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Techniques for Obtaining Fabric Data From Coarse Clastic Sediments*

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ABSTRACT.—Studies of coarse clastic sediments have been difficult because of the tedious and time-consuming methods used for description and classification. Exploratory investigation into the utilization of optical scanning and computer techniques in the study of coarse clastic sediments indicates that more rapid and accurate analyses can be made. Three optical scanners exist which when linked to a digital computer may provide geologists with a tool that can be used for analyzing coarse clastic sediments as well as a variety of other geological phenomena.

The IBM 2281 Film Scanner is an input device for converting images of rock fabric and texture recorded on photographic film into digital data. Photographs of outcrops or thin sections of rocks are placed between a cathode ray tube and a photomultiplier tube, and a light beam passing through the film is either sensed or not sensed by the photomultiplier tube, depending upon the nature of the image on the film. This response is an expression of texture and fabric which can be turned over to the computer for storage and processing.

A photomultiplier tube is also used with a point-counting mechanism called the Ameda System. However, the light coming through the photograph and a microscope lens system is analyzed by an electronic circuit, which tabulates and accumulates the results.

Fraunhofer diffraction patterns produced by an optical data processing system and laser light can be used to determine fabric of a rock as well as relative size frequency of a coarse clastic sediment.

Results of this study indicate that three techniques have real potential, but some critical problems must be solved before a finished procedure is available for use in sedimentological studies. The most critical of these is adapting one of the optical scanners so that a photograph of a coarse clastic sediment may be accurately digitized. Results also indicate that future technological developments in the field of optical scanning will solve this problem and make possible a method of analyzing clastic sediments that can be applied to sedimentological studies of conglomerates, sandstones, and possibly other rock types.

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*A thesis submitted to the faculty of the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, May 6, 1968.

INTRODUCTION

Studies of coarse clastic sediments have long presented serious problems because of the tedious and time-consuming methods used to obtain size-frequency distributions, and sedimentary fabric data. The equal area polar coordinate plot proposed by Krumbein (1939, 1940, 1942) requires approximately 1¼ hours to mark 50-75 pebbles. With this method, the pebbles are marked in the field and subsequently reoriented on the two-circle goniometer in the laboratory. Since the pebbles must be transported back to the lab the size of the sample is limited. A modification of the equal area polar coordinate plot was proposed by Schlee (1957). This technique allows two experienced operators to measure approximately 35 pebbles per hour, and all measurements are made in the field. Both of these techniques are applicable only to unconsolidated gravels.

Conglomerates, like other types of sediments, are products of environmental conditions. but they may be deposited through a wide range of conditions. They commonly have a wide variation in composition and may be formed from essentially all kinds of rocks, including shale, mud, and peat which may produce gravels and boulders (Twenhofel, 1947). Not only are studies of coarse clastics tedious and time consuming, they are also subjective because of the wide variation of environments in which they may be deposited. Therefore, rapid and accurate methods of description are needed so that reliable interpretations of the depositional environment of conglomerates can be made.

METHODS OF STUDY

The initial objective of this study was to develop a computer method of analyzing and differentiating different types of coarse clastic deposits. To achieve this objective it was proposed that outcrops of coarse clastics be photographed, using black and white film to record the textural characteristics displayed by the deposit. Then, using optical scanning equipment, the image on the photograph was to be digitized and the resulting data fed into the computer for final processing and calculation of statistical measures such as sorting, mean, standard deviation, and others that numerically express the characteristics of the deposit. After processing hundreds of coarse clastic deposits of known origin in this manner, parameters may be established that might be used to describe and classify corresponding types of deposits found in the geologic record. The parameters would be a function of measurable textural properties of the deposit such as size-frequency distribution, preferred orientation of elongate grains, and coefficient of stratification.

When the preliminary investigation began it became evident that a considerable portion of the project would involve development of techniques that would convert the textural aspects of a coarse clastic deposit, as recorded on a photograph of the outcrop, into a form that could be utilized by the computer. Several methods of extracting the data from the photograph have been investigated. Silhouettes of large clasts were inked over on a photograph, and then the matrix was bleached out to allow scanning with laser light. An attempt was made by Dr. J. W. Harbaugh of Stanford University to mathematically calculate two-dimensional fourier transforms from data extracted manually from the photograph, and three different optical scanners have been employed in an attempt to digitize the image on the photograph so that computer processing could be possible. The problem of converting graphic and pictorial data into a form that allows computer processing is not restricted to the field of geology, although the nature of most geologic data makes the solution an attractive goal.

The present objective of this study is limited to investigation of existing optical scanning methods that will convert images on film into digitized data which can be utilized by a computer for calculating sorting coefficients, means, standard deviations, and other statistical measures used to interpret coarse clastic sediments. The equipment investigated includes the IBM 2281 Film Scanner, the Ameda System, and optical data processing using laser light. Initially, the objective was to link one of the optical scanners to a computer so that digitizing of a photograph could be conducted simultaneously in one operation. Time and monetary limitations have restricted the study to investigation and evaluation of existing optical scanners, and no attempt has been made to link one of these scanners to a computer.

