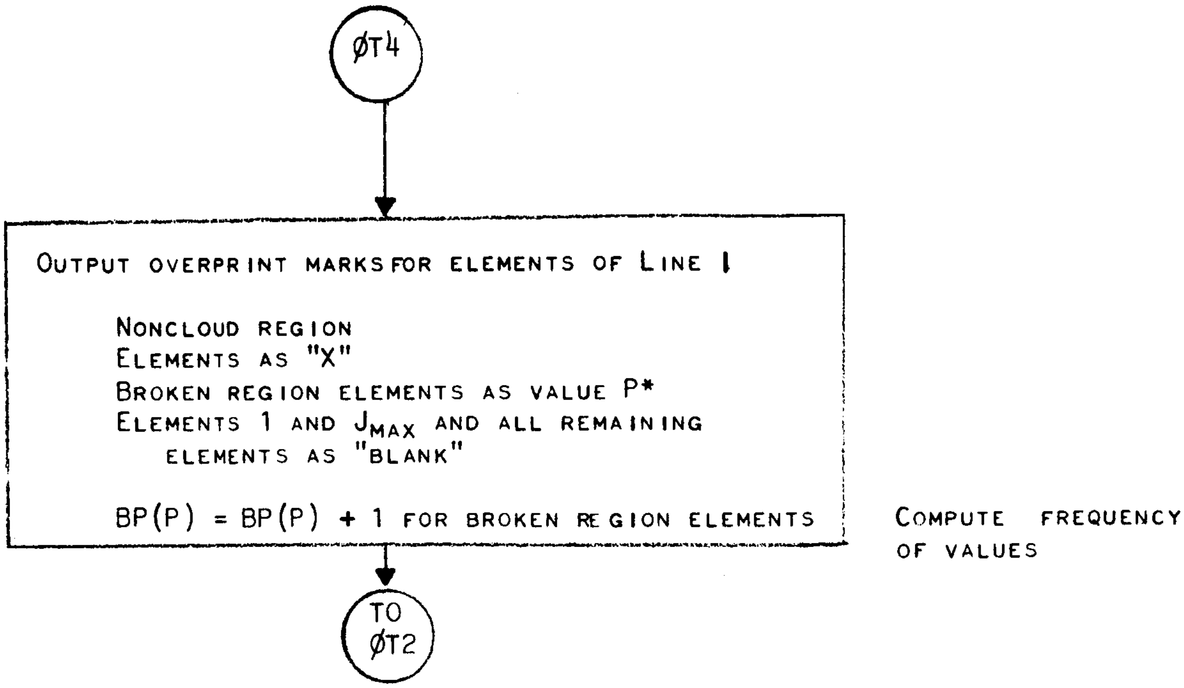
FIGURE 2-3/PAGE 7


BR9
J = J + 1
MOVE SQUARE ONE COLUMN RIGHT
IS SQUARE AT OR PAST END OF LINE?
J ≥ J LAST
N
<
TO BR2
IS SQUARE AT BOTTOM OF PICTURE?
Y
IS SQUARE PAST END OF LINE?
J > J LAST
N
=
I = I LAST
N
SET BR4 TO B
TO BR2
Y
BR9A
SET BR3 TO C
TO BR2
Y
BR9B
I = I + 1
MOVE SQUARE ONE LINE DOWN
IS SQUARE AT OR PAST BOTTOM OF PICTURE?
I ≥ I LAST
N
<
TO BRST5
Y
IS SQUARE PAST BOTTOM OF PICTURE?
I > I LAST
N
=
SET BR3 TO B
TO BR1
Y
TO ØT1
TO OUTPUT

OUTPUT



ØT1
SET BP(K) = 0, K = 0(1)9
CLEAR FREQUENCY TABLE
SKIP TO NEW PRINT PAGE
I = 2
TO ØT4
ØT2
OUTPUT "ACTUAL" ELEMENTS OF LINE I
BLACK AS "DOT"
WHITE AS "BLANK"
ADVANCE PRINTER 1 LINE
ØT3
NEXT LINE
I = I + 1
I = I MAX
Y
N
ØT4
COMPUTE
BP = BP(0)+...+BP(9)
FOR EACH K (K = 0(1)9)
OUTPUT
K BROKENNESS VALUE
BP(K) FREQUENCY
BK(K)/BP PERCENT OF TOTAL
OUTPUT
BP TOTAL BROKEN ELEMENTS
E JMAX·IMAX ELEMENTS IN PICTURE
100(BP/E) PERCENT OF PICTURE AREA IN BROKEN REGIONS
EXIT



*P = V-1 WHERE V IS STORED ELEMENT VALUE

Isolated point routine

Flow chart detail BR5 to BR5T

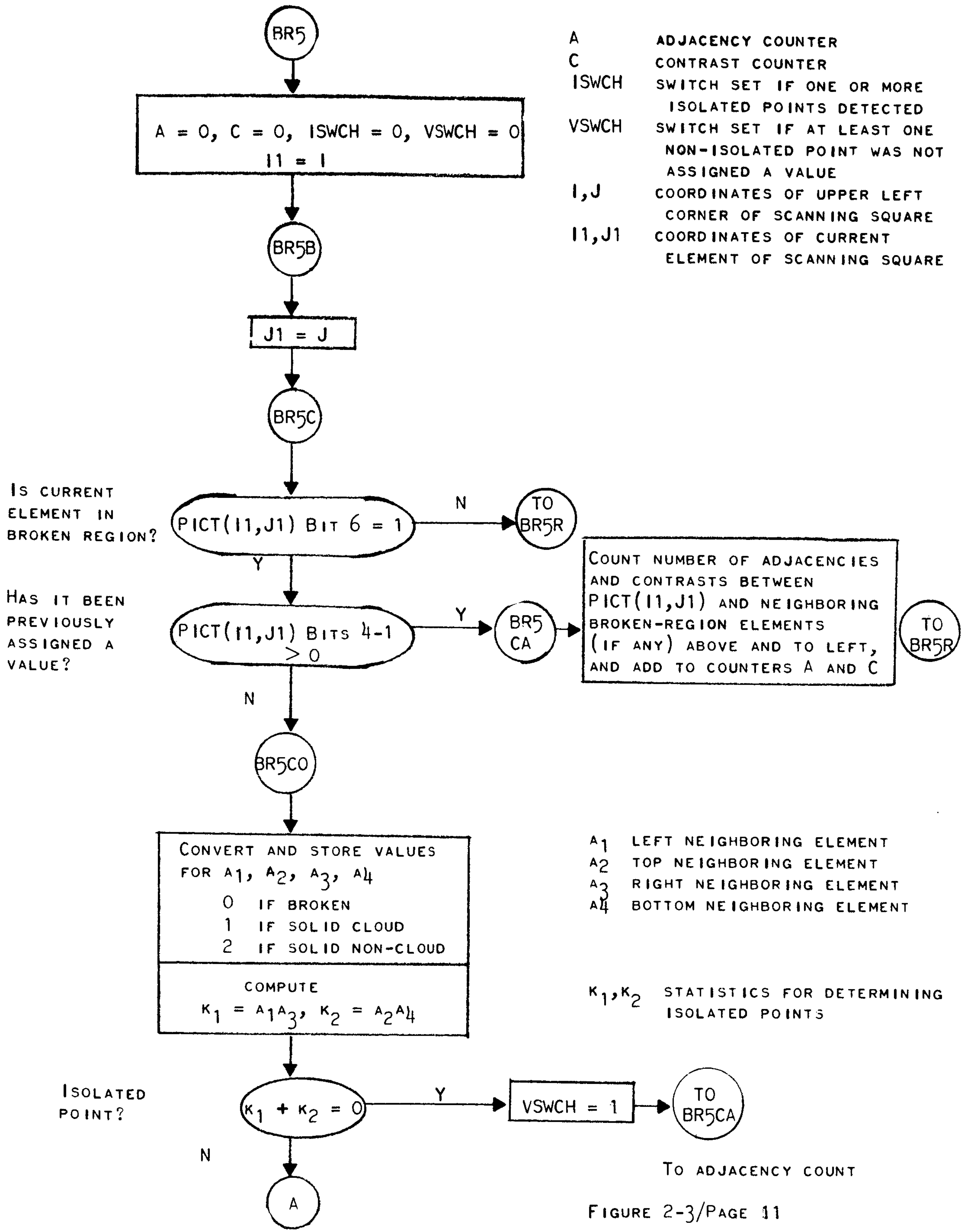


Figure 2-3/Page 11

S SOLID REGION (N OR C)
C CLOUD REGION
N NONCLOUD REGION
/ BROKEN REGION

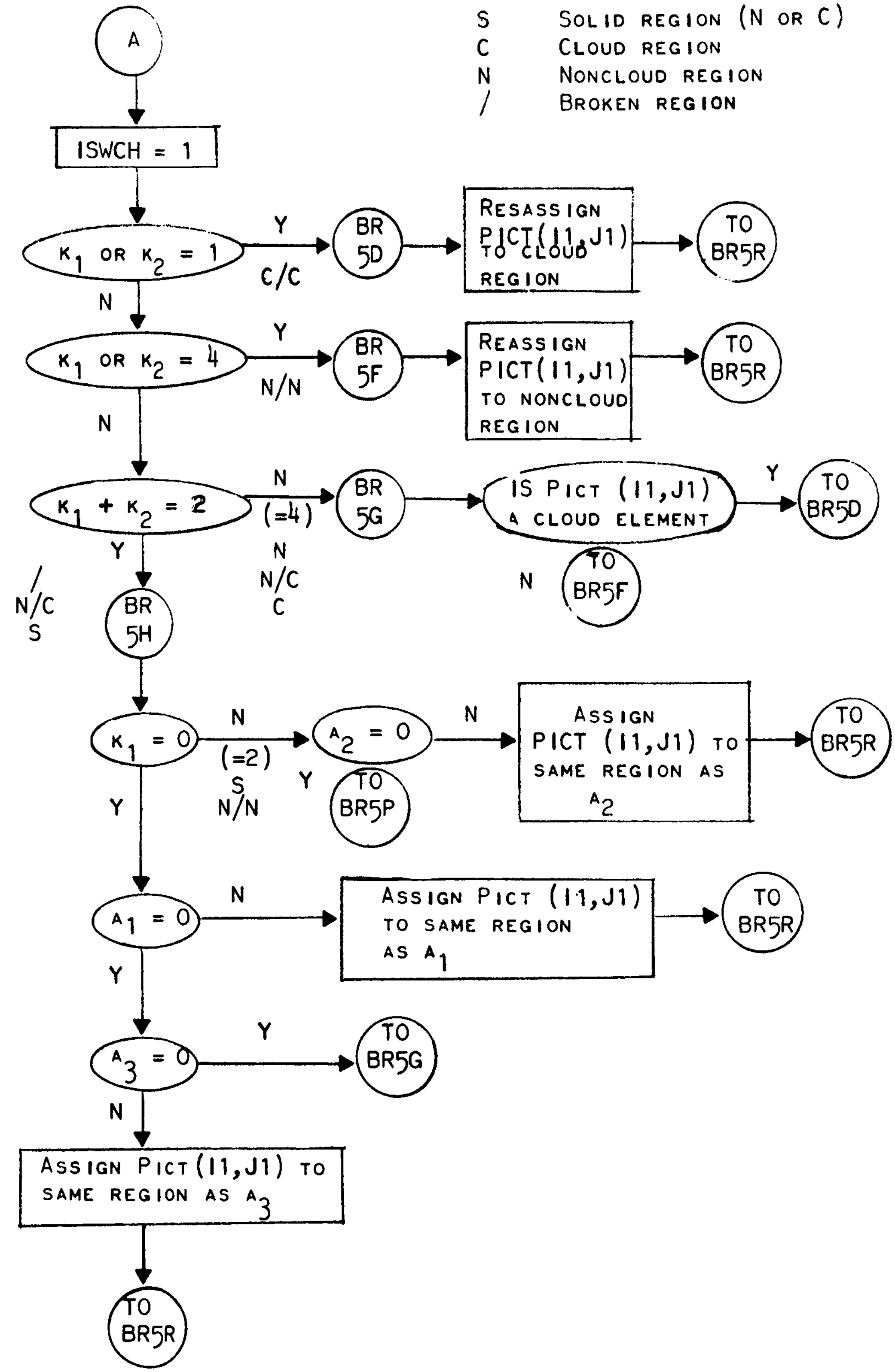


FIGURE 2-3/PAGE 12

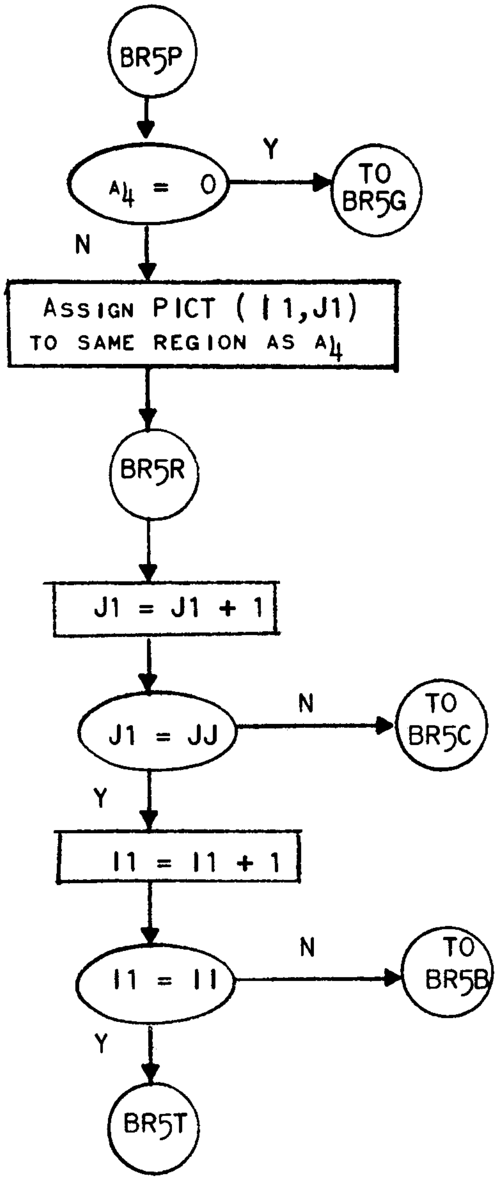

BR5P
A4 = 0
Y
TO BR5G
N
ASSIGN PICT (I1,J1) TO SAME REGION AS A4
BR5R
J1 = J1 + 1
J1 = JJ
N
TO BR5C
Y
I1 = I1 + 1
I1 = II
N
TO BR5B
Y
BR5T

Figure 2-4

SB-2 Symbolic Program Listing

```
*                   SB-2 (SORD-2, BRAND-2) PROGRAM
          LBL       SB2,2
          ENTRY     SABOP2
*                   REQUIRED SUBROUTINES
*                                          BASIC FORTRAN I/O PKG
LZERO     COMMON    1
W2        COMMON    1
W1        COMMON    1
L2        COMMON    1
L1        COMMON    1
BB        COMMON    1
BW        COMMON    1
WR        COMMON    1
T         COMMON    1
S2        COMMON    1
S         COMMON    1
          EXTERN    PUT2
          EXTERN    TAKE2
*                   MACRO INSTRUCTIONS
*                   MACROS USED--EQUL,TEQL,ADST,TAKEM,
*                   PUTM,TNQL,BTEST,CNVST,BRTOSL,SBST,SETV
TEQL      MACRO     X,Y,OUT                TEST (X) NOT EQ(Y)
          CLA       X
          SUB       Y
          TZE       OUT
TEQL      END
TNQL      MACRO     X,Y,OUT                TEST (X) NOT EQ(Y)
          CLA       X
          SUB       Y
          TNZ       OUT
TNQL      END
EQUL      MACRO     Y,X                    SET (Y)=(X)
          CLA       X
          STO       Y
EQUL      END
ADST      MACRO     Z,X,Y                  ADD AND STORE
          CLA       X
          ADD       Y
          STO       Z
ADST      END
TAKEM     MACRO     AZERO,C,I,J
          TSX       TAKE2,4
          PZE       AZERO,2
          PZE       C
          PZE       I
          PZE       J
TAKEM     END
PUTM      MACRO     AZERO,C,I,J
          TSX       PUT2,4
          PZE       AZERO,2
          PZE       C
          PZE       I
          PZE       J
PUTM      END
BTEST     MACRO     DELI,DELJ,OUT          BOUNDARY TEST
          ADST      IDELI,I,DELI
          ADST      JDELJ,J,DELJ
          TAKEM     PICT,JMAX,IDELI,JDELJ
          ANA       =6                     MARKER BITS
          SUB       =2
```

Figure 2-4/Page 1

```
        TZE     OUT                     IF A BOUNDARY POINT
BTEST   END
CNVST   MACRO   A                       CONVERT, STORE ELEMENT VALUES
        TAKEM   PICT,JMAX,I1,J1         FETCH CURR ELEM
        CAS     =5
        TRA     *+4                     IF BROKEN
        TRA     *+1                     IF SOLID
        ARS     1                       CONVERT TO 1 IF WHITE,
        TRA     *+2                     2 IF BLACK
        CLA     =0                      BRKN.  CONVERT TO 0 AND STORE
        STO     A
CNVST   END
*
BRTOSL  MACRO   ASUBN                   BRKN ELEM TO SOLID
        CLA     ASUBN                   ASSIGN CURRENT ELEM (BRKN)
        ALS     1                       TO SAME REGION AS
        STO     ASUBN                   NEIGHBOR ASUBN (SOLID)
        TAKEM   PICT,JMAX,I1,J1
        ARS     4
        ANA     =01                     EXTRACT BLACK/WHITE BIT
        ADD     ASUBN
        PUTM    PICT,JMAX,I1,J1
BRTOSL  END
*
SETV    MACRO   A,V                     SET VARIABLE CONNECTOR
        CLA     V
        STA     A
SETV    END
*
SBST    MACRO   Z,X,Y                   SUBTRACT AND STORE
        CLA     X
        SUB     Y
        STO     Z
SBST    END
*               BEGIN PROGRAM
*               SORD-2   SOLID REGION DELINEATOR SUBRTN
SABOP2  CLA     WR                      SET CONSTANTS,ETC.
        ALS     18
        STD     LIOC
        LDQ     WR
        MPY     =6
        STQ     ER
        SXA     SAVE4,4
        CLA     L2                      TEST PARAMETERS
        SUB     L1
        ADD     =1
        STO     IMAX
        SUB     =1001
        TPL     ERROR                   IF PICTURE TOO LONG
        CLA     W2
        SUB     W1
        ADD     =1
        STO     W
        SUB     =21
        TPL     ERROR                   IF PICTURE TOO WIDE
        CLA     WR
        SUB     =289
        TPL     ERROR                   IF INPUT BUFFER TOO LONG
        CLA     S
        SUB     =31
```

```
        TPL      ERROR                 IF SORD SQ SIZE TOO LARGE
        CLA      S2
        SUB      =31
        TMI      IN1                   IF BRAND SQ SIZE NOT TOO LARGE
ERROR   CALL     PDUMP,S,W2,3          ERROR DUMP OF PARAMETERS
        LXA      SAVE4,4
        TRA      1,4
IN1     LDQ      W
        MPY      =6
        STQ      JMAX
        AXT      20,1
        CLA      =0606060606060
        STO      OTBUF+20,1            SET OUTPUT BUFFER TO BLANKS
        TIX      *-1,1,1
IN2     CLA      W1                    COMPUTE FIRST-ELEMENT NR OF INBUF
        SUB      =1
        XCA
        MPY      =6
        XCA
        ADD      =1
        STO      KZ
        EQUL     I,=1
        EQUL     L,LZERO
IN3     CALL     RDSBIN       READ NEXT TAPE RECORD
        TIX      0,0,9
        TIX      LIOC,1,0
        TIX      0,1,0
        TRA      *+2
LIOC    IORT     INBUF,0,**
        TEQL     L,L1,IN3A             IF FIRST PICT RECORD REACHED
        ADST     L,L,=1
        TRA      IN3
IN3A    EQUL     K,KZ                  INPUT PICTURE FROM TAPE INTO PICT AREA
        EQUL     J,=1
IN4     TAKEM    INBUF,ER,=1,K         TEST ELEMENT AGAINST THRESHOLD
        SUB      T
        SUB      =1
        TPL      IN4A
        CLA      =1                    STORE IN PICT AS BLACK ELEMENT
        TRA      IN4B
IN4A    CLA      =0                    STORE IN PICT AS WHITE ELEMENT
IN4B    PUTM     PICT,JMAX,I,J
IN5     TEQL     J,JMAX,IN5A
        ADST     J,J,=1                IF END OF LINE
        ADST     K,K,=1
        TRA      IN4
IN5A    TEQL     L,L2,IN5B             IF END OF PICT
        ADST     I,I,=1
        ADST     L,L,=1
        CALL     RDSBIN
        TIX      0,0,9
        TIX      LIOC,1,0
        TIX      0,1,0
        TRA      IN3A
IN5B    CLA      IMAX                  COMPUTE COORDINATES OF
        SUB      S                     LOWER RH SQUARE OF PICT
        ADD      =1
        STO      ILAST
        CLA      JMAX
        SUB      S
```

```
         ADD     =1
         STO     JLAST
PSTART   EQUL    I,=1                   MARK PICT ELEMENTS AS BELONGING TO
P1       EQUL    J,=1                   BLACK,WHITE OR BROKEN REGION
P2       STZ     SUM                    COMPUTE NO. BLACK ELEMENTS IN SQUARE
         EQUL    J1,J
         LXA     S,2
P2A      EQUL    I1,I
         LXA     S,1
P2B      TAKEM   PICT,JMAX,I1,J1
         ANA     =1
         ADD     SUM
         STO     SUM
         ADST    I1,=1,I1
         TIX     P2B,1,1
         ADST    J1,=1,J1
         TIX     P2A,2,1
         CLA     BW
         SUB     SUM
         TMI     P2C                    IF SUM GREATER THAN MINIMUM BLACK
         CLA     =2                     ELSE SET MARKER TO WHITE
         TRA     P2D
P2C      CLA     SUM
         SUB     BB
         TMI     P3                     IF SUM LESS THAN MAX. BLACK, NO MARK
         CLA     =4                     ELSE SET MARKER TO BLACK
P2D      STO     M
         EQUL    I1,I                   MARK ALL UNMARKED SQ ELEMENTS
         LXA     S,2
P2E      EQUL    J1,J
         LXA     S,1
P2F      TAKEM   PICT,JMAX,I1,J1
         STO     ELEM
         ANA     =6                     MARKER BITS
         TNZ     P2G                    IF ELEMENT PREVIOUSLY MARKED
         CLA     ELEM                   ELSE MARK ELEMENT
         ADD     M
         PUTM    PICT,JMAX,I1,J1
P2G      ADST    J1,=1,J1
         TIX     P2F,1,1
         ADST    I1,=1,I1
         TIX     P2E,2,1
P3       TEQL    J,JLAST,P3A
         EQUL    J1,J
         ADST    J,J,=1
         EQUL    I1,I
         LXA     S,1
P4       TAKEM   PICT,JMAX,I1,J1
         ANA     =1
         SUB     SUM
         SLW     SUM
         ADST    I1,=1,I1
         TIX     P4,1,1
         ADST    J1,S,J1
         AXT     1,2
         TRA     P2A
P3A      TEQL    I,ILAST,BRST
         ADST    I,I,=1
         TRA     P1
*
```

```
*                       OUTPUT SUBRTN
OT1      CAL      =6B17                  OUTPUT
         CALL     (STH)                  SKIP TO NEW PAGE
         PZE      FMT1,0,-1
         CALL     (FIL)
         AXT      10,4
         STZ      BP+10,4
         TIX      *-1,4,1
         TRA      OT1A
FMT1     BCI      1,(1H1)
OT1A     EQUL     I,=2
         TRA      OT4
OT2      CAL      =6B17                  PRINT LINE OF PICTURE ELEMENTS
         CALL     (STH)
         PZE      FMT2,0,1
         TRA      OT2A
FMT2     BCI      2,(1H9,20A6)           ADVANCE PRINTER AFTER PRINT
OT2A     EQUL     J,=1
OT2B     TAKEM    PICT,JMAX,I,J
         STO      ELEM
         ANA      =040                   BROKEN/SOLID BIT
         TZE      OT2AA                  IF SOLID
         CLA      ELEM
         ARS      4                      BRKN.  SHIFT B/W BIT TO LOW ORDER POS
         TRA      OT2BA
OT2AA    CLA      ELEM
OT2BA    ANA      =1                     EXTRACT ELEMENT BIT
         TZE      OT2BB                  IF WHITE
         CLA      =033                   BLACK ELEMENT SYMBOL=DOT
         TRA      OT2B1
OT2BB    CLA      =060                   WHITE ELEMENT SYMBOL=BLANK
OT2B1    PUTM     OTBUF,ONETWE,=1,J
         TEQL     J,JMAX,OT2C            IF END OF LINE
         ADST     J,J,=1
         TRA      OT2B
OT2C     AXT      20,1                   FEED LINE TO PRINTER
OT2D     LDQ      OTBUF+20,1
         STR
         TIX      OT2D,1,1
         CALL     (FIL)
OT3      ADST     I,I,=1                 OVERPRINT SYMBOLS FOR
         TNQL     I,IMAX,OT4             BOUNDARY AND BROKEN-REGION POINTS,
         CAL      =6B17
         CALL     (STH)
         PZE      FMT4,0,1
         TRA      *+11
HEAD     BCI      6,1             BP       FREQ      PCT
FMT4     BCI      4,(6A6//(1I12,1I9,1I8))
         AXT      10,1
         CLA      =0
         ADD      BP+10,1
         TIX      *-1,1,1
         STO      TOTAL
         AXT      6,1
OT3A     LDQ      HEAD+6,1
         STR
         TIX      OT3A,1,1
         AXT      10,1
OT3B     PXD      0,1
         SUB      =10B17
```

```
        SSP
        XCA
        STR
        LDQ     BP+10,1
        LLS     18
        STR
        LDQ     BP+10,1
        MPY     =100
        DVP     TOTAL
        ALS     1
        SUB     TOTAL
        TMI     *+4
        XCA
        ADD     =1
        XCA
        LLS     18
        STR
        TIX     OT3B,1,1
        CALL    (FIL)
        CAL     =6B17
        CALL    (STH)
        PZE     FMT5,0,1
        LDQ     TOTAL
        LLS     18
        STR
        CALL    (FIL)
        CAL     =6B17
        CALL    (STH)
        PZE     FMT6,0,1
        LDQ     W
        MPY     =6
        XCA
        SUB     =2
        STO     ELEM
        CLA     L2
        SUB     L1
        SUB     =1
        XCA
        MPY     ELEM
        LLS     18
        STQ     ELEM
        STR
        CALL    (FIL)
        CAL     =6B17
        CALL    (STH)
        PZE     FMT7,0,1
        LDQ     TOTAL
        MPY     =100
        LLS     18
        DVP     ELEM
        LLS     18
        STR
        CALL    (FIL)
        TRA     *+22
FMT5    BCI     7,(//(10X,1I10,2X,16H BROKEN ELEMENTS))
FMT6    BCI     7,(//(10X,1I10,2X,20H ELEMENTS IN PICTURE))
FMT7    BCI     7,(//(10X,1I10,2X,15H PERCENT BROKEN))
*                                 LINES 2 THROUGH IMAX-1
        LXA     SAVE4,4
        TRA     1,4                EXIT
```

Figure 2-4/ Page 6

```
OT4     CLA     =060                SET FIRST AND LAST ELEMENTS
        PUTM    OTBUF,ONETWE,=1,ONE    OF LINE TO BLANK
        CLA     =060
        PUTM    OTBUF,ONETWE,=1,JMAX
        EQUL    J,=2
OT4A    TAKEM   PICT,JMAX,I,J
        STO     ELEM
        SUB     =6
        TMI     OT4AA               IF ELEM IN SOLID REGION
        CLA     ELEM                IN BRKN REGION
        ANA     =017                EXTRACT BRKNNESS VALUE BITS
        CAS     =11
        TRA     *+1
        SUB     =1
        SUB     =1
        PAC     0,4
        XCA
        CLA     BP,4
        ADD     =1
        STO     BP,4
        XCA
        TRA     OT4B
OT4AA   CLA     =3
        SUB     ELEM
        TPL     OT4AB               IF ELEM SOLID WHITE
        CLA     =067                SOLID BLACK REGION SYMB = X
        TRA     OT4B
OT4AB   CLA     =060                SOLID WHITE ELEM SYMB = BLANK
OT4B    PUTM    OTBUF,ONETWE,=1,J
        CLA     J
        SUB     JMAX
        ADD     =1
        TZE     OT5                 IF END OF LINE
        ADST    J,J,=1
        TRA     OT4A
OT5     CAL     =6B17               FEED LINE TO PRINTER,
        CALL    (STH)               NO PRINTER ADVANCE
        PZE     FMT3,0,1
        TRA     OT6
FMT3    BCI     2,(1H+,20A6)
OT6     AXT     20,1
OT6A    LDQ     OTBUF+20,1
        STR
        TIX     OT6A,1,1
        CALL    (FIL)
        TRA     OT2
*
*               TEMP STORAGE, CTRS, ETC FOR BRAND-2 AND SORD-2
I       DEC     0                   PICT (MEMORY PICTURE) LINE INDEX
I1      DEC     0
IDELI   DEC     0
ILAST   DEC     0                I COORDINATE OF LOWER RH SQUARE IN PICT
IMAX    DEC     0                   LAST LINE OF PICT
J       DEC     0                   PICT COLUMN INDEX
J1      DEC     0
JDELJ   DEC     0
JLAST   DEC     0                J COORDINATE OF LOWER RH SQUARE IN PICT
JMAX    DEC     0                   LAST COLUMN OF PICT
K       DEC     0                   INPUT BUFFER INDEX
L       DEC     0                   TAPE RECORD INDEX
```

```
SUM      DEC     0                          SQUARE SUM
M        DEC     0                          ELEMENT MARKER
ELEM     DEC     0
ER       DEC     0                          WIDTH OF PICT, IN ELEMENTS
SAVE4    DEC     0
W        DEC     0                          WIDTH OF PICT, IN WORDS
KZ       DEC     0                          FIRST PICT ELEMENT OF INPUT BUFFER
ONETWE   DEC     120
ONE      DEC     1
*
*                BROKEN REGION ANALYZER AND DELINEATOR SUBRTN
BRST     EQUL    I,=2                       CHNGE CODE OF PICT BRKN ELEMENTS
BRST1    EQUL    J,=2                       EXCLUDE BORDER ELEMENTS, NONE BROKEN
BRST2    TAKEM   PICT,JMAX,I,J              NEXT ELEMENT
         TNZ     BRST3A
         CLA     =32                        BRKN WHITE.  CHANGE FROM 0 TO 32
BRST3    PUTM    PICT,JMAX,I,J
         TRA     BRST4
BRST3A   SUB     =1
         TNZ     BRST4                      IF ELEM SOLID
         CLA     =48                        BRKN BLACK.  CHANGE FROM 1 TO 48
         TRA     BRST3
BRST4    ADST    J,J,=1                     NEXT COLUMN OF PICTURE
         TNQL    J,JMAX,BRST2
         ADST    I,I,=1                     NEXT LINE OF PICTURE
         TNQL    I,IMAX,BRST1
         SBST    ILAST,IMAX,S2              SET LINE, COLUMN INDEX FLAGS
         SBST    JLAST,JMAX,S2              FOR SCANNING-SQ OVER WHOLE PICTURE
         EQUL    I,=2                       SQ AT TOP OF PICT (EXCLUDING BORDER)
BRST5    SETV    BR3,V3A
BR1      SETV    BR4,V4A
         EQUL    J,=2                       SQ AT FAR LEFT OF PICT (EXCL BORDER)
BR2      ADST    II,I,S2                    SET ROW, COLUMN INDEX FLAGS
         ADST    JJ,J,S2                    OVER CURRENT SQ
         SETV    BR6,V6A
BR3      TRA     *                          V C
BR3A     EQUL    J1,J
BR3A1    TAKEM   PICT,JMAX,I,J1             ANY BRKN ELEMENTS IN
         ANA     =040                       FIRST ROW OF SQ
         TNZ     BR4                        YES
         ADST    J1,J1,=1
         TNQL    J1,JJ,BR3A1
         TRA     BR9                        NO.  TO NEXT SQUARE POSITION
BR3C     EQUL    I1,I                       ANY BRKN ELEMENTS IN SQ
BR3C1    EQUL    J1,J
BR3C2    TAKEM   PICT,JMAX,I1,J1
         ANA     =040
         TNZ     BR5                        YES
         ADST    J1,J1,=1
         TNQL    J1,JJ,BR3C2
         ADST    I1,I1,=1
         TNQL    I1,II,BR3C1
         TRA     OT1                        NO.  TO OUTPUT
BR4      TRA     *                          V C
BR4A     EQUL    I1,I
BR4A1    TAKEM   PICT,JMAX,I1,J             ANY BRKN ELEMENTS IN
         ANA     =040                       FIRST COL OF SQ
         TNZ     BR5                        YES
         ADST    I1,I1,=1
         TNQL    I1,II,BR4A1
```

```
         TRA      BR9                           NO
*                 ISOLATED POINT PROCESSING
BR5      EQUL     ISWCH,=0                      SET SWITCHES
         EQUL     VSWCH,=0
         EQUL     A,=0                          CLEAR CTRS
         EQUL     C,=0
         EQUL     I1,I
BR5B     EQUL     J1,J
BR5C     TAKEM    PICT,JMAX,I1,J1               CURRENT ELEMENT
         STO      ELEM
         ANA      =040                          BROKEN/SOLID BIT
         TZE      BR5R                          IF NOT BROKEN
         CLA      ELEM
         ANA      =017                          VALUE BITS OF BRKN ELEMENT
         TZE      BR5C0                         IF NOT PREVIOUSLY ASSIGNED A VALUE
BR5CA    ADST     JDELJ,J1,=-1                  ADJACENCY AND CONTRAST COUNT
         TAKEM    PICT,JMAX,I1,JDELJ LEFT NEIGHBORING ELEMENT
         STO      ELEM2
         ANA      =040
         TZE      BR5CB                         IF NOT BRKN
         ADST     A,A,=1                        BRKN.  COUNT 1 ADJACENCY
         CLA      ELEM
         ERA      ELEM2
         ANA      =020                          B/W BIT = 1 IF A CONTRAST
         TZE      BR5CB                         IF ALIKE (NO CONTRAST)
         ADST     C,C,=1                        ELSE COUNT 1 CONTRAST
BR5CB    ADST     IDELI,I1,=-1
         TAKEM    PICT,JMAX,IDELI,J1 UPPER NEIGHBORING ELEMENT
         STO      ELEM2
         ANA      =040
         TZE      BR5R
         ADST     A,A,=1
         CLA      ELEM
         ERA      ELEM2
         ANA      =020
         TZE      BR5R
         ADST     C,C,=1
         TRA      BR5R
BR5C0    ADST     J1,J1,=-1                     CONVERT, STORE REGION
         CNVST    A1                            VALUES FOR A1, A2, A3, A4   LEFT NBR
         ADST     J1,J1,=2
         CNVST    A3                            RIGHT NEIGHBOR
         ADST     J1,J1,=-1                     RESTORE COLUMN INDEX
         ADST     I1,I1,=-1
         CNVST    A2                            TOP NBR
         ADST     I1,I1,=2
         CNVST    A4                            BOTTOM NBR
         ADST     I1,I1,=-1                     RESTORE LINE INDEX
         LDQ      A1                            COMPUTE STATISTICS
         MPY      A3                            FOR DETERMINING ISOLATED PTS
         STQ      K1
         LDQ      A2
         MPY      A4
         STQ      K2
         CLA      K1
         ADD      K2
         TNZ      BR5C1                         IF ISLTD PT (BETW 2 SOLID PTS)
         EQUL     VSWCH,=1                      AT LEAST 1 NON-ISL,NON-VALUED PT
         TRA      BR5CA                         TO ADJACENCY COUNT
BR5C1    EQUL     ISWCH,=1                      AT LEAST 1 ISL PT
```

```
         TEQL     K1,=1,BR5D             IF SW/SW
         TNQL     K2,=1,BR5E
BR5D     TAKEM    PICT,JMAX,I1,J1        CHANGE CURR ELEM FROM BRKN
         ARS      4                      TO SOLID WHITE
         ANA      =01                    EXTRACT B/W BIT
         ADD      =2
BR5D1    PUTM     PICT,JMAX,I1,J1
         TRA      BR5R
BR5E     TEQL     K1,=4,BR5F             IF SB/SB
         TNQL     K2,=4,BR5F1
BR5F     TAKEM    PICT,JMAX,I1,J1        CHANGE CURR ELEM
         ARS      4                      FROM BRKN TO SOLID BLACK
         ANA      =1
         ADD      =4
         TRA      BR5D1
BR5F1    CLA      K1
         ADD      K2
         SUB      =2
         TZE      BR5H                   IF SB/SW,//S
BR5G     TAKEM    PICT,JMAX,I1,J1        SB/SW,SB/SW
         ANA      =020                   EXTRACT B/W BIT
         TNZ      BR5F                   IF CURRENT ELEMENT BLACK
         TRA      BR5D                   IF CURRENT ELEMENT WHITE
BR5H     TEQL     K1,=0,BR5I             IF LEFT OR RGT NBR BRKN
         TEQL     A2,=0,BR5P             IF TOP SOLID, BOTTOM BRKN
         BRTOSL   A2                     ELSE MERGE ELEMENT INTO TOP REGION
         TRA      BR5R
BR5I     TEQL     A1,=0,BR5J             IF LEFT BRKN, RIGHT SOLID
         BRTOSL   A1                     ELSE MERGE ELEMENT INTO LEFT REGION
         TRA      BR5R
BR5J     TEQL     A3,=0,BR5G             IF LEFT SOLID, RIGHT BRKN
         BRTOSL   A3                     ELSE MERGE ELEMENT INTO RIGHT REGION
         TRA      BR5R
BR5P     TEQL     A4,=0,BR5G             IF TOP SOLID, BOTTOM BRKN
         BRTOSL   A4                     ELSE MERGE ELEMENT INTO BOTTOM REGION
BR5R     ADST     J1,J1,=1               NEXT COL OF SQ
         TNQL     J1,JJ,BR5C
         ADST     I1,I1,=1               NEXT ROW OF SQUARE
         TNQL     I1,II,BR5B
BR5T     TNQL     VSWCH,=1,BR9           IF ALL BRKN PTS PREVSLY ASGND VALUE
         TNQL     ISWCH,=1,BR7           IF NO ISOLATED PTS
*                 END OF ISOLATED PT PROCESSING
BR6      TRA      *                      V C
BR6A     SETV     BR6,V6B
         TRA      BR3
BR7      LDQ      C                      NUMBER OF CONTRASTS WITHIN SQ
         MPY      =10
         DVP      A                      NUMBER OF ADJACENCIES WITHIN SQ
         XCA
         ADD      =1
         STO      V                      V=P+1,   P=INTEGER(B/10)
*                                        B = BROKENNESS PERCENTAGE
BR8      EQUL     I1,I                   WITHIN SQ, SET EACH
BR8A     EQUL     J1,J                   BRKN ELEM VALUE IF LSTH V, TO V
BR8B     TAKEM    PICT,JMAX,I1,J1
         STO      ELEM
         ANA      =040                   BROKEN/SOLID BIT
         TZE      BR8C                   IF NOT BROKEN
         CLA      ELEM                   ELSE IF BROKEN,
         ANA      =017                   EXTRACT VALUE BITS
```

```
         SUB     V
         TPL     BR8C                  IF NEW ELEM VALUE NOT GRTH OLD
         CLA     ELEM
         ANA     =060                  CLEAR OUT OLD VALUE
         ADD     V                     PUT IN NEW
         PUTM    PICT,JMAX,I1,J1
BR8C     ADST    J1,J1,=1              NEXT COLUMN OF SQ
         TNQL    J1,JJ,BR8B
         ADST    I1,I1,=1              NEXT ROW OF SQ
         TNQL    I1,II,BR8A
BR9      ADST    J,J,=1                MOVE SQ 1 COL RIGHT
         CLA     J
         SUB     JLAST
         TMI     BR2                   IF SQ NOT AT END OF LINE
         TNZ     BR9B                  IF SQ PAST END OF LINE
         TEQL    I,ILAST,BR9A          IF SQ AT BOTTOM OF PICT (LAST POS)
         SETV    BR4,V4B
         TRA     BR2
BR9A     SETV    BR3,V3C
         TRA     BR2
BR9B     ADST    I,I,=1                MOVE SQ 1 LINE DOWN
         CLA     I
         SUB     ILAST
         TMI     BRST5                 IF SQ NOT AT BOTTOM OF PICTURE
         TNZ     OT1                   IF PAST BOTTOM, TO OUTPUT
         SETV    BR3,V3B
         TRA     BR1
*
*                TEMP STORAGE, CONSTNANTS, ETC FOR BRAND-2
V3A      PZE     BR3A                  VAR CONNECTOR SETTINGS
V3B      PZE     BR4
V3C      PZE     BR3C
V4A      PZE     BR4A
V4B      PZE     BR5
V6A      PZE     BR6A
V6B      PZE     BR7
ISWCH    DEC     0
VSWCH    DEC     0
K1       DEC     0
K2       DEC     0
V        DEC     0                     STORED VALUE OF BRKN ELEMENT
ELEM2    DEC     0                     NEIGHBOR ELEMENT
II       DEC     0                     SQ PROCESSING
JJ       DEC     0                     FLAGS
A1       DEC     0                     TEMP STORAGE FOR
A2       DEC     0                     ISOLATED-PT SUBRTN
A3       DEC     0
A4       DEC     0
A        DEC     0                     ADJACENCY CTR
C        DEC     0                     B/W CONTRAST CTR
TOTAL    DEC     0
*                BUFFERS, WORK AREAS
INBUF    BSS     288
OTBUF    BSS     120
BP       BSS     10
PICT     BSS     20000
         END
```

References

2.1 Walter A. Marggraf, Weather Satellite Data Processing, General Dynamics/Astronautics Contract No. AF 19 (604)-8861, Final Report to Air Force Cambridge Research Laboratories, Office of Aerospace Research, Bedford, Massachusetts, January 1964.

PART III

SB-2 Applications: Delineation and Analysis of Two-Brightness-Level Meteorological Pictures

ABSTRACT

This Part describes the application of program SB-2 to TIROS VI pictures illustrative of various types of meteorological patterns. Interrelationships among key parameters are investigated, and optimum values determined. The relationship is investigated between the brokenness statistic and meteorological phenomena exhibited in the pictures.

3.1 Introduction

The principal objective of Part III is to investigate the relationship of the brokenness statistic (ref. Part II) to meteorological phenomena exhibited in TIROS pictures. Prior to its accomplishment, the interrelationships existing among critical program parameters, such as threshold value, SORD scanning square size, BRAND scanning square size, and related statistics are investigated, on the basis of which optimal or near-optimal parameter values are selected.

Also, looking toward a possible space system implementation of selected SB-2 techniques in the future, means of their simplification should be considered, with the aim of reducing processing time and simplifying the required equipment for their implementation. One such means is considered in this Part: placing the SORD scanning square on the points of a grid instead of in every possible position over the picture. Placing the square in every n-th position (yielding a "grid spacing" of n) results in a reduction of the total number of positions of the square by a factor of n^2, with a nearly corresponding reduction in processing time. The results achieved with various grid spacings are compared among themselves as well as with the "full processing" result of placing the square in all possible positions.

In examining the relationship between the brokenness statistic and meteorological phenomena, care is exercised to determine whether variations observed among different examples of the same pattern are significant with respect to variations observed between different patterns *per se*. The overall percentage of brokenness observed over a specific area, usually that of a whole picture (of approximately 58,000 elements) is also considered in its relationship to meteorological pattern variation.

Patterns selected for investigation were vortices, band structures, and cell structures. Though pattern variations within these categories are exhibited in the examples selected, these are not singled out for detailed analysis at the present stage of investigation, which is more concerned with the overall structural nature rather than specific details of the patterns. It is believed that further refinements of methods already developed may be subsequently applicable to such finer distinctions as between well-defined and ill-defined vortical shapes, continuous and cellular bands, and small-cell and large-cell areas.

The basic results of the analysis which follows are exhibited in pictorial form. The statistical observations deduced from these are in no way intended to supplant this basic display of results. The adage "one picture is worth a thousand words" could not be more appropriately expressed than in the context of meteorological picture analysis.

Eleven TIROS VI pictures were selected for the analyses described in this and succeeding Parts of the report, exhibiting the three meteorological pattern types cited above. These were selected from a larger set of about sixty TIROS VI pictures which were in turn chosen on the basis of a microfilm reader examination of about 500 film strips supplied by the NASA Goddard Space Flight Center, Greenbelt, Maryland.

The film strips are listed by orbit number in the Catalogue of Meteorological Satellite Data--TIROS VI Television Cloud Photography (Reference 2.1) as containing frames exhibiting one or more of the meteorological patterns in question.

Pictures are referred to in the report by number prefaced by the letter P. A list of the pictures selected for analysis with a citation of their TIROS orbit, frame number, and meteorological pattern classification is presented in Table 3-1. The pictures themselves are shown in semi-photographic form in Figure 3-1. They were produced by a Stromberg-Carlson SC 4020 photoelectrostatic printer which reproduces tones in sixteen brightness levels, providing a fair approximation to photographic quality.

3.2 Investigation of the Brightness Threshold

Probably the most significant parameter for the SB-2 program is the brightness threshold. That threshold value must be selected which yields a picture at two levels of brightness most closely approximating the picture at sixty-four levels of brightness, particularly in respect to exhibiting significant meteorological patterns. Too low a value will result in an "overexposed" picture distinguishing only the very darkest noncloud elements; too high a value will result in an "underexposed" picture distinguishing only the very lightest cloud elements. Sophisticated and unsophisticated techniques have been devised for selection of a threshold based on examination of the set of elements comprising the picture (human judgment is still probably most frequently used), and hence the present analysis is concerned primarily with the investigation of the effects of threshold variation on other significant phenomena observed in the picture.

For the analysis, pictures exhibiting two meteorological patterns were selected: P4 exhibits a pronounced vortex and P41 exhibits a parallel cloud and noncloud band structure. For each picture the threshold was varied from a high value of 28 decreasing in steps of 4 to a low value of 16, a total of four threshold levels per picture. The other parameters, held constant for the analysis, were set as follows:

Table 3-1

Characteristics of

TIROS VI Pictures Sampled for Analysis

Picture Designation	Orbit Number	Frame Number	Meteorological Patterns Represented
P2	005	31	Cells--small
P4	034	31	Vortex--pronounced
P8	048	26	Bands--cloud, straight, cellular and noncloud, straight, continuous
P10	077	30	Cells--reticulated
P12	091	27	Bands--noncloud, straight, cellular and noncloud, curved, cellular
P22	347	9	Vortex--pronounced
P26	376	1	Vortex
P41	Unidentified		Bands--cloud, straight, continuous
P44	538	28	Cells--small Bands--cloud, curved, continuous
P49	620	23	Cells--large
P51	694	18	Vortex--pronounced

Figure 3-1

Reproductions of

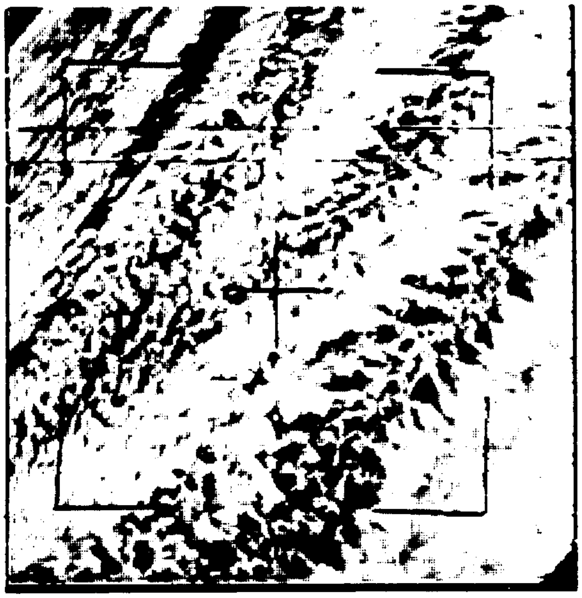
TIROS VI Pictures Sampled for Analysis

P2

P4

P8

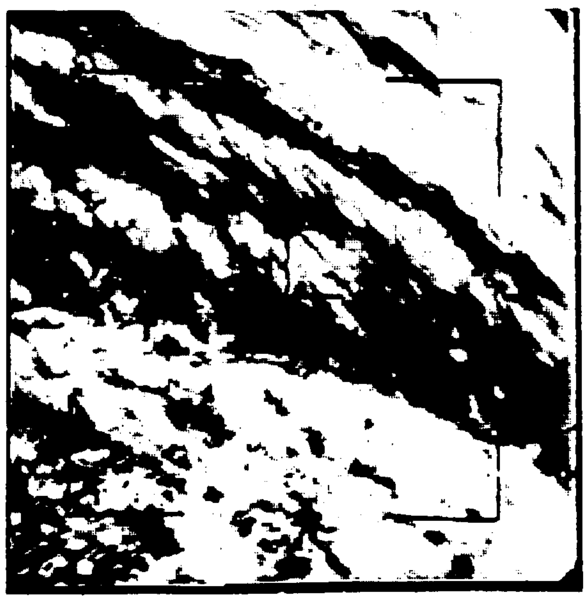
P10



P12

P22

P26



P41

Figure 3-1/Page 2

P44

P49

P51

SORD scanning square size (S):	5
BRAND scanning square size (S2):	5
Solid cloud criterion (BW):	2 or fewer noncloud elements in scanning square
Solid noncloud criterion (BB):	2 or fewer cloud elements in scanning square

The output of SB-2 for the analysis is shown as the eight pictures of Figure 3-2. For both P4 and P41 a threshold value of 24 appears best to preserve the basic meteorological pattern features. At threshold 16, rudimentary elements of the vortex survive, but the band structure has virtually disappeared.

The effect of threshold variation on the percentage distribution of the brokenness statistic over the whole picture was first noted. Figure 3-3 presents bar graphs of this distribution for both pattern types at each of the four threshold levels.

It is first interesting to note that the general shape of the distribution, bimodal with peaks at brokenness value zero and another value ranging from 2 to 5, is the same for all eight combinations. It might be safely conjectured that this is characteristic of the distribution in general.

However, there is a markedly discernible shift in the second modal value for both meteorological pattern types as the threshold drops successively from 28 to 16; furthermore, the shift is different for each pattern. For the vortex the modal value shifts leftward from 3 at T=28 to 2 at T=24, then to the right successively to 4 at T=20 and 5 at T=16. Over the four levels the shift describes a curve which bends in a concave direction to the left (i. e. with the bight pointing to the left).

Figure 3-2

SB-2 Pictorial Output for Cloud/Noncloud Threshold Variation

(Note: Though the original photographs (Figure 3-1) are square, these computer printouts from them are vertically oblong in shape. This is because the 7094 printer "element" is not square (as in the photograph) but vertically oblong. This remark applies in general to the computer printouts shown in this report.)

P4 (Vortex)

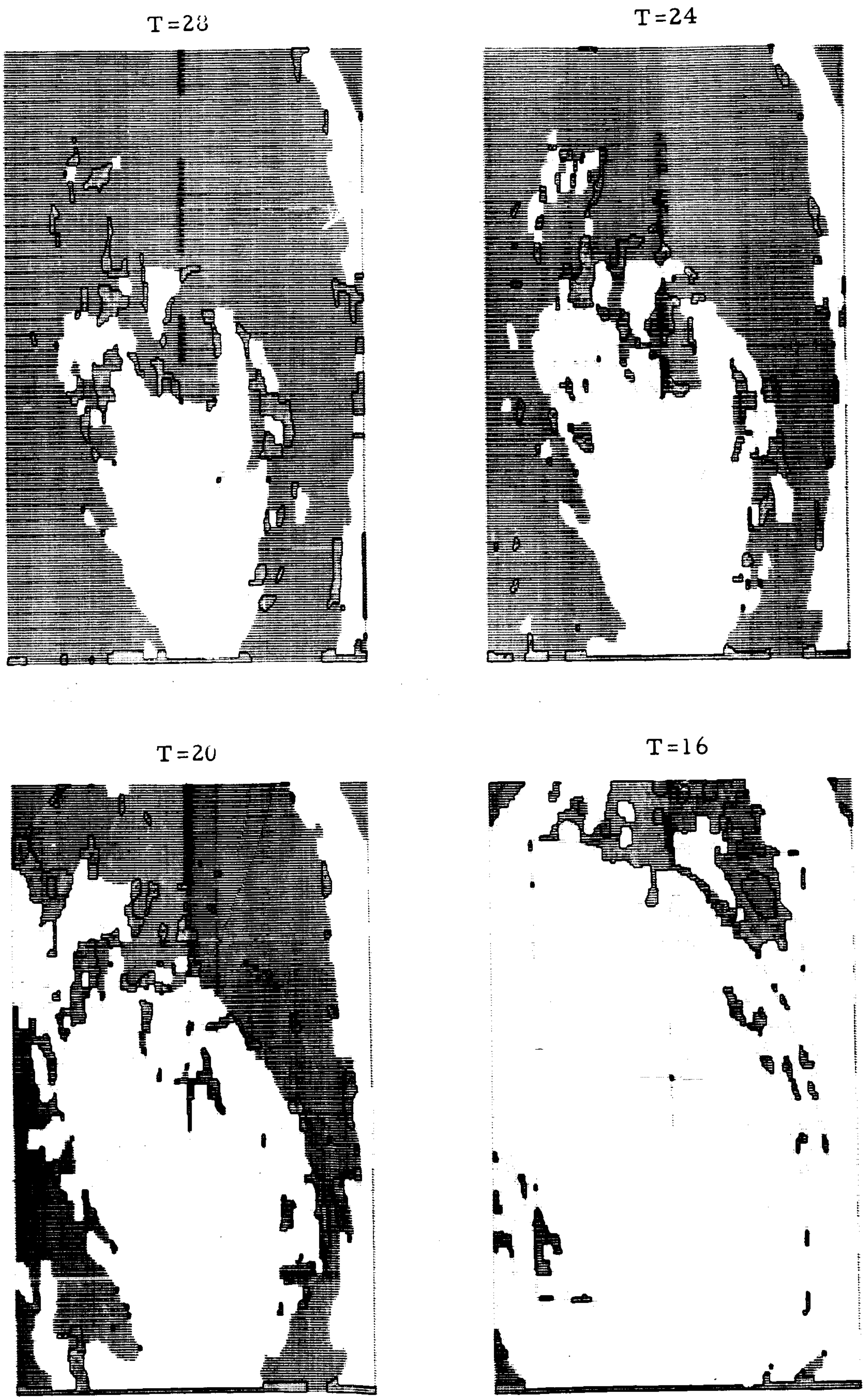
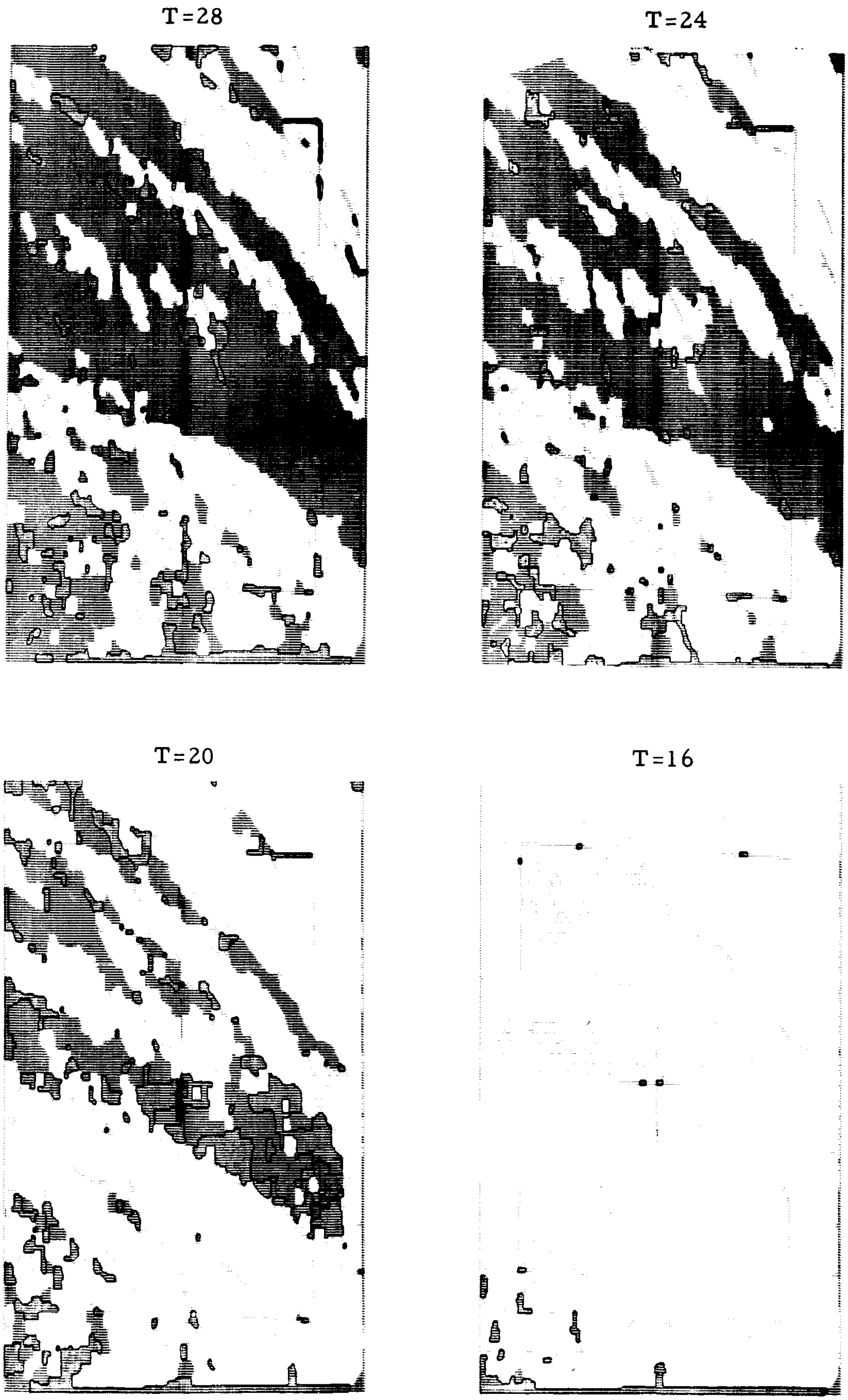


Figure 3-2/Page 1

P41 (Bands)



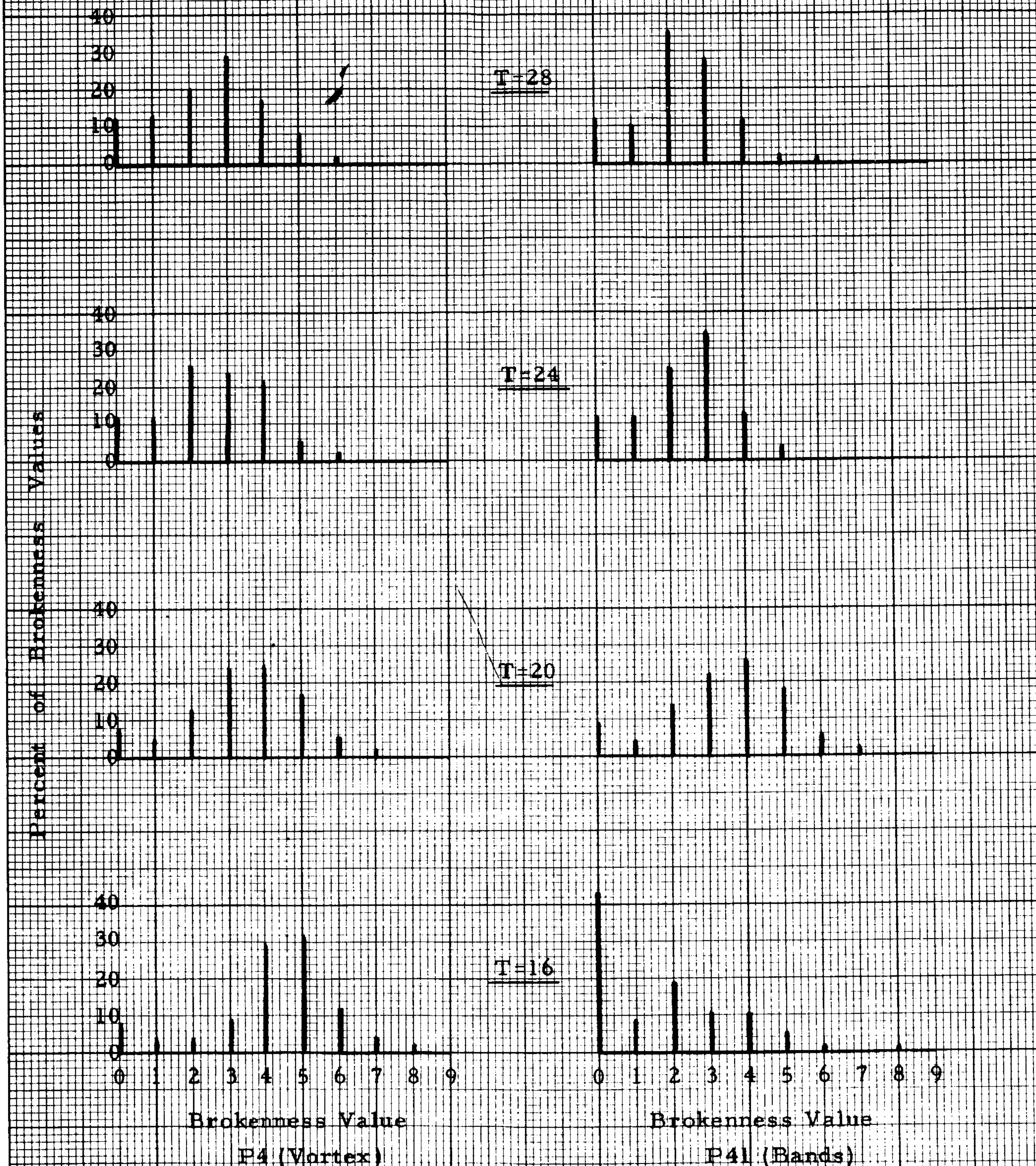


Figure 3-3

Relationship Between Cloud/Noncloud Threshold and SB-2 Brokenness Distribution

For the band structure, on the other hand, the curve starts on the uppermost threshold level at a modal brokenness value of 2, shifting to the right to 3 and 4 successively, then returning abruptly leftward to a modal value of 2. This curve bends in a concave direction to the right.

Interpreting these results physically, a leftward shift in the mode value (and also in the distribution as a whole) indicates a general decrease in brokenness over the picture; a rightward shift, a general increase in brokenness over the picture. In the case of the vortex, a lowering of the threshold from 28 to 24 apparently had the general effect of removing isolated patches of noncloud within larger cloud areas; but from 24 to 20 and then to 16, the effect was apparently to open up isolated patches of cloud areas within larger noncloud areas. Analogous (though oppositely operating) effects are noted for the band structure.

It may be conjectured at this point that the difference in the modal shift at varying threshold levels may serve to distinguish a vortical pattern from a band-structure pattern, or perhaps at least to distinguish a pattern essentially circular or curved in structure from one essentially linear in structure. To achieve greater confidence in this result the experiment might be performed on two groups of perhaps ten pictures each representing within each group significant variations of the patterns under study.

Also important in this context is the relationship between threshold variation and the percent of total picture area classified as broken, or "overall percent broken". For the set of eight pictures under consideration we have the following results:

Pattern	Percent of Total Area Broken for Threshold Value: 28	24	20	16
Vortex (P4)	6	7	10	10
Bands (P41)	8	8	11	2

In general, the results suggest that the overall percent broken increases as the threshold value decreases until a critical maximum point is reached, whereupon the figure falls off sharply. For P41 the maximum value evidently occurs in the neighborhood of T=20; a sharp falloff to a percentage of only 2 is observed at the threshold level of 16. For P4, the maximum value of 10% is reached in the neighborhood of T=16; further threshold reduction could be expected to cause a sharp falloff.

Of further interest here is the observation that for both pictures the threshold value producing the maximum overall percent broken is less than the threshold value (T=24) which most accurately depicts the picture pattern structure; i.e. the best threshold, from the standpoint of pattern delineation, is not that which maximizes the overall percent broken, contrary to what one might expect.

The same set of eight pictures was used to study the relationship between threshold variation and broken region size. The results are shown in Figure 3-4, which plots for each threshold/pattern combination the percentage distribution of regions by size (the size of a region is defined as the number of picture elements it contains). The size is expressed in ranges of 10 starting with 0 - to - 9 and continuing through 90 - to - 99 with a final category of size 100 and over. The general

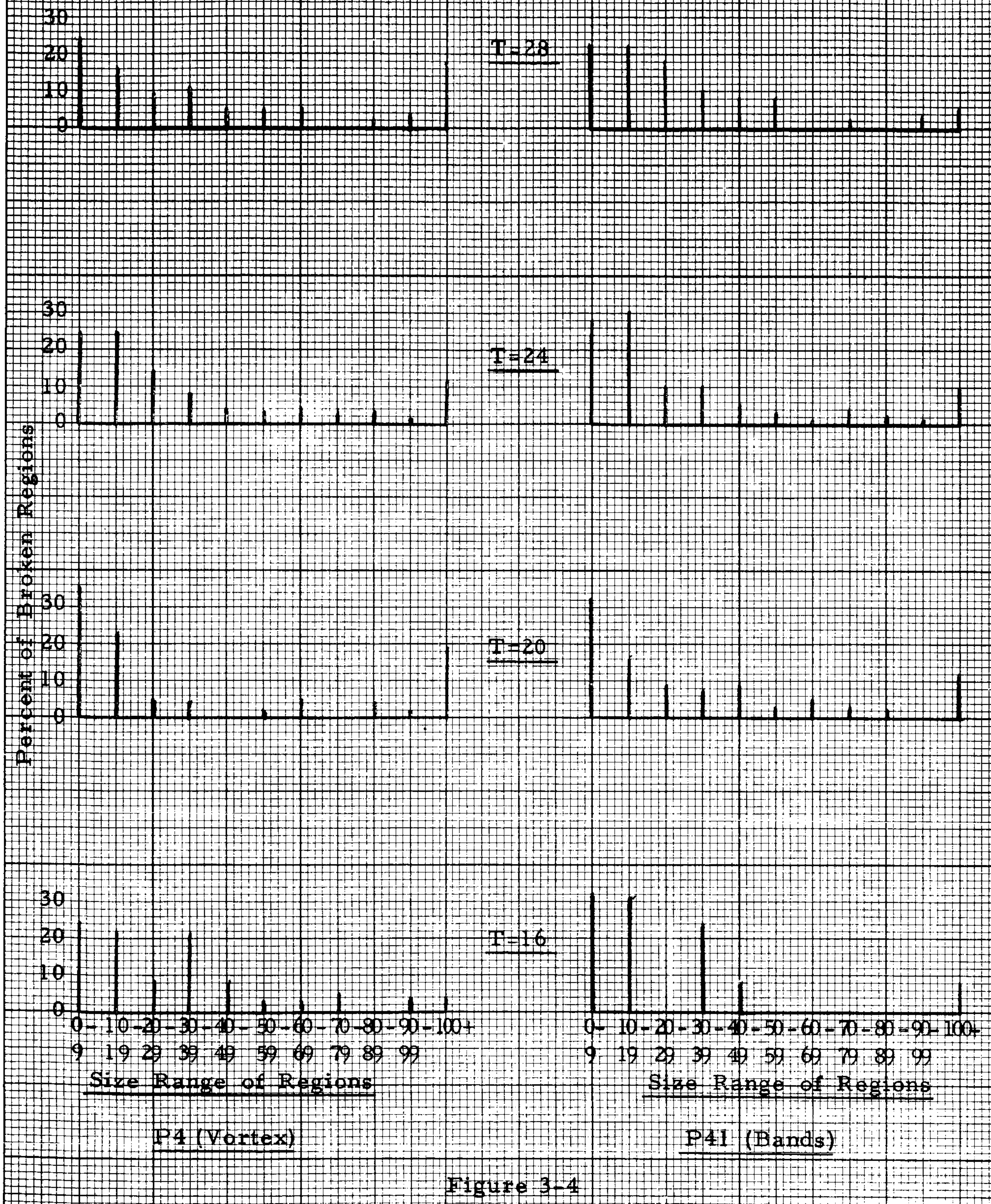


Figure 3-4

Relationship Between Cloud/Noncloud Threshold and Broken Region Size shape of the distribution is constant with a modal value occurring at the left and a sharp drop occurring in values as size increases. Decreasing the threshold value appears to have no marked effect on the distribution shape. However, at a given threshold level, inspection of the two graphs shows that region size appears to be generally smaller for the bands than for the vortex. For both patterns at all threshold levels, at least forty percent of the regions are smaller than 20 picture elements in area.

It is surprising to note that in general, as the threshold decreases the total number of broken regions in the picture decreases, which is contrary to expectation since we have seen that the total broken area in general increases. The relationship observed here was as follows:

	Total Number of Broken Regions for Threshold Value			
Pattern	28	24	20	16
Vortex (P4)	55	76	73	37
Bands (P41)	116	91	91	13

Also of interest is the relationship between threshold variation and the distribution of broken regions according to the maximum brokenness value observed within a region. For the same set of pattern/threshold value combinations, Figure 3-5 plots the percentage distribution of broken regions according to maximum brokenness value. For both patterns the effect of lowering the threshold is analogous to that observed for the distribution of brokenness values per se (Figure 3-3). In the present case the modal value shifts are the same,

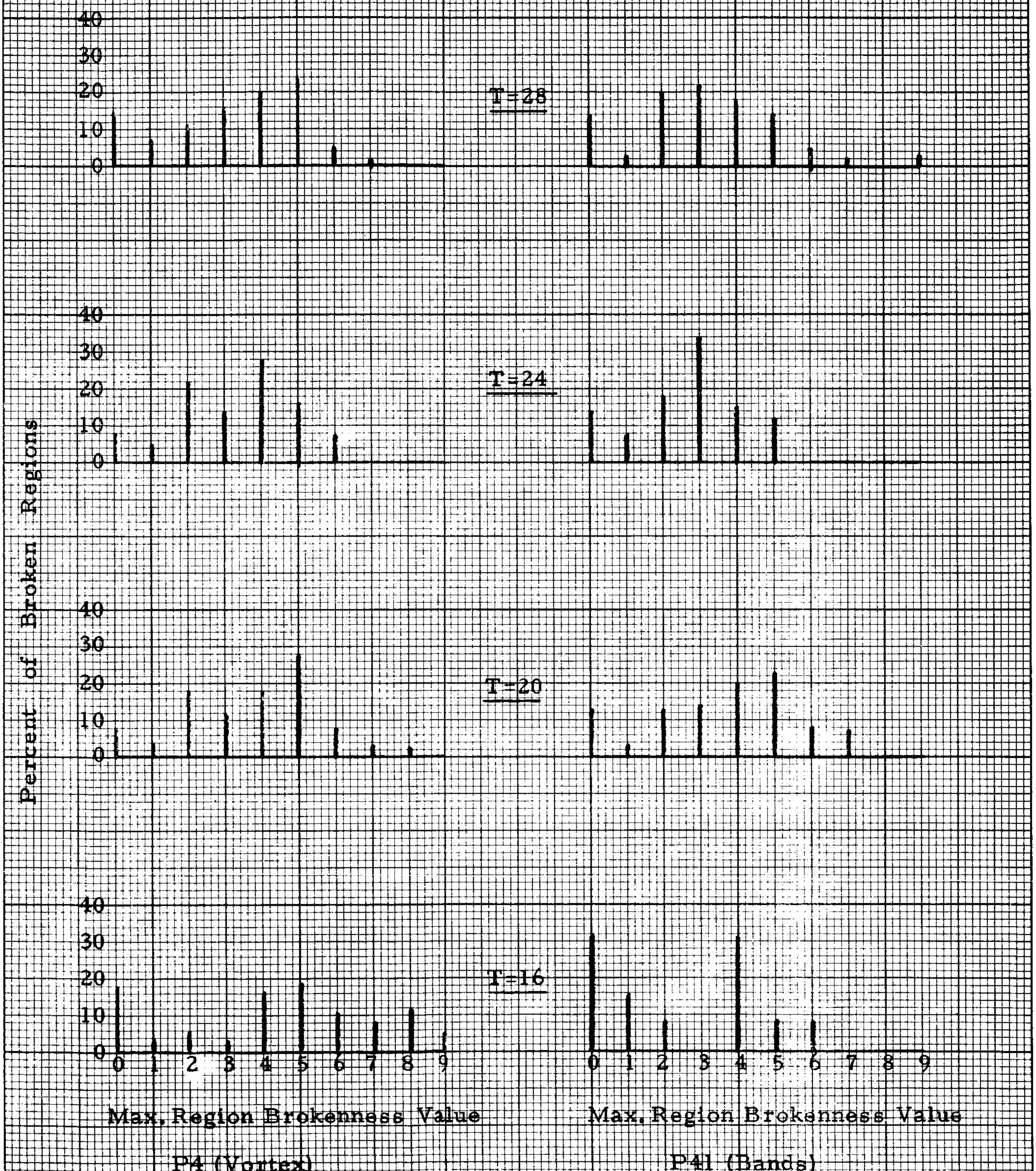


Figure 3-5

Relationship between Cloud/Noncloud Threshold and Distribution of Broken Regions by Maximum Brokenness Value describing a leftwardly-bending concave curve in the case of the vortex, and a rightwardly-bending concave curve in the case of the bands. This shows, essentially, that the distribution of the maximum brokenness value among regions is independent of the distribution of brokenness values over the picture. That is, there are neither any concentrations of a high value which would reduce the percentage of regions having this as a maximum value relative to the percentage of the value itself, nor any excessive "spreading out" of a maximum value among regions which would tend relatively to increase this percentage. In other words, the results suggest that for the present purpose, the determination of threshold effects, the distribution of maximum brokenness values within regions may adequately represent the brokenness value distribution itself.

3.3 Investigation of SORD Scanning Square Size

Having selected a threshold value which accurately depicts the meteorological pattern structure in a picture, the parameter upon which the output of program SB-2 is most dependent is undoubtedly the size (S) of the SORD scanning square. Intuitively one suspects that a small size will result in a picture subdivided into a great number of small broken regions interspersed with solid regions. As the square size increases, assuming that the "noise" parameters are kept constant[1], small local patches of solid cloud or noncloud are more apt

1. That is, kept constant is the noise ratio, i.e. the ratio of the quantity BW (the maximum number of noncloud elements allowed in a "solid cloud" scanning square area or BB (the maximum number of cloud elements allowed in a "solid noncloud" scanning square area) to the scanning square area. In all investigations described in this report the "BW ratio" is equal to the "BB ratio".

to be assimilated into intervening broken areas, with the result that larger, more connected broken regions appear. The next investigation to be described was conducted to examine this process.

The analysis was performed on the vortex picture P4. All parameters except S were held constant, and S varied over four levels: 5, 10, 12, and 15. The constant parameters were assigned the following values:

BRAND scanning square size (S2):	3
Noise ratio (ref. note 1 above):	8/100
Cloud/noncloud threshold (T):	24

The pictorial results for the four values of S are shown in Figure 3-6. It is immediately evident that the results for the lowest value (S=5) are markedly different from those for the three higher values which are quite similar. The lowest value yields a scattering of many small broken regions mostly clustered within the area of the "whorl" of the vortex. The other three values each yield three large broken regions plus a small quantity of smaller ones; the large regions occupy the area of the "whorl" and two other areas flanking the central cloud portion of the vortex. For the two intermediate values of S, "holes" of solid cloud appear in the larger broken regions, of which all but one disappear at S=15. The result for S=15 appears to be most successful from the standpoint of a simple yet effective classification of the picture into solid and broken areas. However, even the result for S=10 resembles this sufficiently to make significant

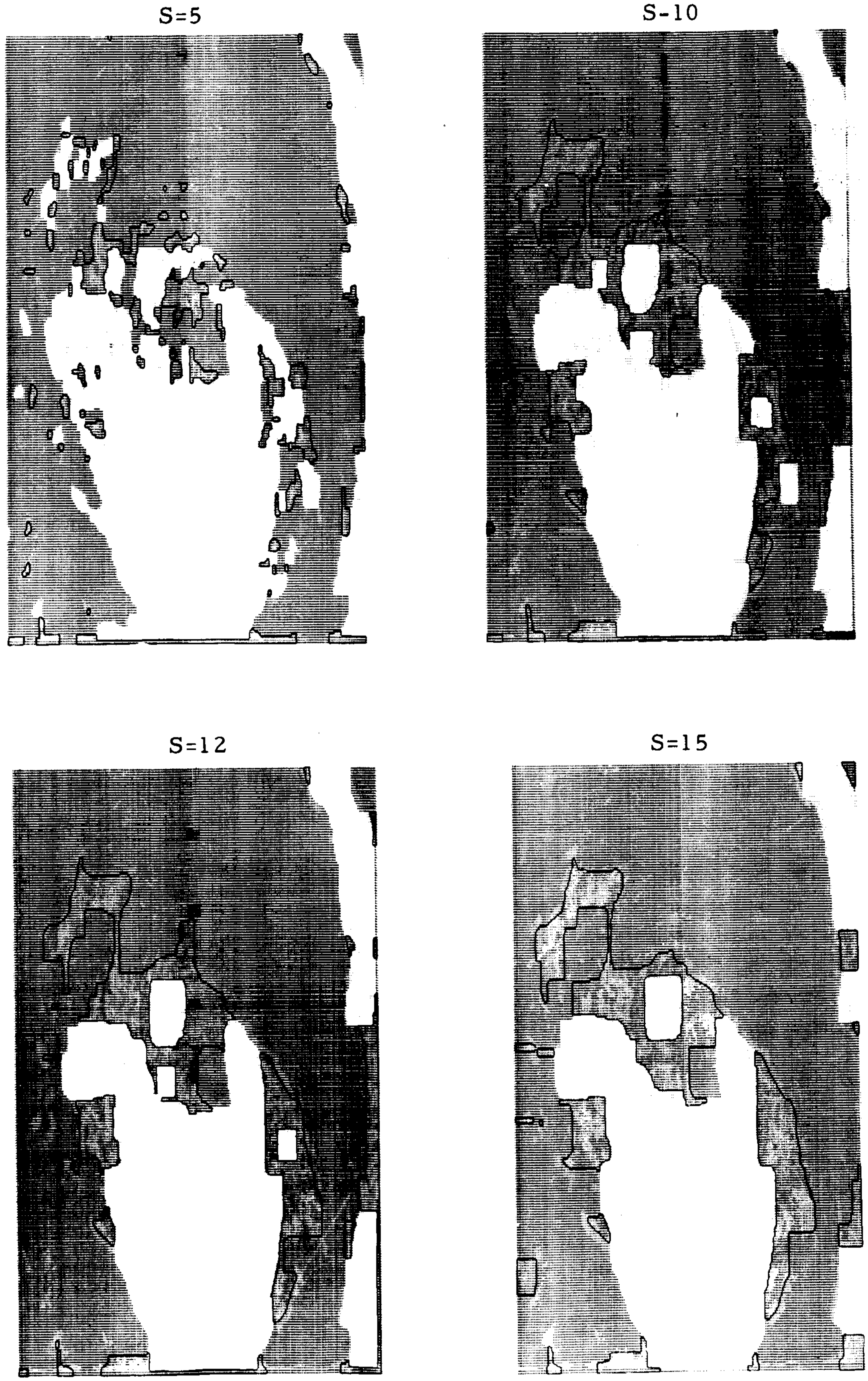


Figure 3-6

SB-2 Pictorial Output for SORD Square Size Variation the consideration of a tradeoff of pictorial result versus processing time.[2] In any event it is clear that for the three larger S-values the "interesting" parts of the pattern have been effectively delineated by the SORD process.

The effect of SORD square size variation upon the brokenness distribution is noted in Figure 3-7, which presents the percentage distribution of the brokenness value for each of the four levels of S. The constant value of 3 was chosen for the BRAND square size (S2) for reasons which will be presented in the next section. Over the four levels the brokenness distribution is independent of variation in the SORD scanning square size. This is clearly according to expectation for the three larger S-values, which are all large in comparison with S2, but it is not intuitively evident in the case S=5.

These results (ref. also note 2) suggest that the value S=12 is the most satisfactory compromise between quality of end results and processing time, assuming processing is performed by an IBM 7094 computer.

As might be expected, the percent of the whole picture area classified as broken increases as S increases. Results for the four levels were

S	Percent of Picture Area Classified "Broken"
5	7
10	12
12	13
15	15

2. Actual processing times on the 7094 computer for the four values of S in ascending order were in the ratio of approximately 7:14:16:19. If specialized hardware were built to accomplish the processing the magnitude of these differences could be no doubt reduced by proper desi gn techniques.

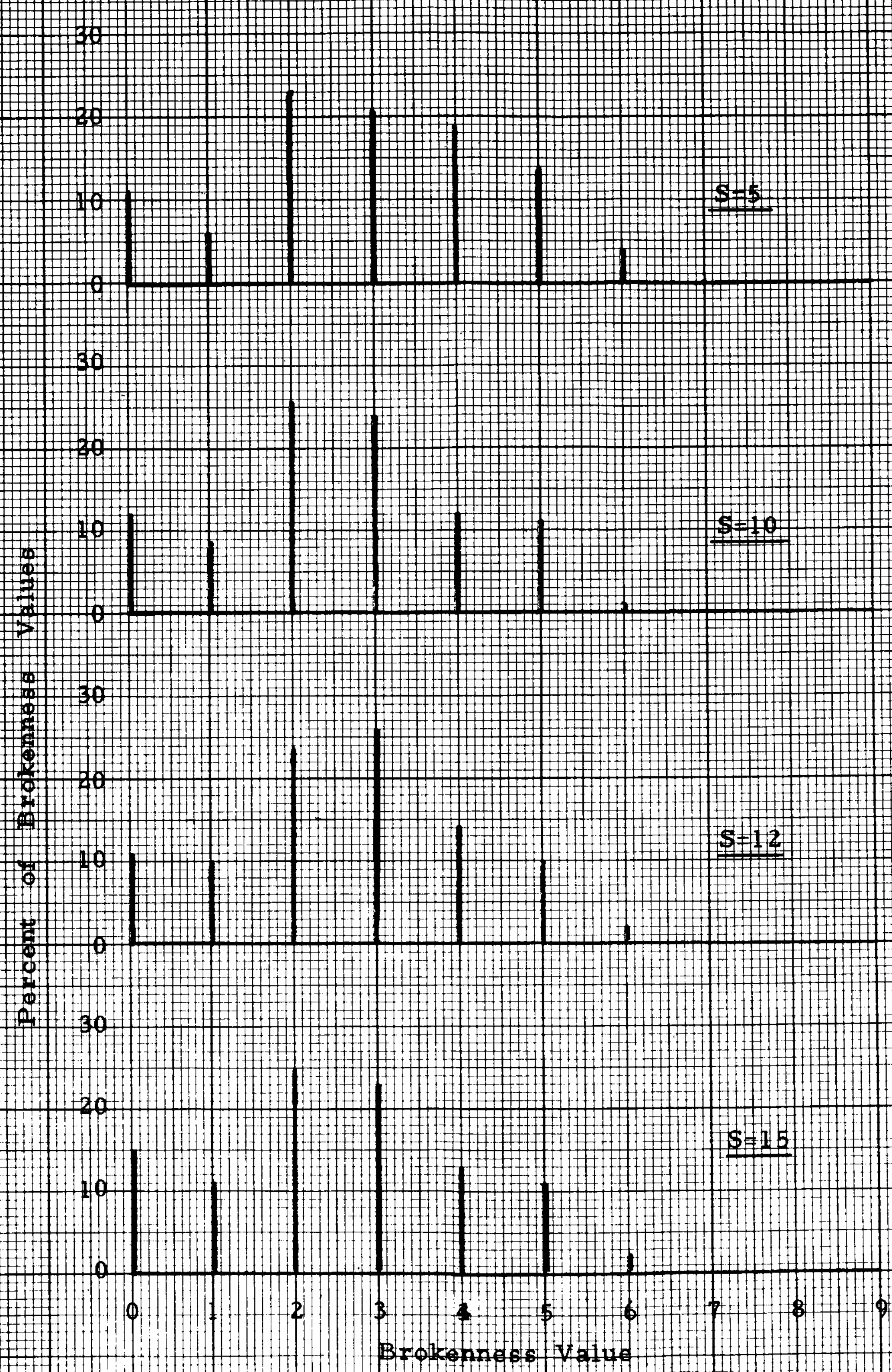


Figure 3-7

Relationship Between SORD Square Size and SB-2 Brokenness Distribution

3.4 Investigation of BRAND Scanning Square Size

The BRAND scanning square size (S2) can be expected to bear a closer relationship to the brokenness distribution. For small values of S2 one obtains a brokenness value based on small neighborhoods about the central picture element. As S2, and hence the neighborhood, increases in size the brokenness value becomes less subject to local fluctuations in contrast and tends to "average out". An analysis was performed to explore this process in further detail. Four levels of S2 were selected: 3, 5, 8, and 15. Other parameter values were held constant at the following levels:

SORD scanning square size (S)[3]:	5
Noise ratio (ref. note 1 above):	8/100
Cloud/noncloud threshold (T):	24

The pictorial results are not shown in this case, because the shapes of the broken areas are dependent only upon the SORD square size and essentially independent of the BRAND square size, as consideration of the logical processing will show (ref. Part II).[4] The information of interest here, the percentage distribution of brokenness values for the four levels of S2, is shown in Figure 3-8. Though present the effect of increasing S2 is, especially on the three lower levels, less than one might expect. From S2=3 to S2=5 the

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3. With the following exception: when S2=15, S was also set at 15. Since the previous analysis indicates that S and the brokenness distribution are independent, this should be valid for the present purpose. In any event it will be seen that in practice 15 is not a useful value to choose for S2 under any circumstances.

4. Pictorial output from the standpoint of broken shapes for the three lower values of S2 will thus be the same as the output for S=5 for the preceding analysis, and for S2=15, the same as the output for S=15 for the preceding analysis (ref. note 3).

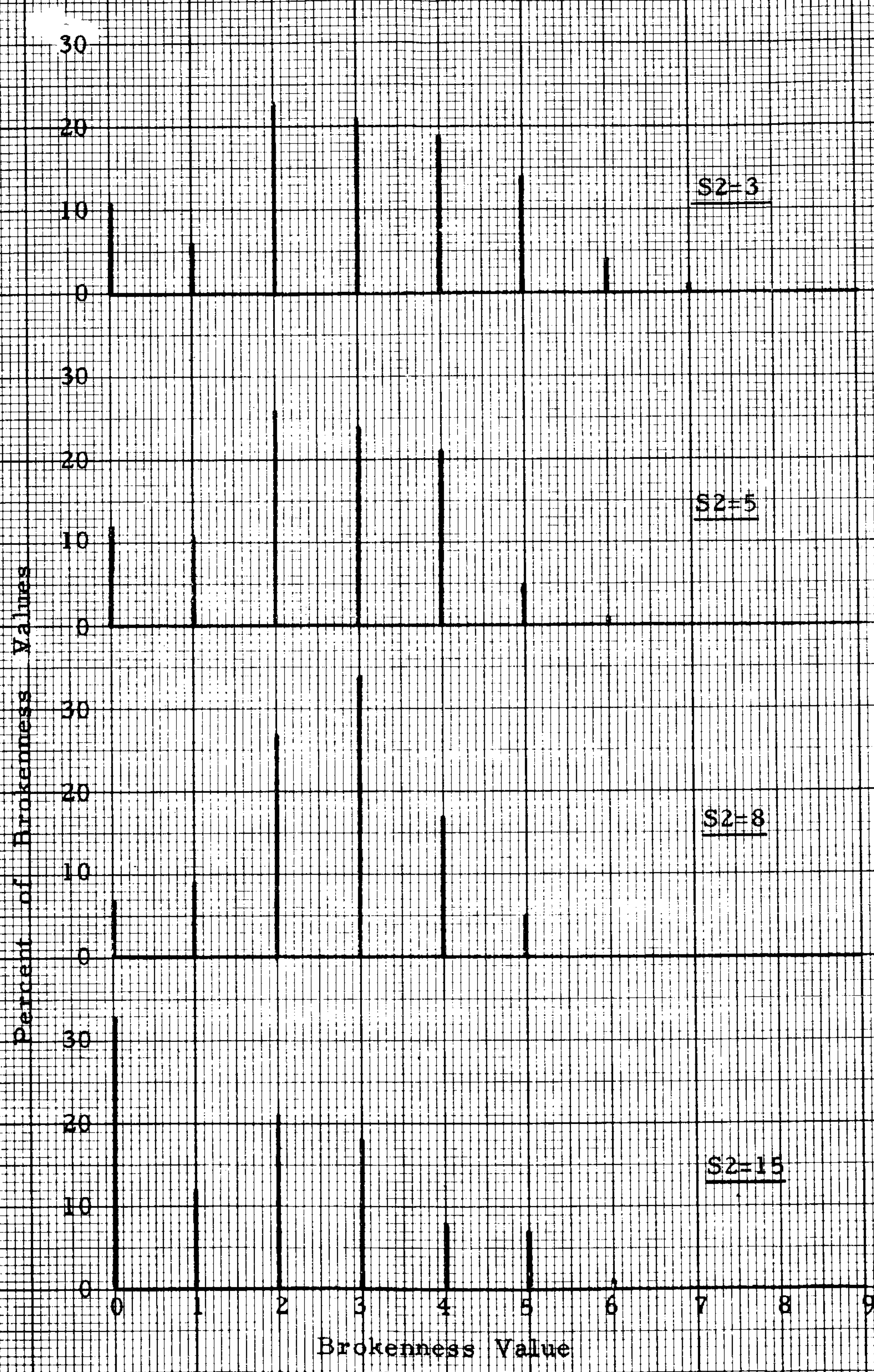


Figure 3-8

Relationship Between BRAND Square Size and SB-2 Brokenness Distribution

distribution clusters somewhat more closely about the modal value of 2. At S2=8 the modal value shifts to 3, with, however, more pronounced clustering about this value. At S2=15 the modal value has shifted to 0 with a second smaller mode at 2.

The overall effect of increasing S2 is therefore to shift the distribution to the left, supporting the contention that smaller values such as S2=3 are to be preferred as expressing more accurately the BRAND concept of brokenness in the immediate neighborhood of a picture element.

3.5 Investigation of SORD Scanning Square Grid Spacing

The next analysis considers whether the pictorial output of SB-2 would be significantly changed by departing from the normal practice of placing the scanning square in every possible position over the picture, with the idea of considering departure in pictorial output from "full processing" output as a tradeoff against reduction in processing time. Three grid spacings were considered: 1 (the normal "full processing" case), 3, and 5. In the second case the square is moved 3 elements to the right for each successive row position, resulting in a reduction of positions by a factor of 9; for the third case the reduction factor is evidently 25. The other parameters held constant for the experiment were the following:

SORD scanning square size (S):	15
BRAND scanning square size (S2):	3
Noise ratio (ref. note 1 above):	8/100
Cloud/noncloud threshold (T):	24

The pictorial results for the three spacings are shown in Figure 3-9. They are strikingly similar, the principal effect being a decrease in the smoothness of region boundaries (an increase in stepwise angularity) as the grid spacing increases. Also noticeable is an increase in the percent of total picture area classified as broken, which is to be expected since the classification of a scanning square area as broken occurs only after initial attempts to classify it as solid cloud or noncloud have failed; the greater the grid spacing, the fewer of these attempts are made.

The effect of an increase in grid spacing on the brokenness value distribution is shown in Figure 3-10. The effect is almost negligible, indicating that BRAND processing is virtually unaffected by grid spacing changes, even though the percent of total picture classified as broken increased as follows:

Grid Spacing	Percent of Total Picture Classified "Broken"
1	15
3	18
5	23

Processing times for the three outputs in ascending grid-spacing order varied in the ratio 19:11:8, indicating a considerable (if not inversely proportional) decrease in time saving.

The overall results indicate that the grid spacing technique produces results sufficiently closely approximating the results of "full processing" to warrant its serious consideration as a technique for reducing processing time in future hardware or software systems.

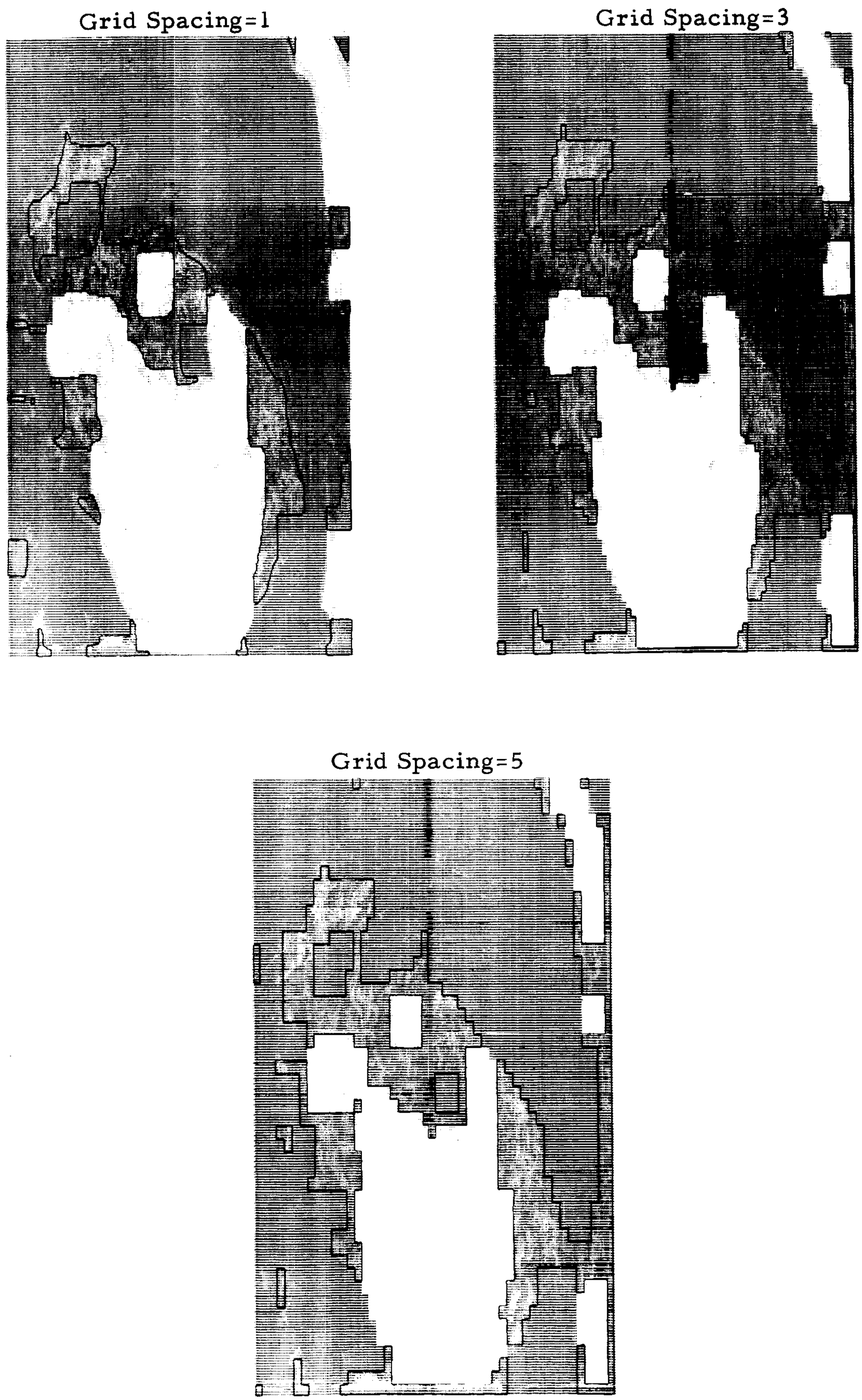


Figure 3-9

SB-2 Pictorial Output for Grid Spacing Variation

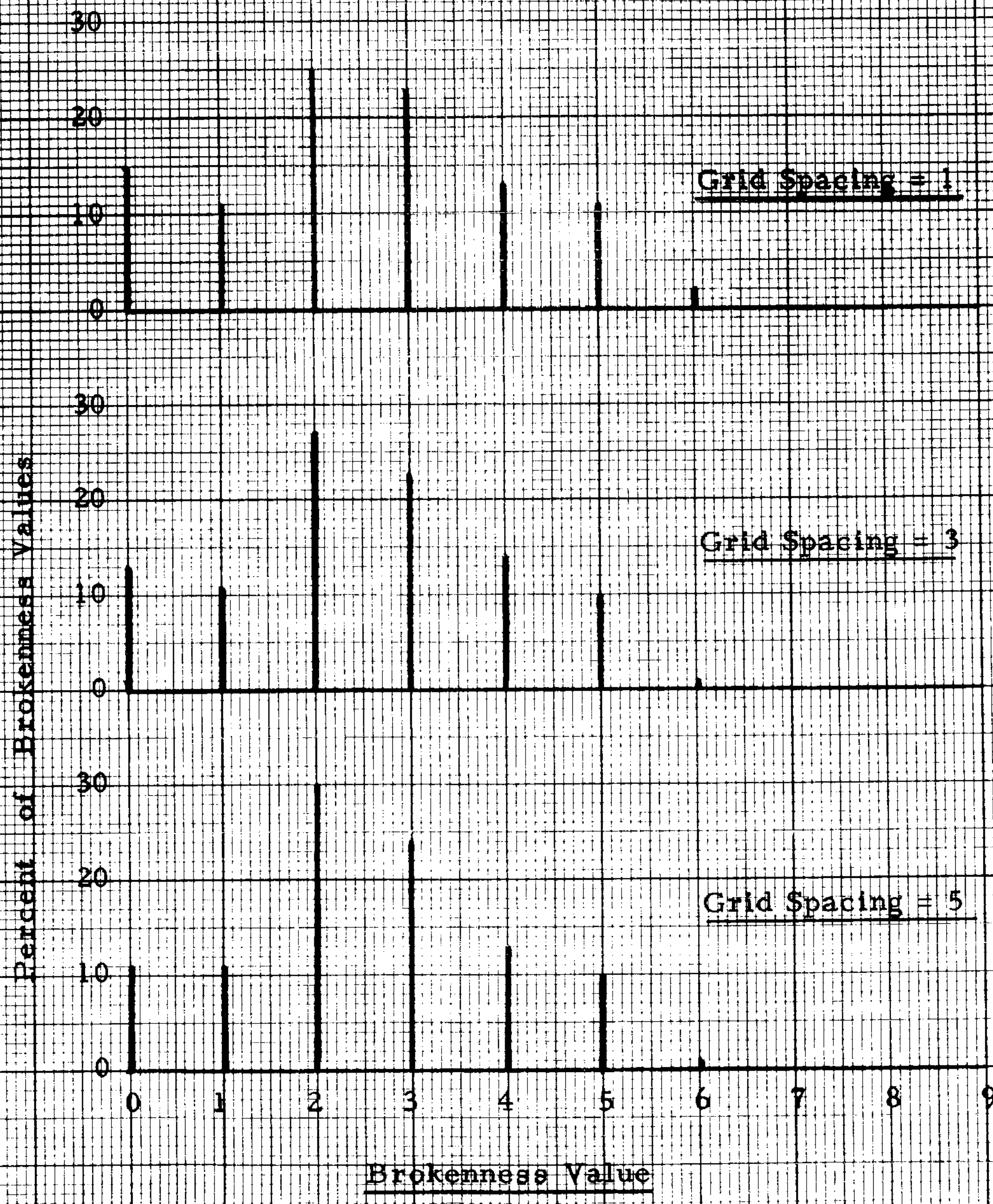


Figure 3-10

Relationship Between Scanning Square Grid Spacing and SB-2 Brokenness Distribution

3.6 Investigation of Meteorological Pattern Variation

The investigations outlined in preceding sections have enabled the determination of significant relationships between SB-2 program input parameters, on the basis of which parameter values can be selected for the investigations to follow. These are concerned directly with the question of whether the brokenness statistic is significantly sensitive to change in meteorological pattern or to variations in a particular pattern exhibited in different pictures.

On the basis of the previous investigations and visual examination of pictorial outputs a threshold value of 24 has been determined to be most desirable. It is recognized that this may be the result of the characteristics of the selected data set; Arking (Ref. 3.1) and others have pointed out that variations in sun angle, camera angle and other factors can cause wide variations in picture brightness which in turn produce corresponding variation in the "best" threshold value. Arking found that the value could safely be expected to remain constant over a given serial sequence of pictures, but tended to vary significantly between sequences. In the present case the value of 24 has been found to be satisfactory not only for the set of pictures selected for analysis in this report but also for the larger set of about sixty pictures from which it was drawn (ref. Sec. 3.1).

The SORD scanning square size found to be most satisfactory, as mentioned above, is 12. This decision, reached on the basis of preceding analyses, can be expected to be valid for any digital cloud picture data of the type dealt with here.

The most satisfactory BRAND scanning square size has been found in a preceding section to be 3. This is the best choice, in a discrete approximation of a "real world" environment, to a neighborhood in the "immediate vicinity" yet not small enough to give rise to inaccuracies occasioned by the discrete nature of the data (with a scanning square of size 2, for example, only eight different values of the brokenness statistic are computationally possible, due to the restricted number of possible cloud/noncloud element adjacency combinations).

A set of nine pictures was selected for the present experiment. Three (P4, P51, and P56) exhibit a vortex, three (P8, P12, and P44) a band structure, and three (P2, P10, and P49) a cell structure. To recapitulate, the fixed parameters chosen for the set were the following:

SORD Scanning Square Size (S):	12
SORD Scanning Square Grid Spacing:	1
BRAND Scanning Square Size (S2):	3
Noise Ratio (ref. note 1 above):	8/100
Cloud/noncloud Threshold (T):	24

SB-2 program output for the nine pictures is shown in Figure 3-11.

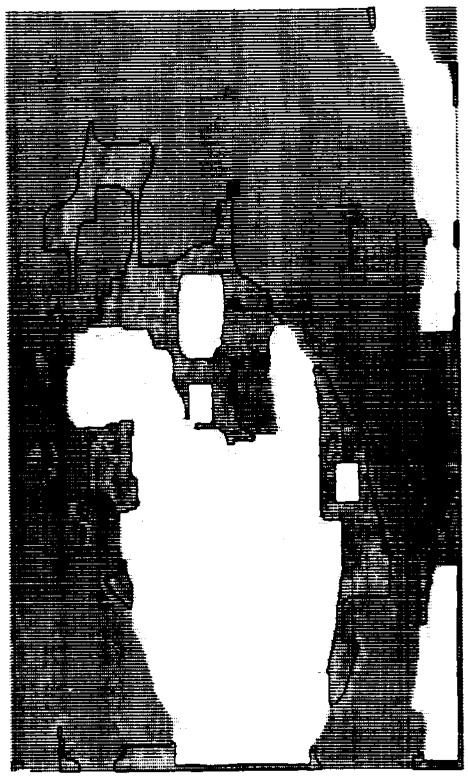
Two pronounced vortices and one less pronounced vortex comprise the set of pictures in the first group. The patterns are clearly discernible in all three pictures: in P4, by the shapes of the large broken areas and by the boundary marking the vortical cloud center; in P51 by a single large broken area and by a similar boundary; and in P26 principally by broken and solid noncloud shapes on a cloud background. For vortices, the pattern appears thus to be revealed both by shape, and by line as the boundary between different textural regions.

In the second (band structure) group, the first two pictures (P8 and P12) exhibit parallel sets of bands; the third (P44), a single large band. In this case the patterns may be discerned entirely by region boundaries.

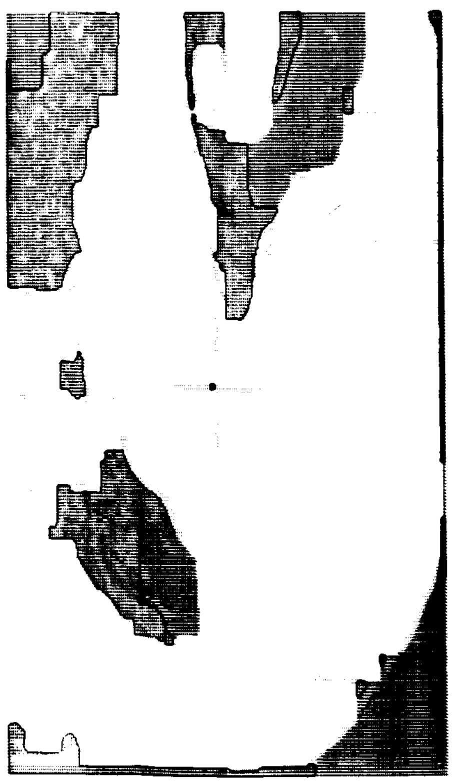
Figure 3-11

SB-2 Pictorial Output for Meteorological Pattern Variation

Vortex

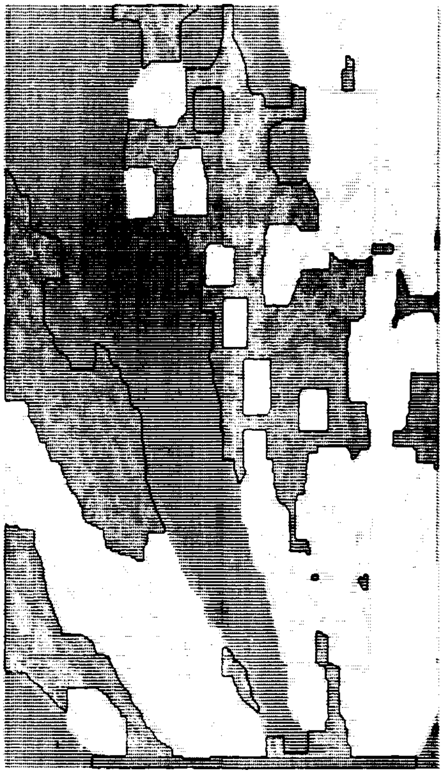


P4

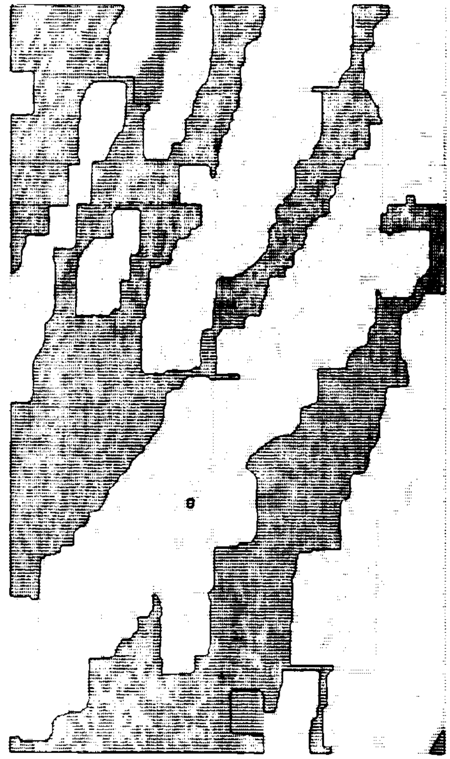


P26

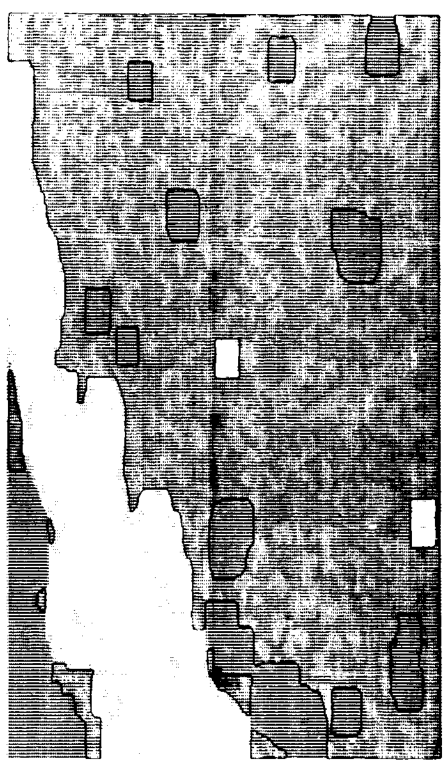
Figure 3-11/Page 1



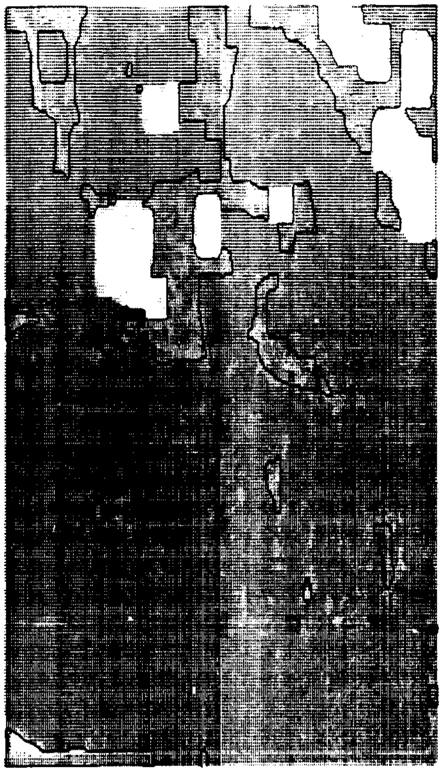
P8



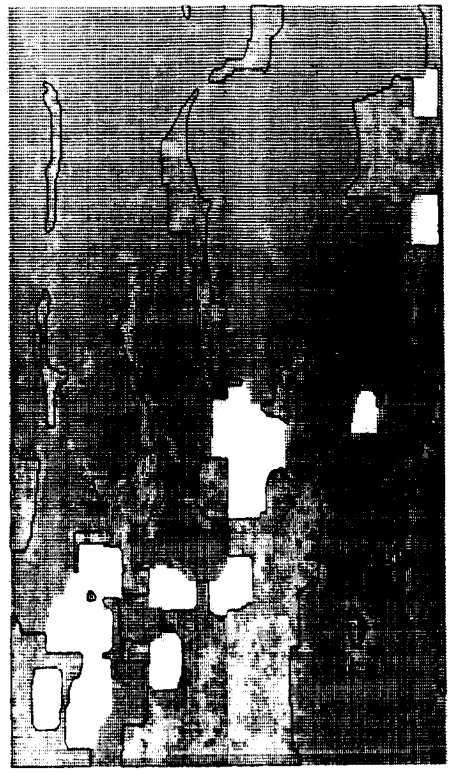
P12



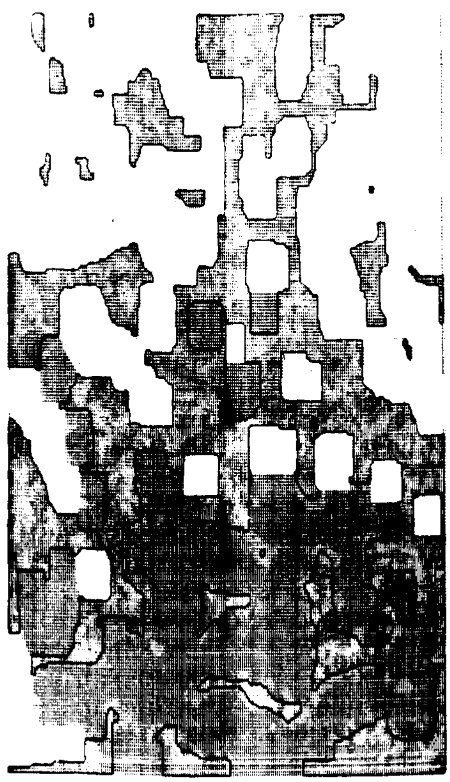
P44



P2



P10



P49

In the third (cell structure) group the cell patterns are revealed in various ways. In P2 the cells appear principally as broken or cloud shapes on a noncloud background; in P10, similarly; and in P49, as broken, cloud, or noncloud shapes on a contrasting background. The detection of cell patterns will thus require the generalized ability to distinguish a cellular shape from its background, where the cell may be cloud, noncloud, or broken.

These results indicate that for recognition of vortex, band, and cell pattern types techniques (1) to detect and analyze both line and shape and (2) to distinguish regions as either foreground shapes or background will be required. The ability of program SB-2 to provide inputs for these types of analysis is clearly demonstrated by the examples of Figure 3-11.

The brokenness statistic percentage distribution was also examined as a possible means of distinguishing the three pattern types. A plot of the brokenness distribution for the nine pictures of Figure 3-11 is shown in Figure 3-12. The form of the distribution is essentially the same for all pictures, bimodal with a small peak at brokenness value 0 and a large peak at value 2 or 3. Within the same pattern group the distributions are almost exactly similar. Between pattern groups it is evident that the band-structure distributions are significantly displaced to the right from those of the other two groups. Between the latter, however, no displacement is graphically evident. This is further evidenced by examination of the mean brightness for each picture within groups and for each group as a whole:

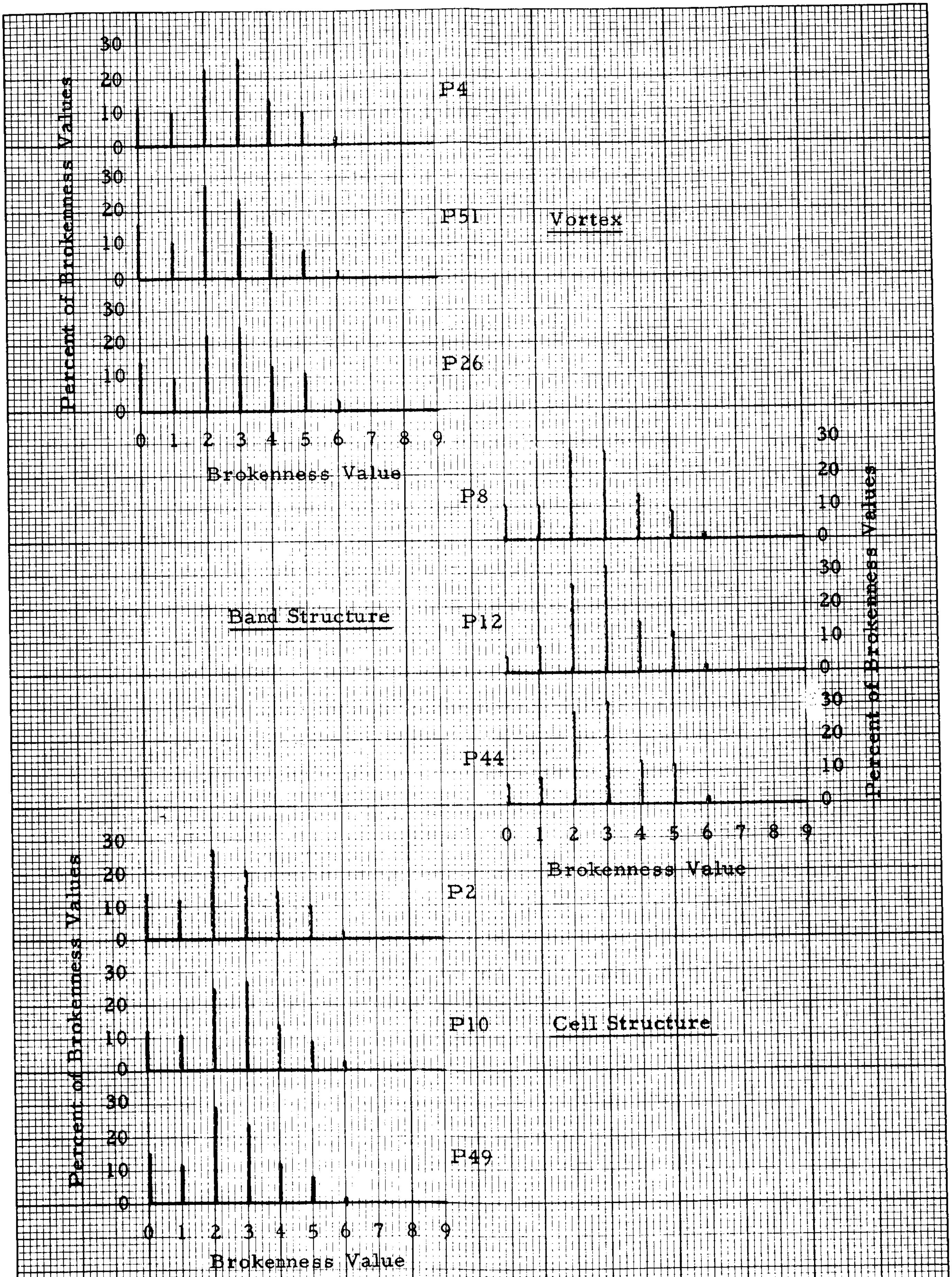


Figure 3-12

Relationship Between Meteorological Pattern Type and SB-2 Brokenness Distribution

Mean Brokenness Value

Pattern	Picture 1	Picture 2	Picture 3	Group Mean
Vortex	2.52	2.35	2.56	2.47
Band Structure	2.58	2.86	2.81	2.74
Cell Structure	2.47	2.55	2.36	2.46

On the basis of these results a reasonable ability of the brokenness statistic to distinguish bands from the other two pattern types is indicated. No significant ability to distinguish the other two is indicated.

In comparison with the brokenness statistic, the percent of picture classified as broken was found to differ between pattern groups more significantly.

Percent Classified "Broken"

Picture	Picture 1	Picture 2	Picture 3	Group Mean
Vortex	13	19	14	15
Band Structure	30	34	68	44
Cell Structure	14	25	33	24

Here again the results for band structure are significantly different from the results for the other two patterns; in addition, the results for cell structure and vortex are also clearly distinguishable.

References

3.1 Arking, A. "Latitudinal Distribution of Cloud Cover from TIROS III Photographs," Science 143, 1964, pp. 569-572.

PART IV

SB-3: A Computer Program for Plotting Solid Regions and Brokenness Contours on a Digital Picture of N Brightness Levels

ABSTRACT

This part describes a computer program which is an extension of program SB-2 to pictures of N discrete levels of brightness. This program was developed to make full use of the SB-2 technique by applying it to all levels of brightness simultaneously, and to compare SB-3 and SB-2 results to determine if this extension in concept yields an accompanying increase in processing capability.

4.1 Introduction and General Description

The concepts of program SB-2 have proved valid for the restrictive class of pictures for which it was designed: pictures containing two brightness levels defined by a single threshold, elements being classified as "cloud" or "noncloud" according as their brightness values lie above or below this threshold. The question arises as to whether the picture subdivision techniques of SB-2 can be applied to a multi-brightness-level picture, i.e. one whose elements are grouped into N brightness levels where N is greater than two. The quantity N is considered also to be considerably less than 64, the number of possible discrete TIROS picture data brightness values, and hence the multi-level picture remains an abstraction from the original: but an abstraction which hopefully can extract more of its inherent pattern structure with a minimum of increase in complexity of method and interpretation of results. Experimental results presented in Part V provide indications for selection of an "optimal" value of N.

These considerations constitute the basis for implementing the program described in this section, which is designated SB-3 to indicate its relationship to its progenitor, SB-2. SB-3 is completely analogous to SB-2; in other words it operates in exactly the same manner except in those instances where changes are necessitated by the extension to more than two brightness levels. For example, one brightness threshold will no longer suffice; N-1 are now required. The concept of adjacent element "contrast" must be extended to take into account varying differences between brightness levels. Other such examples will become apparent in what follows.

The progenitor SB-2 program applies the BRAND-2 technique of extracting localized information from "broken" areas as delineated by SORD-2. This part of the report describes the modifications made in the SB-2 program required to extend it to several levels of brightness, and discusses the special features of the resulting SB-3 program for automatically selecting brightness ranges of significance and interest. In comparison with program SB-2, program SB-3 is expected to yield more definitive shapes of solid and broken regions and a more significant broken region analysis which considers the degree of contrast between elements.

The SB-3 program, written for the IBM 7090/94 computer, consists of two parts. The first part is SORD-2 program (Reference 1.1-IV) modified as follows: The picture is divided into N ranges of brightness whose end points are defined by user-selected or computer-determined thresholds (ref. Sec. 4.5). The SORD analysis is then performed defining as "solid" those regions in which at least the specified number of elements within the scanning square have brightness values lying within the same range of brightness. Each range defines one of the N brightness levels of the picture. Regions not classified as "solid" at any level are classified "broken."

The BRAND analysis of the broken regions then follows as for SB-2, except that a "contrast" between the brightness values of adjacent elements is assigned a value proportional to the absolute value of the difference in levels. These values are summed over the scanning square. The degree of brokenness is then defined as the ratio of this sum to the expected value of the sum for a random picture of N brightness levels (Sec. 4.4). The number 0 overprints an element whose degree of brokenness is less than 0.1; the number 1 overprints the element whose ratio is from 0.1 to less than 0.2; etc., and the number 9 overprints all elements whose ratio is 0.9 or greater.

SB-3 produces a picture printout similar to SB-2 except that solid regions and elements are displayed at N levels instead of 2. A brokenness value frequency distribution is also produced. In addition, the output consists of (1) a frequency table of the brightness distribution of the elements of the original picture with the corresponding brightness level and region symbols assigned to each value, (2) a list containing values of N, the mean element brightness, and the median element brightness over the picture, and (3) the parameters used when the brightness ranges are assigned by the program (Sec. 4.5).

Printouts of the annotated picture and of the brightness frequency table are selectively optional. The user may also bypass the SORD and BRAND processing and print out the picture with element level values only. A more detailed explanation of the program and its use follows.

4.2 Input

The data input for the program consists of a digital representation of the picture in exactly the same format as for SB-2. The picture is read from magnetic tape into memory. The element brightness values range from 0 through 63 and are stored as six six-bit elements per word. Some processing may be done on input depending on the option selected (Sec. 4.3, 4.5). The maximum picture size is 8000 words.

Any number of pictures may be processed in a single run. Pictures and options are selected by means of the operating parameters.

4.3 Operating Parameters

One set of picture parameters, which define its location on magnetic tape, is required for each picture of a given set to be processed. The program will process each picture until sensing a signal that the end of the set of picture parameters is reached. The <u>program parameters</u>, which define the processing for each picture, are constant for all pictures processed in a run.

All parameters must be supplied to a <u>driver program</u> in the proper order and format. A symbolic listing of the driver program is included in Figure 4-4.

The SB-3 operating parameters are listed below, with a more detailed explanation following where necessary.

<u>Picture Parameters</u>

Parameter	Definition	Allowable Range Min.	Allowable Range Max.
L1	First line of tape picture	1	Tape limit
L2	Last line of tape picture	1	Tape limit*
W1	First word of picture line	1	50**
W2	Last word of picture line	1	W1+19**

* Total number of words, $(W_2 - W_1 + 1) x (L_2 - L_1 + 1)$, must be less than 8,000.

** May not exceed the number of words per line (WR below).

Program Parameters

Parameter	Definition	Allowable Range Min.	Max.
N	Number of levels of brightness	1	32
T	First of N-1 thresholds which will divide the levels. If these are not assigned, thresholds will be computed (Sec. 4.5)	1	63
S	Scanning square side length (in elements) for SORD processing	1	30
S2	Scanning square side length (in elements) for BRAND processing	1	30
WR	Words per line of tape picture	1	50
SIGMA	Percent of brightness range times ten over which thresholds will be spaced if thresholds are to be computed. If this is not assigned, a value will be computed (Sec. 4.5)	0	1000
B1, . . . , BN	Minimum number of non-conforming elements that will prevent a "solid region" classification for region i, i=1, . . . , N.	1	S^2
SYME	The first, and darkest, of N symbols for element level printout		
SYMR	The first, and darkest, of N symbols for solid region overprint		
SW1	Frequency table printout switch: On - frequency table printout Off - no frequency table printout	*	

*See note next page.

Parameter	Definition	Allowable Range Min.	Max.
SW2	Picture printout switch: On - picture printout Off - no picture printout	*	
SW3	SORD-BRAND bypass switch: On - only element printout Off - full processing	*	

* Insertion of a non-zero card will turn on these switches. If no card is inserted, the terminating zero card turns the switch off (See driver program listing, Figure 4-4).

A threshold is the least upper bound of the corresponding brightness level. All elements having a brightness value below the first threshold are assigned to level 1. All equal to it are assigned at the next level, level 2. Those greater are compared with the next threshold and assigned similarly. Those equal to or exceeding the last, the (N-1)st, threshold are assigned to level N. If the thresholds are not assigned by the user, the program senses a zero terminating card and automatically computes thresholds, as described in Section 4.5. SIGMA is used in the case where the computer determines the thresholds; it specifies the percent of data to be included in the range of brightness over which the program is to space the thresholds. This value also will be computed if not assigned (Section 4.5).

The definition of solid regions, which can be different for each level, is supplied by parameters B1 through BN. If two or more levels are assignable by this definition,[1] the darkest level which satisfies the definition is selected for the given region.

Picture parameters and scanning square size are defined the same as for SB-2 (see Section 2.5).

4.4 Sample Output

A sample picture annotated by SB-3 is presented in Figure 4-1. As in SB-2, a brokenness frequency table of the results of the BRAND analysis (not shown here) follows the picture output.

The brightness frequency distribution table containing the key to the symbols used in the annotated picture as produced by the program appears in Figure 4-2. This table contains the frequency distribution of the brightness values of the elements of the actual picture, the element symbol for the level to which elements at the respective brightness value are assigned, and the overprint symbol for elements which lie in regions defined as "solid" at that level. Below the table is a list showing the number of levels of brightness into which the picture is divided, the mean brightness of the picture, and the median brightness of the elements of the picture. If the user has selected the option which computes the thresholds which divide the levels, the upper and lower cutoffs and the

---

1. This is possible only if B_1 is greater than $S^2/2$, unlikely in a typical application.

Figure 4-1

Sample Picture Annotated by SB-3 Program

Figure 4-2

SB-3 Brightness Frequency Distribution Output

FREQUENCY TABLE

BRIGHTNESS	FREQUENCY	ELEMENT SYMBOL	REGION SYMBOL
0	100	$	W
1	60	$	W
2	79	$	W
3	48	$	W
4	38	$	W
5	24	$	W
6	11	$	W
7	5	$	W
8	6	$	W
9	8	$	W
10	12	$	W
11	24	$	W
12	120	$	W
13	268	$	W
14	375	$	W
15	855	$	W
16	1858	$	W
17	2820	$	W
18	3156	$	W
19	2278	$	W
20	1570	/	V
21	1249	/	V
22	869	/	V
23	760	/	V
24	679	/	V
25	616	/	V
26	582	/	V
27	531	–	'
28	553	–	'
29	590	–	'
30	807	–	'
31	936	–	'
32	858	–	'
33	864	–	'
34	986		
35	923		
36	765		
37	796		
38	922		
39	379		
40	264		
41	111		
42	35		
43	20		
44	17		
45	3		
46	3		
47	4		
48	3		
49	0		
50	0		
51	0		
52	0		
53	0		
54	0		
55	0		

56	0
57	0
58	0
59	0
60	0
61	0
62	0
63	0

NUMBER OF LEVELS (N) . 4

MEAN BRIGHTNESS . . . 23

MEDIAN BRIGHTNESS . . 21

LOWER CUT-OFF 13

UPPER CUT-OFF 39

SIGMA 950

SIGMA value (Sec. 4. 5) are also listed.

The picture chosen for illustration is P4 of Figure 3-1. The annotation is for four levels of brightness with the thresholds computed by the program. The symbols were chosen to obtain the best optical correspondence with the relative brightness of the elements of the actual picture. The element symbols are ($), (/), (-), and ( ), representing the darkest through lightest levels respectively (the last symbol representing a "blank"). The overprint symbols defining the "solid" regions to which these elements are assigned are (W), (V), ('), and ( ). Elements within solid regions are represented by (W$), (V/), ('-), and ( ); that is, (W) over ($) for "solid black," (V) over (/) for "solid dark gray," (') over (-) for "solid light gray," and ( ) over ( ) for solid white.

Within solid regions the possible combinations of elements symbols and their meanings are as follows:

Symbol	Components	Element Classification	Solid Region Classification
W$	W over $	Black	Black
W/	W over /	Dark Gray	Black
W-	W over -	Light Gray	Black
W	W over blank	White	Black
V$	V over $	Black	Dark Gray
V/	V over /	Dark Gray	Dark Gray

Symbol	Components	Element Classification	Solid Region Classification
V	V over -	Light Gray	Dark Gray
V	V over blank	White	Dark Gray
$	' over $	Black	Light Gray
/	' over /	Dark Gray	Light Gray
'	' over -	Light Gray	Light Gray
'	' over blank	White	Light Gray
$	blank over $	Black	White
/	blank over /	Dark Gray	White
-	blank over -	Light Gray	White
blank	blank over blank	White	White

Element symbols overprinted with a decimal digit lie within a broken region. The symbol represents the level value of the element and the number signifies its brokenness value.

Figure 4-2 indicates that the mean brightness of this picture was 23 and the median brightness was 21. The SIGMA value of 950 indicates that 95% of the elements have brightnesses which lie between the lower cutoff at 13 and the upper cutoff at 39.

The elements of very low brightness of 0 to 6 in the frequency table (see Figure 4-2) are border elements and not part of the picture. They lie below the lower cutoff and do not affect the assignment of the thresholds.

4.5 Logical Description

The general processing technique of SB-3 follows that of SB-2. (The logical description of SB-2 appears in Section 2.5.) However, where six bits were adequate in SB-2 to store all the information for each element, SB-3 requires twelve. This information is stored in two tables in memory designated PICT and PICT2. The bit configuration of the information for each element in each table is as follows:

PICT	OXXXXX
PICT2	YOZZZZ

Field X contains the element level value with range 0 to 31. Field Y contains a bit designating whether the element is located in a broken or solid region (0=solid, 1=broken). Field Z contains the brokenness value with range 0 to 9. The two tables have the same structure; successive six-bit groups are stored consecutively by picture row, packed six to a computer word.

The element brightness values, 0 through 63, are read in from the input data tape one line at a time. The program then checks to see if the user has assigned the thresholds, or whether they are to be computed. In the former event the program checks Switch 1 to determine if a printout of the frequency distribution of the brightness values is required. If this switch is off, no printout is required; the picture is read in from the tape and checked against these thresholds immediately. Each element is assigned the level value corresponding to the lowest threshold greater than its brightness value, which is stored in computer memory (table PICT, Field X).

If on the other hand the thresholds are not assigned by the user, or if a frequency table printout is required, the entire picture is read unaltered into memory as a frequency count of brightness values is made. Next, if the thresholds were not specified by the user, they are computed.

The element brightness values are checked against the computed thresholds and the level values substituted in memory for the brightness values.

In computing thresholds the program uses the following technique: N-1 thresholds are spaced evenly over the range of the frequency distribution which contains a predetermined percentage of element brightness values. This percentage can be assigned by the user by setting SIGMA equal to 10 times the desired percent. If not assigned, this will be computed as:

$$\text{SIGMA} = 1000 - (200/N)$$

where N is the number of levels.

SIGMA is then subtracted from 1000, divided by 1000 and multiplied by the total number of elements in the picture. The result of this computation is the number of elements that the program, in spacing thresholds, "cuts off," half at each end of the brightness frequency distribution. The threshold values are then spaced evenly over the range between these "cutoffs."

SORD is now performed, delineating the solid and broken regions according to the criteria defined in Section 4.3.

BRAND analysis follows as in SB-2 with the following exceptions. The degree of brokenness is redefined as follows: The number of adjacencies (A) is still the total number of bordering broken elements adjacent to each element within the scanning square. However, a contrast has the value of the magnitude of the difference in brightness levels of bordering broken elements. The sum of these values is the contrast count C. The brokenness value is now defined as:

$$10C/KA$$

where K is the expected value of $(\frac{C}{A})$ for a random picture of N levels of brightness. Assuming a uniform distribution of brightness levels for the random picture, it can be shown that the expected value of K is:

$$\frac{N}{3} - \frac{1}{3N}$$

C rarely exceeds this value in an ordered picture but when it does the brokenness value is defined as 9.

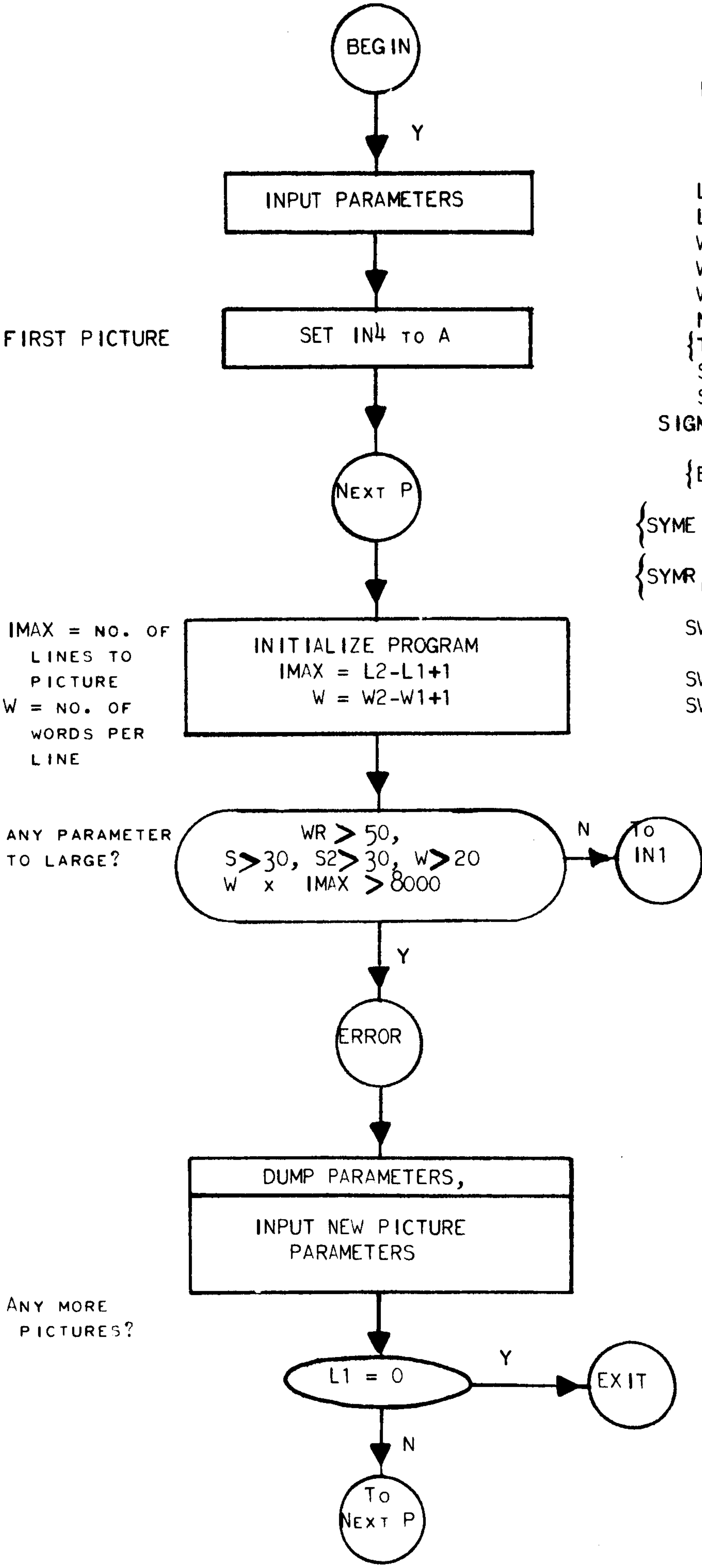
The method of recognizing isolated points and reassigning them to solid regions was also changed in SB-3. An isolated point, as in SB-2, is defined as any broken region point which does not have at least two broken elements adjacent to it at right angles (with respect to the element being tested) to each other. This test is made by checking the two opposite horizontal elements for brokenness. If they are both solid the test fails; the element is isolated. If either is broken the same check is made on the opposite vertical elements. If either of these is broken, the element is non-isolated.

If a point is isolated, further tests are then made to determine the solid region to which it should most logically be assigned. Details of this process are contained in the flow chart, Figure 4-3.

The logical flow chart for SB-3 is presented in Figure 4-3 and the IBM 7094 symbolic program listing, which includes the "driver" program with the parameters used for the sample run illustrated above in Section 4.3, is presented in Figure 4-4.

Figure 4-3

SB-3 Flow Chart



TAPES

INPUT TAPE: PICTURE TAPE

PARAMETERS

L1	FIRST LINE OF TAPE-PICTURE
L2	LAST LINE OF TAPE-PICTURE
W1	FIRST WORD OF PICTURE-LINE
W2	LAST WORD OF PICTURE-LINE
WR	WORDS PER LINE OF TAPE-PICTURE
N	NUMBER OF LEVELS OF BRIGHTNESS
$\{T_i\}$	SET OF N-1 THRESHOLDS
S	SORD SCANNING SQUARE SIZE
S2	BRAND SCANNING SQUARE SIZE
SIGMA	PCT DATA x10 WANTED IN RANGE OF THRESHOLDS
$\{B_i\}$	SET OF N NON-CONFORMING ELEMENTS REQUIRED FOR BROKEN REGIONS
$\{SYME_i\}$	SET OF N SYMBOLS FOR ELEMENT LEVEL PRINTOUT
$\{SYMR_i\}$	SET OF N SYMBOLS FOR REGION LEVEL OVERPRINT
SW1	SWITCH 1 ON FOR FREQUENCY TABLE PRINTOUT
SW2	SWITCH 2 ON FOR PICTURE PRINTOUT
SW3	SWITCH 3 ON FOR NO REGION OVERPRINT.

FIGURE 4-3/PAGE 1

INPUT

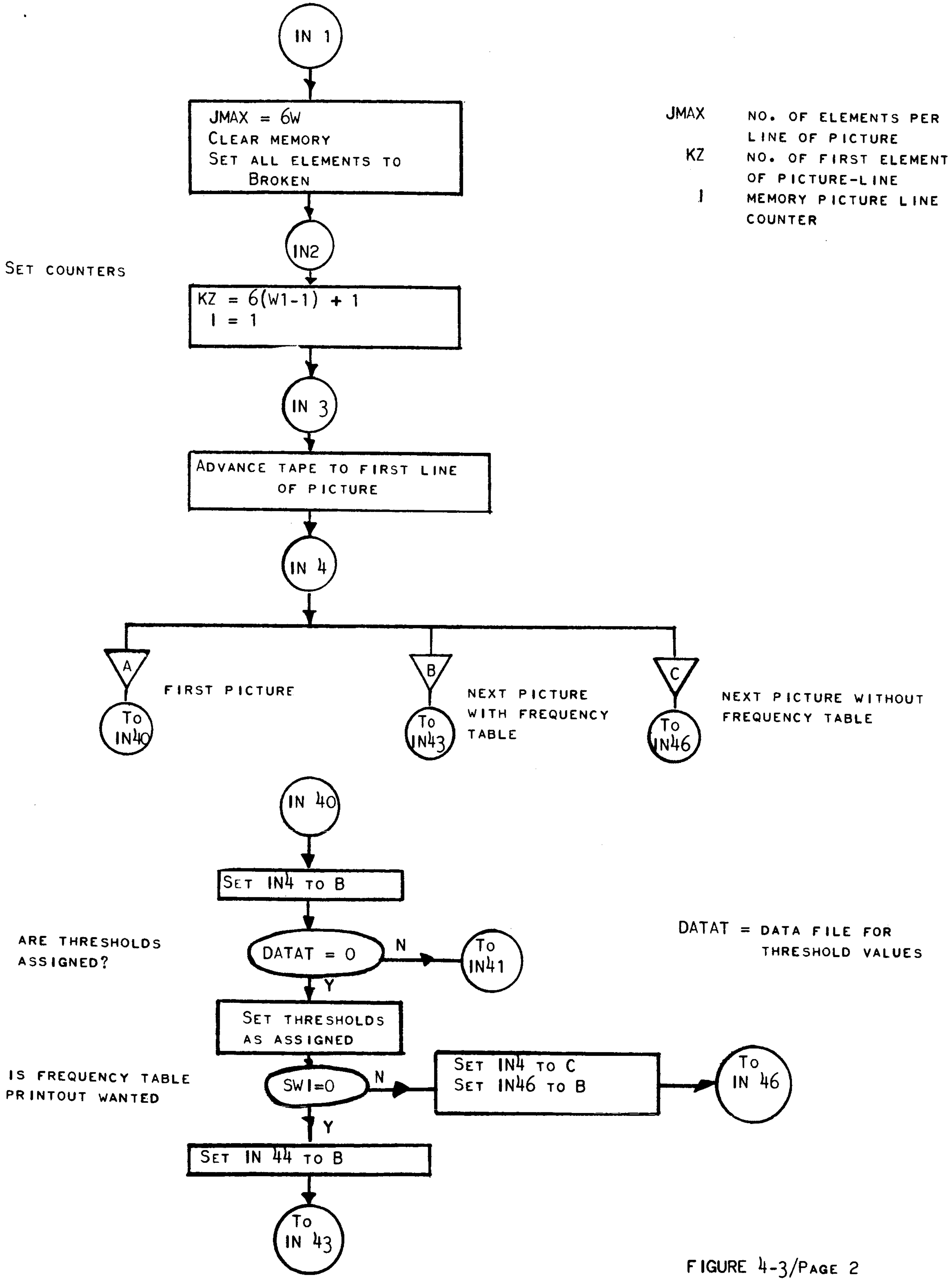


FIGURE 4-3/PAGE 2

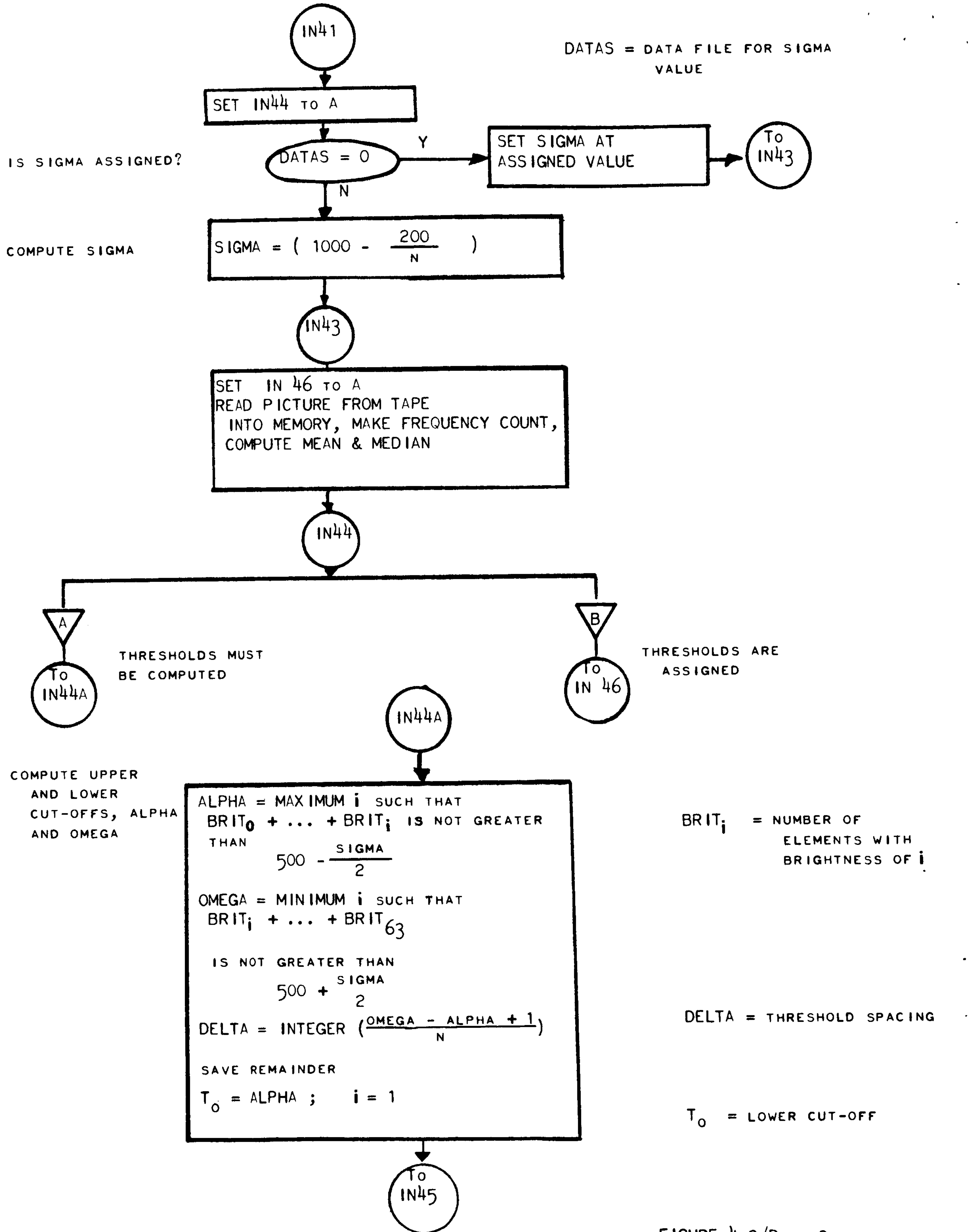
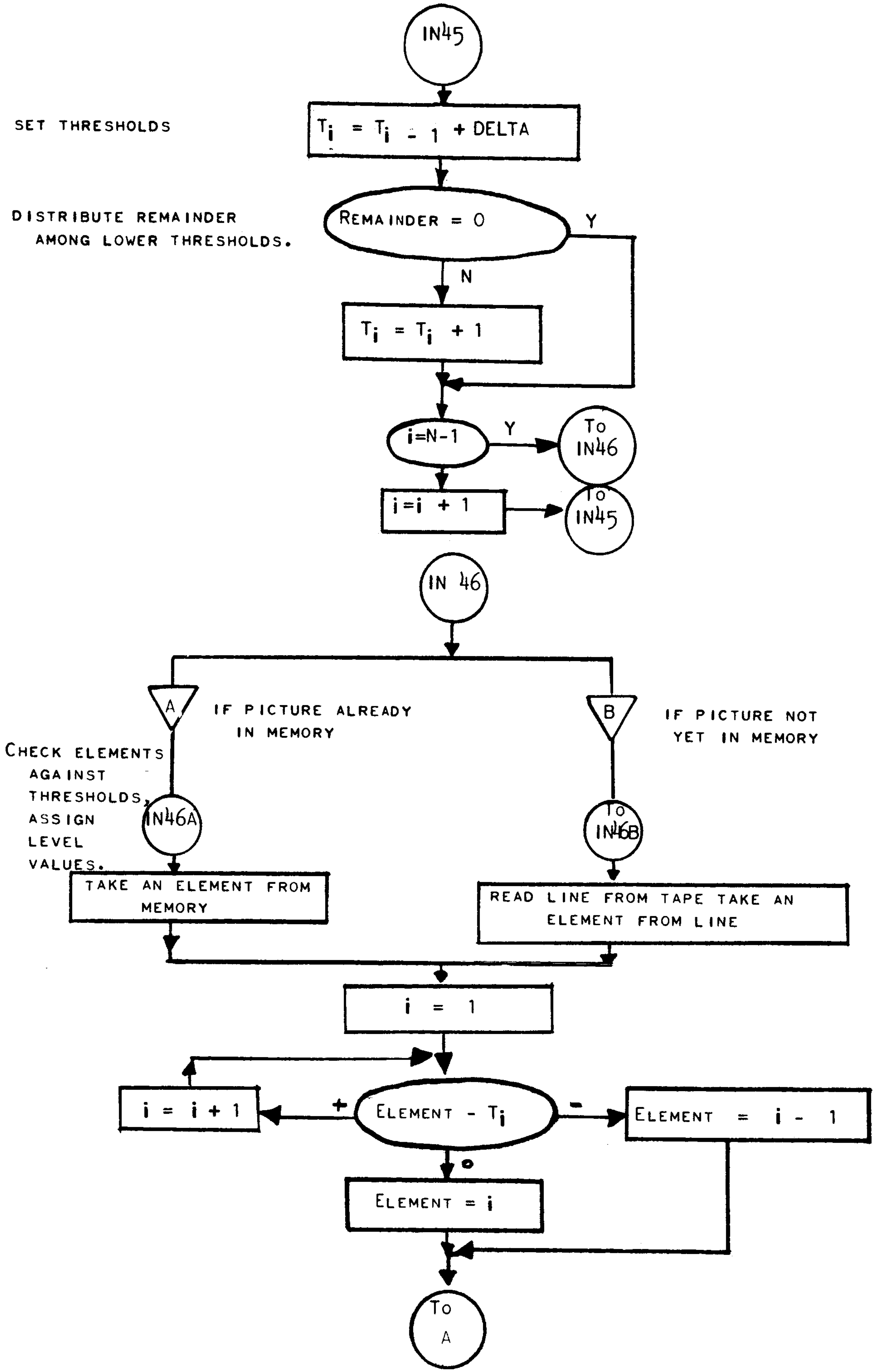


FIGURE 4-3/PAGE 3


IN45
SET THRESHOLDS
Ti = Ti - 1 + DELTA
DISTRIBUTE REMAINDER AMONG LOWER THRESHOLDS.
REMAINDER = 0
Y
N
Ti = Ti + 1
i=N-1
Y
To IN46
i=i + 1
To IN45
IN 46
A
IF PICTURE ALREADY IN MEMORY
B
IF PICTURE NOT YET IN MEMORY
CHECK ELEMENTS AGAINST THRESHOLDS, ASSIGN LEVEL VALUES.
IN46A
To IN46B
TAKE AN ELEMENT FROM MEMORY
READ LINE FROM TAPE TAKE AN ELEMENT FROM LINE
i = 1
i = i + 1
+
ELEMENT - Ti
-
ELEMENT = i - 1
0
ELEMENT = i
To A

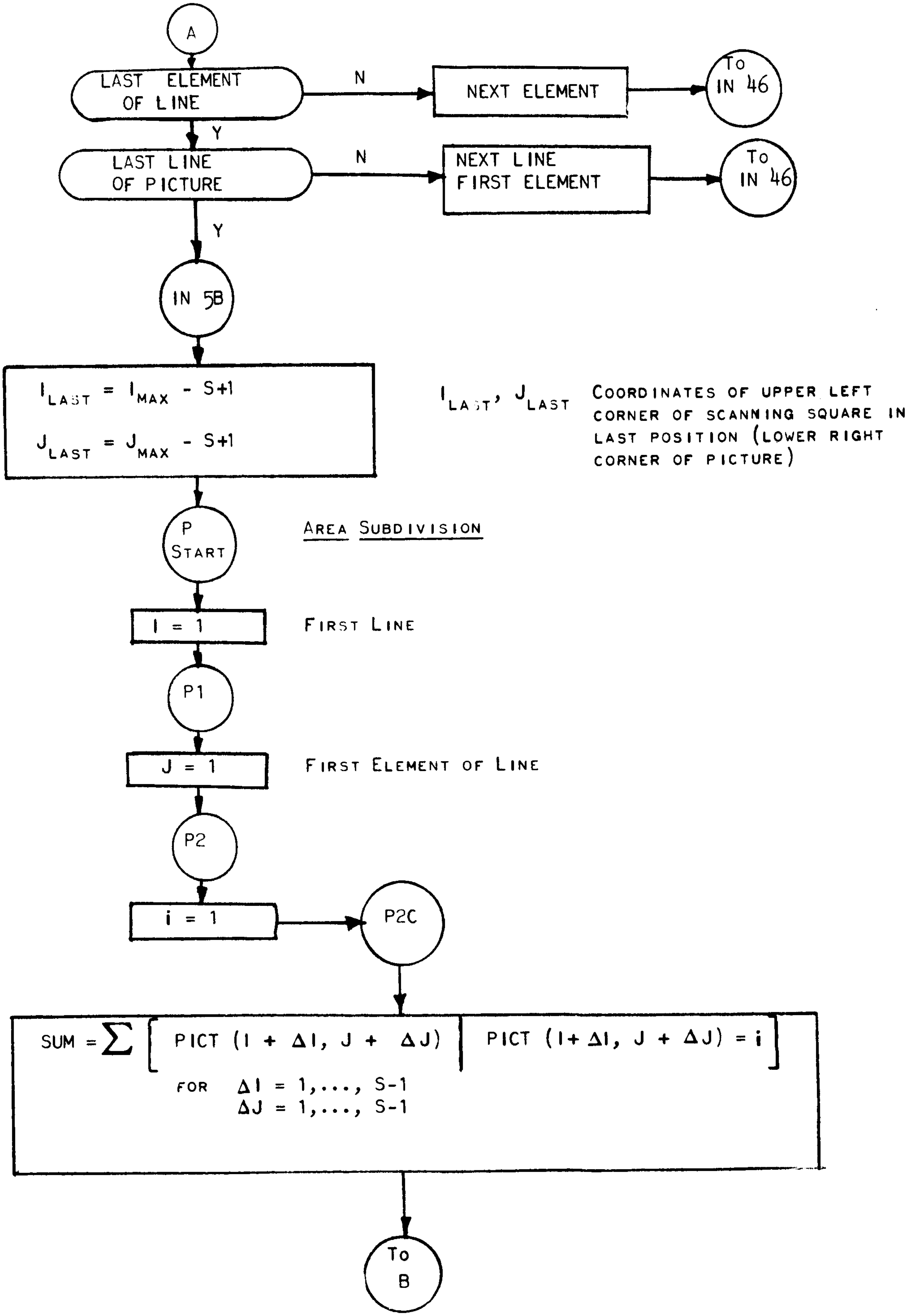


FIGURE 4-3/PAGE 5

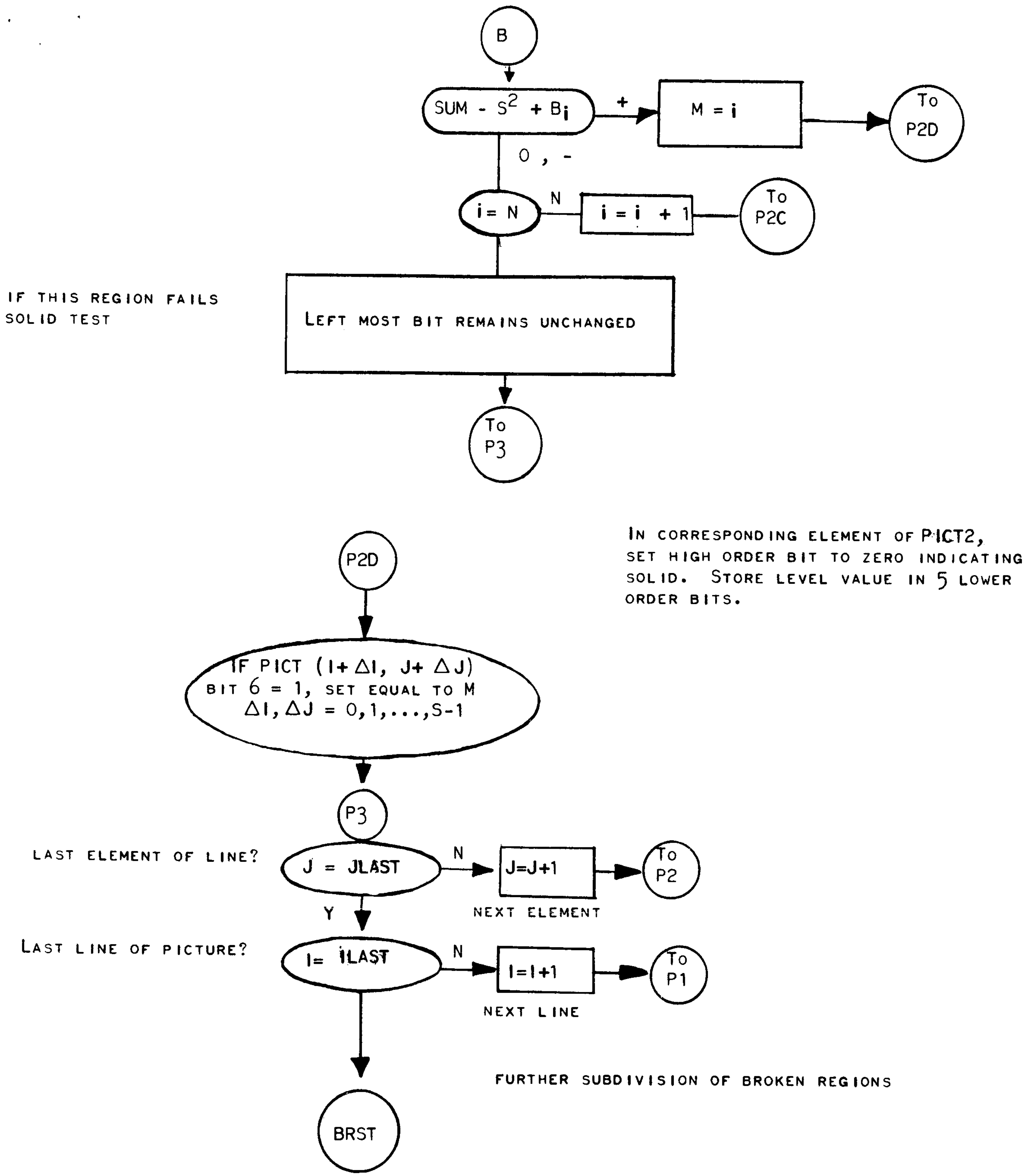


FIGURE 4-3/PAGE 6

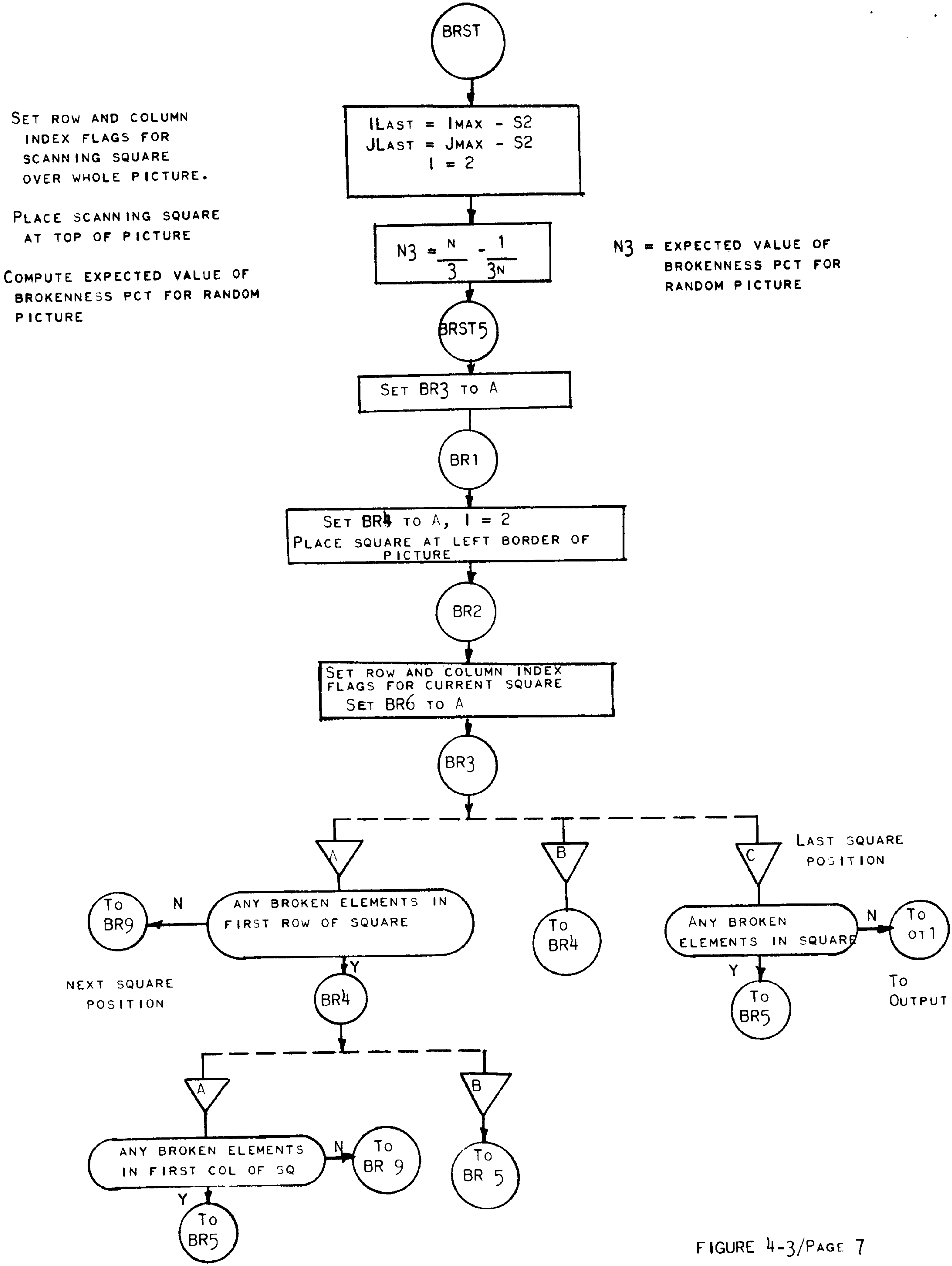


FIGURE 4-3/PAGE 7

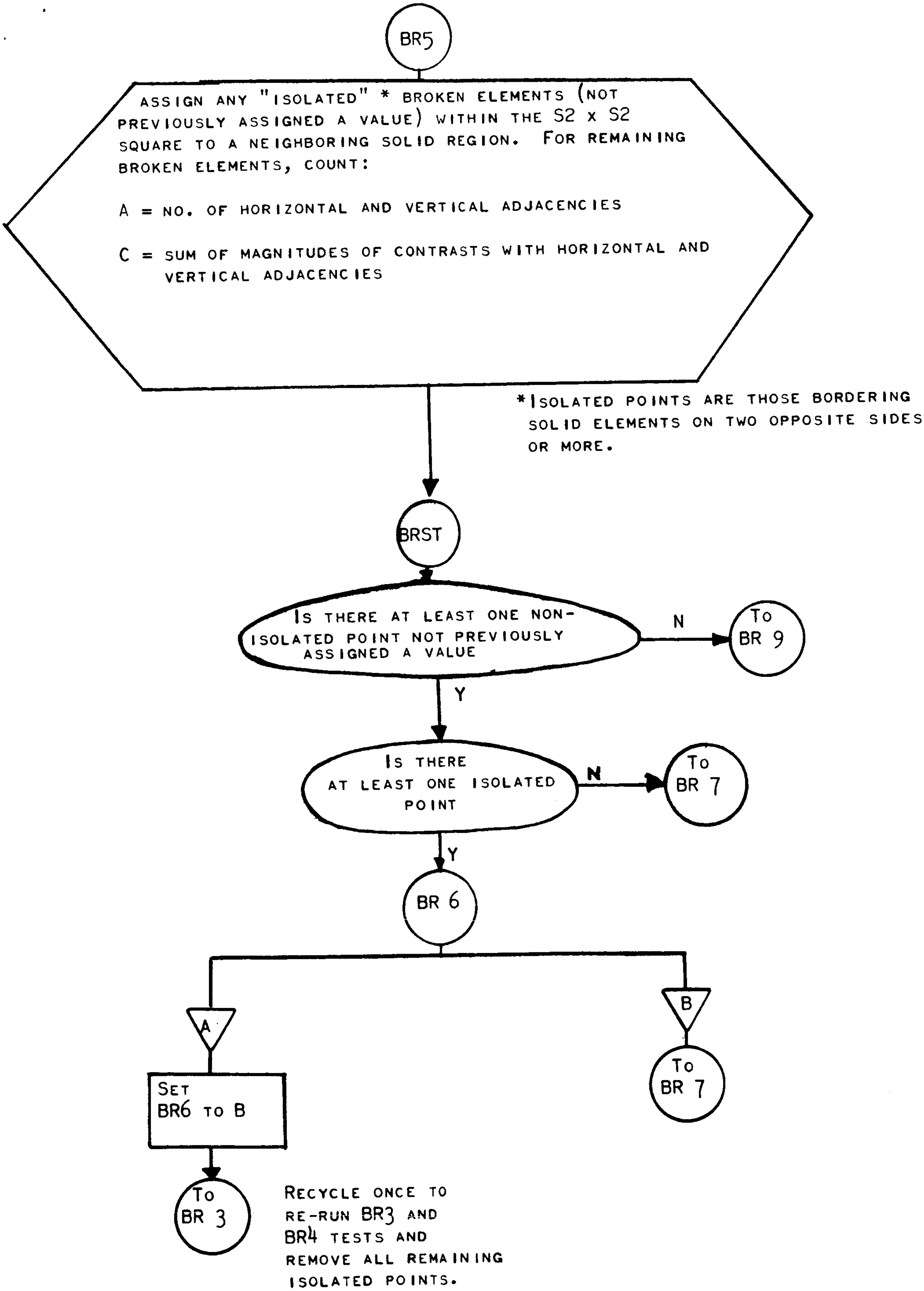


FIGURE 4-3/PAGE 8

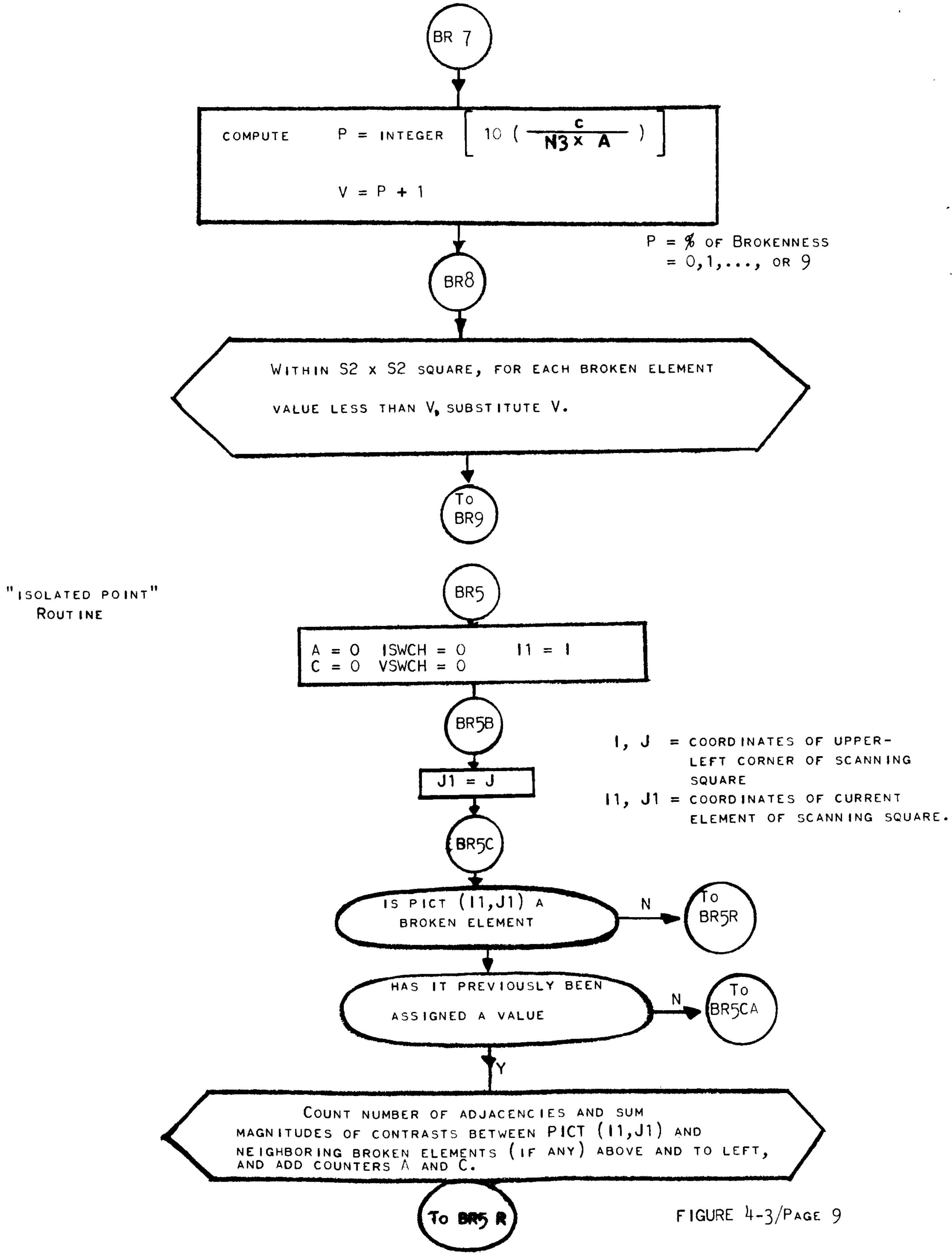


FIGURE 4-3/PAGE 9

ISOLATED POINT ROUTINE

ISOLATED POINT

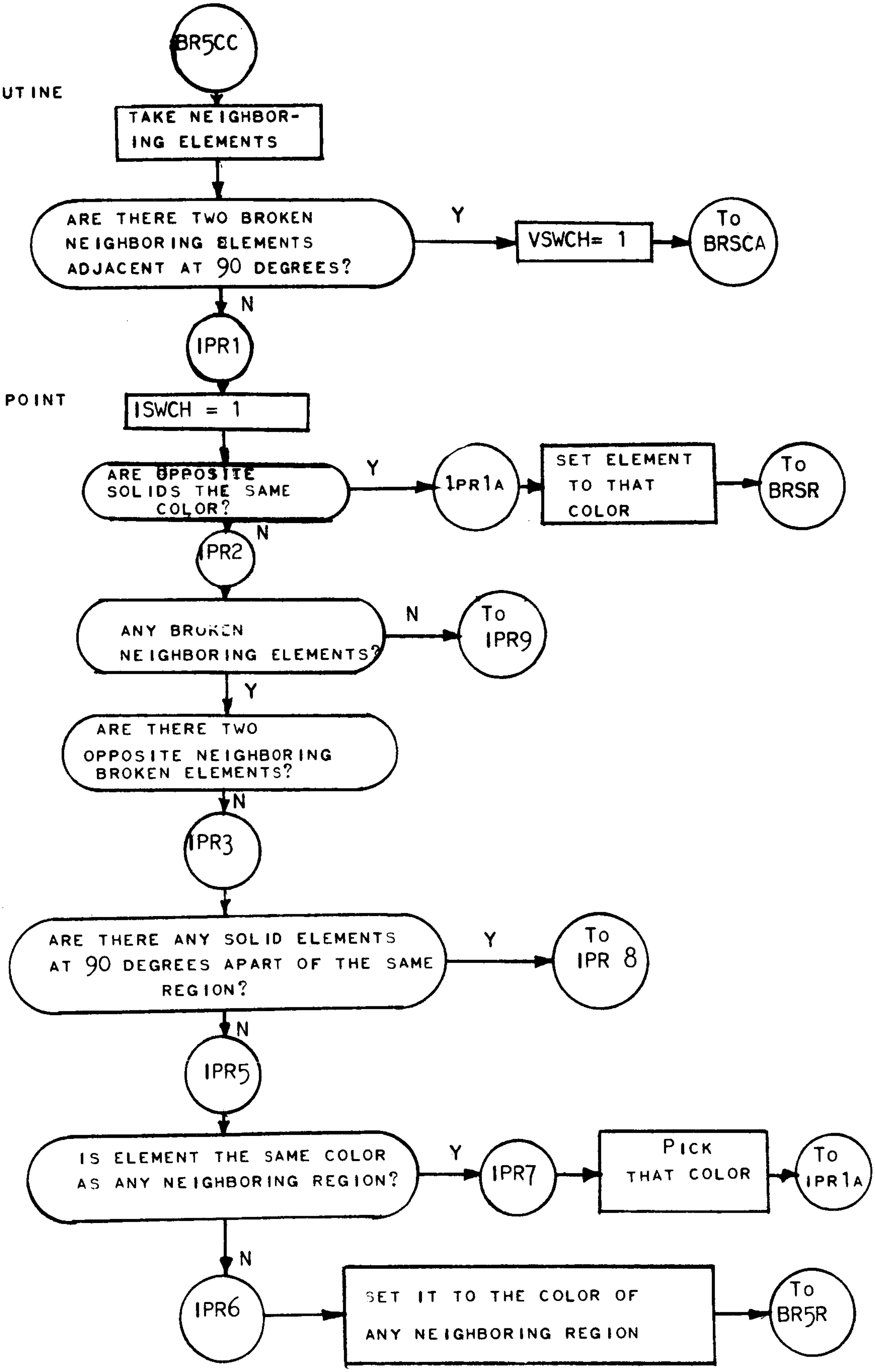


FIGURE 4-3/PAGE 10

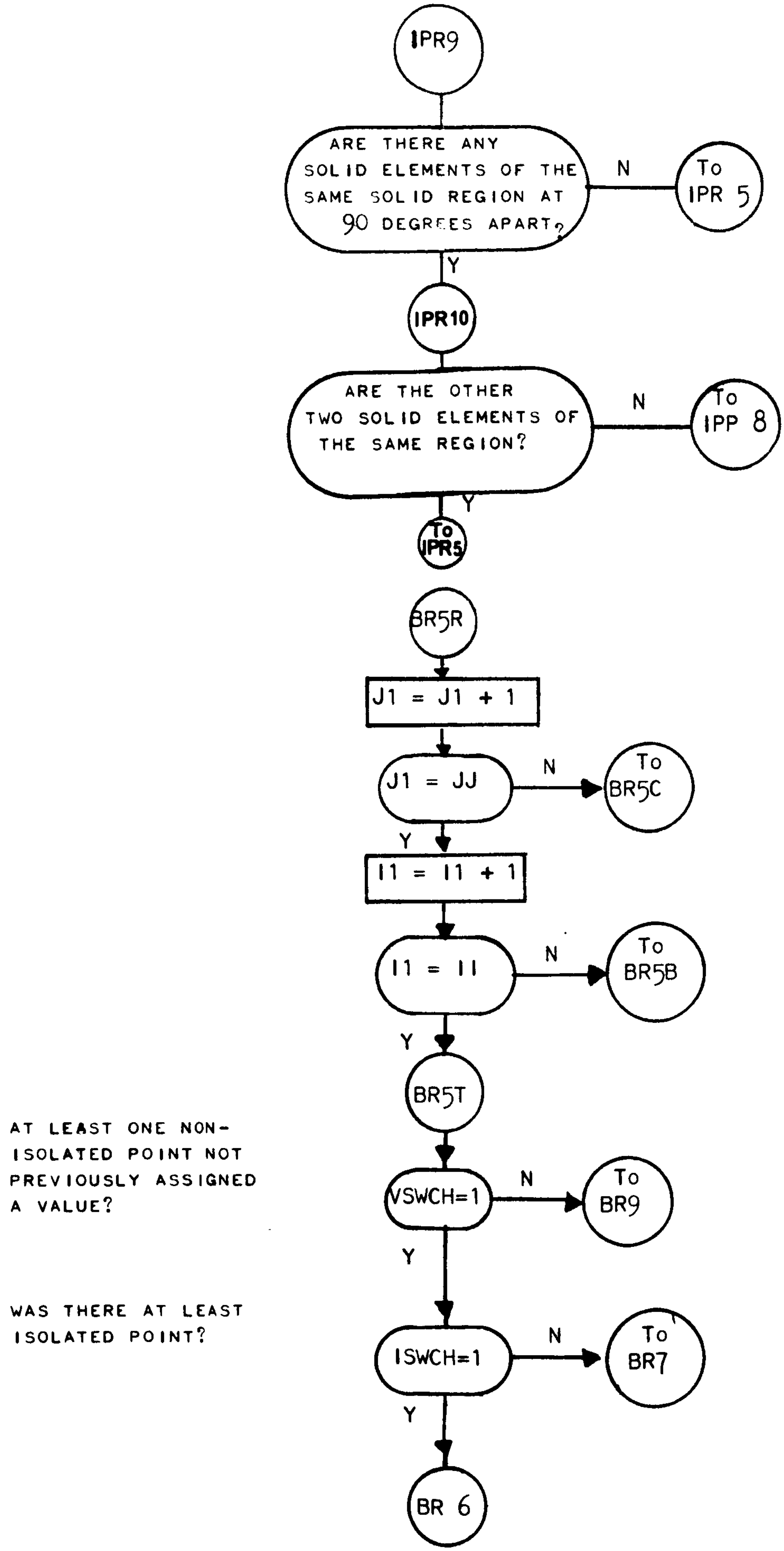


FIGURE 4-3/PAGE 11

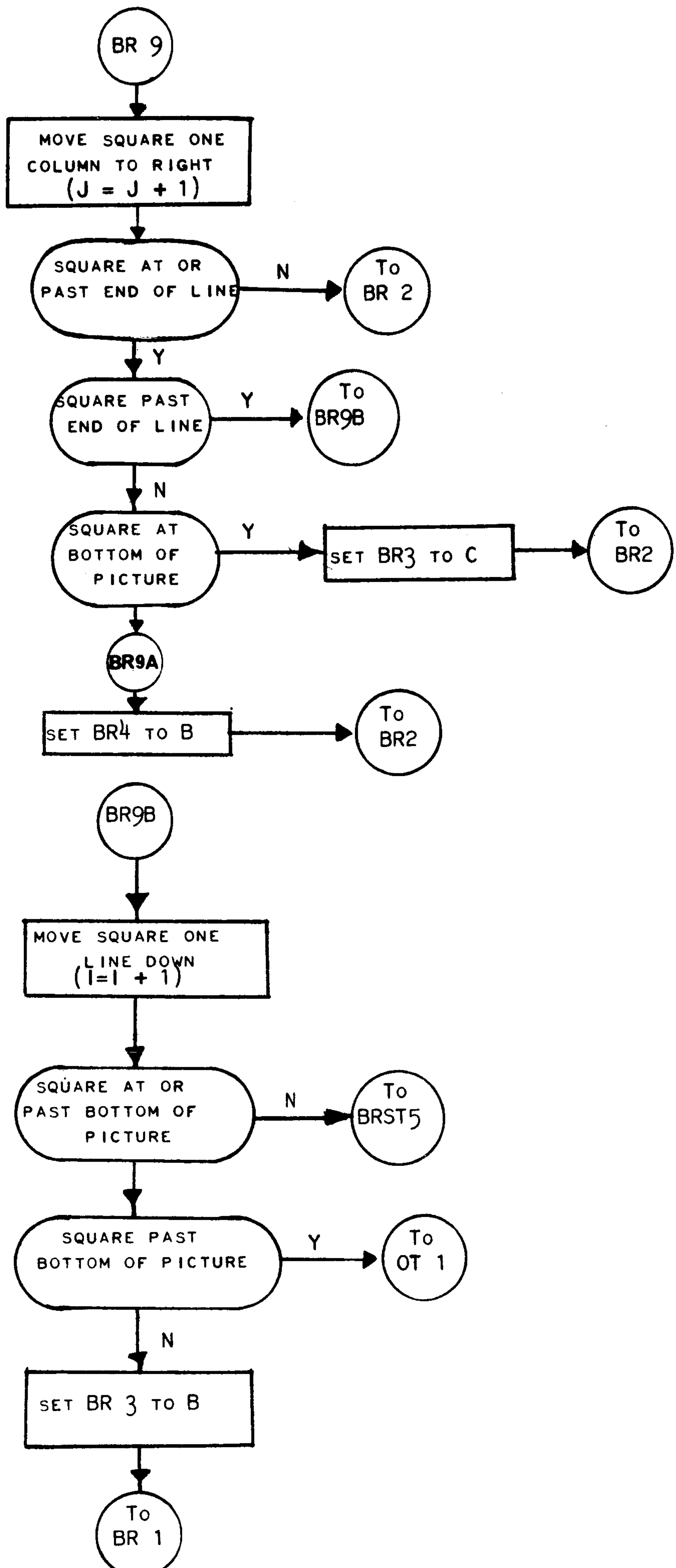


FIGURE 4-3/PAGE 12

OUTPUT

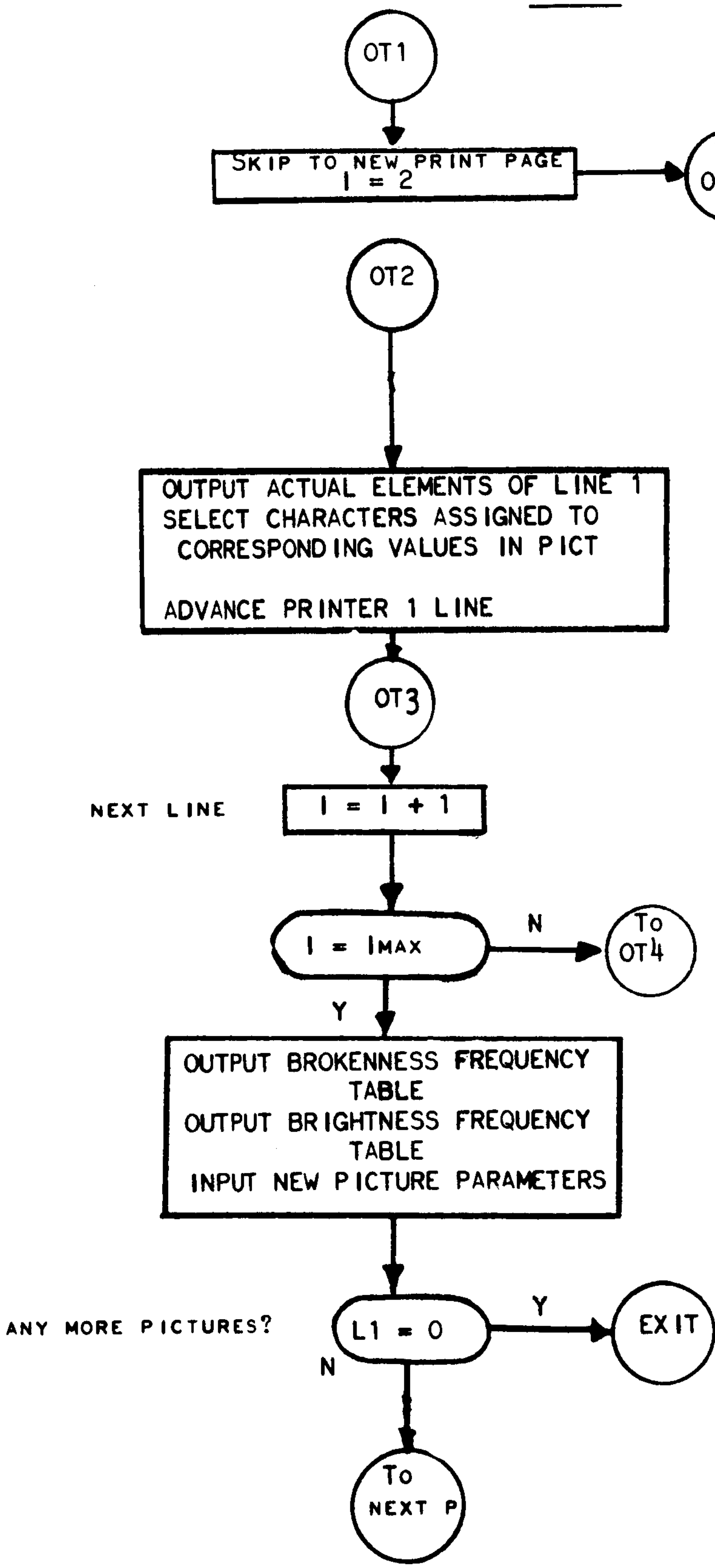


FIGURE 4-3/PAGE 13

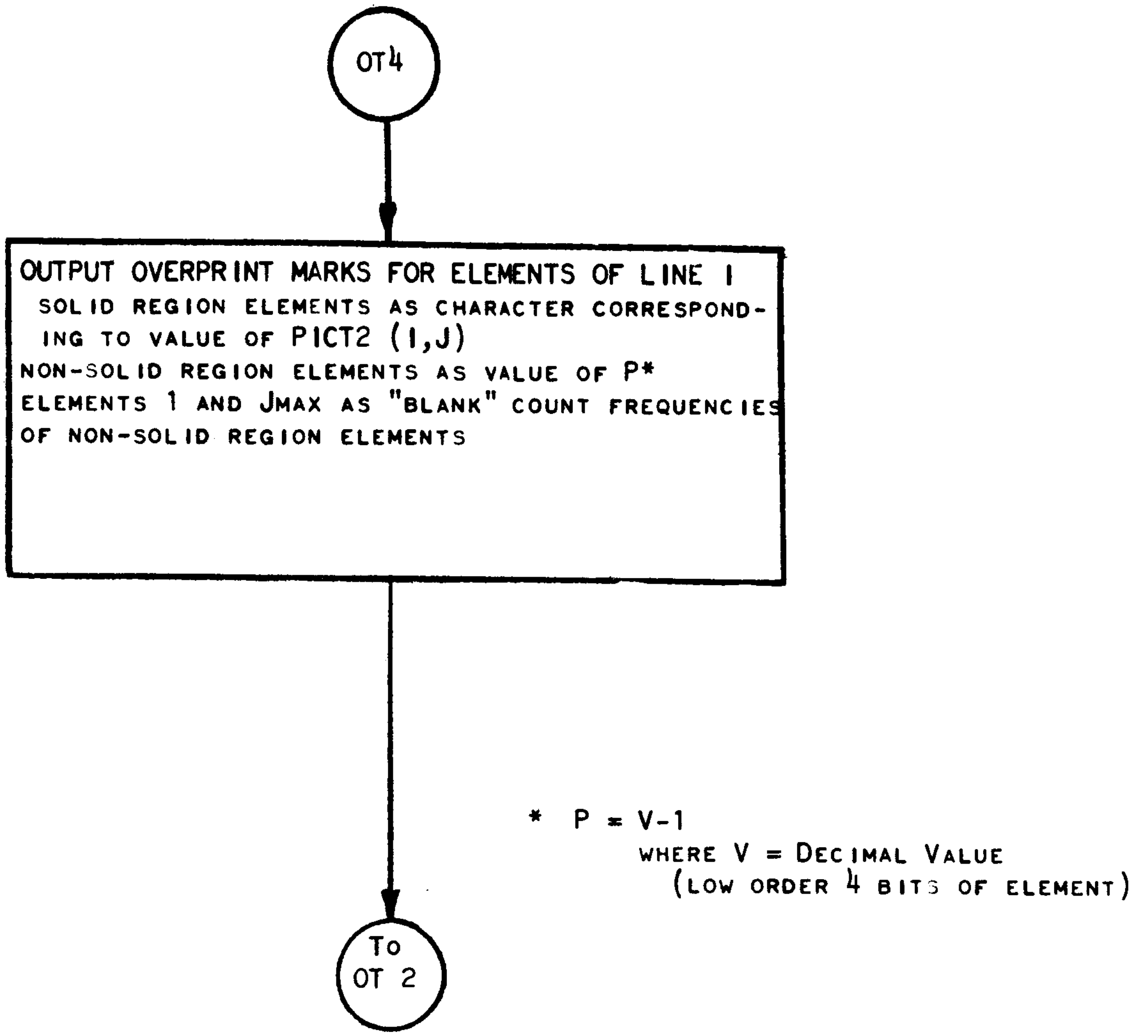


FIGURE 4-3/PAGE 14

Figure 4-4

SB-3 Symbolic Program Listing

```
*       DRIVER -- BRAND 3
        TRA     BEGIN
*    INSERT DATA IN THE FOLLOWING ORDER - -
*       HERE - -   N       EQU      ***  (VALUE OF N)
N       EQU     4
DATA    EQU     *
*   HERE - -  S, S2, WR, FOLLOWED BY  L1, L2, W1, W2  FOR EACH PICTURE
        DEC     5               S
        DEC     3               S2
        DEC     39              WR
        DEC     774             L1      PICTURE  1
        DEC     1013            L2
        DEC     1               W1
        DEC     20              W2
        DEC     774             L1      PICTURE  2
        DEC     1013            L2
        DEC     20              W1
        DEC     39              W2
        DEC     0          TERMINATING ZERO, END OF PICTURE PARAMETER FILE
NB1     EQU     *
*    HERE - -  B1, B2, . . . , BN
        DEC     3               B1
        DEC     3               B2
        DEC     3               B3
        DEC     3               B4
NSYMF   EQU     *
*    HERE - - ELEMENT SYMBOLS, DARKEST THRU LIGHTEST,INCLUDING BLANK
        BCI     1,$
        BCI     1,/
        BCI     1,-
        BCI     1,
NSYMR   EQU     *
*    HERE - - OVERPRINT SYMBOLS- -  FORMAT- -   BCI     1,*
        BCI     1,W
        BCI     1,V
        BCI     1,'
        BCI     1,
NDATAT  EQU     *
*    HERE - -  THRESHOLD VALUES IF ASSIGNED BY USER
        DEC     0          TERMINATING ZERO, THRESHOLDS NORMALLY COMPUTED
NDATAS  EQU     *
*    HERE - -  SIGMA VALUE IF ASSIGNED BY USER
        DEC     0          SIGMA NORMALLY COMPUTED
NSW1    EQU     *
*    IF FREQUENCY TABLE PRINTOUT IS WANTED, PUT NON-ZERO CARD HERE
        DEC     1          SWITCH  ON
        DEC     0          SWITCH NORMALLY OFF
NSW2    EQU     *
*    IF PICTURE PRINTOUT IS WANTED, PUT NON-ZERO CARD HERE
        DEC     1          SWITCH  ON
        DEC     0          SWITCH NORMALLY OFF
NSW3    EQU     *
*       IF ONLY ELEMENT PRINTOUT IS WANTED, PUT NON-ZERO CARD HERE
        DEC     0          SWITCH NORMALLY OFF
BEGIN   AXT     7,1
        CLA     DATA+7,1
        STO     S+7,1
        TIX     *-2,1,1
        AXT     N,1
        CLA     NB1+N,1
```

```
         STO      B1+N,1
         TIX      *-2,1,1
         AXT      N-1,1
         CLA      NDATAT+N-1,1
         STO      DATAT+N-1,1
         TIX      *-2,1,1
         AXT      N,1
         SXA      N2,1
         CLA      NDATAS
         STO      DATAS
         CLA      NSW1
         STO      SW1
         CLA      NSW2
         STO      SW2
         CLA      NSW3
         STO      SW3
         AXT      N,1
         CLA      NSYME+N,1
         STO      SYME+N,1
         CLA      NSYMR+N,1
         STO      SYMR+N,1
         TIX      *-4,1,1
         CALL     B3DRV
         AXT      4,1
         CLA      DATA+3,2
         TXI      *+1,2,-1
         STO      L1+4,1
         TIX      *-8,1,1
         NZT      L1
         TRA      OUT
         CALL     NEXTP
OUT      CAL      =9B17
         CALL     (RWT)
         CALL     EXIT
SW3      COMMON   1
SW2      COMMON   1
SW1      COMMON   1
DATAS    COMMON   1
N2       COMMON   1
DATATN   COMMON   32
DATAT    COMMON   1
SYMRN    COMMON   32
SYMR     COMMON   1
SYMEN    COMMON   32
SYME     COMMON   1
BN       COMMON   32
B1       COMMON   1
W2       COMMON   1
W1       COMMON   1
L2       COMMON   1
L1       COMMON   1
WR       COMMON   1
S2       COMMON   1
S        COMMON   1
SUMN     COMMON   32
SUM      COMMON   1
TN       COMMON   32
         END
```

Figure 4-4 / Page 2

```
*                BRAND - 3
        LBL      SB3,2
        ENTRY    B3DRV
        ENTRY    NEXTP
*                REQUIRED SUBROUTINES
*                                        BASIC FORTRAN I/O PKG
        EXTERN   PUT2
        EXTERN   TAKE2
*                MACRO INSTRUCTIONS
*                MACROS USED--EQUL,TEQL,ADST,TAKEM,
*                PUTM,TNQL,BTEST,CNVST,BRTOSL,SBST,SETV
TEQL    MACRO    X,Y,OUT                 TEST (X) NOT EQ(Y)
        CLA      X
        SUB      Y
        TZE      OUT
TEQL    END
TNQL    MACRO    X,Y,OUT
        CLA      X
        SUB      Y
        TNZ      OUT
TNQL    END
EQUL    MACRO    Y,X
        CLA      X
        STO      Y
EQUL    END
ADST    MACRO    Z,X,Y
        CLA      X
        ADD      Y
        STO      Z
ADST    END
TAKEM   MACRO    AZERO,C,I,J
        TSX      TAKE2,4
        PZE      AZERO,2
        PZE      C
        PZE      I
        PZE      J
TAKEM   END
PUTM    MACRO    AZERO,C,I,J
        TSX      PUT2,4
        PZE      AZERO,2
        PZE      C
        PZE      I
        PZE      J
PUTM    END
BTEST   MACRO    DELI,DELJ,OUT           BOUNDARY TEST
        ADST     IDELI,I,DELI
        ADST     JDELJ,J,DELJ
        TAKEM    PICT,JMAX,IDELI,JDELJ
        ANA      =6                      MARKER BITS
        SUB      =2
        TZE      OUT                     IF A BOUNDARY POINT
BTEST   END
*
SETV    MACRO    A,V                     SET VARIABLE CONNECTOR
        CLA      V
        STA      A
SETV    END
*
SBST    MACRO    Z,X,Y                   SUBTRACT AND STORE
        CLA      X
```

```
         SUB     Y
         STO     Z
SBST     END
*
*                BEGIN PROGRAM
B3DRV    SETV    IN4,V40
         SXA     SAVE,4
         LDQ     S
         MPY     S
         STQ     SSQ
DRV1     CLA     =1
         STO     L
DRV2     TSX     SABOP2,4
         ADST    SAVE2,SAVE2,=4
         LAC     SAVE2,2
         LXA     SAVE,4
         TRA     1,4
NEXTP    CLA     L
         CAS     L1
         TRA     REW
         TRA     DRV2
         TRA     DRV2
REW      CAL     =9B17
         CALL    (RWT)
         TRA     DRV1
*
SABOP2   CLA     WR                      SET CONSTANTS,ETC.
         ALS     18
         STD     LIOC
         LDQ     WR
         MPY     =6
         STQ     ER
         SXA     SAVE4,4
         CLA     L2                      TEST PARAMETERS
         SUB     L1
         ADD     =1
         STO     IMAX
         CLA     W2
         SUB     W1
         ADD     =1
         STO     W
         SUB     =21
         TPL     ERROR                   IF PICTURE TOO WIDE
         CLA     WR
         SUB     =51
         TPL     ERROR                   IF INPUT BUFFER TOO LONG
         LDQ     IMAX
         MPY     W
         STQ     ELEM
         TIX     PICT2-PICT,0,0
         CLA     *-1
         ANA     =077777
         SUB     ELEM
         TMI     ERROR
         CLA     S
         SUB     =31
         TPL     ERROR                   IF SORD SQ SIZE TOO LARGE
         CLA     S2
         SUB     =31
         TMI     IN1                     IF BRAND SQ SIZE NOT TOO LARGE
```

```
ERROR   CALL    PDUMP,S,W2,3         ERROR DUMP OF PARAMETERS
        LXA     SAVE4,4
        TRA     1,4
*
IN1     LDQ     W
        MPY     =6
        STQ     JMAX
        AXT     PICT2-PICT,1  STORE ZEROS IN PICT
        STZ     PICT2,1
        TIX     *-1,1,1
        AXT     PICT2-PICT,1  STORE ONES IN 6TH BIT OF PICT2
        CLA     =040404040404O
        STO     2*PICT2-PICT,1
        TIX     *-1,1,1
        AXT     20,1
        CLA     =060606060606O
        STO     OTBUF+20,1           SET OUTPUT BUFFER TO BLANKS
        TIX     *-1,1,1
IN2     CLA     W1                   COMPUTE FIRST-ELEMENT NR OF INBUF
        SUB     =1
        XCA
        MPY     =6
        XCA
        ADD     =1
        STO     KZ
        EQUL    I,=1
IN3     TEQL    L,L1,IN4
        ADST    L,L,=1
        CALL    RDSBIN
        TIX     0,0,9
        TIX     LIOC,1,0
        TIX     0,1,0
        TRA     IN3
LIOC    IORT    INBUF,0,**
IN4     TRA     IN40
IN40    SETV    IN4,V43       FIRST PICTURE
        NZT     DATAT         ARE THRESHOLDS ASSIGNED
        TRA     IN41          IF NO
        LXA     N2,1
        TXI     *+1,1,-1
        AXT     0,2
        CLA     DATAT,2
        STO     TN+1,1
        TXI     *+1,2,-1
        TIX     *-3,1,1
        CLA     SW1           IS FREQUENCY TABLE PRINTOUT WANTED
        TZE     *+4
        SETV    IN44,V46      IF YES
        TRA     IN43
        SETV    IN46,V46B
        SETV    IN4,V46
        TRA     IN46
IN41    SETV    IN44,V44A     COMPUTE THRESHOLDS
        NZT     DATAS         IS SIGMA ASSIGNED
        TRA     IN42          IF NO
        CLA     DATAS         IF YES, READ SIGMA
        STO     SIGMA
        TRA     IN43
IN42    LDQ     =200          COMPUTE SIGMA
        CLA     =0
```

```
        DVP     N2
        XCA
        SUB     =1000
        SSP
        STO     SIGMA
IN43    SETV    IN46,V46A        PREPARE TO READ PICTURE
        AXT     64,1
        STZ     BRIT+64,1        CLEAR FREQUENCY TABLE
        TIX     *-1,1,1
XX1     TIX     INBUF,0,PICT
        CLA     XX1
        ADD     W2
        STA     IN43B
        ARS     18
        ADD     W
        STA     IN43B+1
IN43A   LXA     W,1
IN43B   LDQ     INBUF,1
        STQ     PICT,1
        AXT     6,2
IN43C   LGL     6
        ANA     =077
        PAC     0,4
        CLA     BRIT,4
        ADD     =1
        STO     BRIT,4
        TIX     IN43C,2,1
        TIX     IN43B,1,1
        CAL     IN43B+1
        ADD     W
        STA     IN43B+1
        TEQL    L,L2,IN43D
        ADST    L,L,=1
        CALL    RDSBIN
        TIX     0,0,9
        TIX     LIOC,1,0
        TIX     0,1,0
        TRA     IN43A
IN43D   CLA     BRIT             TOTAL ELEMENTS
        AXT     63,1
        ADD     BRIT+64,1
        TIX     *-1,1,1
        STO     TOTAL2
        ARS     1                MEDIAN BRIGHTNESS
        AXT     64,1
        SUB     BRIT+64,1
        TMI     *+2
        TIX     *-2,1,1
        PCA     0,1
        ADD     =64
        STA     BRITMD
        AXT     63,1             MEAN BRIGHTNESS
        STZ     BRITMU
        CLA     =1
IN43E   STO     ELEM
        LDQ     BRIT+64,1
        MPY     ELEM
        XCA
        ADD     BRITMU
        STO     BRITMU
```

```
        CLA     ELEM
        ADD     =1
        TIX     IN43E,1,1
        CLA     =0
        LDQ     BRITMU
        DVP     TOTAL2
        STQ     BRITMU
IN44    TRA     IN44A
IN44A   CLA     =1000           COMPUTE LOWER CUT-OFF
        SUB     SIGMA
        XCA
        MPY     TOTAL2
        DVP     =2000
        STQ     ELEM
        XCA
        AXT     64,1
        SUB     BRIT+64,1
        TMI     *+2
        TIX     *-2,1,1
        PCA     0,1
        ADD     =64
        STA     ALPHA
        CLA     ELEM            COMPUTE UPPER CUT-OFF
        AXC     63,1
        SUB     BRIT,1
        TMI     *+2
        TXI     *-2,1,1
        PCA     0,1
        STO     OMEGA
        ADD     =1
        SUB     ALPHA           COMPUTE THRESHOLD INTERVALS
        XCA
        CLA     =0
        DVP     N2              DIVIDE BY N
        STQ     ELEM            (DELTA T)
        ADD     =1
        PAX     0,2             REMAINDER
        CLA     ALPHA           COMPUTE THRESHOLDS
        LXA     N2,1
        TXI     *+1,1,-1
IN45    ADD     ELEM            ADD DELTA T
        TIX     IN45A,2,1
        STO     TN+1,1
        TIX     IN45,1,1
        TRA     IN46
IN45A   ADD     =1              DISTRIBUTE REMAINDER AMONG LOWER INTERVALS
        TRA     *-4
IN46    TRA     IN46A
IN46A   SETV    IN46C,V46D      IF PICTURE ALREADY IN MEMORY
        EQUL    I,=1
        CLA     XX1
        ARS     18
AAA     ADD     W
        STA     IN46AB
AAAA    STA     IN46AD
IN46AA  LXA     W,1
IN46AB  LDQ     INBUF,1
        AXT     6,2
IN46AC  LGL     6
        ANA     =077
```

```
          LXA     N2,4
          TXI     *+1,4,-1
          CAS     TN+1,4
          TIX     *-1,4,1         IF HIGH, CHECK NEXT THRESHOLD
          TXI     *+1,4,-1        IF EQUAL, SET AT NEXT LEVEL
          PCA     0,4             IF LOW, SET AT THIS LEVEL
          ADD     N2
          SUB     =1
          ANA     =077
          STO     ELEM
          CAL*    IN46AD
          ALS     6               SHIFT WORD IN STORAGE
          ADD     ELEM
IN46AD    SLW     PICT,1
          TIX     IN46AC,2,1
          TIX     IN46AB,1,1
          TRA     IN46C
IN46B     SETV    IN46C,V46E
          CLA     XX1
          ADD     W2
          STA     IN46AB
          ARS     18
BBB       ADD     W
          TRA     AAAA
IN46C     TRA     IN46D
IN46D     TEQL    I,IMAX,IN5B     LAST LINE
          ADST    I,I,=1          NEXT LINE OF PICT FROM MEMORY
          CLA     IN46AD
          TRA     AAA
IN46E     TEQL    L,L2,IN5B       LAST LINE
          ADST    L,L,=1
          CALL    RDSBIN          NEXT LINE FROM TAPE
          TIX     0,0,9
          TIX     LIOC,1,0
          TIX     0,1,0
          CLA     IN46AD
          TRA     BBB
IN5B      CLA     IMAX                    COMPUTE COORDINATES OF
          SUB     S                       LOWER RH SQUARE OF PICT
          ADD     =1
          STO     ILAST
          CLA     JMAX
          SUB     S
          ADD     =1
          STO     JLAST
          ZET     SW3
          TRA     OT1
          TRA     PSTART
PSTART    EQUL    I,=1                    MARK PICT ELEMENTS AS BELONGING TO
          LMTM
P1        EQUL    J,=1                    BLACK,WHITE OR BROKEN REGION
P2        LXA     N2,1
          AXT     0,2
          STZ     SUM,2
          TXI     *+1,2,-1
          TIX     *-2,1,1
          EQUL    J1,J
          LXA     S,2
P2A       EQUL    I1,I
          LXA     S,1
```

```
P2B      TAKEM    PICT,JMAX,I1,J1
         PAC      0,3
         CLA      SUM,3
         ADD      =1
         STO      SUM,3
         ADST     I1,=1,I1
         TIX      P2B,1,1
         ADST     J1,=1,J1
         TIX      P2A,2,1
         LXA      N2,3
         AXT      0,5
P2C      CLS      SSQ               CHECK AGAINST THRESHOLDS
         ADD      B1,5
         ADD      SUM,5
         TPL      P2CC              IF SOLID
         TXI      *+1,5,-1
         TIX      P2C,3,1
         TRA      P3                 IF BROKEN
P2CC     PXA      0,3
         SUB      N2
         SLW      M                 SET MARKER TO SOLID LEVEL
P2D      EQUL     I1,I              MARK ALL UNMARKED SQUARES
         LXA      S,2
P2E      EQUL     J1,J
         LXA      S,1
P2F      TAKEM    PICT2,JMAX,I1,J1
         STO      ELEM
         ANA      =040
         TZE      P2G               IF MARKED
         CLA      M
         PUTM     PICT2,JMAX,I1,J1
P2G      ADST     J1,=1,J1
         TIX      P2F,1,1
         ADST     I1,=1,I1
         TIX      P2E,2,1
P3       TEQL     J,JLAST,P3A
         EQUL     J1,J
         ADST     J,J,=1
         EQUL     I1,I
         LXA      S,1
P4       TAKEM    PICT,JMAX,I1,J1
         PAC      0,3
         CLA      SUM,3
         SUB      =1
         STO      SUM,3
         ADST     I1,=1,I1
         TIX      P4,1,1
         ADST     J1,S,J1
         AXT      1,2
         TRA      P2A
P3A      TEQL     I,ILAST,BRST          TO BRIGHTNESS SUBDIV OF BRKN AREAS
         ADST     I,I,=1
         TRA      P1
*
*
*                 BROKEN REGION ANALYZER AND DELINEATOR SUBRTN
BRST     SBST     ILAST,IMAX,S2         SET LINE, COLUMN INDEX FLAGS
         SBST     JLAST,JMAX,S2         FOR SCANNING-SQ OVER WHOLE PICTURE
         EQUL     I,=2                  SQ AT TOP OF PICT (EXCLUDING BORDER)
         CLA      =0
```

```
        LDQ     =1B17
        DVP     =3
        CLA     =0
        DVP     N2
        STQ     N3
        CLA     =0
        LDQ     N2
        LLS     18
        DVP     =3
        XCA
        SUB     N3
        STO     N3
        EMTM
BRST5   SETV    BR3,V3A
BR1     SETV    BR4,V4A
        EQUL    J,=2                SQ AT FAR LEFT OF PICT (EXCL BORDER)
BR2     ADST    II,I,S2             SET ROW, COLUMN INDEX FLAGS
        ADST    JJ,J,S2             OVER CURRENT SQ
        SETV    BR6,V6A
BR3     TRA     *                   V C
BR3A    EQUL    J1,J
BR3A1   TAKEM   PICT2,JMAX,I,J1      ANY BROKEN ELEMENTS IN
        ANA     =040                FIRST ROW OF SQ
        TNZ     BR4                 YES
        ADST    J1,J1,=1
        TNQL    J1,JJ,BR3A1
        TRA     BR9                 NO.  TO NEXT SQUARE POSITION
BR3C    EQUL    I1,I                ANY BRKN ELEMENTS IN SQ
BR3C1   EQUL    J1,J
BR3C2   TAKEM   PICT2,JMAX,I1,J1
        ANA     =040
        TNZ     BR5                 YES
        ADST    J1,J1,=1
        TNQL    J1,JJ,BR3C2
        ADST    I1,I1,=1
        TNQL    I1,II,BR3C1
        TRA     OT1                 NO.  TO OUTPUT
BR4     TRA     *                   V C
BR4A    EQUL    I1,I
BR4A1   TAKEM   PICT2,JMAX,I1,J      ANY BROKEN ELEMENTS IN
        ANA     =040                FIRST COL OF SQ
        TNZ     BR5                 YES
        ADST    I1,I1,=1
        TNQL    I1,II,BR4A1
        TRA     BR9                 NO
*               ISOLATED POINT PROCESSING
BR5     EQUL    ISWCH,=0            SET SWITCHES
        EQUL    VSWCH,=0
        EQUL    A,=0                CLEAR CTRS
        EQUL    C,=0
        EQUL    I1,I
BR5B    EQUL    J1,J
BR5C    TAKEM   PICT2,JMAX,I1,J1     CURRENT ELEMENT
        STO     ELEM
        ANA     =040                BROKEN/SOLID BIT
        TZE     BR5R                IF NOT BROKEN
        CLA     ELEM
        ANA     =017                VALUE BITS OF BRKN ELEMENT
        TZE     BR5C0               IF NOT PREVIOUSLY ASSIGNED A VALUE
BR5CA   ADST    JDELJ,J1,=-1        ADJACENCY AND CONTRAST COUNT
```

```
        TAKEM   PICT2,JMAX,I1,JDELJ LEFT NEIGHBORING ELEMENT
        STO     ELEM2
        ANA     =040
        TZE     BR5CB                 IF NOT BRKN
        ADST    A,A,=1                BRKN.  COUNT 1 ADJACENCY
        TAKEM   PICT,JMAX,I1,JDELJ
        STO     ELEM2
        TAKEM   PICT,JMAX,I1,J1
        STO     ELEM
        SUB     ELEM2
        TZE     BR5CB            IF ZERO, NO CONTRAST
        SSP
        ADD     C                IF NOT ZERO, ADD DIFFERENCE TO CONTRAST
        STO     C
BR5CB   ADST    IDELI,I1,=-1
        TAKEM   PICT2,JMAX,IDELI,J1 UPPER NEIGHBORING ELEMENT
        STO     ELEM2
        ANA     =040
        TZE     BR5R
        ADST    A,A,=1
        TAKEM   PICT,JMAX,IDELI,J1
        STO     ELEM2
        TAKEM   PICT,JMAX,I1,J1
        STO     ELEM
        SUB     ELEM2
        TZE     BR5R
        SSP
        ADD     C
        STO     C
        TRA     BR5R
BR5C0   ADST    J1,J1,=-1
        TAKEM   PICT2,JMAX,I1,J1    LEFT NEIGHBORING ELEMENT
        LRS     6
        STQ     K2
        ADST    J1,J1,=2
        TAKEM   PICT2,JMAX,I1,J1    RIGHT NEIGHBORING ELEMENT
        LDQ     K2
        LRS     6
        STQ     K2
        ADST    J1,J1,=-1           RESTORE COLUMN INDEX
        ADST    I1,I1,=-1
        TAKEM   PICT2,JMAX,I1,J1    TOP NEIGHBORING ELEMENT
        LDQ     K2
        LRS     6
        STQ     K2
        ADST    I1,I1,=2
        TAKEM   PICT2,JMAX,I1,J1    BOTTOM NEIGHBORING ELEMENT
        LDQ     K2
        LLS     30
        PAI                      SET INDICATORS
        ADST    I1,I1,=-1
        STI     K1
        CLA     =040400000       90 DEGREE BROKEN
        AXT     0,1
        TIF     IPR1             IF NO
        ALS     12
        AXC     12,1             REMEMBER WHICH
        TIF     IPR1             IF NO
        EQUL    VSWCH,=1         NON-ISOLATED POINT
        TRA     BR5CA
```

```
IPR1     EQUL     ISWCH,=1          ISOLATED POINT
         PIA                        ARE OPPOSITE SOLIDS IN THE SAME REGION
         ARS      6
         ERA      K1
         ARS      0,1
         ANA      =0770000
         TNZ      IPR2              IF NO
         PIA
         ARS      12,1              IF YES
IPR1A    PUTM     PICT2,JMAX,I1,J1     CHANGE ELEMENT TO SAME
         TRA      BR5R
IPR2     CAL      =040404040000        ANY ADJACENT BROKEN ELEMENTS
         TIF      IPR9              IF NO
         CLA      =040400000        IF YES, OPPOSITE BROKEN ELEMENTS
         TIO      IPR5              IF YES
         ALS      12
         TIO      IPR5
         STL      A1                IF NO, ARE ANY 90 DEGREE SOLIDS THE SAME
         TRA      IPR3
         TRA      IPR4
IPR3     PIA
         ARS      6
         ERA      K1
         LGR      30
         PIA
         ARS      12
         ERA      K1
         ARS      12
         LGR      12
         PIA
         ARS      18
         ERA      K1
         ARS      12
         LGR      6
         ADST     A1,A1,=1
         TRA*     A1
IPR4     AXT      6,1
         LGL      6
         ANA      =077
         TZE      IPR8              IF YES
         TIX      *-3,1,1
IPR5     TAKEM    PICT,JMAX,I1,J1      IF NO, CHECK ELEMENT COLOR AGAINST
         STO      ELEM                    SURROUNDING REGION COLORS
         LDQ      K1
         AXT      4,1
IPR5A    LGL      6
         ERA      ELEM
         ANA      =077
         TZE      IPR7              IF MATCH
         TIX      IPR5A,1,1
         LDQ      K1                IF NONE MATCH, ARBITRARILY SET COLOR
         LGL      1
         LBT
         TRA      IPR6              NEIGHBORING ELEMENT IS SOLID
         LGL      6
         TRA      *-3
IPR6     LGL      5
         TRA      IPR1A
IPR7     CLA      ELEM              SET TO SOLID REGION
         TRA      IPR1A
```

```
IPR8    CAL     =0142214302214
        TRA     *+2
        ARS     6
        TIX     *-1,1,1
        ANA     =077
        STA     *+2
        PIA
        ARS     0
        TRA     IPR1A
IPR9    STL     A1              ARE ANY 90 DEGREE SOLIDS THE SAME
        TRA     IPR3
        AXT     6,1
        LGL     6
        ANA     =077
        TZE     IPR10           IF YES
        TIX     *-3,1,1
        TRA     IPR5            IF NO
IPR10   SXA     A2,1            ARE THE OTHER TWO THE SAME
        LGL     6
        TZE     IPR5
        TIX     *-2,1,1
        LXA     A2,1
        TRA     IPR8            IF NO
BR5R    ADST    J1,J1,=1                NEXT COL OF SQ
        TNQL    J1,JJ,BR5C
        ADST    I1,I1,=1                NEXT ROW OF SQUARE
        TNQL    I1,II,BR5B
BR5T    TNQL    VSWCH,=1,BR9            IF ALL BRKN PTS PREVSLY ASGND VALUE
        TNQL    ISWCH,=1,BR7            IF NO ISOLATED PTS
*               END OF ISOLATED PT PROCESSING
BR6     TRA     *                       V C
BR6A    SETV    BR6,V6B
        TRA     BR3
BR7     LDQ     N3
        MPY     A
        STQ     A
        LDQ     C
        MPY     =10B17
        DVP     A
        XCA
        ADD     =1
        STO     V
*                                       B = BROKENNESS PERCENTAGE
BR8     EQUL    I1,I                    WITHIN SQ, SET EACH
BR8A    EQUL    J1,J                    BRKN ELEM VALUE IF LSTH V, TO V
BR8B    TAKEM   PICT2,JMAX,I1,J1
        STO     ELEM
        ANA     =040                    BROKEN/SOLID BIT
        TZE     BR8C                    IF NOT BROKEN
        CLA     ELEM                    ELSE IF BROKEN,
        ANA     =017                    EXTRACT VALUE BITS
        SUB     V
        TPL     BR8C                    IF NEW ELEM VALUE NOT GRTH OLD
        CLA     ELEM
        ANA     =060                    CLEAR OUT OLD VALUE
        ADD     V                       PUT IN NEW
        PUTM    PICT2,JMAX,I1,J1
BR8C    ADST    J1,J1,=1                NEXT COLUMN OF SQ
        TNQL    J1,JJ,BR8B
        ADST    I1,I1,=1                NEXT ROW OF SQ
```

```
         TNQL    I1,II,BR8A
BR9      ADST    J,J,=1                 MOVE SQ 1 COL RIGHT
         CLA     J
         SUB     JLAST
         TMI     BR2                    IF SQ NOT AT END OF LINE
         TNZ     BR9B                   IF SQ PAST END OF LINE
         TEQL    I,ILAST,BR9A           IF SQ AT BOTTOM OF PICT (LAST POS)
         SETV    BR4,V4B
         TRA     BR2
BR9A     SETV    BR3,V3C
         TRA     BR2
BR9B     ADST    I,I,=1                 MOVE SQ 1 LINE DOWN
         CLA     I
         SUB     ILAST
         TMI     BRST5                  IF SQ NOT AT BOTTOM OF PICTURE
         TNZ     OT1                    IF PAST BOTTOM, TO OUTPUT
         SETV    BR3,V3B
         TRA     BR1
*
*                OUTPUT SUBRTN
OT1      CAL     =6B17
         CALL    (STH)                  SKIP TO NEW PAGE
         PZE     FMT1,0,-1
         CALL    (FIL)
         AXT     10,4
         STZ     BP+10,4
         TIX     *-1,4,1
OT1A     EQUL    I,=2
         NZT     SW3
         TRA     OT4
OT2      CAL     =6B17                  PRINT LINE OF PICTURE ELEMENTS
         CALL    (STH)
         PZE     FMT2,0,1
OT2A     EQUL    J,=1
OT2B     TAKEM   PICT,JMAX,I,J
         PAC     0,1
         CAL     SYME,1
         ARS     30
OT2B1    PUTM    OTBUF,ONETWE,=1,J
         TEQL    J,JMAX,OT2C            IF END OF LINE
         ADST    J,J,=1
         TRA     OT2B
OT2C     AXT     20,1                   FEED LINE TO PRINTER
OT2D     LDQ     OTBUF+20,1
         STR
         TIX     OT2D,1,1
         CALL    (FIL)
OT3      ADST    I,I,=1                 OVERPRINT SYMBOLS FOR
         TNQL    I,IMAX,OT4             BOUNDARY AND BROKEN-REGION POINTS,
         ZET     SW3
         TRA     OT3BB
OT3A     CAL     =6B17
         CALL    (STH)
         PZE     FMT4,0,1
         AXT     10,1
         CLA     =0
         ADD     BP+10,1
         TIX     *-1,1,1
         STO     TOTAL
         AXT     6,1
```

```
        LDQ     HEAD+6,1
        STR
        TIX     *-2,1,1
        AXT     10,1
OT3B    PXD     0,1
        SUB     =10B17
        SSP
        XCA
        STR
        LDQ     BP+10,1
        LLS     18
        STR
        LDQ     BP+10,1
        MPY     =100
        DVP     TOTAL
        ALS     1
        SUB     TOTAL
        TMI     *+4
        XCA
        ADD     =1
        XCA
        LLS     18
        STR
        TIX     OT3B,1,1
        CALL    (FIL)
        CAL     =6B17
        CALL    (STH)
        PZE     FMT5,0,1
        LDQ     TOTAL
        LLS     18
        STR
        CALL    (FIL)
        CAL     =6B17
        CALL    (STH)
        PZE     FMT6,0,1
        LDQ     W
        MPY     =6
        XCA
        SUB     =2
        STO     ELEM
        CLA     L2
        SUB     L1
        SUB     =1
        XCA
        MPY     ELEM
        LLS     18
        STQ     ELEM
        STR
        CALL    (FIL)
        CAL     =6B17
        CALL    (STH)
        PZE     FMT7,0,1
        LDQ     TOTAL
        MPY     =100
        LLS     18
        DVP     ELEM
        LLS     18
        STR
        CALL    (FIL)
OT3BB   NZT     SW1
```

```
        TRA     OT3W
        CAL     =6B17          FREQUENCY TABLE
        CALL    (STH)
        PZE     FMT8,0,1
        AXT     3,1            HEADINGS
        LDQ     HEAD2+3,1
        STR
        TIX     *-2,1,1
        AXT     11,1
        LDQ     HEAD3+11,1
        STR
        TIX     *-2,1,1
        AXT     64,1
OT3C    PCA     0,1
        ADD     =64
        ANA     =077
        XCA
        LLS     18
        STR
        LDQ     BRIT+64,1      FREQUENCY
        LLS     18
        STR
        XCA
        LXA     N2,2
        TXI     *+1,2,-1
        PCA     0,1
        ADD     =64
        ANA     =077
        CAS     TN+1,2
        TIX     *-1,2,1
        TXI     *+1,2,-1
        PCA     0,2
        ADD     N2
        SUB     =1
        PAC     0,2
        LDQ     SYME,2
        CAL     =0606060606060
        LGR     30
        STR
        LDQ     SYMR,2
        CAL     =0606060606060
        LGR     30
        STR
        TIX     OT3C,1,1
        CALL    (FIL)
        CAL     =6B17          SUB-TABLE
        CALL    (STH)
        PZE     FMT9,0,1
        AXT     4,1
        LDQ     HEAD4+4,1
        STR
        TIX     *-2,1,1
        LDQ     N2
        LLS     18
        STR
        AXT     5,2
        ZET     DATAT
        AXT     2,2
OT3D    AXT     4,1
XX4     LDQ     HEAD4+8,1
```

```
         STR
         TIX       *-2,1,1
XX5      LDQ       BRITMU
         LLS       18
         STR
         CLA       XX4
         ADD       =4
         STA       XX4
         CLA       XX5
         ADD       =1
         STA       XX5
         TIX       OT3D,2,1
         SETV      XX4,VXX4
         SETV      XX5,VXX5
         CALL      (FIL)
*                                    LINES 2 THROUGH IMAX-1
OT3W     LXA       SAVE4,4
         TRA       1,4               EXIT
OT3X     NZT       SW1          IF NO TABLE PRINTOUT IS WANTED
         TRA       OT3A
OT4      CLA       =060              SET FIRST AND LAST ELEMENTS
         ZET       SW3
         TRA       OT2
         PUTM      OTBUF,ONETWE,=1,ONE   OF LINE TO BLANK
         CLA       =060
         PUTM      OTBUF,ONETWE,=1,JMAX
         EQUL      J,=2
OT4A     TAKEM     PICT2,JMAX,I,J
         STO       ELEM
         ANA       =040
         TZE       OT4AA        IF ELEMENT IS IN A SOLID REGION
         CLA       ELEM              IN BRKN REGION
         ANA       =017              EXTRACT BRKNNESS VALUE BITS
         CAS       =11
         CLA       =11
         SUB       =1
         SUB       =1
         PAC       0,4
         XCA
         CLA       BP,4
         ADD       =1
         STO       BP,4
         XCA
         NZT       SW2
         TRA       OT7
         TRA       OT4B
OT4AA    LAC       ELEM,1
         NZT       SW2
         TRA       OT3
         CAL       SYMR,1
         ARS       30
OT4B     PUTM      OTBUF,ONETWE,=1,J
         CLA       J
         SUB       JMAX
         ADD       =1
         TZE       OT5
         ADST      J,J,=1
         TRA       OT4A
OT5      CAL       =6B17             FEED LINE TO PRINTER,
         CALL      (STH)             NO PRINTER ADVANCE
```

```
        PZE     FMT3,0,1
OT6     AXT     20,1
OT6A    LDQ     OTBUF+20,1
        STR
        TIX     OT6A,1,1
        CALL    (FIL)
        TRA     OT2
OT7     CLA     J
        SUB     JMAX
        ADD     =1
        TZE     OT8
        ADST    J,J,=1
        TRA     OT4A
OT8     ADST    I,I,=1
        EQUL    J,=2
        TEQL    I,IMAX,OT3A
        TRA     OT4A
*
FMT1    BCI     1,(1H1)
FMT2    BCI     2,(1H9,20A6)        ADVANCE PRINTER AFTER PRINT
FMT3    BCI     2,(1H+,20A6)
FMT4    BCI     4,(6A6//(1I12,1I9,1I8))
FMT5    BCI     7,(//(10X,1I10,2X,16H BROKEN ELEMENTS))
FMT6    BCI     7,(//(10X,1I10,2X,20H ELEMENTS IN PICTURE))
FMT7    BCI     7,(//(10X,1I10,2X,15H PERCENT BROKEN))
FMT8    BCI     7,(3A6//11A6//(1I16,1I13,6X,1A6,9X,1A6))
FMT9    BCI     3,(//(/4A6,1I7))
HEAD    BCI     6,1           BP       FREQ      PCT
HEAD2   BCI     3,1  FREQUENCY TABLE
HEAD3   BCI     8,          BRIGHTNESS  FREQUENCY  ELEMENT SYMBOL
        BCI     3, REGION SYMBOL
HEAD4   BCI     4,  NUMBER OF LEVELS (N) .
        BCI     4,  MEAN BRIGHTNESS  . . .
        BCI     4,  MEDIAN BRIGHTNESS  . .
        BCI     4,  LOWER CUT-OFF  . . . .
        BCI     4,  UPPER CUT-OFF  . . . .
        BCI     4,  SIGMA  . . . . . . . .
*
*               TEMP STORAGE, CTRS, ETC FOR BRAND-2 AND SORD-2
I       DEC     0                   PICT (MEMORY PICTURE) LINE INDEX
I1      DEC     0
IDELI   DEC     0
ILAST   DEC     0              I COORDINATE OF LOWER RH SQUARE IN PICT
IMAX    DEC     0                   LAST LINE OF PICT
J       DEC     0                   PICT COLUMN INDEX
J1      DEC     0
JDELJ   DEC     0
JLAST   DEC     0              J COORDINATE OF LOWER RH SQUARE IN PICT
JMAX    DEC     0                   LAST COLUMN OF PICT
L       DEC     0                   TAPE RECORD INDEX
M       DEC     0                   ELEMENT MARKER
ELEM    DEC     0
ER      DEC     0                   WIDTH OF PICT, IN ELEMENTS
SAVE4   DEC     0
W       DEC     0                   WIDTH OF PICT, IN WORDS
KZ      DEC     0                   FIRST PICT ELEMENT OF INPUT BUFFER
ONETWE  DEC     120
ONE     DEC     1
*               TEMP STORAGE, CONSTNANTS, ETC FOR BRAND-2
V3A     PZE     BR3A                VAR CONNECTOR SETTINGS
```

```
V3B     PZE     BR4
V3C     PZE     BR3C
V4A     PZE     BR4A
V4B     PZE     BR5
V6A     PZE     BR6A
V6B     PZE     BR7
ISWCH   DEC     0
VSWCH   DEC     0
K1      DEC     0
K2      DEC     0
V       DEC     0                       STORED VALUE OF BRKN ELEMENT
ELEM2   DEC     0                       NEIGHBOR ELEMENT
II      DEC     0                       SQ PROCESSING
JJ      DEC     0                       FLAGS
A1      DEC     0                       TEMP STORAGE FOR
A2      DEC     0                       ISOLATED-PT SUBRTN
A       DEC     0                       ADJACENCY CTR
C       DEC     0                       B/W CONTRAST CTR
TOTAL   DEC     0
*
*         BRAND - 3 VARIABLES
TOTAL2  DEC     0
BRITMU  DEC     0
BRITMD  DEC     0
ALPHA   DEC     0
OMEGA   DEC     0
SIGMA   DEC     0
N3      DEC     0
SSQ     DEC     0
SAVE    DEC     0
SAVE2   DEC     0
V40     PZE     IN40
V46B    PZE     IN46B
V46     PZE     IN46
V43     PZE     IN43
V44A    PZE     IN44A
V46A    PZE     IN46A
V46D    PZE     IN46D
V46E    PZE     IN46E
VXX4    PZE     HEAD4+8
VXX5    PZE     BRITMU
*
*               BUFFERS, WORK AREAS
INBUF   BSS     50
OTBUF   BSS     20
BP      BSS     10
BRIT    BSS     64
PICT    BSS     8000
PICT2   BSS     8000
*
SW3     COMMON  1
SW2     COMMON  1
SW1     COMMON  1
DATAS   COMMON  1
N2      COMMON  1
DATATN  COMMON  32
DATAT   COMMON  1
SYMRN   COMMON  32
SYMR    COMMON  1
SYMEN   COMMON  32
```

```
SYME    COMMON  1
BN      COMMON  32
B1      COMMON  1
W2      COMMON  1
W1      COMMON  1
L2      COMMON  1
L1      COMMON  1
WR      COMMON  1
S2      COMMON  1
S       COMMON  1
SUMN    COMMON  32
SUM     COMMON  1
TN      COMMON  32
        END
```

PART V

SB-3 Applications: Delineation and Analysis of Multi-Brightness-Level Meteorological Pictures

ABSTRACT

This Part describes the application of program SB-3 to TIROS VI pictures illustrating the same pattern types as analyzed by Program SB-2. Using fixed values for other parameters derived from SB-2 analyses, the effects of varying the number of brightness levels and SORD square size are examined, and optimum values selected for pattern processing. The relationship is investigated between the brokenness statistic and meteorological phenomena exhibited in the pictures. Comparisons of program SB-3 and SB-2 analyses are made where appropriate.

5.1 Introduction

In Part III, optimum parameter values were determined for the application of program SB-2 to meteorological picture processing. In Part V there are employed in the analogous application of program SB-3. A new and probably most important parameter must also be considered for SB-3: the number of brightness levels (N) into which to subdivide the picture prior to processing. Also, it is intuitively conjectured that the SORD scanning square size (S) may have a different optimum value for SB-3 than for SB-2. The conjecture is that with a greater number of brightness levels, a given square size will probably result, for SB-3 as compared with SB-2, in the classification of a relatively greater proportion of the picture as "broken." For in order to be classified as "solid" at a given level the brightness value must lie within a range of values which becomes smaller in proportion to the overall range of values as N increases. Therefore the probability of classifying an element as broken increases as N increases. Hence to achieve SB-3 results comparable to those achieved for SB-2--yielding significant solid as well as broken regions--the scanning square size should be smaller.

It will be seen that the investigation to be described in the next section, which selects preferred values for S and N, supports this conjecture. In Section 5.3 the pattern types analyzed by program SB-2 are analyzed by program SB-3. In Section 5.2 the relationship of the percent of picture area classified "broken" to variation in the parameters S and N is examined. In Section 5.3 its relationship and the relationship of the brokenness statistic itself to meteorological pattern variation are examined.

5.2 Investigation of SORD Scanning Square Size and the Number of Brightness Levels

The object of this investigation is to determine the combination of SORD square size (S) and number of levels (N) which most satisfactorily subdivides a picture into solid and broken areas. Two extremes are to be avoided: One, using too small a value for S and too large a value for N, results in the annotation of too much picture detail. The result is a printout of many small regions which (though perhaps reflecting fine structural details of the picture) does not sufficiently reduce for subsequent analysis the complexities of the original picture. The other extreme is the use of too large a square size and too few brightness levels: the result, in the extreme, is that 100% of the picture area is classified as broken.

For the present investigation N and S were varied simultaneously for a single picture (P4, depicting a vortex), N taking the values 2, 3, 4, and 5 and S taking the values 5, 8, and 10. The twelve pictorial outputs representing all paired combinations of these parameters are shown in Figure 5-1. The three outputs with N=2 were produced by program SB-2 (rather than SB-3) and are included for comparative purposes. (The format and interpretation of SB-3 printouts is described in detail in Section 4.4.) Other parameters fixed for these outputs were a noise ratio of 8/100 and a BRAND scanning square size (S2) of 3. Threshold values for the SB-3 outputs were derived by the computer (Secs. 4.4, 4.5); the values actually assigned, along with the computed "cutoff range" (Sec. 4.5) of the brightness distribution, are as follows:

Figure 5-1

SB-3 Pictorial Output for Variation

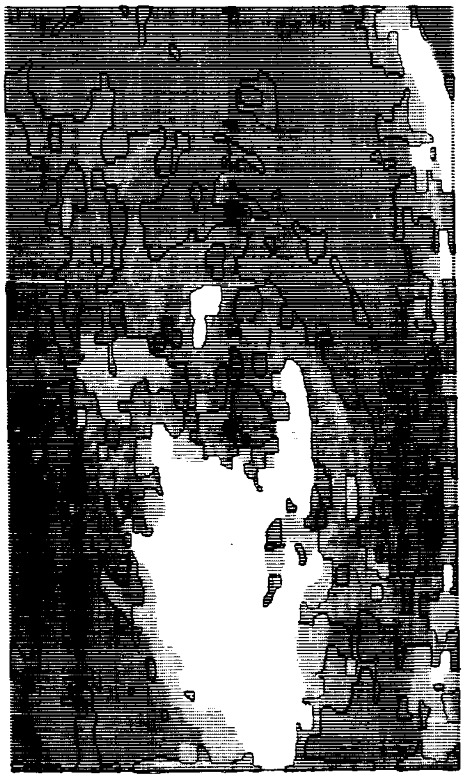
in SORD Square Size and Number of Brightness Levels

Square Size (S)=5

N=2

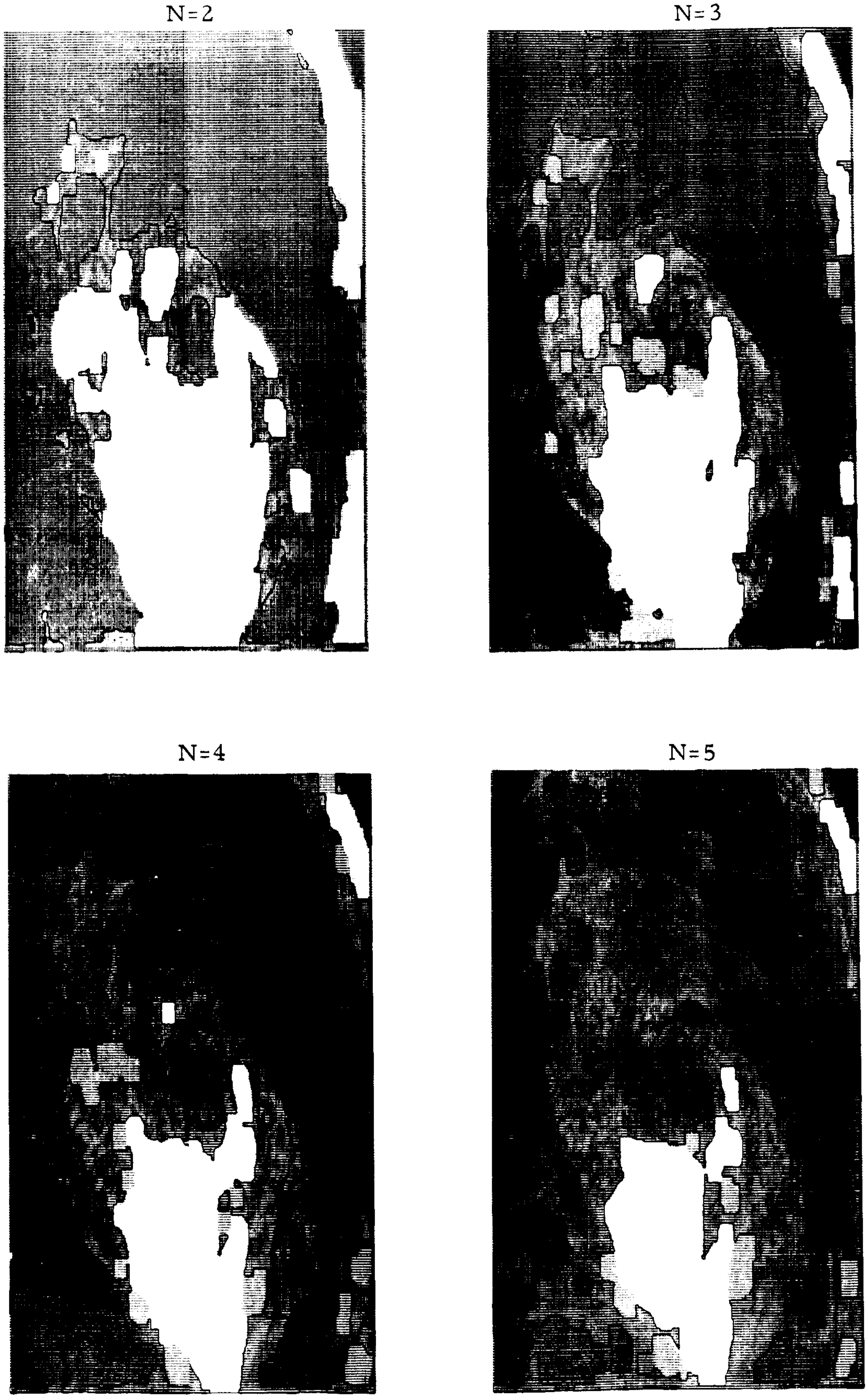
N=3

N=4



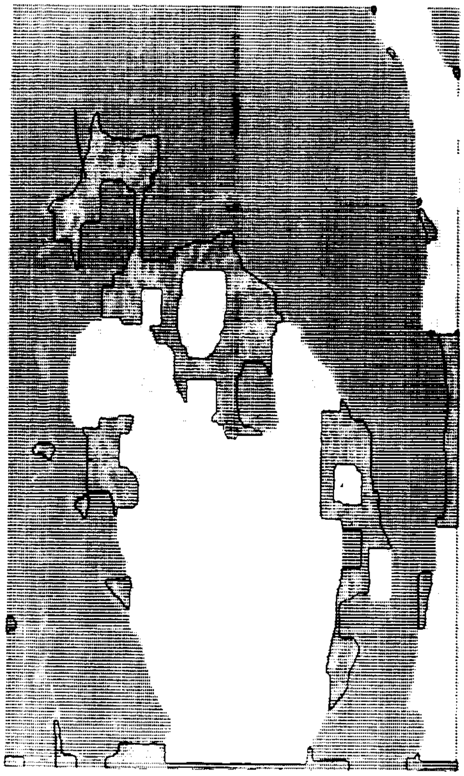
N=5

Square Size (S)=8



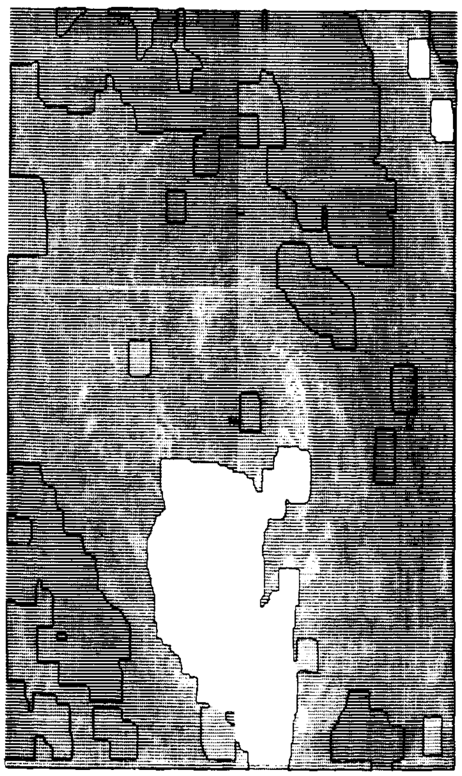
Square Size (S)=10

N=2

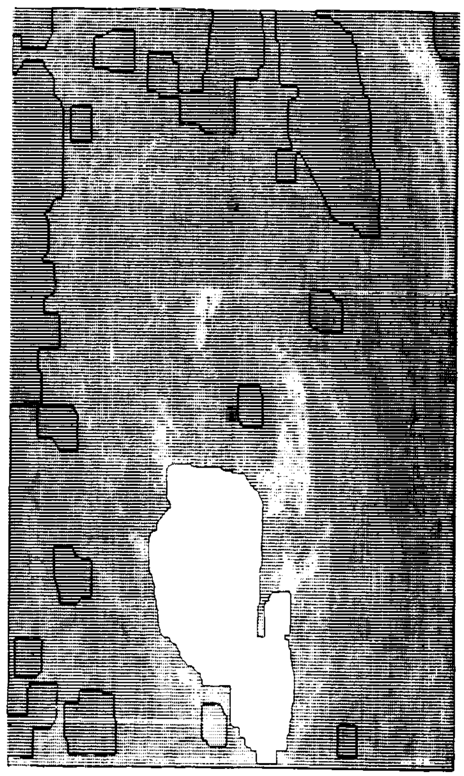


N=3

N=4



N=5



Number of Brightness Levels (N)	Cutoff Range Min. -Max.	Computed Thresholds
3	15-40	24, 33
4	14-40	21, 28, 35
5	13-40	19, 25, 31, 36

For the SB-2 outputs, the cloud/noncloud threshold was set at 24.

Considering first the level S=5, the general effect of increasing the number of brightness levels is to subdivide an increasing proportion of the picture into small regions. At N-values of 3 and 4 long thin areas appear representing minor structural elements of the vortex, but at the expense of the additional subdivision. For all values of N on this level, the picture appears too detailed and hence difficult to interpret.

At the next level, S=8, the number of delineated regions decreases markedly while region size shows a corresponding increase. For N=3 the picture is adequately subdivided into a large "solid black" region surrounding the vortical area which consists of a broken area interspersed with a few "solid gray" regions. Below this appears the "solid white" center of the vortex. At this square size level, N=3 is to be preferred, for at N=4 and N=5 the number of regions has increased to the point of excessive detail.

At level S=10, a simply subdivided picture is produced for all values of N. But at N=4 and N=5 the proportion of broken area has increased to the extent of eliminating too much of the "solid black" area surrounding the vortex. At N=3, however, this is very adequately represented, along with a single connected broken area surrounding the "solid white" vortical area, and fewer isolated patches of "solid gray" than evidenced in the picture with parameter combination S=8 and N=3.

The preferred parameter values are therefore N=3 and S=10. The first choice may seem surprising in view of the SB-3 program capability of processing as many as fifteen brightness levels, but it is dictated by the criterion of avoiding excessive detail in picture subdivision. The choice of N=3 represents a substantial improvement over N=2 as processed by program SB-2.

The effect of variations in S and N on the percent of picture area classified as broken is interesting to note:

SORD Scanning Square Size (S)	Percent of Picture Classified Broken for Levels of N			
	2	3	4	5
5	7	16	30	38
8	11	24	42	53
10	12	38	63	76

It is evident that an increase in either variable tends to increase the overall percent broken; furthermore the relative increase itself increases as either variable increases independently of the other.

As conjectured above, this is to be expected on consideration of the logical operation of programs SB-2 and SB-3 (Parts II, IV).

5.3 Investigation of Meteorological Pattern Variation

In the preceding section it was determined that the vortex picture P4 is best output by SB-3 at three brightness levels and with a SORD scanning square size of 10. In this section these parameter values are fixed as input for SB-3 processing of a sample of nine pictures representative of the three pattern types (vortex, band structure, cell structure) analyzed by program SB-2. As before, pattern types are represented in three groups of three pictures each, as follows:

Pattern Type	Representative Pictures
Vortex	P4, P51, P26
Band Structure	P8, P12, P41
Cell Structure	P2, P10, P49

SB-3 output for these pictures is shown in Figure 5-2.

The other input parameters are fixed at the values used in the preceding section: a BRAND scanning square size (S2) of 3 and a noise ratio of 8/100 for all solid-region levels. Threshold (T) and distribution cutoff values were determined by the computer with the following results:

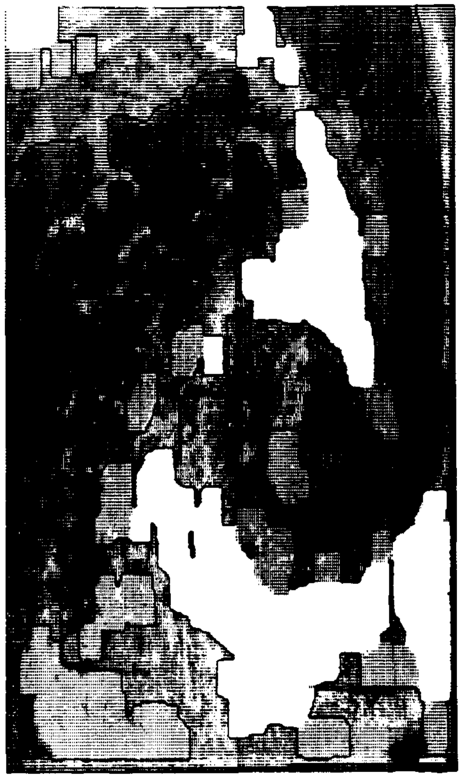
Pattern Group	Picture	Distribution Cutoff Range	Computed Threshold Separating Solid-Region Levels Black/Gray	Gray/White
Vortex	P4	15-40	24	32
	P51	15-38	23	31
	P26	14-37	22	30
Bands	P8	14-40	23	32
	P12	15-42	25	34
	P41	15-42	25	34
Cells	P2	14-33	21	28
	P10	14-35	22	29
	P49	16-45	26	36

Threshold values are somewhat higher and the range somewhat larger for the band-structure group than for the vortex group. The first

Figure 5-2

SB-3 Pictorial Output for Meteorological Pattern Variation

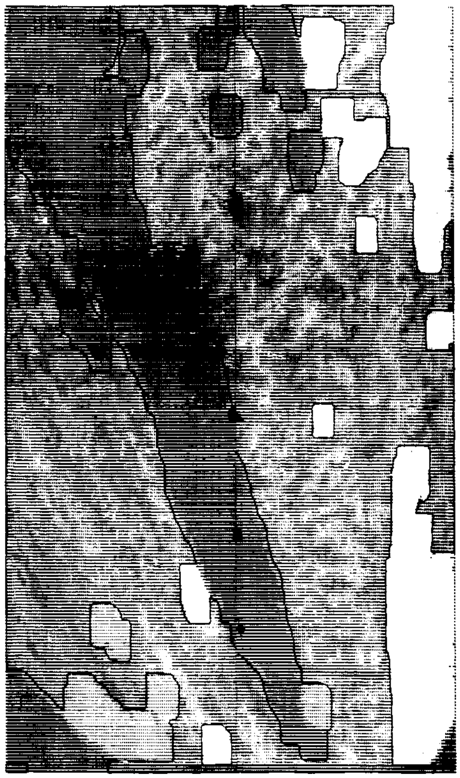
P4



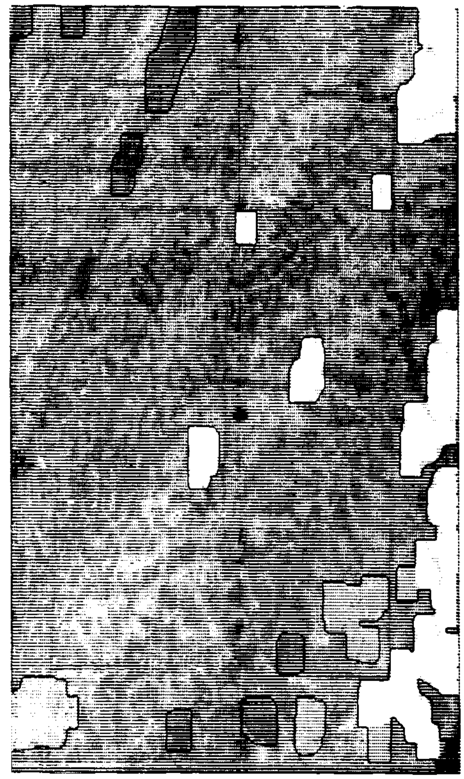
P51

P26

Band Structure



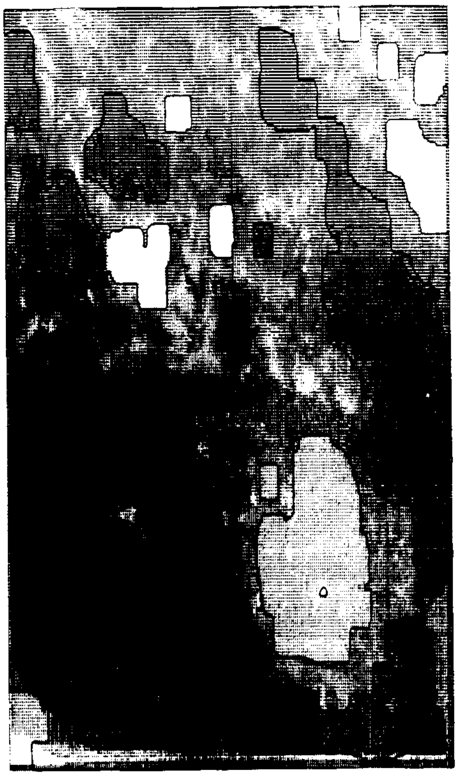
P8



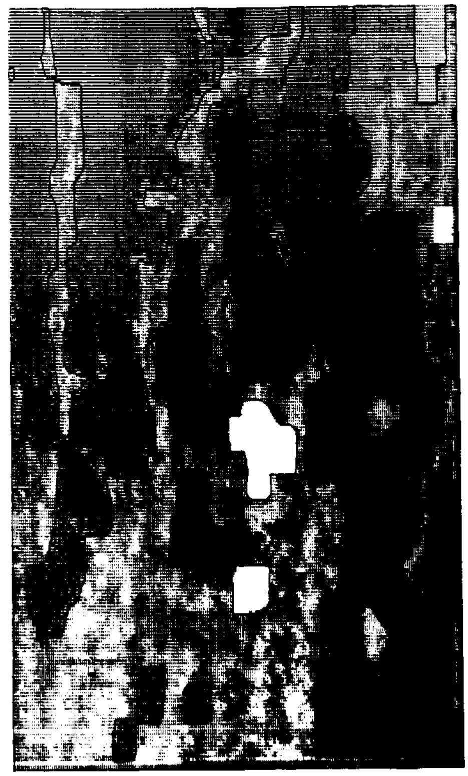
P12

P41

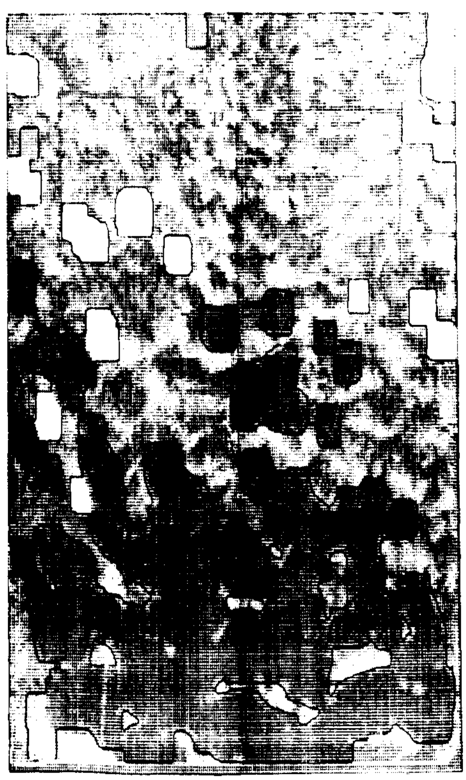
Figure 5-2/Page 2



P2



P10



P49

two pictures of the cell-structure group have lower threshold values and a smaller range than the average of either of the first two groups; however, P49 of the cell structure group has a higher set of threshold values and a larger range than any other picture in the group. Therefore it must be concluded that this sample provides insufficient evidence concerning the relationship between assigned threshold value and pattern type, if any.

Of the vortex group, SB-3 output for P4 at the present set of parameter values was examined in the preceding section, and found to represent a very adequate subdivision of the picture into broken and solid areas. The output for P51 is somewhat more detailed, but examination of the original photograph (Figure 3-1) justifies this result. The darkest areas of the photograph appear as a large solid-black region in the upper right portion and a set of smaller solid-black regions in the upper left portion of the SB-3 output. The vortical spiral and terminating "spur" appear in the output as two solid-white regions flanking a broken region perforated with smaller solid black and solid gray regions. The lower left portion is adequately represented by a large solid gray region. In the SB-3 output of P26 the extremity of the "hook" curving down from the left corner is more pronounced than in the photograph, being represented by a large broken region surrounding a solid gray region. The region of small cells in the left corner appears in the SB-3 output as a large broken region. Picture subdivision is accomplished with relatively few regions.

Of the band-structure group, P8 and P41 are represented principally by large solid black and broken regions (interspersed with smaller solid white regions) whose shapes bring out the parallel band structure quite adequately. In P12, however, most of the band structure is classified broken. Closer examination of the bands reveals that in fact they are made up of small cells. The program classified these, as well as their relatively lighter (but not solid) background, as broken, resulting in a few solid white and solid gray smaller regions appearing on a large broken background. This suggests that a further subdivision within the "broken" category might prove useful in some instances to distinguish relatively dark broken regions (the cellular bands in this case) from relatively light broken regions (the background).

Considering finally the cell-structure group, we see that the results for P2 appear only at first glance to be inconsistent with the photograph. Closer examination shows that the cell areas of the photograph have been linked together in a single connected broken region, flanked by two large solid black regions corresponding to the darkest areas of the photograph. The contrast between a large solid gray region and the large broken region enclosing it appears weaker in the photograph than in the SB-3 output, but clearly discernible nonetheless. The trivial detail of the few very small cells appearing in this area is omitted in the SB-3 output. In P10 a similar treatment is observed: a single large connected broken region represents the large cells of the photograph, confirming the not immediately evident fact that these cells are actually connected in the photograph as well. The remainder of the SB-3 output appears as large connected solid black regions save for a few isolated regions of solid gray and solid black. The shapes of the regions correspond closely to the broad shape outlines of the photograph. The remaining picture, P49, is represented by SB-3 as solid black connected regions and some isolated solid white regions on a broken background. Logically (though not necessarily psychologically) speaking, it is also true of the photograph that the lighter (cloud) area, being more connected and somewhat greater in area, forms the background for the darker (noncloud) areas.

Considering now the application of program SB-3 to the distinguishing or identification of meteorological patterns, the same general observations apply here as for program SB-2. Patterns show up as lines between texturally distinct regions or as shapes of regions on a texturally distinct background, and hence tools should next be developed for analyzing these simple geometric configurations. Comparison of SB-2 and SB-3 output for the sample picture set indicates that SB-3 is capable of eliciting more subtle elements of pattern structure in truer conformity to the photograph, but possibly at the expense of a more complex presentation of this structure than might be required for the initial task of determining whether a picture does in fact contain an interesting pattern. It is recommended that further investigation be conducted to examine relative capabilities of SB-3 and SB-2 for this task, with the objective of its accomplishment by the simplest possible means.

Consistent with previous analyses, the relationship between pattern type and the percentage distribution of the brokenness statistic was investigated. The results are shown in graphic form in Figure 5-3. There appears a noticeable difference in the form of the distribution for the vortex group as distinguished from the other two groups. The vortex group distributions all have a single mode with a monotonically decreasing falloff to the tails on either side. All distributions in the cell structure group and two out of three in the band structure group are bimodal. The third distribution in the latter group is unimodal but there is not a monotonically decreasing

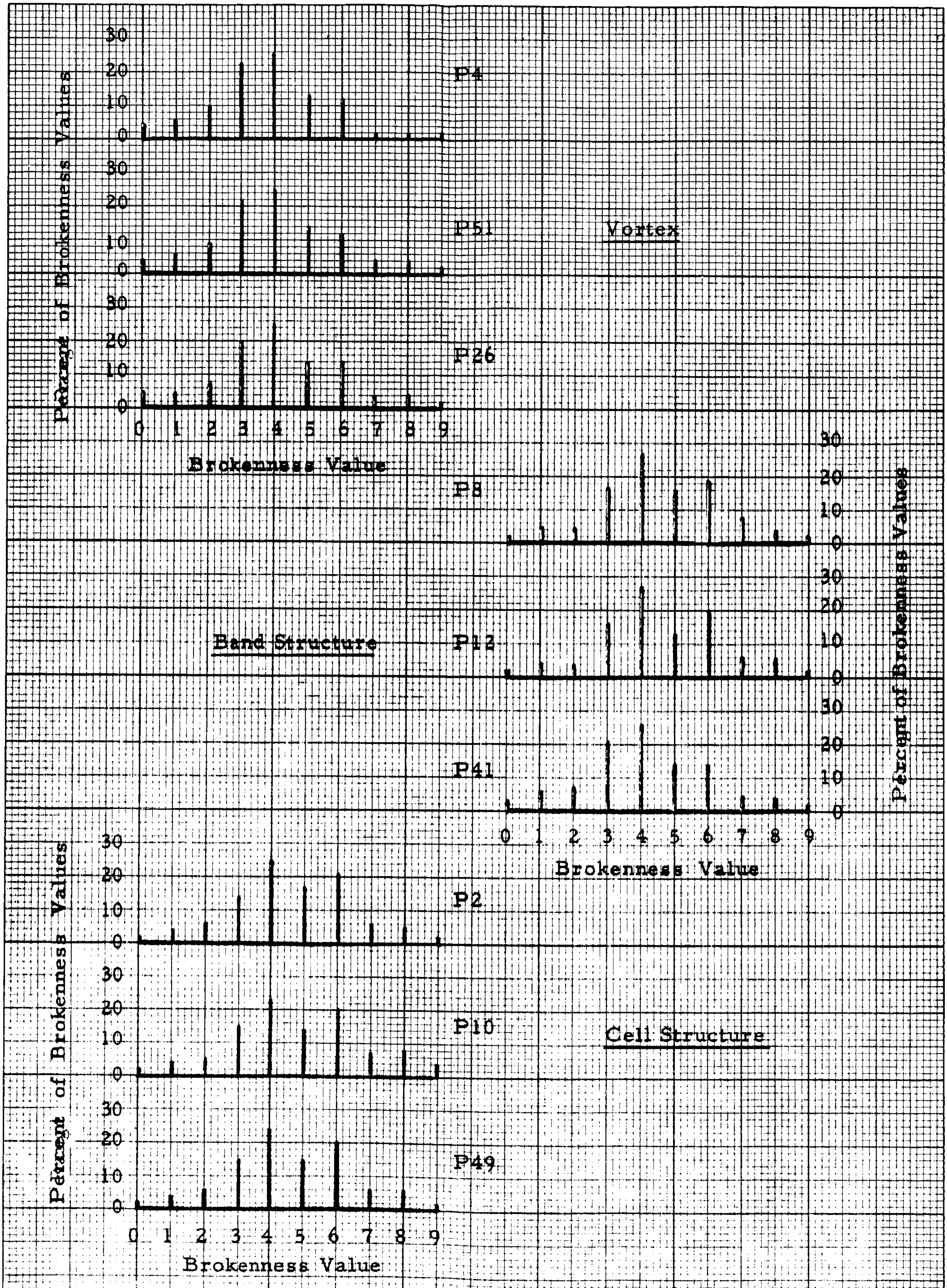


Figure 5-3
Relationship Between Meteorological Pattern Type and SB-3 Brokenness Distribution

falloff to the right of the mode (the percentages for brokenness values 5 and 6 are equal). This is the first indication of a basic structural difference in the brokenness distribution for differing pattern types. If further sampling confirms this result, testing for the number of modes in the distribution could serve as a means of distinguishing a vortex from the other two patterns (the distributions for the latter, however, are not significantly different in structure). Furthermore, the physical basis for the observation might be discoverable by a component analysis of cell structure and band structure patterns. As a result of further analysis it might be concluded that the two modal values (observed as 4 and 6 in Figure 5-3) tend to be concentrated at particular areas within the pattern structure; discovery of such concentrations might then serve as a means of identifying the pattern.

Within each group the distributions are remarkably similar. All nine distributions have a maximum mode of 4, and in all distributions frequencies of at least one percent were recorded for all ten brokenness values. The analogous analysis for SB-2 yielded nonzero percentages for the upper three brokenness values of 7, 8, and 9 for all distributions, with no mode exceeding 3. This is undoubtedly due to the necessity of taking into account for SB-3 the relative contrast between adjacent elements depending upon by how many brightness levels they differ; one would expect higher brokenness values on the average, even allowing for the slight change in definition of "brokenness value" necessary for SB-3. No other significant differences between the distributions for different pattern type groups appear to be displayed by the graphs.

The following percentages of total picture area classified as broken were observed for the nine pictures:

Pattern Type	Percent of Area Classified Broken for Picture 1	2	3	Mean %
Vortex	38	47	29	38
Cell Structure	59	85	47	64
Band Structure	43	43	60	49

The mean values indicate that in terms of relative brokenness of pattern type the rank ordering is cells, bands and vortices.[1] One would certainly expect cells to rank highest, but one might also expect, prior to experience, to find the order of bands and vortices reversed. However even within the cell structure group one notes a wide range of values (47 to 85), possibly explainable by further investigation of structural variations within each pattern type.

1. This assumes that the patterns appear in the pictures all at the same scale. In all cases almost the entire picture area is occupied by the pattern.

PART VI

PAX: A Computer Program for Extracting Pattern Structures from Meteorological Pictures

ABSTRACT

A computer program is described which locates and delineates linear pattern structures present in digital two-brightness-level meteorological pictures. The program produces a printout of the annotated picture plus a frequency distribution of brokenness values (ref. Part II) over the picture. The primary purpose of the program is to transform a raw digital picture into a form which can be input to a future pattern recognition process.

6.1 Introduction and General Description

Program SB-2 (ref. Part II) was designed to subdivide a digital picture into solid and broken areas; the resulting solid areas have an approximately uniform brightness in comparison with the broken areas which typically contain highly interspersed cloud and noncloud picture elements. This program further analyzes the broken regions, computing for each element a brokenness value based on the extent that the element contrasts with its immediate neighbors.

Consider now the problem of delineating--or "extracting" a line pattern from a digital picture. The lines of a pattern may be seen in a photograph as (1) the edge between two texturally different regions or (2) a line of one texture distinguished from a background of another texture. Within a neighborhood of this edge or line, the brokenness values are likely to be at a local maximum. For since in either case the neighborhood includes a transition area from one texture to another (solid cloud to solid noncloud, solid cloud to broken, or solid noncloud to broken), within it there will be a relatively high concentration of contrasting elements. If we now compute brokenness values over the whole picture (instead of only within broken regions as for SB-2) and mark (overprint) those elements which equal or exceed a specified threshold value, we have a means of delineating these local maxima. The result is an extraction of the line pattern.

An edge between two solid regions, or a solid line on a solid background, will evidently be extracted by employing this technique. Those parts of broken regions with a high degree of brokenness will be extracted as areas. For a broken region in general the extraction will include the boundary between it and the adjacent solid region(s), since the brokenness values along the region boundary tend to a maximum in transition from one region to another. The extraction of a broken region will thus include its boundary plus none, part, or possibly all of its interior.

The PAX program is an adaption of SB-2 to perform pattern extraction as just described. The critical input parameters are the cloud/noncloud threshold (T), the brokenness value threshold (T2) and the brokenness value square size (S2).[1] The format of the picture on magnetic tape and its input to computer memory is the same for PAX as for SB-2. Here however SORD processing is omitted, and the brokenness value (ref. Part II) computed for every element of the picture based on parameters T2 and S2. The program then outputs the digital picture based on the threshold T, with an overprint of the PAX-extracted elements. It then outputs a frequency distribution of the brokenness values computed over the whole picture.

---

1. This is conceptually the same as the BRAND scanning square size used in the SB-2 program.

The PAX program provides a new and interesting application of the brokenness statistic. In program SB-2 it serves as a tool of analysis of broken regions; in the PAX program, as a means of transforming a digital picture into a form which can be input to a future pattern recognition process. For if PAX can single out the pattern that the process is to identify, the complexity of the subsequent task of recognition is reduced by a significant order of magnitude.

6.2 Input

This is exactly the same as for program SB-2 (Sec. 2.2). The same input tapes may be used interchangeably between SB-2 and PAX.

6.3 Operating Parameters

The following parameters are required for operation of the PAX program. Their values are supplied by DEC cards included in the symbolic program deck, as described in Sec. 2.2:

Parameter	Definition	Allowable Range Min.	Allowable Range Max.
T	Cloud/noncloud threshold	0	63
T2	Brokenness value threshold	1	9

Parameter	Definition	Allowable Range Min.	Max.
L1	First line of tape picture	1	Tape limit
L2	Last line of tape picture	1	L1 + 999
W1	First word of tape picture	1	288
W2	Last word of tape picture	1	W1 + 19
S2	Scanning square side length for brokenness value computation (ref. note 1)	1	30
WR	Words per line of tape picture	1	288

The brokenness value threshold (T2) is used to classify picture elements as either belonging or not belonging to the PAX-extracted pattern, depending upon whether the computed brokenness value (of range 0 through 9) equals or exceeds T2, or is less than T2, respectively.

Other parameter definitions are the same as given for program SB-2 (Sec. 2.2). It is noted that in comparison with program SB-2, the PAX program dispenses with three SB-2 parameters: The SORD scanning square size (S) and the "noise" ratio parameters (BB and BW).

6.4 Sample Output

A sample picture annotated by PAX is presented in Figure 6-1. The sample pictorial output is from P51, depicting a vortex. The vortical structure is clearly expressed in the outlined solid cloud

Figure 6-1

Sample Picture Annotated by PAX Program

extending in the shape of a hook from the upper right corner downward and to the left; by the outlined noncloud shape extending in a spiral clockwise upward from the lower right corner; and by the noncloud shape curving upward and to the left from the center of the vortex. The basic parameters input for the production of Figure 6-1 were T=24, T2=3, and S2=2.

The PAX overprint depicting the pattern structure consists of the characters "$" and "/". The former, which occurs with much greater frequency, depicts all picture elements having a brokenness value of T2 (equal to 3 in the sample output) or greater; the latter depicts all elements having a brokenness value of one less than the threshold T2 (equal to 2 in the sample output). The output thus in effect displays the PAX overprint for two successive threshold values (hence the restriction that T2 have a minimum value of 1).

A tabular output of the brokenness value frequencies for Figure 6-1 is shown in Figure 6-2. For each brokenness value the table lists (1) its frequency and (2) the percent of total picture area labeled with the given value.

6.5 Logical Description

The logical operation of PAX has been briefly outlined in Sec. 6.1. It may be considered as the following adaptation of program

BROKENNESS VALUE	FREQUENCY	PERCENT
0	33006	58
1	2755	5
2	5431	10
3	7493	13
4	0	0
5	5021	9
6	2047	4
7	579	1
8	72	0
9	0	0

Figure 6-2

Output of Brokenness Value Frequencies for Figure 6-1

SB-2 (ref. Part II). If the "noise parameters" BB and BW are set so that all picture elements will be classified as broken,[2] then following execution of SORD the BRAND process of computing brokenness values will be performed over the whole picture. Now modify the output program so that PAX overprinting is substituted for SORD and BRAND overprinting; i.e., so that all elements whose brokenness value equals or exceeds the brokenness threshold T2 are overprinted with the character "$", those whose value is equal to one less than this threshold are overprinted with the character "/", and all other elements are not overprinted. Also modify the brokenness value frequency output to omit output of the information following the frequency table (ref. Figure 2-2). As a result SB-2 is transformed into PAX.

In actuality, program SB-2 was substantially rewritten to produce a more efficient version of PAX. SORD processing is omitted entirely. After input of the picture from magnetic tape the program performs BRAND processing (ref. Sec. 2.5) over the whole picture (omitting "isolated point" processing, which is not necessary since all elements are classified broken) and proceeds directly to the output program, modified as described above.

---

2. E.g., by inputting SORD scanning square size S=1, and noise parameters BB=1, BW=2.

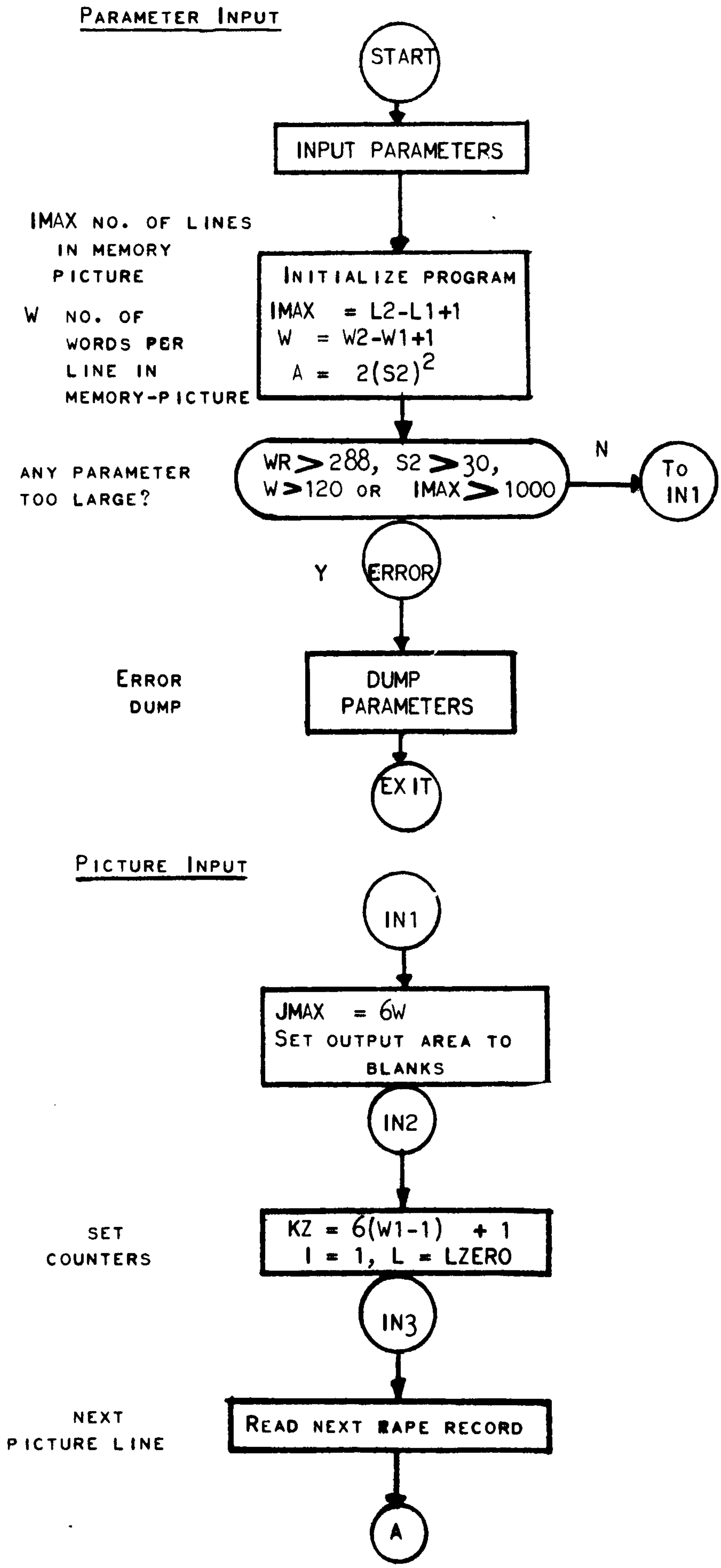
To accomplish this, one modification was made in the format of picture elements initially stored in memory. On input a noncloud picture element is assigned the value 16 and a cloud element the value 0. This avoids having to assign a bit to identify an element as broken (since all are broken) and provides the four rightmost bit positions of the six-bit picture element for storage of the brokenness value. That is, the following values can be assigned on input:

Element	Value Assigned by PAX	Bit Pattern
Cloud	0	000000
Noncloud	16	010000

In all other respects logical operation of PAX is the same as for SB-2 (ref. Sec. 2.5). The logical flow chart of PAX is presented as Figure 6-3. The IBM 7094 symbolic program listing for PAX is presented as Figure 6-4.

Figure 6-3

PAX Flow Chart



TAPES

INPUT TAPE: PICTURE TAPE

PARAMETERS

T	CLOUD/NONCLOUD THRESHOLD
T2	BROKENNESS-VALUE THRESHOLD
L1	FIRST LINE OF TAPE-PICTURE
L2	LAST LINE OF TAPE-PICTURE
W1	FIRST WORD OF TAPE-PICTURE
W2	LAST WORD OF TAPE-PICTURE
W_R	WORDS PER LINE OF TAPE-PICTURE
S2	SCANNING SQUARE SIZE FOR BRAND PROCESSING
A	NUMBER OF ADJACENCIES FOR S2xS2 SQUARE

JMAX	NO. OF ELEMENTS PER LINE IN MEMORY PICTURE
KZ	NO. OF FIRST ELEMENT OF TAPE-PICTURE
I	MEMORY-PICTURE LINE COUNTER
L	TAPE-PICTURE LINE COUNTER
LZERO	MASTER TAPE LINE COUNTER

FIGURE 6-3/ PAGE 1

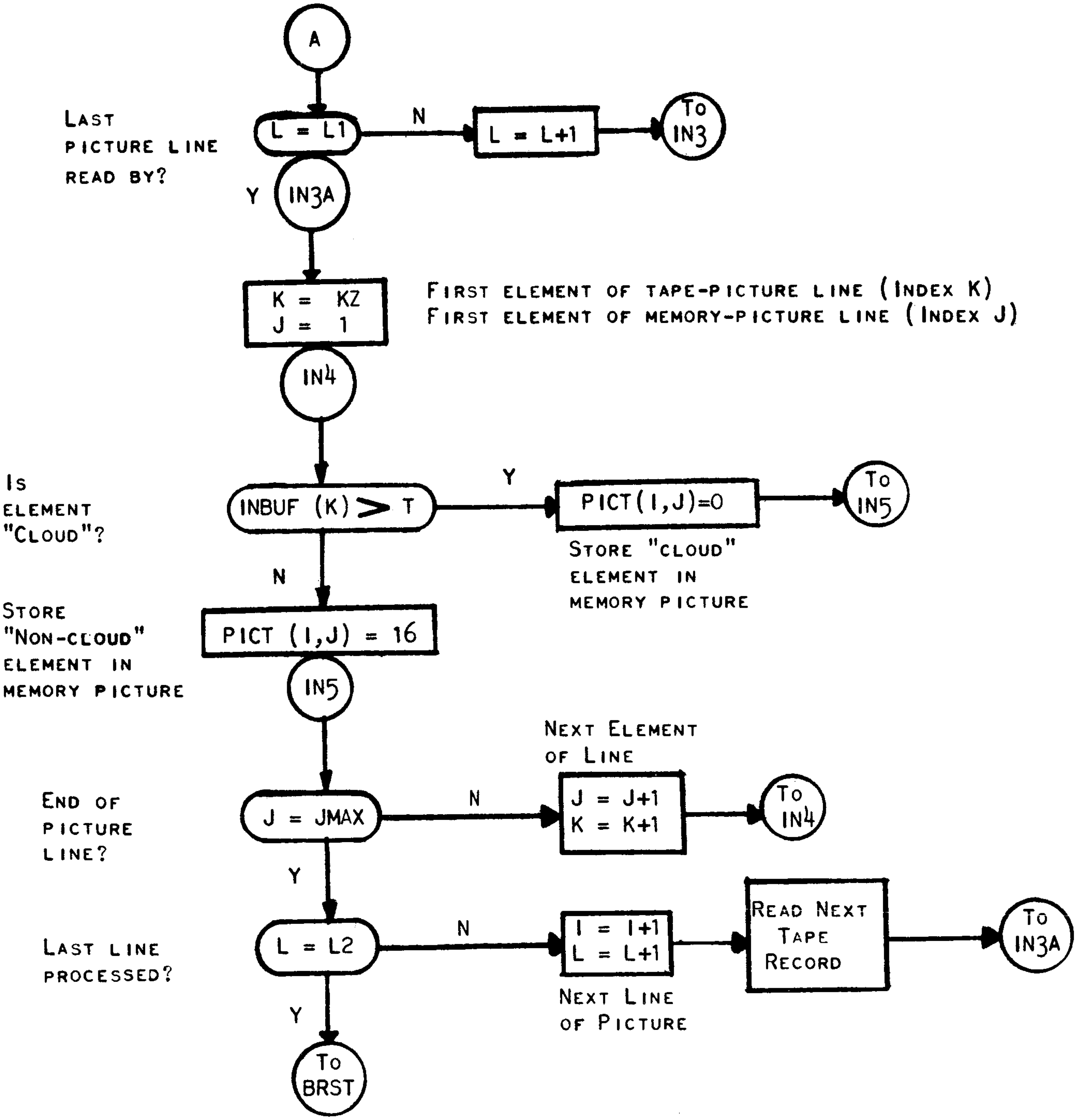
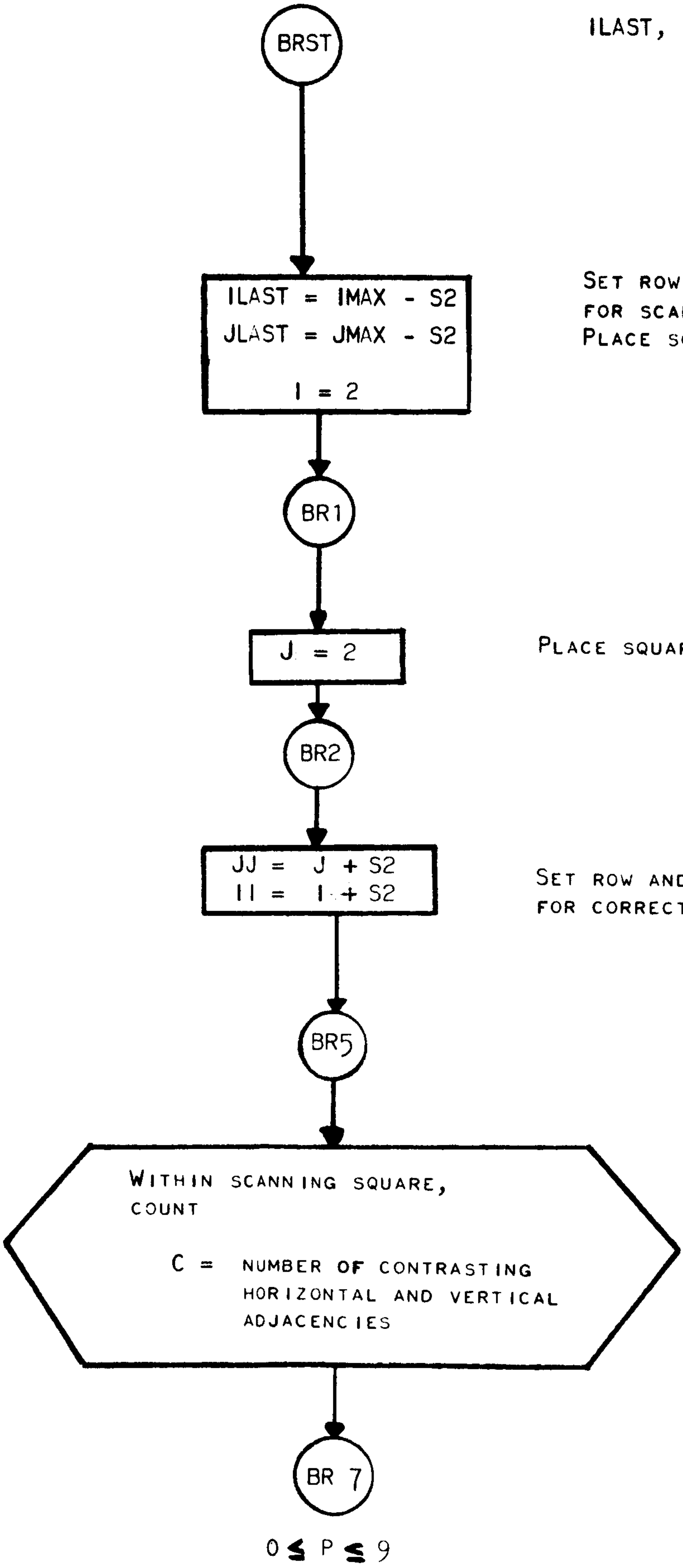


FIGURE 6-3/PAGE 2



ILAST, JLAST — COORDINATES OF UPPER LEFT CORNER OF SCANNING SQUARE IN LAST POSITION (LOWER RIGHT CORNER OF PICTURE)

SET ROW AND COLUMN INDEX FLAGS FOR SCANNING SQUARE OVER WHOLE PICTURE. PLACE SCANNING SQUARE AT TOP OF PICTURE

PLACE SQUARE AT LEFT BORDER OF PICTURE

SET ROW AND COLUMN INDEX FLAGS II, JJ FOR CORRECT SQUARE POSITION

NOTE: DETAIL OF FLOW FROM BR5 TO BR7 FOLLOWS MAIN FLOW CHART

FIGURE 6-3/PAGE 3

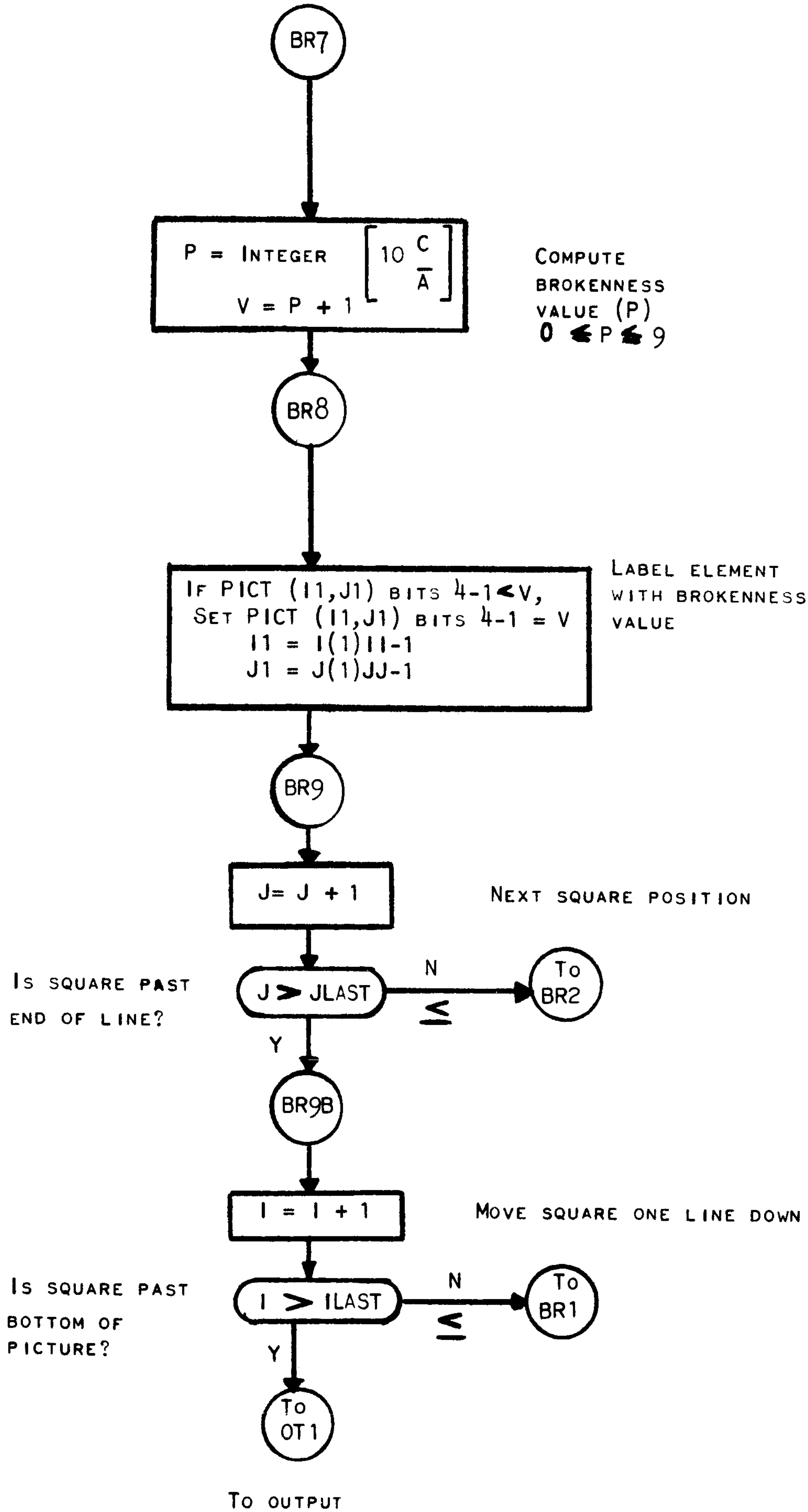


FIGURE 6-3/PAGE 4

OUTPUT

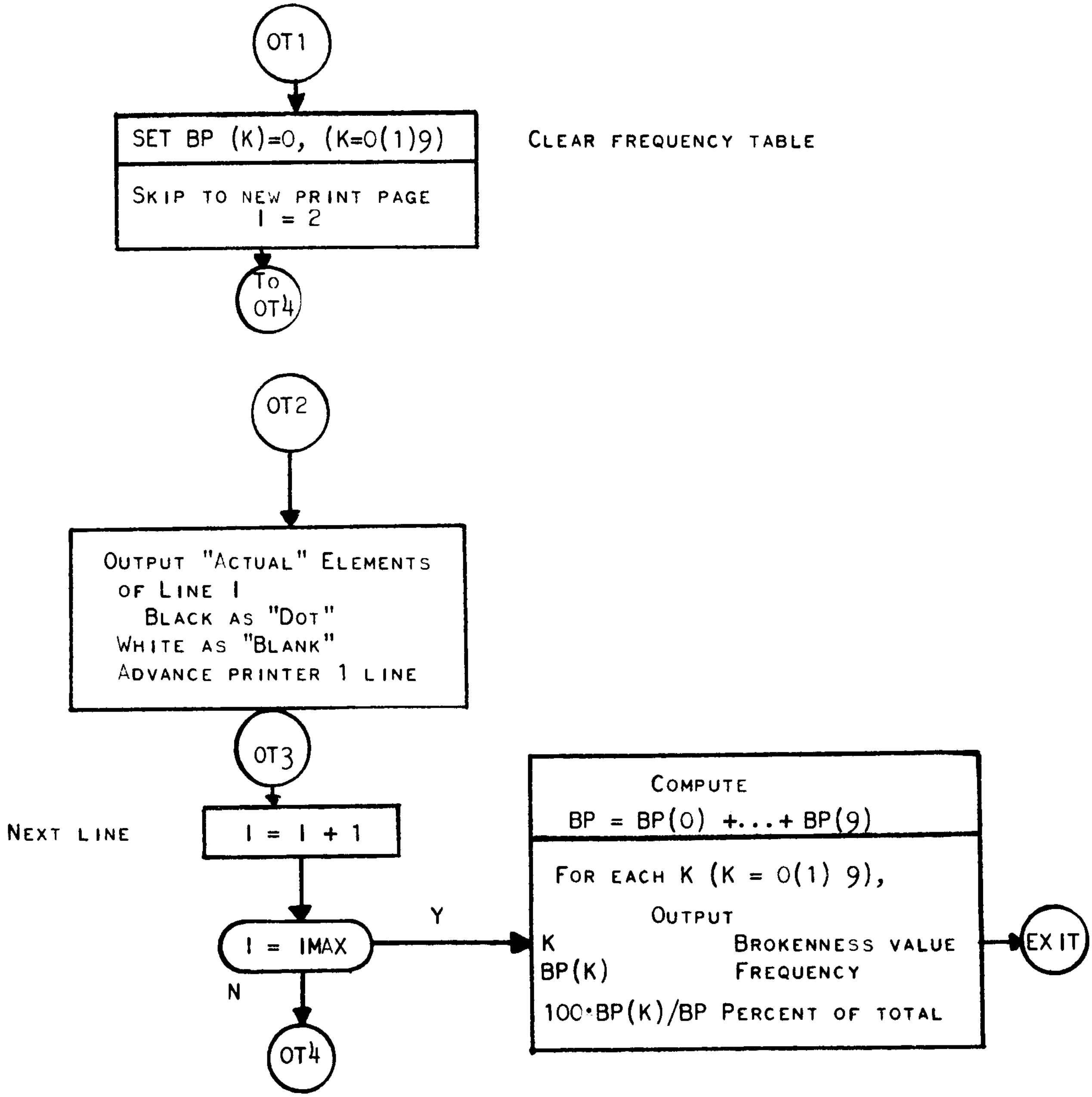
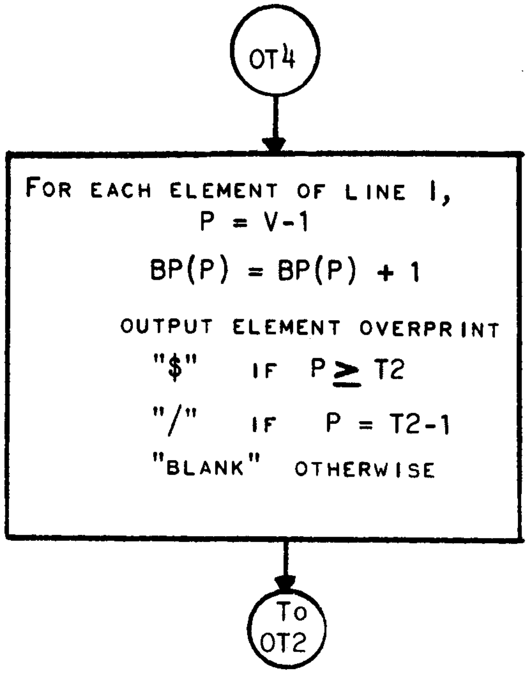


FIGURE 6-3/PAGE 5



V = STORED BROKENNESS VALUE FOR ELEMENT

COMPUTE FREQUENCY OF BROKENNESS VALUES

OUTPUT PAX OVERPRINT

FIGURE 6-3/PAGE 6

Counting of Contrasts (Detail, BR5 to BR7)

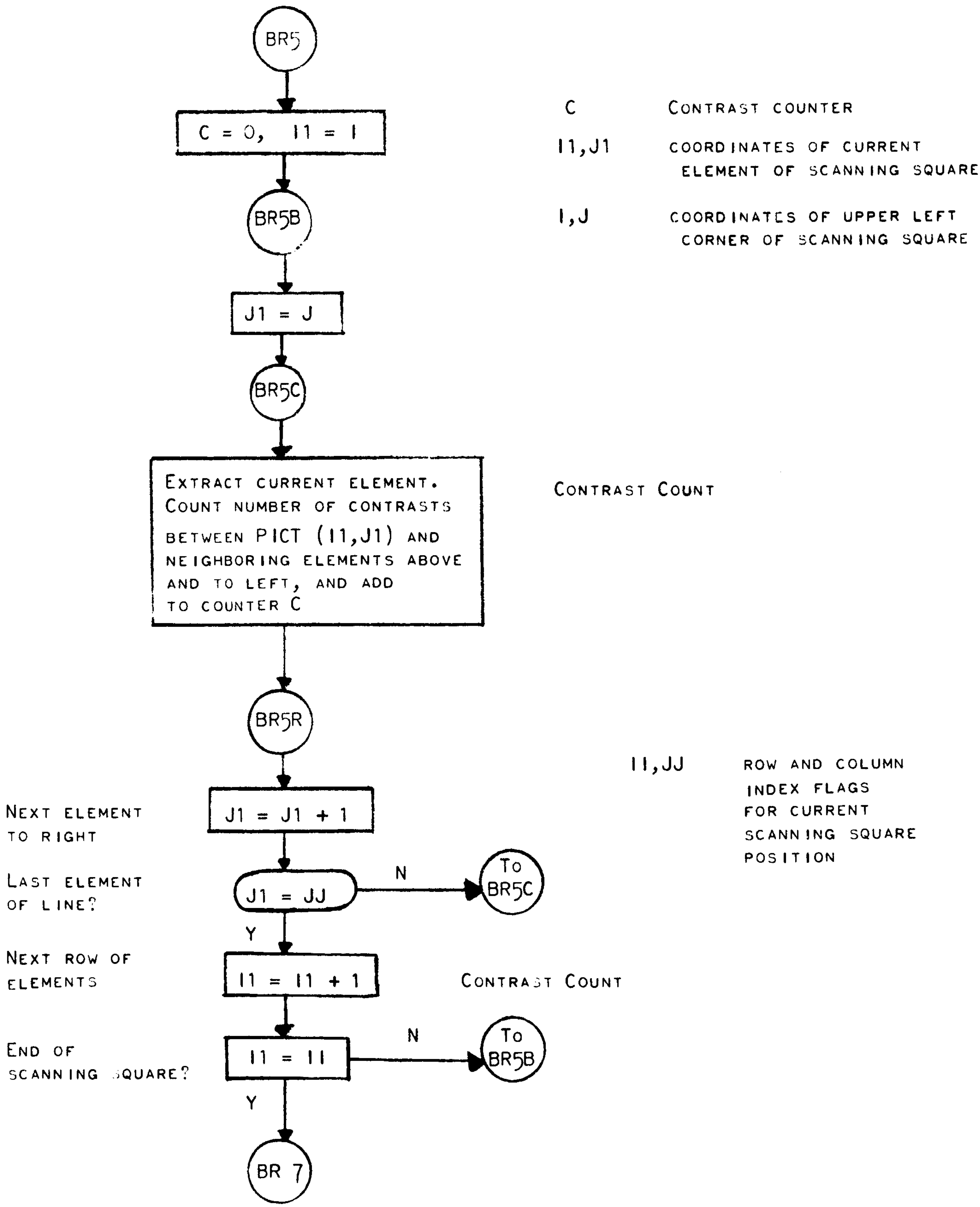


FIGURE 6-3/Page 7

Figure 6-4

PAX Symbolic Program Listing

```
                 PAX      PATTERN EXTRACTOR PROGRAM
                 REQUIRED SUBROUTINES
*                                      BASIC FORTRAN I/O PKG
*                                      PUT
*                                      TAKE
         ENTRY   SABOP2
LZERO    COMMON  1
W2       COMMON  1
W1       COMMON  1
L2       COMMON  1
L1       COMMON  1
         COMMON  2
WR       COMMON  1
T        COMMON  1
S2       COMMON  1
T2       COMMON  1
         EXTERN  PUT2
         EXTERN  TAKE2
*                MACRO INSTRUCTIONS
*                MACROS USED--EQUL,TEQL,ADST,TAKEM,
*                PUTN,TNQL,SBST,SETV
TEQL     MACRO   X,Y,OUT               TEST (X) NOT EQ(Y)
         CLA     X
         SUB     Y
         TZE     OUT
TEQL     END
TNQL     MACRO   X,Y,OUT               TEST (X) NOT EQ(Y)
         CLA     X
         SUB     Y
         TNZ     OUT
TNQL     END
EQUL     MACRO   Y,X                   SET (Y)=(X)
         CLA     X
         STO     Y
EQUL     END
ADST     MACRO   Z,X,Y                 ADD AND STORE
         CLA     X
         ADD     Y
         STO     Z
ADST     END
TAKEM    MACRO   AZERO,C,I,J
         TSX     TAKE2,4
         PZE     AZERO,2
         PZE     C
         PZE     I
         PZE     J
TAKEM    END
PUTM     MACRO   AZERO,C,I,J
         TSX     PUT2,4
         PZE     AZERO,2
         PZE     C
         PZE     I
         PZE     J
PUTM     END
*
SETV     MACRO   A,V                   SET VARIABLE CONNECTOR
         CLA     V
         STA     A
SETV     END
*
```

```
SBST    MACRO   Z,X,Y                 SUBTRACT AND STORE
        CLA     X
        SUB     Y
        STO     Z
SBST    END
*               BEGIN PROGRAM
*               PATTERN EXTRACTION SUBROUTINE
SABOP2  CLA     WR                    SET CONSTANTS,ETC.
        ALS     18
        STD     LIOC
        LDQ     WR
        MPY     =6
        STQ     ER
        SXA     SAVE4,4
        CLA     L2                    TEST PARAMETERS
        SUB     L1
        ADD     =1
        STO     IMAX
        SUB     =1001
        TPL     ERROR                 IF PICTURE TOO LONG
        CLA     W2
        SUB     W1
        ADD     =1
        STO     W
        SUB     =21
        TPL     ERROR                 IF PICTURE TOO WIDE
        CLA     WR
        SUB     =289
        TPL     ERROR                 IF INPUT BUFFER TOO LONG
        LDQ     S2                    COMPUTE NO. OF ADJACENCIES
        MPY     S2                    FOR SCANNING SQUARE
        LLS     1
        STQ     A
        CLA     S2
        SUB     =31
        TMI     IN1                   IF BRAND SQ SIZE NOT TOO LARGE
ERROR   CALL    PDUMP,T2,W2,3         ERROR DUMP OF PARAMETERS
        TRA     1,4
9N1     LDQ     W
        MPY     =6
        STQ     JMAX
        AXT     20,1
        CLA     =0606060606060
        STO     OTBUF+20,1            SET OUTPUT BUFFER TO BLANKS
        TIX     *-1,1,1
9N2     CLA     W1                    COMPUTE FIRST-ELEMENT NR OF INBUF
        SUB     =1
        XCA
        MPY     =6
        XCA
        ADD     =1
        STO     KZ
        EQUL    I,=1
        EQUL    L,LZERO
IN3     CALL    RDSBIN         READ NEXT TAPE RECORD
        TIX     0,0,9
        TIX     LIOC,1,0
        TIX     0,1,0
        TRA     *+2
LIOC    IORT    INBUF,0,**
```

```
        TEQL    L,L1,IN3A              IF FIRST PICT RECORD REACHED
        ADST    L,L,=1
        TRA     IN3
IN3A    EQUL    K,KZ                   INPUT PICTURE FROM TAPE INTO PICT AREA
        EQUL    J,=1
9N4     TAKEM   INBUF,ER,=1,K          TEST ELEMENT AGAINST THRESHOLD
        SUB     T
        SUB     =1
        TPL     IN4A
        CLA     =16                    STORE IN PICT AS BLACK ELEMENT
        TRA     IN4B
IN4A    CLA     =0                     STORE IN PICT AS WHITE ELEMENT
IN4B    PUTM    PICT,JMAX,I,J
9N5     TEQL    J,JMAX,IN5A
        ADST    J,J,=1                 IF END OF LINE
        ADST    K,K,=1
        TRA     IN4
IN5A    TEQL    L,L2,BRST              IF END OF PICT
        ADST    I,I,=1
        ADST    L,L,=1
        CALL    RDSBIN
        TIX     0,0,9
        TIX     LIOC,1,0
        TIX     0,1,0
        TRA     IN3A
*
*               OUTPUT SUBRTN
OT1     CAL     =6B17                  OUTPUT
        CALL    (STH)                  SKIP TO NEW PAGE
        PZE     FMT1,0,-1
        CALL    (FIL)
        AXT     10,4
        STZ     BP+10,4
        TIX     *-1,4,1
        TRA     OT1A
6MT1    BCI     1,(1H1)
OT1A    EQUL    I,=2
        TRA     OT4
OT2     CAL     =6B17                  PRINT LINE OF PICTURE ELEMENTS
        CALL    (STH)
        PZE     FMT2,0,1
        TRA     OT2A
FMT2    BCI     2,(1H9,20A6)           ADVANCE PRINTER AFTER PRINT
OT2A    EQUL    J,=1
OT2B    TAKEM   PICT,JMAX,I,J
        ANA     =020                   ELEMENT BIT
        TZE     OT2BB                  IF WHITE
        CLA     =033                   BLACK ELEMENT SYMBOL=DOT
        TRA     OT2B1
OT2BB   CLA     =060                   WHITE ELEMENT SYMBOL=BLANK
OT2B1   PUTM    OTBUF,ONETWE,=1,J
        TEQL    J,JMAX,OT2C            IF END OF LINE
        ADST    J,J,=1
        TRA     OT2B
OT2C    AXT     20,1                   FEED LINE TO PRINTER
OT2D    LDQ     OTBUF+20,1
        STR
        TIX     OT2D,1,1
```

```
         CALL      (FIL)
OT3      ADST      I,I,=1                 OVERPRINT SYMBOLS FOR
         TNQL      I,IMAX,OT4             BOUNDARY AND BROKEN-REGION POINTS,
         CAL       =6B17
         CALL      (STH)
         PZE       FMT4,0,1
         TRA       *+11
HEAD     BCI       6,1          BP      FREQ      PCT
6MT4     BCI       4,(6A6//(1I12,1I9,1I8))
         AXT       10,1
         CLA       =0
         ADD       BP+10,1
         TIX       *-1,1,1
*
         STO       TOTAL
         AXT       6,1
OT3A     LDQ       HEAD+6,1
         STR
         TIX       OT3A,1,1
         AXT       10,1
OT3B     PXD       0,1
*
         SUB       =10B17
         SSP
         XCA
         STR
         LDQ       BP+10,1
*
         LLS       18
         STR
         LDQ       BP+10,1
         MPY       =100
         DVP       TOTAL
         ALS       1
         SUB       TOTAL
         TMI       *+4
         XCA
         ADD       =1
         XCA
         LLS       18
         STR
         TIX       OT3B,1,1
         CALL      (FIL)
         LXA       SAVE4,4
         TRA       1,4                    EXIT
OT4      CLA       =060                   SET FIRST AND LAST ELEMENTS
         PUTM      OTBUF,ONETWE,=1,ONE        OF LINE TO BLANK
         CLA       =060
         PUTM      OTBUF,ONETWE,=1,JMAX
         EQUL      J,=2
OT4A     TAKEM     PICT,JMAX,I,J
         ANA       =017                   EXTRACT BRKNNESS VALUE BITS
         CAS       =11
         TRA       *+1
         SUB       =1
         SUB       =1
         PAC       0,4
         XCA
```

```
        CLA     BP,4
        ADD     =1
        STO     BP,4
        XCA
        SUB     T2
        TMI     OT4AB
        CLA     =O53                   AT OR ABOVE T2, ELEM SYMB = $
        TRA     OT4B
OT4AB   ADD     =1
        TZE     OT4AC
        CLA     =O60                   BELOW T2-1, ELEM SYMB = BLANK
        TRA     OT4B
OT4AC   CLA     =O61                   AT T2-1, ELEM SYMB = SLASH
        PUTM    OTBUF,ONETWE,=1,J
        CLA     J
        SUB     JMAX
        ADD     =1
        TZE     OT5                    IF END OF LINE
        ADST    J,J,=1
        TRA     OT4A
OT5     CAL     =6B17                  FEED LINE TO PRINTER,
        CALL    (STH)                  NO PRINTER ADVANCE
        PZE     FMT3,0,1
        TRA     OT6
FMT3    BCI     2,(1H+,20A6)
OT6     AXT     20,1
OT6A    LDQ     OTBUF+20,1
        STR
        TIX     OT6A,1,1
        CALL    (FIL)
        TRA     OT2
*
*               TEMP STORAGE, CTRS, ETC
9       DEC     0                      PICT (MEMORY PICTURE) LINE INDEX
91      DEC     0
9DELI   DEC     0
ILAST   DEC     0                      I COORD OF LOWER RH SQUARE IN PICT
*               BROKEN REGION ANALYZER AND DELINEATOR SUBRTN
9MAX    DEC     0                      LAST LINE OF PICT
J       DEC     0                      PICT COLUMN INDEX
J1      DEC     0
JDELJ   DEC     0
JLAST   DEC     0                   J COORDINATE OF LOWER RH SQUARE IN PICT
JMAX    DEC     0                      LAST COLUMN OF PICT
K       DEC     0                      INPUT BUFFER INDEX
L       DEC     0                      TAPE RECORD INDEX
5LEM    DEC     0
ER      DEC     0                      WIDTH OF PICT, IN ELEMENTS
SAVE4   DEC     0
W       DEC     0                      WIDTH OF PICT, IN WORDS
KZ      DEC     0                      FIRST PICT ELEMENT OF INPUT BUFFER
ONETWE  DEC     120
ONE     DEC     1
*
BRST    SBST    ILAST,IMAX,S2          SET LINE, COLUMN INDEX FLAGS
        SBST    JLAST,JMAX,S2          FOR SCANNING-SQ OVER WHOLE PICTURE
        EQUL    I,=2                   SQ AT TOP OF PICT (EXCLUDING BORDER)
BR1     EQUL    J,=2                   SQ AT TOP OF PICT (EXCLUDING BORDER)
```

```
BR2     ADST    II,I,S2              SET ROW, COLUMN INDEX FLAGS
        ADST    JJ,J,S2              OVER CURRENT SQ
BR5     EQUL    C,=0
        EQUL    I1,I
2R5B    EQUL    J1,J
2R5C    TAKEM   PICT,JMAX,I1,J1      CURRENT ELEMENT
        STO     ELEM
2R5CA   ADST    JDELJ,J1,=-1         ADJACENCY AND CONTRAST COUNT
        TAKEM   PICT,JMAX,I1,JDELJ LEFT NEIGHBORING ELEMENT
        ERA     ELEM
        ANA     =020                 B/W BIT = 1 IF A CONTRAST
        TZE     BR5CB                IF ALIKE (NO CONTRAST)
        ADST    C,C,=1               ELSE COUNT 1 CONTRAST
2R5CB   ADST    IDELI,I1,=-1
        TAKEM   PICT,JMAX,IDELI,J1 UPPER NEIGHBORING ELEMENT
        ERA     ELEM
        ANA     =020
        TZE     BR5R
        ADST    C,C,=1
BR5R    ADST    J1,J1,=1             NEXT COL OF SQ
        TNQL    J1,JJ,BR5C
        ADST    I1,I1,=1             NEXT ROW OF SQUARE
        TNQL    I1,II,BR5B
BR7     LDQ     C                    NUMBER OF CONTRASTS WITHIN SQ
        MPY     =10
        DVP     A                    NUMBER OF ADJACENCIES WITHIN SQ
        XCA
        ADD     =1
        STO     V                    V=P+1,   P=INTEGER(B/10)
*                                    B = BROKENNESS PERCENTAGE
BR8     EQUL    I1,I                 WITHIN SQ, SET EACH
BR8A    EQUL    J1,J                 BRKN ELEM VALUE IF LSTH V, TO V
2R8B    TAKEM   PICT,JMAX,I1,J1
        STO     ELEM
        ANA     =017                 EXTRACT VALUE BITS
        SUB     V
        TPL     BR8C                 IF NEW ELEM VALUE NOT GRTH OLD
        CLA     ELEM
        ANA     =060                 CLEAR OUT OLD VALUE
        ADD     V                    PUT IN NEW
        PUTM    PICT,JMAX,I1,J1
BR8C    ADST    J1,J1,=1             NEXT COLUMN OF SQ
        TNQL    J1,JJ,BR8B
        ADST    I1,I1,=1             NEXT ROW OF SQ
        TNQL    I1,II,BR8A
2R9     ADST    J,J,=1               MOVE SQ 1 COL RIGHT
        CLA     JLAST
        SUB     J
        TPL     BR2                  IF SQ NOT AT END OF LINE
2R9B    ADST    I,I,=1               MOVE SQ 1 LINE DOWN
        CLA     ILAST
        SUB     I
        TPL     BR1                  IF SQ NOT AT BOTTOM OF PICTURE
        TRA     OT1                  ELSE TO OUTPUT
*
*               TEMP STORAGE, CONSTANTS, ETC
V       DEC     0                    STORED VALUE OF BRKN ELEMENT
II      DEC     0                    SQ PROCESSING
```

```
JJ      DEC    0                    FLAGS
1       DEC    0                    ADJACENCY CTR
3       DEC    0                    B/W CONTRAST CTR
TOTAL   DEC    0
*              BUFFERS, WORK AREAS
9NBUF   BSS    288
OTBUF   BSS    120
2P      BSS    10
PICT    BSS    20000
        END
```

PART VII

PAX Applications: Pattern Structure Extraction from Meteorological Pictures

ABSTRACT

This Part describes the application of the PAX program to TIROS VI pictures illustrating various meteorological pattern types. Critical input parameters are examined and optimum values determined for PAX processing of a representative set of patterns. The pattern extraction capabilities of PAX are discussed, and the relationship between pattern structure and the brokenness statistic is examined.

7.1 Introduction

The two principal input parameters to the PAX program are investigated in detail in Part VII. The first of these is the brokenness value threshold (T2); elements whose brokenness value lies at or above this threshold make up the extracted pattern, indicated by the over-printed "$" characters. The second parameter is the scanning square size (S2) upon which computations of brokenness value directly depend.

On the basis of these investigations optimal values for S2 and T2 were selected as inputs to PAX in processing a set of pictures exhibiting the three meteorological pattern types analyzed with programs SB-2 and SB-3: vortices, bands, and cells. The resulting pictorial outputs provide a basis for a critical evaluation of the capability of PAX to extract a meteorological pattern structure from a digital picture. PAX-processed pictures are then evaluated as input to a next-generation pattern recognizer program.

Finally, variations in the brokenness value distribution are related to variations of patterns within a single pattern group, and between the three pattern groups. The efficacy of the PAX brokenness statistic as a pattern discriminator is considered.

7.2 Investigation of the Brokenness Threshold

The objective of this investigation is to determine the brokenness threshold value (T2) which most effectively brings out the structure of a meteorological pattern. Too low a value will permit too many picture elements to be included in the extracted structure, resulting in lines which are too thick or "clumsy" to bring out structural detail. Raising the threshold will cause a thinning of these lines.

Too high a value produces gaps in the structure which become larger as the threshold increases.

The investigation was conducted by processing picture P4, a vortex, at four threshold levels: 2, 3, 5, and 6. The scanning square size (S2) was held constant at 2 (the next section presents evidence to support this choice of level). The cloud/noncloud threshold (T) was held constant at 24, on the basis of previous investigations (ref. Part III). The PAX pictorial outputs are shown in Figure 7-1.

At the two lower levels (T2=2 and 3) the edges of the vortical pattern and the curving band at the right of the picture are strikingly highlighted. The broken area at the left of the vortical cloud center is outlined by a pattern of curved lines and smaller solid areas. Though the results for the two levels are generally similar, a closer examination shows thinner and more distinct, yet connected, lines at the level T2=3.

The two upper levels (T2=5 and 6) both produce highly disconnected lines and isolated patches of overprint which fail to convey the pattern structure. The band edge in the upper right corner is not marked in either picture. It is interesting to note the striking difference between the pictorial outputs at the two middle levels[1] as contrasted with the difference between the two lower and two higher levels.

On the basis of these observations it is evident that T2=3 is the optimal threshold level. In section 7.3 it is employed for PAX processing of other examples of a vortex and for cell and band structures.

---

1. With S2=2 no value T2=4 is possible (ref. Sec. 3.4), and so the values 3 and 5 are adjacent on the brokenness scale.

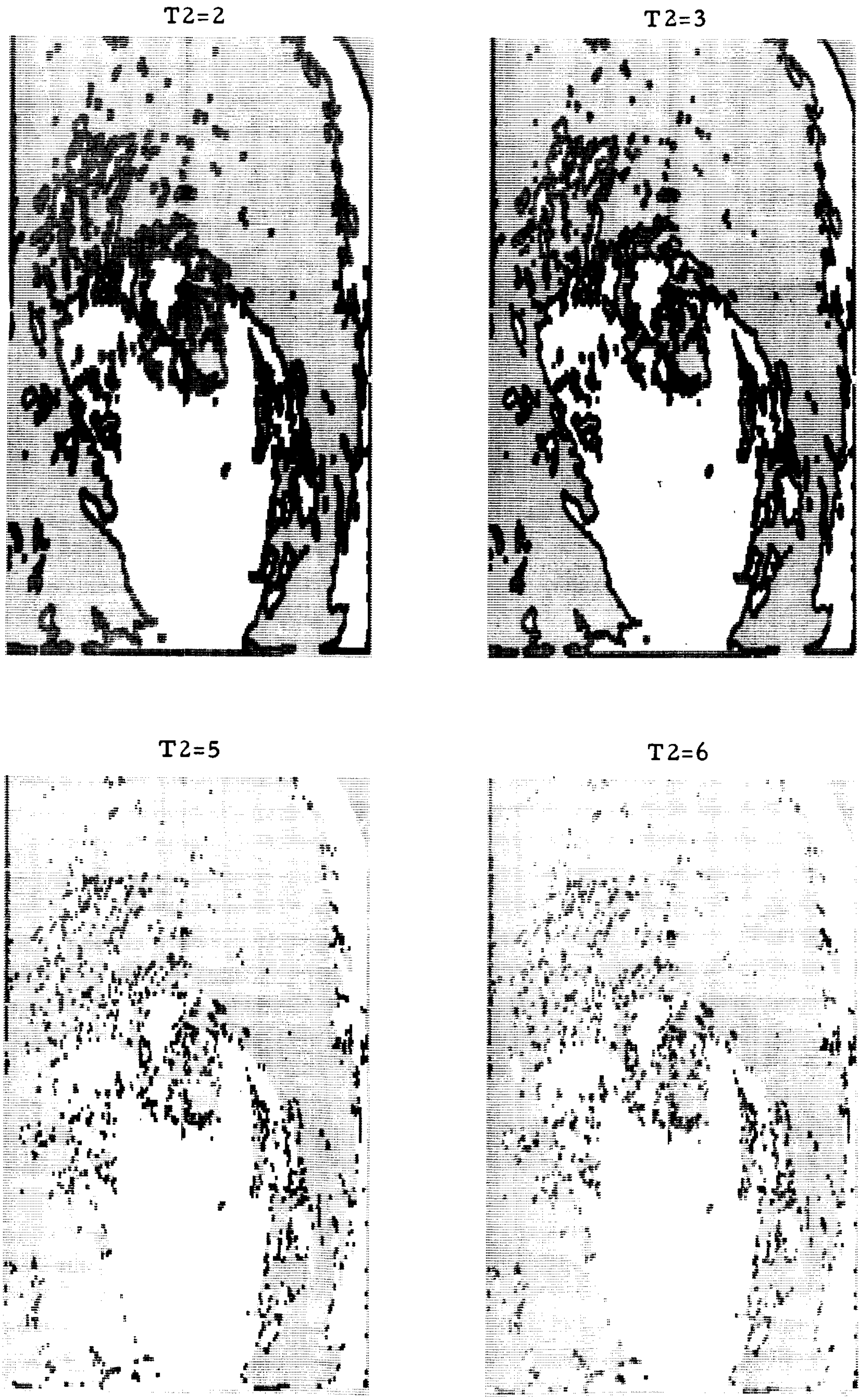


Figure 7-1

PAX Pictorial Output for Brokenness Threshold Variation

7.3 Investigation of Scanning Square Size

Logical considerations governing the choice of PAX scanning square size are analogous to those governing the choice of BRAND scanning square size (Sec. 3.4), except that in this case the criterion for selection is the sharpness and precision of the extracted pattern structure rather than the ability to reproduce the best approximation to a continuous neighborhood about a picture element. For SB-2 and SB-3 analysis the value below this, S2=2,was selected; also the value S2=3 itself and one value above it, S2=5. Pictorial output from P4 (exhibiting a vortex) for these three levels is shown in Figure 7-2. The fixed parameter values were a brokenness-value threshold (T2) of 3 and a cloud/noncloud threshold (T) of 24.

In Section 3.4 the effect on the brokenness statistic of increasing the BRAND square size has been mentioned: as square size increases an averaging process operates with increasing effect to "smooth out" local variations in the statistic. This effect is clearly demonstrated in Figure 7-2. At level S2=2 the pattern structure lines are clear and distinct. At level S2=3 they become wider and "fuzzier" with a few small gaps appearing. At level S2=5 many lines have merged into areas and wide gaps have appeared; yet the general outline of the pattern is still discernible. Examining the pictures in order of increasing S2 level gives the viewer an impression of progressively "myopic" images. On the basis of the criteria discussed above, S2=2 is evidently the optimum level (again cf. the selection of S2=3 for programs SB-2 and SB-3).

Variation in the brokenness value percentage distribution over the three levels is of some interest; the three graphs are shown in Figure 7-3. The general form of the distribution is the same for

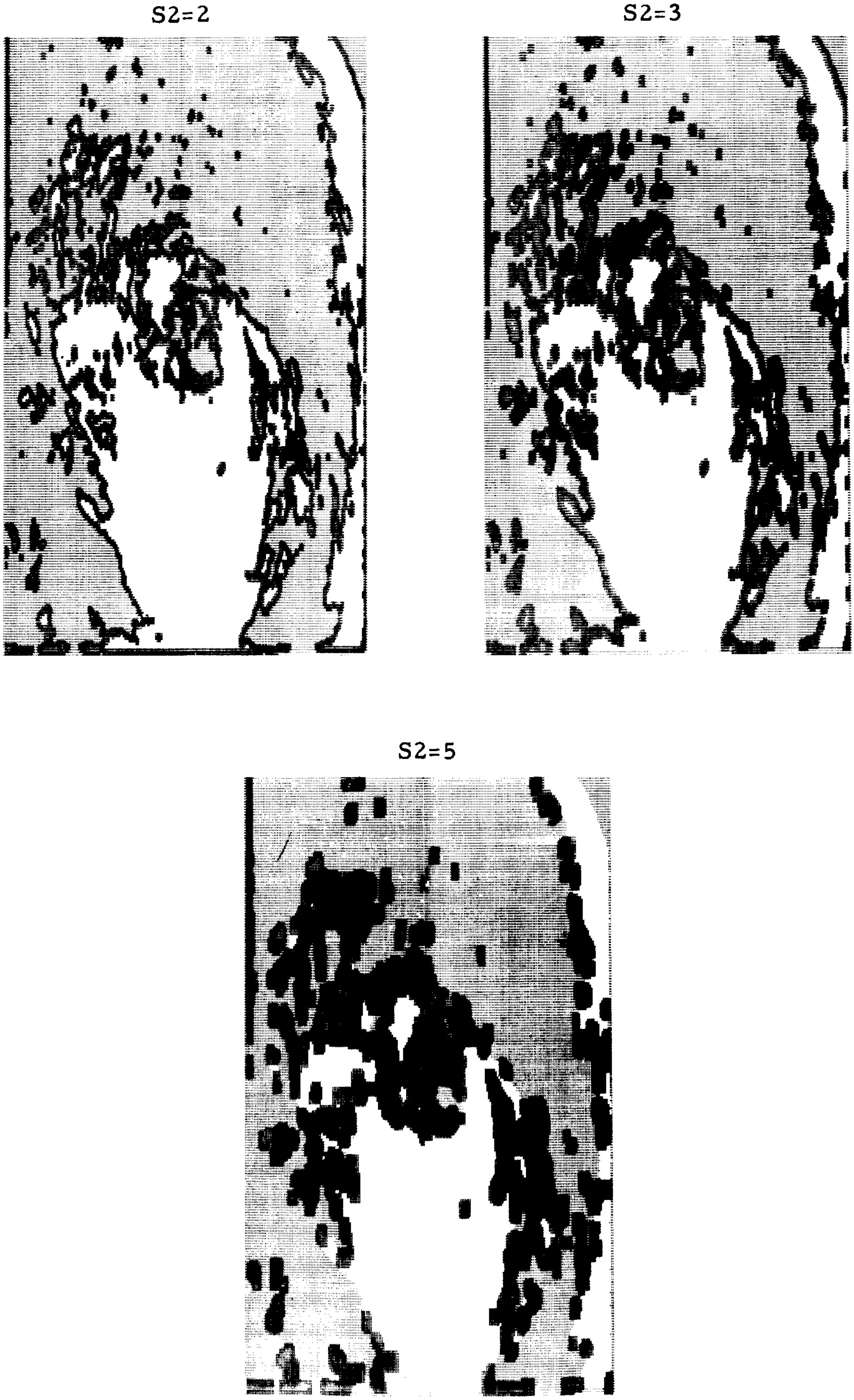


Figure 7-2

PAX Pictorial Output for Scanning Square Size Variation

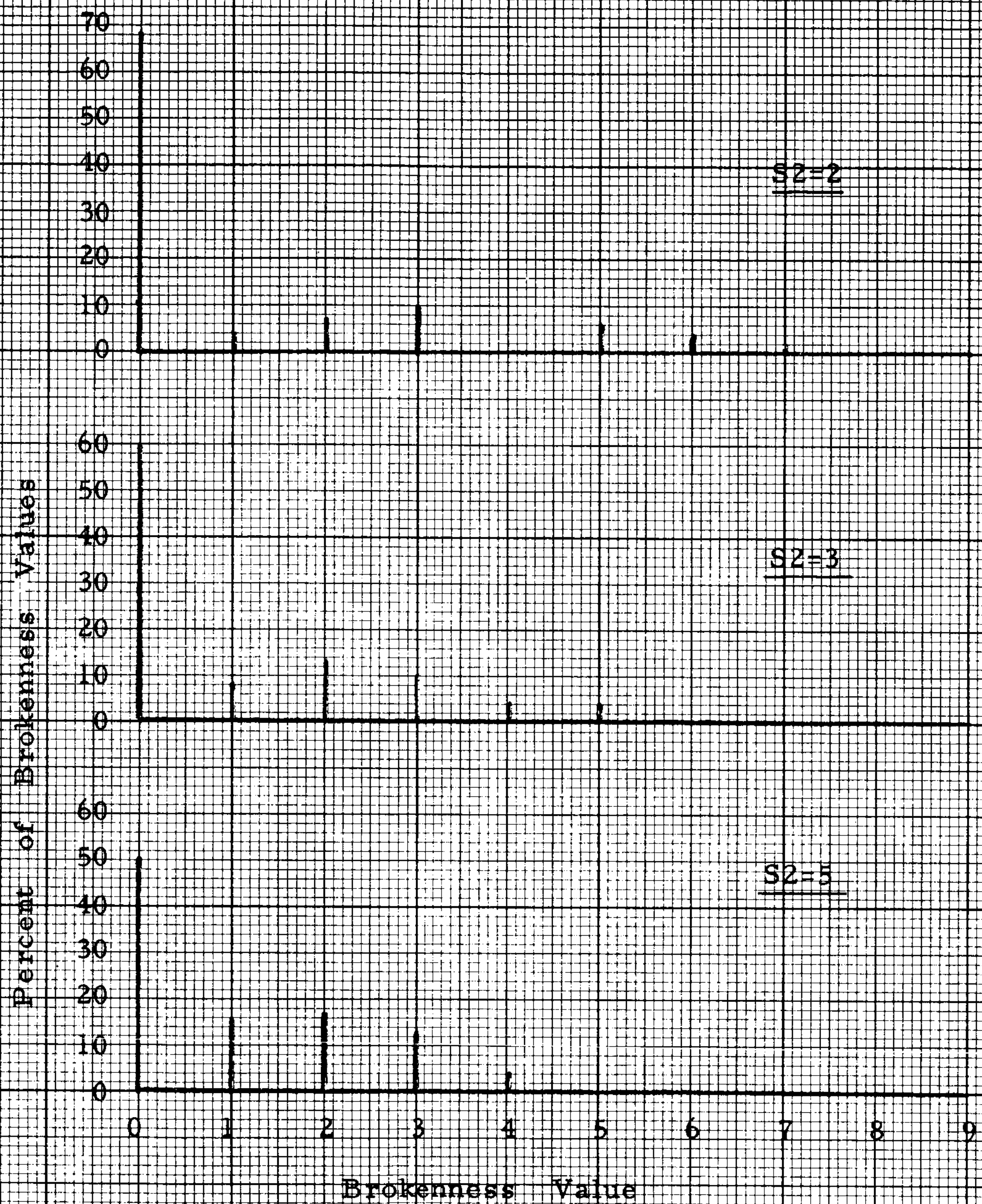


Figure 7-3

Relationship Between PAX Scanning Square Size and Brokenness Distribution all levels: bimodal with the (significantly) larger mode at brokenness value 0 and the smaller mode at 2 or 3. The effects of increasing the square size are (1) to reduce the larger mode and (2) to shift the rest of the distribution to the left. Both effects are clearly discernible in the graphs. As the square size increases the "averaging effect" is seen to compress the range of observed values leftward from the high values, and at the same time rightward from the zero value.

7.4 Application to Meteorological Pattern Processing

Investigations described in Sections 7.2 and 7.3 have established optimum values of 2 and 3 for the scanning square size and brokenness-value threshold. These values and the cloud/noncloud threshold value of 24 were input as fixed parameters for PAX processing of a set of nine pictures representing the three meteorological pattern types (vortex, band structure, cell structure) analyzed also by programs SB-2 and SB-3 (Parts III, V). These pictures are grouped as follows:

Pattern	Pictures
Vortex	P4, P51, P26
Band Structure	P8, P12, P41
Cell Structure	P2, P10, P49

The pictorial output is shown in Figure 7-4.

The PAX program has extracted the structure of the vortical patterns with striking success. In P4 the boundary of the vortical cloud area in the lower central area of the picture and the band curving along the right side of the picture are both clearly traced. Less noticeable, but also distinct, is a grouping of marked cells describing a curve starting from the upper left corner and descending in a concave line downward and to the right. Examination of the

Figure 7-4

PAX Pictorial Output for Meteorological Pattern Processing

Vortex

P4

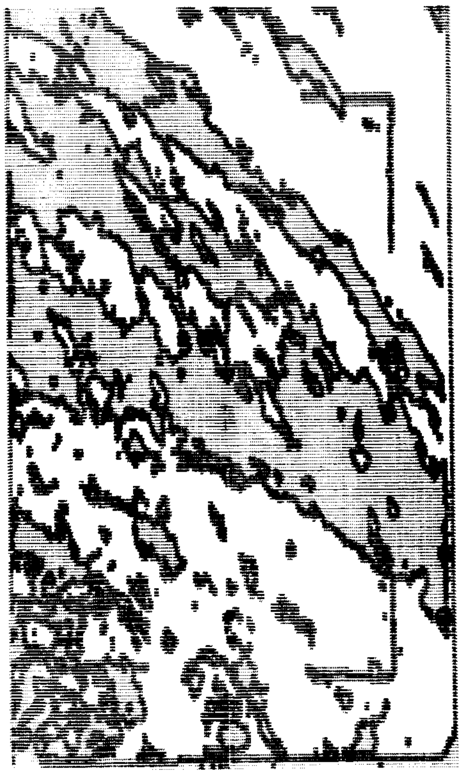
P51

P26

Figure 7-4/Page 1

P8

P12



P41

P2

P10

P49

photographic representation of P4 (Figure 3-1) shows that this corresponds to a thin light curve which, despite its non-distinctness, contributes very significantly to the vortical character of the pattern. The basic structure of the vortex is thus not only clearly extracted, but enhanced, in the PAX output.

In P26 this is also true: the vortical whorl in the upper right center area of the picture shows more clearly in the PAX output than in the photograph. Also clearly traced is the curving line outlining the left edge of the vortical pattern. The broken region of which this curve is the right edge is marked almost in its entirety by the PAX overprint. The vortical spiral, culminating in a radiating spur normal to the spiral's direction, is clearly bordered in the PAX output. The larger cloud cells appearing to the left of and above the whorl are outlined by overprinting.

The band structures of P8, P12 and P41 are all clearly brought out by the program, enhancement being most evident in P8. In the three pictures the PAX overprint depicts the parallel linear structure of the pattern, essentially straight in P8 and P12, and slightly curved in P41. Each picture contains one or more non-cloud bands of sufficient width to be bordered on both sides by overprinting.

In the cell-structure group large cloud cells appear with an overprinted border; smaller cells, as solid regions of overprint. Cell outlines are in general easier to perceive in the PAX output than in the photograph for either cloud cells on a noncloud background (P8 and P12) or the reverse (P41, upper half of picture).

The fact that patterns are easier to see in the PAX representation than in a photograph is significant in itself; but more significant is the fact that this improvement in "perceivability" is much greater as far as the computer is concerned. The elements of the photographic representation are presented to the machine over a range of sixty-four gray levels. After PAX processing, the picture image has been transformed so that the overprinted areas representing the pattern structure are distinguishable, logically, from the rest of the picture--where this was not true before. In this sense the computer can "see" the pattern whereas before it could not. The conclusion of this discussion is that the patterns identified in the PAX-processed picture are now susceptible to recognition analysis by the computer; that is, the next step is to distinguish between patterns and/or identify them directly by data processing and possibly in future by special-purpose hardware.

It is of some interest to investigate the relationship between the brokenness value distribution and meteorological pattern type. The brokenness value percentage distributions for the nine PAX pictorial outputs under discussion are plotted by pattern group in Figure 7-5.[2]

All distributions have the characteristic shape encountered previously: a peak mode at brokenness value 0 and a second peak at value 3. Some differences, however, may be noticed in the percentage of brokenness values equal to zero. For all three of the vortex outputs (P4, P51, P26), this percentage exceeds 55. This is true for only one of the band structure outputs (P41) and two of the cell structure outputs (P2 and P10). This difference is apparently due simply to

---

2. No brokenness value of 4 appears on the horizontal scale because the size of the scanning square is 2 (ref. note 1 above).

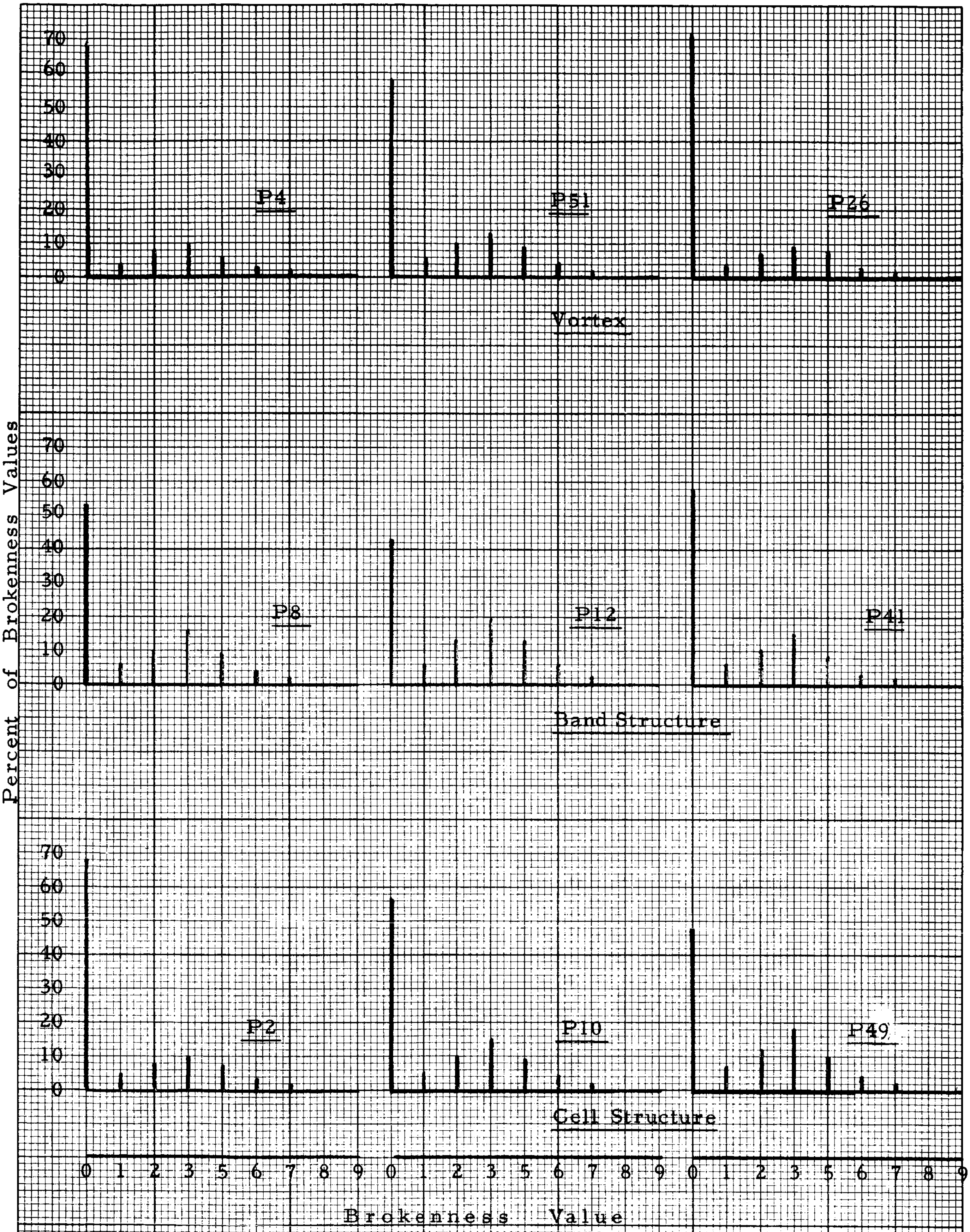


Figure 7-5

Relationship Between Meteorological Pattern Type and PAX Brokenness Distribution the greater proportion of solid area which is unmarked by PAX, as an inspection of the outputs of Figure 7-4 shows. The three pictures with a zero-value-percentage below 55 (P8, P12, and P49) are all more heavily overprinted than the others. Thus, though the zero-value-percentage may in some sense give an indication of the "complexity" of a pattern, the sample results indicate that it is of limited value as a pattern discriminator.

PART VIII

Utility Programs for Meteorological Picture Processing

ABSTRACT

This Part describes utility programs and subroutines for use in conjunction with the major programs presented in the preceding parts of this report and for extending analysis to properties of cloud pictures beyond those treated thus far. These include executive or "driver" programs for SB-2 and PAX, a matrix print-out subroutine, a gradient magnitude subroutine, a picture print-out subroutine, and a frequency count subroutine.

8.1 Driver Programs for SB-2 and PAX

The driver programs for the SB-2 and PAX programs are designed to supply parameters and data to the main program with a minimum of user effort. Use of these driver programs enables the user to assemble the main program in binary card format and call it as a subroutine.

The standard drivers for these programs accept any number of sets of the parameters defining the location of a picture on the input tape, and one set of all other parameters. This permits the processing of any number of pictures given one cloud/noncloud threshold and one BRAND square size for PAX (see Part VI) and also with one SORD square size and one set of noise values for SB-2 (see Part II).

For each of the above programs there are two other driver programs, one permitting the varying of the threshold, and one permitting the varying of the square sizes and noise values. Each of these does this by an outer loop which executes the program for the selected set of pictures combined with each set of parameters input successively.

Symbolic listings of these drivers are presented in Figure 8-1: the standard driver, variable square size driver, and variable threshold driver for SB-2, followed by the analogous drivers for PAX.

8.2 Matrix Printout Subroutine: MXDUMP

The MXDUMP subroutine is used to print out matrices which are stored in computer memory in the same format as the pictures for input to the programs presented in this report. A call of MXDUMP will result in a printout in an ordered matrix

Figure 8-1

Driver Program Symbolic Listings

```
*       FAP
*        STANDARD DRIVER FOR SB-2
*                PARAMETER STORAGE
*                PARAMETERS MUST BE INPUT TO COMMON STORAGE
*                PRIOR TO ENTRY
LZERO   COMMON   1                    MASTER LINE COUNTER
W2      COMMON   1                    LAST WORD OF TAPE PICTURE LINE
W1      COMMON   1                    FIRST WORD OF TAPE PICTURE LINE
L2      COMMON   1                    LAST TAPE PICTURE LINE
L1      COMMON   1                    FIRST TAPE PICTURE LINE
BB      COMMON   1                MIN. BLACK ELEMENTS/SQUARE, BLACK REGION
BW      COMMON   1                MAX. BLACK ELEMENTS/SQUARE, WHITE REGION
WR      COMMON   1                    WORDS PER TAPE RECORD
T       COMMON   1                    THRESHOLD
S2      COMMON   1                    SQUARE SIZE - BRAND
S       COMMON   1                    SQUARE SIZE - SORD
B2DRV   AXT      6,1                                                   001
MOVE    CLA      DATA+6,1                                              002
        STO      S+6,1                S,T,W,BB,BW                      003
        TIX      MOVE,1,1                                              004
        AXC      DATA+6,1             INITIALIZE CURRENT LINE OF       005
        SXA      CURLIN,1             DATA TABLE                       006
        CLA      =1                   INITIALIZE MASTER LINE CTR       006/1
        STO      LZERO                                                 006/2
        CLA      0,1                                                   006/3
        STO      L1                                                    006/4
        TRA      PARAMS                                                006/5
LOOP    LXA      CURLIN,1             LOAD PICTURE DIMENSION           007
        CLA      0,1                  PARAMS  I-TH PICT   L1 L2 W1 W2  008
        TNZ      PROC                 TEST LAST PICTURE                009
        CAL      =9B17                FINAL TAPE REWIND                009/1
        CALL     (RWT)                                                 009/2
        CALL     EXIT                 YES                              010
PROC    STO      L1                   NO                               011
        CLA      -3,1                 LAST LINE PREVIOUS PICTURE       011/02
        SUB      0,1                  FIRST LINE, CURRENT PICTURE      011/04
        TMI      NOREW                IF CURRENT PICT LATER ON TAPE    011/06
REW     CLA      =1                   ELSE INITIALIZE MLC              011/10
        STO      LZERO                TO FIRST TAPE RECORD             011/12
        CAL      =9B17                AND REWIND TAPE                  011/14
        CALL     (RWT)                                                 011/16
        TRA      PARAMS                                                011/18
NOREW   CLA      -3,1                 LAST LINE PREV PICT              011/20
        ADD      =1                   INITIALIZE MLC TO                011/22
        STO      LZERO                NEXT TAPE RECORD                 011/24
PARAMS  CLA      1,1                                                   012
        STO      L2                                                    013
        CLA      2,1                                                   014
        STO      W1                                                    015
        CLA      3,1                                                   016
        STO      W2                                                    017
        TXI      *+1,1,-4                                              018
        SXA      CURLIN,1                                              019
        CALL     SABOP2               PROCESS I-TH PICTURE             020
        TRA      LOOP                 TO NEXT PICTURE                  021
CURLIN  DEC      0                    - (ADDR CURR LINE DATA TBL)      022
DATA    DEC      8
        DEC      3                    SQUARE SIZE - BRAND              023/1
        DEC      24                   THRESHOLD                        024
        DEC      39                   NO. WDS PER TAPE RECORD          025
```

Figure 8-1/Page 1

```
     DEC       5
     DEC       59
     DEC       774
     DEC       1013
     DEC       1
     DEC       20
     DEC       774
     DEC       1013
     DEC       20
     DEC       39
     DEC       0
     END
```

Figure 8-1/Page 2

```
*       FAP
*        VARIABLE THRESHOLD DRIVER FOR  SB-2
*                SB2D-T   SB-2 DRIVER TO RUN A SET OF
*                PICTURES WITH VARIABLE THRESHOLD
*                PARAMETER STORAGE
*                PARAMETERS MUST BE INPUT TO COMMON STORAGE
*                PRIOR TO ENTRY
LZERO   COMMON   1                  MASTER LINE COUNTER
W2      COMMON   1                  LAST WORD OF TAPE PICTURE LINE
W1      COMMON   1                  FIRST WORD OF TAPE PICTURE LINE
L2      COMMON   1                  LAST TAPE PICTURE LINE
L1      COMMON   1                  FIRST TAPE PICTURE LINE
BB      COMMON   1              MIN. BLACK ELEMENTS/SQUARE, BLACK REGION
BW      COMMON   1              MAX. BLACK ELEMENTS/SQUARE, WHITE REGION
WR      COMMON   1                  WORDS PER TAPE RECORD
T       COMMON   1                  THRESHOLD
S2      COMMON   1                  SQUARE SIZE - BRAND
S       COMMON   1                  SQUARE SIZE - SORD
TSTART  CLA      =1                                                  000/01
        STO      TTLIN              FIRST LINE OF THRESHOLD TBL      000/02
TLOOP   LAC      TTLIN,1                                             000/03
        CLA      TTBL,1             CURRENT THRESHOLD                000/04
        TNZ      T1                                                  000/05
        CALL     EXIT                                                000/06
T1      STO      DATA+2             SET THRESHOLD                    000/07
        TXI      *+1,1,-1           NEXT LINE OF TTBL                000/08
        SCA      TTLIN,1                                             000/09
B2DRV   AXT      6,1                                                 001
MOVE    CLA      DATA+6,1                                            002
        STO      S+6,1              S,T,W,BB,BW                      003
        TIX      MOVE,1,1                                            004
        AXC      DATA+6,1           INITIALIZE CURRENT LINE OF       005
        SXA      CURLIN,1           DATA TABLE                       006
        CLA      =1                 INITIALIZE MASTER LINE CTR       006/1
        STO      LZERO                                               006/2
        CLA      0,1                                                 006/3
        STO      L1                                                  006/4
        TRA      PARAMS                                              006/5
LOOP    LXA      CURLIN,1           LOAD PICTURE DIMENSION           007
        CLA      0,1                PARAMS  I-TH PICT    L1 L2 W1 W2 008
        TNZ      PROC               TEST LAST PICTURE                009
        CAL      =9B17              FINAL TAPE REWIND                009/1
        CALL     (RWT)                                               009/2
        TRA      TLOOP              YES                              010
PROC    STO      L1                 NO                               011
        CLA      -3,1               LAST LINE PREVIOUS PICTURE       011/02
        SUB      0,1                FIRST LINE, CURRENT PICTURE      011/04
        TMI      NOREW              IF CURRENT PICT LATER ON TAPE    011/06
REW     CLA      =1                 ELSE INITIALIZE MLC              011/10
        STO      LZERO              TO FIRST TAPE RECORD             011/12
        CAL      =9B17              AND REWIND TAPE                  011/14
        CALL     (RWT)                                               011/16
        TRA      PARAMS                                              011/18
NOREW   CLA      -3,1               LAST LINE PREV PICT              011/20
        ADD      =1                 INITIALIZE MLC TO                011/22
        STO      LZERO              NEXT TAPE RECORD                 011/24
PARAMS  CLA      1,1                                                 012
        STO      L2                                                  013
        CLA      2,1                                                 014
        STO      W1                                                  015
```

```
        CLA     3,1                                             016
        STO     W2                                              017
        TXI     *+1,1,-4                                        018
        SXA     CURLIN,1                                        019
        CALL    SABOP2       PROCESS I-TH PICTURE               020
        TRA     LOOP         TO NEXT PICTURE                    021
CURLIN  DEC     0            - (ADDR CURRENT LINE, DATA TBL)    021/0
TTLIN   DEC     0            CURRENT LINE OF TTBL               021/1
TTBL    DEC     0            TABLE OF THRESHOLDS                021/2
*               STARTS HERE
        DEC     24
        DEC     0            END-OF-TABLE SENTINEL
DATA    DEC     30           SQUARE SIZE - SORD                 023
        DEC     3            SQUARE SIZE - BRAND                023/1
        DEC     24           THRESHOLD                          024
        DEC     39           NO. WDS PER TAPE RECORD            025
        DEC     72           MAX BLACK ELEM/SQ, WHITE REGION    026
        DEC     828          MIN BLACK ELEM/SQ, BLACK REGION    027
        DEC     774
        DEC     1013
        DEC     1
        DEC     20
        DEC     774
        DEC     1013
        DEC     20
        DEC     39
        DEC     0
        END
```

```
*       FAP
*        VARIABLE SQUARE SIZE AND NOISE VALUE DRIVER FOR  SB-2
*      SB2D-S    SB-2 DRIVER PROGRAM FOR VARIABLE SQ SIZE AND NOISE VALUES
*                PARAMETER STORAGE
*                PARAMETERS MUST BE INPUT TO COMMON STORAGE
*                PRIOR TO ENTRY
LZERO   COMMON   1                 MASTER LINE COUNTER
W2      COMMON   1                 LAST WORD OF TAPE PICTURE LINE
W1      COMMON   1                 FIRST WORD OF TAPE PICTURE LINE
L2      COMMON   1                 LAST TAPE PICTURE LINE
L1      COMMON   1                 FIRST TAPE PICTURE LINE
BB      COMMON   1              MIN. BLACK ELEMENTS/SQUARE, BLACK REGION
BW      COMMON   1              MAX. BLACK ELEMENTS/SQUARE, WHITE REGION
WR      COMMON   1                 WORDS PER TAPE RECORD
T       COMMON   1                 THRESHOLD
S2      COMMON   1                 SQUARE SIZE - BRAND
S       COMMON   1                 SQUARE SIZE - SORD
        CLA      =1                                                000/03
        STO      STLIN                                             000/04
SLOOP   LAC      STLIN,1                                           000/05
        CLA      STBL,1                                            000/06
        TNZ      S1                                                000/07
        CALL     EXIT                                              000/08
S1      STO      DATA              SET  S                          000/09
        CLA      STBL+1,1                                          000/10
        STO      DATA+1            SET  S2                         000/11
        CLA      STBL+2,1                                          000/12
        STO      DATA+4            SET  BW                         000/13
        CLA      STBL+3,1                                          000/14
        STO      DATA+5            SET  BB                         000/15
        TXI      *+1,1,-4                                          000/16
        SCA      STLIN,1                                           000/17
B2DRV   AXT      6,1                                               001
MOVE    CLA      DATA+6,1                                          002
        STO      S+6,1             S,T,W,BB,BW                     003
        TIX      MOVE,I,1                                          004
        AXC      DATA+6,1          INITIALIZE CURRENT LINE OF      005
        SXA      CURLIN,1          DATA TABLE                      006
        CLA      =1                INITIALIZE MASTER LINE CTR      006/1
        STO      LZERO                                             006/2
        CLA      0,1                                               006/3
        STO      LI                                                006/4
        TRA      PARAMS                                            006/5
LOOP    LXA      CURLIN,1          LOAD PICTURE DIMENSION          007
        CLA      0,1               PARAMS  I-TH PICT   L1 L2 W1 W2 008
        TNZ      PROC              TEST LAST PICTURE               009
        CAL      =9B17             FINAL TAPE REWIND               009/1
        CALL     (RWT)                                             009/2
        TRA      SLOOP             YES                             010
PROC    STO      LI                NO                              011
        CLA      -3,1              LAST LINE PREVIOUS PICTURE      011/02
        SUB      0,1               FIRST LINE, CURRENT PICTURE     011/04
        TMI      NOREW             IF CURRENT PICT LATER ON TAPE   011/06
REW     CLA      =1                ELSE INITIALIZE MLC             011/10
        STO      LZERO             TO FIRST TAPE RECORD            011/12
        CAL      =9B17             AND REWIND TAPE                 011/14
        CALL     (RWT)                                             011/16
        TRA      PARAMS                                            011/18
NOREW   CLA      -3,1              LAST LINE PREV PICT             011/20
        ADD      =1                INITIALIZE MLC TO               011/22
```

```
         STO      LZERO                NEXT TAPE RECORD                   011/24
PARAMS   CLA      1,1                                                     012
         STO      L2                                                      013
         CLA      2,1                                                     014
         STO      W1                                                      015
         CLA      3,1                                                     016
         STO      W2                                                      017
         TXI      *+1,1,-4                                                018
         SXA      CURLIN,1                                                019
         CALL     SABOP2               PROCESS I-TH PICTURE               020
         TRA      LOOP                 TO NEXT PICTURE                    021
CURLIN   DEC      0                    - (ADDR CURRENT LINE, DATA TBL)    021/0
STLIN    DEC      0                    CURRENT LINE, STBL                 021/1
STBL     DEC      0                    TBL OF SQ SIZES, NOISE VALUES      021/3
*     TABLE STARTS HERE    S,S2,BW,BB  IN SUCCESSIVE SETS
         DEC      5
         DEC      3
         DEC      2
         DEC      23
         DEC      5
         DEC      8
         DEC      2
         DEC      23
         DEC      15
         DEC      3
         DEC      18
         DEC      207
         DEC      0                    END-OF-TABLE SENTINEL
DATA     DEC      5                    SQUARE SIZE - SORD                 023
         DEC      5                    SQUARE SIZE - BRAND                023/1
         DEC      24                   THRESHOLD                          024
         DEC      39                   NO. WDS PER TAPE RECORD            025
         DEC      2                    MAX BLACK ELEM/SQ, WHITE REGION    026
         DEC      23                   MIN BLACK ELEM/SQ, BLACK REGION    027
         DEC      774
         DEC      1013
         DEC      2
         DEC      21
         DEC      774
         DEC      1013
         DEC      19
         DEC      38
         DEC      0
         END
```

```
*       FAP
*        STANDARD DRIVER FOR  PAX
*                FOR PICTURES WITH VARIABLE SQUARE SIZES
*                PARAMETER STORAGE
*                PARAMETERS MUST BE INPUT TO COMMON STORAGE
*                PRIOR TO ENTRY
LZERO    COMMON  1                  MASTER LINE COUNTER
W2       COMMON  1                  LAST WORD OF TAPE PICTURE LINE
W1       COMMON  1                  FIRST WORD OF TAPE PICTURE LINE
L2       COMMON  1                  LAST TAPE PICTURE LINE
L1       COMMON  1                  FIRST TAPE PICTURE LINE
         COMMON  2
WR       COMMON  1                  WORDS PER TAPE RECORD
T        COMMON  1                  THRESHOLD--BRIGHTNESS
S2       COMMON  1                  SQUARE SIZE - BRAND
T2       COMMON  1                  THRESHOLD--BROKENNESS
B2DRV    AXT     6,1                                                 001
MOVE     CLA     DATA+6,1                                            002
         STO     T2+6,1             LOAD T2,T,W                      003
         TIX     MOVE,1,1                                            004
         AXC     DATA+6,1           INITIALIZE CURRENT LINE OF       005
         SXA     CURLIN,1           DATA TABLE                       006
         CLA     =1                 INITIALIZE MASTER LINE CTR       006/1
         STO     LZERO                                               006/2
         CLA     0,1                                                 006/3
         STO     L1                                                  006/4
         TRA     PARAMS                                              006/5
LOOP     LXA     CURLIN,1           LOAD PICTURE DIMENSION           007
         CLA     0,1                PARAMS  I-TH PICT   L1 L2 W1 W2  008
         TNZ     PROC               TEST LAST PICTURE                009
         CAL     =9B17              FINAL TAPE REWIND                009/1
         CALL    (RWT)                                               009/2
         CALL    EXIT                                                000/06
PROC     STO     L1                 NO                               011
         CLA     -3,1               LAST LINE PREVIOUS PICTURE       011/02
         SUB     0,1                FIRST LINE, CURRENT PICTURE      011/04
         TMI     NOREW              IF CURRENT PICT LATER ON TAPE    011/06
REW      CLA     =1                 ELSE INITIALIZE MLC              011/10
         STO     LZERO              TO FIRST TAPE RECORD             011/12
         CAL     =9B17              AND REWIND TAPE                  011/14
         CALL    (RWT)                                               011/16
         TRA     PARAMS                                              011/18
NOREW    CLA     -3,1               LAST LINE PREV PICT              011/20
         ADD     =1                 INITIALIZE MLC TO                011/22
         STO     LZERO              NEXT TAPE RECORD                 011/24
PARAMS   CLA     1,1                                                 012
         STO     L2                                                  013
         CLA     2,1                                                 014
         STO     W1                                                  015
         CLA     3,1                                                 016
         STO     W2                                                  017
         TXI     *+1,1,-4                                            018
         SXA     CURLIN,1                                            019
         CALL    SABOP2             PROCESS I-TH PICTURE             020
         TRA     LOOP               TO NEXT PICTURE                  021
CURLIN   DEC     0                  - (ADDR CURRENT LINE, DATA TBL)  021/0
STBL     DEC     0                  TBL OF SQUARE SIZES
*                                   STARTS HERE
         DEC     5
         DEC     0                  END-OF-TABLE SENTINEL
```

```
DATA     DEC     3                  THRESHOLD--BROKENNESS
         DEC     0                  SQUARE SIZE--PAX  (S2)
         DEC     24                 THRESHOLD--BRIGHTNESS
         DEC     39                 NO. WDS PER TAPE RECORD            025
         DEC     0
         DEC     0
*                TBL OF PICTURE DIMENSIONS   L1,L2,W1,W2  IN EACH SET
         DEC     774
         DEC     1013
         DEC     1
         DEC     20
         DEC     774
         DEC     1013
         DEC     20
         DEC     39
         DEC     0
         END
```

```
*       FAP
*       VARIABLE THRESHOLD DRIVER FOR  PAX
*               PAD-T   DRIVER FOR PAX   PATTERN EXTRACTOR PROGRAM
*               FOR PICTURES WITH VARIABLE THRESHOLDS
*               PARAMETER STORAGE
*               PARAMETERS MUST BE INPUT TO COMMON STORAGE
*               PRIOR TO ENTRY
LZERO   COMMON  1                 MASTER LINE COUNTER
W2      COMMON  1                 LAST WORD OF TAPE PICTURE LINE
W1      COMMON  1                 FIRST WORD OF TAPE PICTURE LINE
L2      COMMON  1                 LAST TAPE PICTURE LINE
L1      COMMON  1                 FIRST TAPE PICTURE LINE
        COMMON  2
WR      COMMON  1                 WORDS PER TAPE RECORD
T       COMMON  1                 THRESHOLD--BRIGHTNESS
S2      COMMON  1                 SQUARE SIZE - BRAND
T2      COMMON  1                 THRESHOLD--BROKENNESS
TSTART  CLA     =1                                                000/01
        STO     TTLIN             FIRST LINE OF THRESHOLD TBL     000/02
TLOOP   LAC     TTLIN,1                                           000/03
        CLA     TTBL,1            CURRENT THRESHOLD               000/04
        TNZ     T1                                                000/05
        CALL    EXIT                                              000/06
T1      STO     DATA+2            SET THRESHOLDS                  000/07
        CLA     TTBL+1,1                                          000/08
        STO     DATA                                              000/09
        TXI     *+1,1,-2          NEXT LINES OF TTBL              000/10
        SCA     TTLIN,1                                           000/11
B2DRV   AXT     6,1                                               001
MOVE    CLA     DATA+6,1                                          002
        STO     T2+6,1            LOAD T2,T,W                     003
        TIX     MOVE,1,1                                          004
        AXC     DATA+6,1          INITIALIZE CURRENT LINE OF      005
        SXA     CURLIN,1          DATA TABLE                      006
        CLA     =1                INITIALIZE MASTER LINE CTR      006/1
        STO     LZERO                                             006/2
        CLA     0,1                                               006/3
        STO     L1                                                006/4
        TRA     PARAMS                                            006/5
LOOP    LXA     CURLIN,1          LOAD PICTURE DIMENSION          007
        CLA     0,1               PARAMS  I-TH PICT   L1 L2 W1 W2 008
        TNZ     PROC              TEST LAST PICTURE               009
        CAL     =9B17             FINAL TAPE REWIND               009/1
        CALL    (RWT)                                             009/2
        TRA     TLOOP             YES                             010
PROC    STO     L1                NO                              011
        CLA     -3,1              LAST LINE PREVIOUS PICTURE      011/02
        SUB     0,1               FIRST LINE, CURRENT PICTURE     011/04
        TMI     NOREW             IF CURRENT PICT LATER ON TAPE   011/06
REW     CLA     =1                ELSE INITIALIZE MLC             011/10
        STO     LZERO             TO FIRST TAPE RECORD            011/12
        CAL     =9B17             AND REWIND TAPE                 011/14
        CALL    (RWT)                                             011/16
        TRA     PARAMS                                            011/18
NOREW   CLA     -3,1              LAST LINE PREV PICT             011/20
        ADD     =1                INITIALIZE MLC TO               011/22
        STO     LZERO             NEXT TAPE RECORD                011/24
PARAMS  CLA     1,1                                               012
        STO     L2                                                013
        CLA     2,1                                               014
```

```
         STO    W1                                                   015
         CLA    3,1                                                  016
         STO    W2                                                   017
         TXI    *+1,1,-4                                             018
         SXA    CURLIN,1                                             019
         CALL   SABOP2          PROCESS I-TH PICTURE                 020
         TRA    LOOP            TO NEXT PICTURE                      021
CURLIN   DEC    0               - (ADDR CURRENT LINE, DATA TBL)      021/0
TTLIN    DEC    0               CURRENT LINE OF TTBL                 021/1
TTBL     DEC    0               TBL OF THRESHOLDS   T,T2 IN EACH SET
*                               STARTS HERE
         DEC    24
         DEC    3
         DEC    0               END-OF-TABLE SENTINEL
DATA     DEC    0               THRESHOLD--BROKENNESS
         DEC    5               SQUARE SIZE--PAX
         DEC    0               THRESHOLD--BRIGHTNESS
         DEC    39              NO. WDS PER TAPE RECORD              025
         DEC    0
         DEC    0
*               TBL OF PICTURE DIMENSIONS   L1,L2,W1,W2  IN EACH SET
         DEC    774
         DEC    1013
         DEC    20
         DEC    39
         DEC    0
         END
```

```
*      FAP
*       VARIABLE SQUARE SIZE DRIVER FOR  PAX
*               PAD-S   DRIVER FOR PAX   PATTERN EXTRACTOR PROGRAM
*               FOR PICTURES WITH VARIABLE SQUARE SIZES
*               PARAMETER STORAGE
*               PARAMETERS MUST BE INPUT TO COMMON STORAGE
*               PRIOR TO ENTRY
LZERO   COMMON  1                    MASTER LINE COUNTER
W2      COMMON  1                    LAST WORD OF TAPE PICTURE LINE
W1      COMMON  1                    FIRST WORD OF TAPE PICTURE LINE
L2      COMMON  1                    LAST TAPE PICTURE LINE
L1      COMMON  1                    FIRST TAPE PICTURE LINE
        COMMON  2
WR      COMMON  1                    WORDS PER TAPE RECORD
T       COMMON  1                    THRESHOLD--BRIGHTNESS
S2      COMMON  1                    SQUARE SIZE - BRAND
T2      COMMON  1                    THRESHOLD--BROKENNESS
TSTART  CLA     =1                                                  000/01
        STO     TTLIN                FIRST LINE OF THRESHOLD TBL    000/02
TLOOP   LAC     TTLIN,1                                             000/03
        CLA     STBL,1               CURRENT SQUARE SIZE            000/04
        TNZ     T1                                                  000/05
        CALL    EXIT                                                000/06
T1      STO     DATA+1               SET SQUARE SIZE                000/07
        TXI     *+1,1,-1             NEXT LINE OF STBL              000/10
        SCA     TTLIN,1                                             000/11
B2DRV   AXT     6,1                                                 001
MOVE    CLA     DATA+6,1                                            002
        STO     T2+6,1               LOAD T2,T,W                    003
        TIX     MOVE,1,1                                            004
        AXC     DATA+6,1             INITIALIZE CURRENT LINE OF     005
        SXA     CURLIN,1             DATA TABLE                     006
        CLA     =1                   INITIALIZE MASTER LINE CTR     006/1
        STO     LZERO                                               006/2
        CLA     0,1                                                 006/3
        STO     L1                                                  006/4
        TRA     PARAMS                                              006/5
LOOP    LXA     CURLIN,1             LOAD PICTURE DIMENSION         007
        CLA     0,1                  PARAMS  I-TH PICT   L1 L2 W1 W2 008
        TNZ     PROC                 TEST LAST PICTURE              009
        CAL     =9B17                FINAL TAPE REWIND              009/1
        CALL    (RWT)                                               009/2
        TRA     TLOOP                YES                            010
PROC    STO     L1                   NO                             011
        CLA     -3,1                 LAST LINE PREVIOUS PICTURE     011/02
        SUB     0,1                  FIRST LINE, CURRENT PICTURE    011/04
        TMI     NOREW                IF CURRENT PICT LATER ON TAPE  011/06
REW     CLA     =1                   ELSE INITIALIZE MLC            011/10
        STO     LZERO                TO FIRST TAPE RECORD           011/12
        CAL     =9B17                AND REWIND TAPE                011/14
        CALL    (RWT)                                               011/16
        TRA     PARAMS                                              011/18
NOREW   CLA     -3,1                 LAST LINE PREV PICT            011/20
        ADD     =1                   INITIALIZE MLC TO              011/22
        STO     LZERO                NEXT TAPE RECORD               011/24
PARAMS  CLA     1,1                                                 012
        STO     L2                                                  013
        CLA     2,1                                                 014
        STO     W1                                                  015
        CLA     3,1                                                 016
        STO     W2                                                  017
```

```
        TXI     *+1,1,-4                                                018
        SXA     CURLIN,1                                                019
        CALL    SABOP2               PROCESS I-TH PICTURE               020
        TRA     LOOP                 TO NEXT PICTURE                    021
CURLIN  DEC     0                    - (ADDR CURRENT LINE, DATA TBL)    021/0
TTLIN   DEC     0                    CURRENT LINE OF STBL               021/1
STBL    DEC     0                    TBL OF SQUARE SIZES
*                                    STARTS HERE
        DEC     5
        DEC     0                    END-OF-TABLE SENTINEL
DATA    DEC     3                    THRESHOLD--BROKENNESS
        DEC     0                    SQUARE SIZE--PAX  (S2)
        DEC     24                   THRESHOLD--BRIGHTNESS
        DEC     39                   NO. WDS PER TAPE RECORD            025
        DEC     0
        DEC     0
*               TBL OF PICTURE DIMENSIONS   L1,L2,W1,W2  IN EACH SET
        DEC     774
        DEC     1013
        DEC     1
        DEC     20
        DEC     774
        DEC     1013
        DEC     20
        DEC     39
        DEC     0
        END
```

format of the decimal representation of the elements of any matrix stored as follows:

1) The six-bit elements of the matrix are stored six to a computer word, left to right representatively; i.e., the leftmost six bits of the computer word represent the leftmost element of the six elements stored in the word, followed in order by the next five elements to its left on the same line of the matrix.

2) The word containing the element in the upper left corner of the matrix is stored at the core location defined as ORIGIN.

3) The width of the matrix in words (one-sixth of the number of elements per line of the matrix) is defined as MXWDTH. The first line of the matrix is stored in MXWDTH words beginning at ORIGIN and occupying progressively higher core positions. The second line of the matrix is stored similarly beginning at ORIGIN + MXWDTH, ..., the i^{th} line at ORIGIN + (i-1) MXWDTH, ..., and so forth.

Any part of the matrix may be printed out. MXDUMP is called by the following calling sequence:

```
CAL   L(N)
CALL  MXDUMP, ORIGIN, MXWDTH, L1, L2, W1, W2
BCI   3, LABEL, HEADING
(RETURN LOCATION)
```

L(N) = the logical tape unit of the output tape
MXDUMP, ORIGIN, & MXWDTH are as defined above
L1 = the first line of the matrix
L2 = the last line of the matrix
W1 = the first word of the line
W2 = the last word of the line

The heading card is optional, but if used must appear as a three word BCI instruction with the first word

LABEL

followed by a space.

The next twelve characters will head the printout.

The following calling sequence produced the sample printout of MXDUMP shown in Figure 8-2.1:

```
CAL   =6B17
CALL  MXDUMP, PICT, WIDTH, L1, L2, W1, W2
BCI   3, LABEL TEST PICTURE
(RETURN LOCATION)
```

The following constants and storage must also be defined:

```
WIDTH  DEC   39
L1     DEC   5
L2     DEC   10
W1     DEC   5
W2     DEC   7
PICT   BSS   1000
```

Figure 8-2.2 presents the symbolic listing for this subroutine.

8.3 Gradient Magnitude Subroutine: (DEL)

The programs which have been developed up to this point have attempted to reduce digitized cloud pictures to those features which an observer would deem optically significant. These programs have, prior to processing, simplified the cloud picture by comparing the original elements with one or more thresholds. As a result, sixty-four possible element values are reduced to two (for SB-2 and PAX) or slightly more (for SB-3).

The program herein described is based on a different approach The picture intensity is treated as a continuous function over the plane of the picture . no prior threshold data reduction takes place. Program (DEL) is one of many programs which could be devised to extract from the original picture mathematical information to be examined for pattern locating and pattern recognizing properties

MATRIX DUMP--ELEMENTS PACKED SIX PER WORD

TEST PICTURE   LINES 3 TO 10   WORDS 5 TO 7

WORDS 5 TO 7

0	0	4	7	11	15	18	27	33	41	54	63	59	54	48	37	31	26
0	0	1	12	17	20	22	26	30	37	48	54	51	50	48	39	35	29
0	1	2	12	18	20	23	25	29	33	41	49	48	46	44	41	37	34
1	4	5	15	20	22	26	28	32	36	44	48	44	44	41	36	32	27
5	8	10	16	21	25	29	31	34	37	39	42	40	38	35	31	27	22
9	12	14	20	24	27	32	35	36	38	40	41	39	36	34	28	24	18
12	13	18	21	25	28	34	38	40	40	39	38	36	35	31	26	20	13
14	15	19	24	26	28	33	36	38	39	35	36	34	33	28	21	17	9
14	16	21	24	24	25	27	29	30	29	27	29	27	26	22	16	10	6

Figure 8-2.1

Sample Output of MXDUMP Subroutine

Figure 8-2.2

MXDUMP Symbolic Program Listing

```
*       FAP
*        MXDUMP  --  MATRIX PRINTOUT ROUTINE
*       RESTORES ALL REGISTERS
        LBL     MXDUMP,2
        ENTRY   MXDUMP
MXDUMP  SLW     TAPENO
        STQ     SAVEMQ
        SXA     XR1,1
        SXA     XR2,2
        SXA     XR4,4
        STI     SAVEI
        CLA*    2,4
        STO     MXWDTH
        CLA*    4,4
        SUB*    3,4
        ADD     =1
        STO     LENGTH
        CLA     1,4
        ANA     =077777
        ADD*    5,4
        SUB     =1
        STO     ORIGIN
        CLA*    3,4
        SUB     =1
        XCA
        MPY     MXWDTH
        XCA
        ADD     ORIGIN
        STO     ORIGIN
        CLA*    5,4
        ALS     18
        STO     W
        LXA     XR4,2
COLUMN  CAL     TAPENO
        CALL    (STH)
        PZE     FMT1,0,1
        CLA     7,2
        CAS     LABEL
        TRA     *+2
        TRA     LABELD
        LDQ     =060606060606060
        STR
        LDQ     =060606060606060
        STR
        CLA     =7
        STA     RETURN
COORDS  LDQ*    3,2
        LLS     18
        STR
        LDQ*    4,2
        LLS     18
        STR
        LDQ*    5,2
        LLS     18
        STR
        LDQ*    6,2
        LLS     18
        STR
        LDQ     W
        STR
```

```
        CLA     W
        ADD     =6B17
        STO     W
        ARS     18
        CAS*    6,2
        TRA     LSTCLM
        TRA     LSTCLM
NOTLST  CLA     W
        SUB     =1B17
        XCA
        STR
        CLA     =6
        STO     ROWDTH
        TRA     SETFMT
LSTCLM  LDQ*    6,2
        LLS     18
        STR
        XCA
        ADD     =7B17
        SUB     W
        ARS     18
        STO     ROWDTH
SETFMT  CALL    (FIL)
        CAL     =0777777770000
        ANS     FMT2+1
        LDQ     ROWDTH
        MPY     =6
        DVP     =10
        ORS     FMT2+1
        XCA
        ALS     6
        ORS     FMT2+1
        CAL     TAPENO
        CALL    (STH)
        PZE     FMT2,0,1
        CLA     ORIGIN
        ADD     =6
        STO     ORIGIN
        STA     LFTWRD
LLINES  LXA     LENGTH,4
        LXA     ROWDTH,2
WWORDS  LDQ*    LFTWRD
SIXFLS  AXT     6,1
        CLA     =0
        LGL     6
        STQ     SAVEQ
        LGR     18
        STR
        LDQ     SAVEQ
        TIX     SIXFLS+1,1,1
        TIX     WWORDS,2,1
        CLA     LFTWRD
        ADD     MXWDTH
        STA     LFTWRD
        TIX     LLINES+1,4,1
        CALL    (FIL)
        LXA     XR4,2
        CLA*    6,2
```

```
         ALS       18
         SUB       W
         TMI       OUT
         TRA       COLUMN
LABELD   LDQ       8,2
         STR
         LDQ       9,2
         STR
         CLA       =10
         STA       RETURN
         TRA       COORDS
OUT      LXA       XR1,1
         LXA       XR2,2
         LXA       XR4,4
         LDI       SAVEI
         LDQ       SAVEMQ
         TRA*      RETURN
LABEL    BCI       1,LABEL.
RETURN   PZE       0,4
LETWRD   PZE       0,2
MXWDTH   DEC       0
LENGTH   DEC       0
ROWDTH   DEC       0
ORIGIN   DEC       0
TAPENO   DEC       0
SAVEMQ   DEC       0
SAVEI    DEC       0
SAVEQ    DEC       0
XR1      DEC       0
XR2      DEC       0
XR4      DEC       0
W        DEC       0
FMT1     BCI       9,(1H136X43HMATRIX DUMP -- ELEMENTS PACKED SIX PER WORD/
         BCI       9,1H-12X2A6,20X5HLINES1I5,4H  TO1I5,20X5HWORDS1I4,4H  TO
         BCI       5,1I4/6H6WORDS1I4,4H  TO1I4)
FMT2     BCI       3,(1H-/1H9(/36I3))
         END
```

and correlated with the results of analyses by other programs. The aim here is to preserve and accumulate information rather than to simplify; that is, to determine which of those properties easily extracted and recognized by a computer discriminate best among cloud shapes and distributions. Emphasis here is on program compatibility, flexibility, and speed.

8.3.1 Theoretical Basis

The magnitude of the gradient of the picture brightness at a point is the maximum change in intensity in the neighborhood of the point. It is therefore expected that well-defined boundaries will be extracted by this subroutine. On the other hand, the program will facilitate the detection of hazy boundaries whose positions are not well-defined, because these will not be represented by a thin line of high gradient value. The significance of their positions can then be considered in shape-defining processes.

It is further expected that a simple integration of the gradient magnitude over large areas of a meteorological picture will reveal whether or not there is a pattern present in that section of the picture. Once a pattern is detected, a local inspection of the gradient magnitude distribution over its functional range will reveal information which can be studied for pattern identification.

The number of boundary elements in the picture may be correlated, for example, with the amount of cloud cover, the number of closed level curves resulting from a threshold slice of the original picture, or any other property extracted from the picture by other subroutines.

8.3.2 Logical Description

This subroutine produces a function proportional to the square of the magnitude of the gradient. Taking the square root at each point is very costly in computer time and there is no real disadvantage in treating the result in this form.

Initial application of this technique to the pictures at hand revealed that values of the function which are less than four are purely a random property of the picture and should be ignored. Further, it was observed that values in the range of 160 and above can be interpreted as being virtually the same, chiefly the result of the divergence of the square of the actual value. By dividing the values by four it was found that the original range of 0 to 255, which includes the range of significance, can be compressed into a range of 0 to 63 which can be stored as a packed matrix in the standard form used in the other programs described in this report.

The values computed correspond to the gradient at a point one half-element width to the left and one half-element width below the point at which the value is stored. The definition used for the gradient was:

$$\left|\nabla I(x,y)\right| = \left\{ \left[I\left(x-\frac{h}{2}, y+\frac{h}{2}\right) - I\left(x+\frac{h}{2}, y-\frac{h}{2}\right) \right]^2 + \left[I\left(x+\frac{h}{2}, y-\frac{h}{2}\right) - I\left(x-\frac{h}{2}, y-\frac{h}{2}\right) \right]^2 \right\}^{1/2}$$

where I is the intensity at the point and h is the distance between elements. x and y are the coordinates of the plane.

The program will read a picture from a tape which is in the format described in the earlier parts of this report, and store the above described function in memory at the location designated in the calling sequence.

In calling this routine the sequence which appears at the head of the listing or equivalent must be used. To locate the picture properly, it is important that the current tape position (tape line number) be stored in the location specified. This value will be changed by the subroutine to that of the final tape position at which the subroutine leaves the input data tape.

The symbolic listing follows as Figure 8-3.1. A sample printout of a (DEL) analysis of P4, depicting a vortex, is shown in Figure 8-3.2. It was produced by the THPICT output routine described in the next section.

8.4 Picture Printout Subroutine: THPICT

This subroutine will produce a symbolic picture representation of any element matrix packed in the standard form described above. Executing the calling sequence which heads the listing of THPICT in Figure 8-4 will call this subroutine.

The following parameters are interpreted as described below:

```
PICT  BSS  10000
L     DEC  240
W     DEC  39
N     DEC  13
T     DEC  15, 24, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42
SS    BCI  1,
      BCI  1, $
      BCI  1, /
      BCI  1, 0
      BCI  1, 1
      BCI  1, 2
      BCI  1, 3
      BCI  1, 4
```

Figure 8-3.1

(DEL) Symbolic Program Listing

```
*      FAP
*      (DEL) -- GRADIENT MAGNITUDE
       LBL      (DEL),2
       ENTRY    (DEL)
***********************************************************************
*                A PROGRAM TO READ A PICTURE FROM TAPE AND STORE 1/4  *
*  OF THE SQUARE OF THE MAGNITUDE OF THE GRADIENT AT EACH ELEMENT IN  *
*  MEMORY                                                             *
***********************************************************************
*  -------- --- -------  CALLING SEQUENCE  --------- -  -------------*
*                                                                     *
*      CAL      L(N)                                                  *
*      CALL     (DEL),WR,L1,L2,W1,W2,PICT,LNCTR                       *
*        (RETURN LOCATION)                                            *
*                                                                     *
*               L(N) = LOGICAL INPUT TAPE UNIT                        *
*               WR = WORDS PER TAPE RECORD                            *
*               L1 = FIRST LINE OF TAPE PICTURE                       *
*               L2 = LAST  LINE OF TAPE PICTURE                       *
*               W1 = FIRST WORD OF TAPE LINE                          *
*               W2 = LAST WORD  OF TAPE LINE                          *
*               PICT = ORIGIN OF PICTURE IN CORE                      *
*               LNCTR = CURRENT TAPE POSITION                         *
*            THE ABOVE REFER TO CORE LOCATIONS CONTAINING THESE VALUES *
***********************************************************************
(DEL)  LMTM
       SXA      RETURN,4
       SLW      L(N)
       STD      D
       STD      DD
       STD      DDD
       STD      DDDD
       CLA      6,4
       STA      P(IJ)
       CLA*     1,4
       PAX      0,1
       SXD      IOB1,1
       SXD      IOB2,1
       CLA*     2,4
       SUB*     7,4
       TMI      REW
       TZE      REW
READ   PAX      0,3
       CALL     RDSBIN
D      TIX      0,0,**
       TIX      IOB1,1,0
       TIX      0,1,0
       TIX      *-4,3,1
       CALL     RDSBIN
DD     TIX      0,0,**
       TIX      IOB2,1,0
       TIX      0,1,0
       LXA      RETURN,4
       CLA*     3,4
       SUB*     2,4
       PAX      0,5
       LBT
       TXI      *+1,5,-1
       PXA      0,5
       ADD*     2,4
```

```
         ADD     =1
         STO*    7,4
         CLA*    5,4
         ADD     =1
         PAX     0,1
         SUB*    4,4
         STO     W
         SCD     DCR1,1
         AXT     0,7
NXLIN    CLA*    4,4
         PAC     0,6
         LDQ     BUF1-1,6
         AXT     6,2
         LGL     6
         ANA     =077
         STO     A1+6,2
         TIX     *-3,2,1
         LDQ     BUF2-1,6
         AXT     6,2
         LGL     6
         ANA     =077
         STO     B1+6,2
         TIX     *-3,2,1
         STZ*    P(IJ)
         AXT     5,2
         AXT     6,3
         TRA     NXELM
NXWRD    LDQ     BUF1-1,6
         AXT     6,2
         LGL     6
         ANA     =077
         STO     A1+6,2
         TIX     *-3,2,1
         LDQ     BUF2-1,6
         AXT     6,2
         LGL     6
         ANA     =077
         STO     B1+6,2
         TIX     *-3,2,1
         TXI     *+1,7,-1
         STZ*    P(IJ)
         AXT     6,2
         AXT     0,3
NXELM    CLA     A1+5,2
         SUB     B1+6,2
         STO     AB
         XCA
         MPY     AB
         STQ     AB
         CLA     A1+6,2
         SUB     B1+5,2
         STO     BA
         XCA
         MPY     BA
         XCA
         ADD     AB
         ARS     2
         LDI     =077
```

```
        TIO     *+2
        CLA     =O77
        ALS     30,3
        ORS*    P(IJ)
        TXI     *+1,3,6
        TIX     NXELM,2,1
        CLA     A1+5
        STO     A0
        CLA     B1+5
        STO     B0
        TXI     *+1,6,-1
DCR1    TXH     NXWRD,6,**
        TXI     *+1,7,-1
        PXA     0,5
        LBT
        TRA     EVEN
        CALL    RDSBIN
DDD     TIX     0,0,**
        TIX     IOB1,1,0
        TIX     0,1,0
        TRA     *+5
EVEN    CALL    RDSBIN
DDDD    TIX     0,0,**
        TIX     IOB2,1,0
        TIX     0,1,0
        LXA     RETURN,4
        TIX     NXLIN,5,1
        TRA     8,4
REW     STZ*    7,4
        CAL     L(N)
        CALL    (RWT)
        LXA     RETURN,4
        CLA*    2,4
        TRA     READ
L(N)    DEC     0
RETURN  DEC     0
W       DEC     0
P(IJ)   PZE     **,7
IOB1    IORT    BUF1,0,**
IOB2    IORT    BUF2,0,**
A0      DEC     0
A1      BSS     6
B0      DEC     0
B1      BSS     6
AP      DEC     0
BA      DEC     0
BUF1    BSS     50
BUF2    BSS     50
        END
```

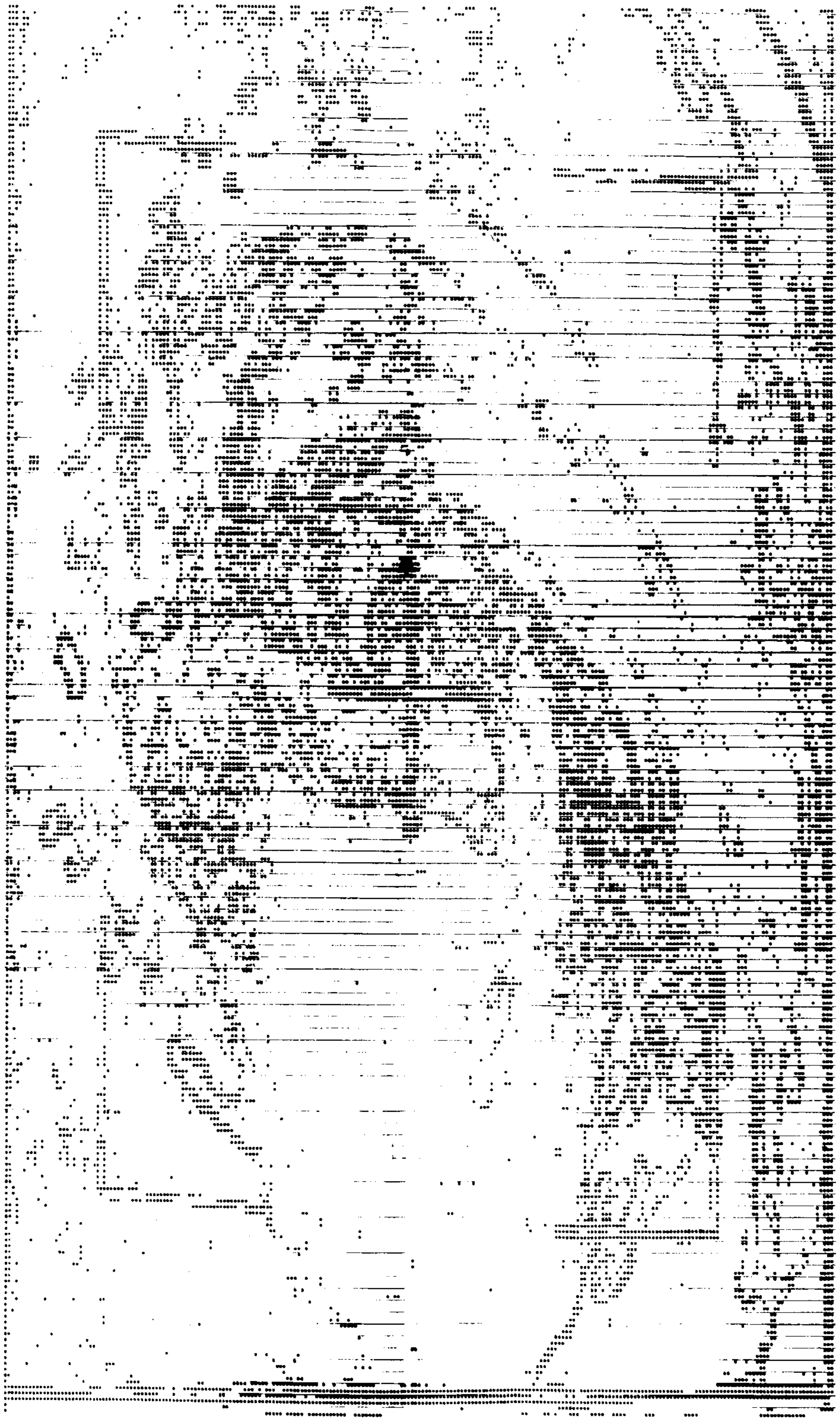


Figure 8-3.2

Sample Picture Output by Gradient Program

Figure 8-4

THPICT Symbolic Program Listing

```
*     FAP
*      PICTURE PRINTOUT
*************************************************************************
*          A SUBROUTINE TO PRINTOUT A MULTI COLOR PICTURE FROM MEMORY   *
*    GIVEN  N  THRESHOLDS AND  N+1  COLOR SYMBOLS                       *
*************************************************************************
*   -------  -  -----   CALLING SEQUENCE  -- ------- -  ---------------*
*                                                                       *
*                                                                       *
*       CAL     L(N)                                                    *
*       CALL    THPICT,PICT,L,W,N,T,SS                                  *
*         (RETURN LOCATION)                                             *
*                                                                       *
*               L(N) = LOGICAL OUTPUT TAPE UNIT                         *
*               PICT = ORIGIN OF PICTURE IN MEMORY                      *
*               L = NUMBER OF LINES IN PICTURE                          *
*               W = NUMBER OF WORDS TO A PICTURE LINE                   *
*               N = NUMBER OF THRESHOLDS                                *
*               T = LOWEST THRESHOLD, LOWEST IN CORE                    *
*               SS = LOWEST SYMBOL, LOWEST IN CORE                      *
*      THE ABOVE REFER TO CORE LOCATIONS CONTAINING THE RESPECTIVE VALUE*
*************************************************************************
        LBL     THPICT,2
        ENTRY   THPICT
THPICT  LMTM
        SLW     L(N)
        CLA     1,4
        STA     OTWRD
        AXT     64,1
        CLA     LTBL
        STO     TABLE+64,1
        TIX     *-1,1,1
        CLA     5,4
        STA     THRESH
        CLA     6,4
        STA     SYMBOL
        AXT     64,1
        CLA*    4,4
        PAX     0,3
        AXT     0,2
LOAD    CAL*    SYMBOL
        ANA     =077000000000
        ORS     TABLE+64,1
        PCA     0,1
        ADD     =65
        ANA     =077
        CAS*    THRESH
        TXI     *+3,2,-1
        TXI     *+2,2,-1
        TIX     LOAD,1,1
        TIX     *-1,3,1
        TXI     *+1,1,-1
        CAL*    SYMBOL
        ANA     =077000000000
        ORS     TABLE+64,1
        TIX     *-1,1,1
        SXA     RETURN,4
        CLA*    3,4
        STO     W
        SUB     =20
        PAX     0,4
```

```
        SCD     DCR2,4
        STZ     WX
OTPUT   CAL     L(N)
        CALL    (STH)
        PZE     FMT1,0,1
        CALL    (FIL)
        LXA     RETURN,4
        CLA*    2,4
        PAX     0,3
        LAC     WX,7
        CLA     W
        SUB     =21
        STO     WW
        TMI     OTLIN
        CLA     =20
        STO     W
OTLIN   LXA     W,2
        CAL     L(N)
        CALL    (STH)
        PZE     FMT2,0,1
OTWRD   LDQ     **,7
        CRQ     TABLE,0,6
        STR
        TXI     *+1,7,-1
        TIX     OTWRD,2,1
        CALL    (FIL)
DCR2    TXI     *+1,7,**
        TIX     OTLIN,3,1
        CLA     WW
        LXA     RETURN,4
        TMI     7,4
        ADD     =2
        STO     W
        CLA     WX
        ADD     =19
        STO     WX
        TRA     OTPUT
W       DEC     0
WW      DEC     0
WX      DEC     0
L(N)    DEC     0
RETURN  DEC     0
LTBL    PZE     TABLE
SYMBOL  PZE     0,2
THRESH  PZE     0,2
FMT1    BCI     1,(1H1)
FMT2    BCI     2,(1H9,20A6)
TABLE   BSS     64
        END
```

```
BCI   1, 5
BCI   1, 6
BCI   1, 7
BCI   1, 8
BCI   1, 9
BCI   1, .
```

The symbols PICT through SS are defined at the head of the THPICT program listing. For output all elements of the matrix whose value is less than 15 will be represented by a blank ( ),

```
          15 to 23 by a ($),
          24 to 31 by a (/),
          32       by a (0),
          33       by a (1),
          34       by a (2),
          35       by a (3),
          36       by a (4),
          37       by a (5),
          38       by a (6),
          39       by a (7),
          40       by a (8),
          41       by a (9),
    and   42 to 63 by a (.)
```

8.5 Frequency Count Subroutine: F(RNG)

This subroutine makes a frequency count of the distribution of the function values stored in a matrix of the form described above. It can count over the entire matrix or any segment thereof. The sums are stored, with the total number of elements whose values are zero, in the location designated SUM and specified in the calling sequence. The totals of the sixty-three other values are stored in progressively higher core locations. The symbolic listing for F(RNG) is presented in Figure 8-5.

Figure 8-5

F(RNG) Symbolic Program Listing

```
*      FAP
*       FREQUENCY DISTRIBUTION    --    F(RNG)
***********************************************************************
*           A SUBROUTINE TO COMPUTE THE FREQUENCY DISTRIBUTION OF A     *
*    FUNCTION OF   X   AND   Y   WHOSE RANGE IS   0   TO   63   AND WHOSE  *
*    DOMAIN IS AN ARRAY PACKED 6 ELEMENTS PER WORD                      *
***********************************************************************
*   -------- --- -------  CALLING SEQUENCE  --------- -  ------ ----   *
*                                                                       *
*       CALL      F(RNG),PICT,WIDTH,L1,L2,W1,W2,SUM                     *
*          (RETURN LOCATION)                                            *
*                                                                       *
*                 PICT = ORIGIN OF MATRIX                               *
*                 WIDTH = NUMBER OF WORDS PER LINE OF MATRIX            *
*                 L1 = FIRST LINE TO OUTPUT                             *
*                 L2 = LAST LINE                                        *
*                 W1 = FIRST WORD OF LINE                               *
*                 W2 = LAST WORD OF LINE                                *
*                 SUM = LOCATION OF SUM TABLE                           *
*    THE ABOVE REFER TO CORE LOCATIONS CONTAINING THE RESPECTIVE VALUES*
***********************************************************************
        LBL     F(RNG),2
        ENTRY   F(RNG)
F(RNG)  LMTM
        SXA     RETURN,4
        CLA     7,4
        STA     SUM
        ADD     =64
        STA     FR(11
        AXT     64,1
FR(11   STZ    **,1
        TIX     *-1,1,1
FR(21   CLA     1,4
        STA     P(LW)
FR(22   CLA*    2,4
        STO     WIDTH
FR(23   CLA*    3,4
        SUB     =1
        XCA
        MPY     WIDTH
        XCA
        ADD*    5,4
        SUB     =1
        PAC     0,7
FR(24   CLA*    6,4
        SUB*    5,4
        ADD     =1
        STO     W
FR(241  SUB     WIDTH
        PAC     0,3
        SXD     FR(32,3
FR(25   CLA*    4,4
        SUB*    3,4
        ADD     =1
        PAX     0,6
FR(26   LDI     =0
FR(30   LXA     W,5
FR(31   LDQ*    P(LW)
        AXT     6,3
FR(311  PIA
```

```
         LGL     6
         PAC     0,2
SUM      CLA     **,2
         ADD     =1
         STO*    *-2
         TIX     FR(311,3,1
         TXI     *+1,7,-1
         TIX     FR(31,5,1
FR(32    TXI     *+1,7,**
         TIX     FR(30,6,1
         LXA     RETURN,4
         TRA     8,4
RETURN   DEC     0
P(LW)    PZE     **,7
W        DEC     0
WIDTH    DEC     0
         END
```

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