ACKNOWLEDGMENTS

The writer expresses appreciation to a number of people who helped make this study possible: Dr. W. K. Hamblin, who suggested the problem, served as major professor, and gave much needed assistance in organizing and completing this phase of the project; Dr. J. K. Rigby, who served as a committee member and also gave many helpful suggestions during the course of the study; Dr. G. C. Carlson, who assisted in obtaining information regarding various scanning equipment; and Miss Alice Durrant, who typed the final draft of the paper.

A special note of appreciation and thanks is extended to my wife, Susanne, for help in typing the numerous rough drafts of the paper and for her constant faith and encouragement.

Finally, this paper would not have been possible without the kind cooperation of many men in industry who made test scans of the photographs at no expense to the writer. The following men must be specifically recognized for their assistance: Dr. J. C. Ludwick and Mr. D. L. Kelly of Gulf Research and Development Company, Mr. Robert Groman of Femco Incorporated, Mr. William Schenck of Technical Operations Incorporated, Mr. Arthur Stein of the Boeing Company, and Dr. V. V. Griffiths of the McDonnell Douglas Corporation.

TECHNIQUES OF OPTICALLY SCANNING AND DIGITIZING PHOTOGRAPHS OF COARSE CLASTIC SEDIMENTS

THE IBM 2281 FILM SCANNER

The IBM 2281 Film Scanner is an input device for converting images on preprocessed film into digital data. A light beam generated by a cathode ray tube is directed along two paths (Text-fig. 1A), one through the film to a photomultiplier tube and the other directly to a second photomultiplier tube. By comparing the amount of light passing through the film with the light intensity of the cathode ray tube beam, the IBM 2281 circuitry determines whether a strike has occurred. A strike is a response which is above the preset level of light threshold sensitivity set by the program. Any one of the 64 threshold values may be selected, thus providing the IBM 2281 with the ability to scan film of different density, contrast, and image quality. Scanning results may be put directly into a computer for program analysis or recorded on magnetic tape for future use.

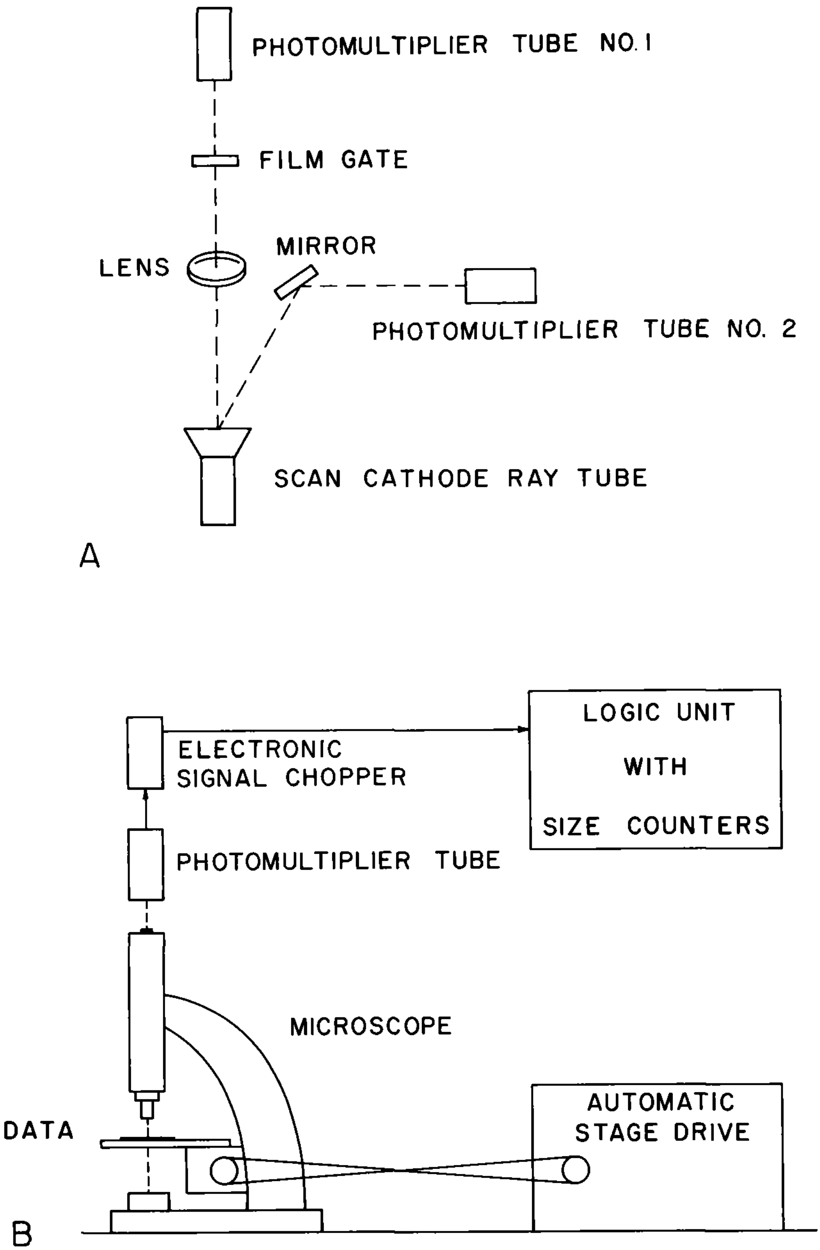
Four subroutines are provided with the scanner for locating, identifying, and analyzing data recorded on film. These subroutines and their basic functions are listed below:

1. The S. GRSP (rectangular scan pattern) subroutine may be utilized to search a rectangular section of the film whose size and location is specified by the operator. When the image being sought is located, it is possible for the operator to have the subroutine record in digital form the points which define the size and shape of the image. Thus when scanning photographs of coarse clastic sediments, a small rectangular section would be searched by the scanner until a grain is located. Then the size and shape information would be digitized and recorded on magnetic tape or fed directly into the computer for analysis. The scanner would repeat this process until all of the grains in the rectangle have been located, scanned and recorded. The operator could then specify another rectangular area on the photograph and the entire process would be repeated until a significant portion or all of the photograph has been scanned and analyzed. Many times the operator may want to use this subroutine to locate only an initial point on an object from which the line-follower or edge-follower subroutine would take control of the scanner and define the size and shape of the object.

2. When the approximate location of an object is known, the S. GPRB (vector probe) subroutine may be used to find an initial point on the object of interest from which the line-follower or edge-follower subroutine would scan and digitize the object. This subroutine provides a one dimensional scan or, in other words, it scans in a straight line between two points or from a given point in any specified direction. When scanning photographs of coarse clastic sediments, the vector probe could be used to initiate the analysis by scanning from an edge of the photograph across the photo in a horizontal direction until a pebble or boulder was located. One of the subroutines would then control scanning until the clast was defined by size and shape. This information would be digitized and processed by the appropriate method. After this was completed the vector probe subroutine would again scan horizontally until another clast was located. This sequence of steps would be repeated until the entire photograph had been scanned and digitized.

3. After the rectangular scan pattern or the vector probe subroutine locates an object, the S. GBLF (basic line follower) subroutine follows the outer margin on both sides and gives the operator equally spaced points along each edge. The operator can then use this information to compute the center line in whatever manner he chooses. This subroutine should only be used to follow noncomplex lines that flow in one continuous direction and thus will find little or no application to analysis of the grains in a coarse clastic sediment.

4. The purpose of the S. GBEF (basic edge follower) subroutine is to scane an object on the film and provide the operator with points that define its configuration. It can be effectively used to scan objects of various complexities, including those with many curves and intersections such as contour map photographs, cloud chamber traces, etc.



TEXT-FIGURE 1.—A. Schematic diagram of the IBM 2281 film scanner. B. Schematic diagram of the Ameda System.

The operator must supply the routine with a starting position commonly determined by the rectangular scan pattern or the vector probe subroutine. This should be a point lying just outside the edge of the object to be scanned. The subroutine controls the scanning and follows the edge in either a clockwise or counterclockwise direction.

When applied to analysis of coarse clastic sediments, the basic edge-follower subroutine would be used in conjunction with either the rectangular scan pattern or vector probe subroutine. The sequence of operation is explained in the above descriptions of those two subroutines. The basic edge-follower subroutine would be the principal scanner control for determining the size and configuration of particles in a coarse clastic deposit (IBM, 1966).

Indications are that most types of geologic data could be scanned and analyzed utilizing one or combinations of the above subroutines. If, however, the operator has unique data that cannot be effectively scanned using the standard subroutines, it is possible to write additional subroutines to control scanning of his data.

Only two IBM 2281 Film Scanners were manufactured, one located in California and the other in Alabama. From September 1966 to January 1967 the writer corresponded with Mr. Arthur Stein of the Boeing Company in Huntsville, Alabama, in an attempt to obtain some test scans of photographs of coarse clastic sediments using an IBM 2281, which was being utilized by their Launch Systems Department. Mr. Stein attempted to scan some photographs of clastic sediments, but the subroutines used are for scanner control designed solely for graphic interpretation, and so he was unable to digitize the data recorded on the variable density photographs.

At the present time, future development of the IBM 2281, as described above, has been abandoned, and IBM is working on other scanners which employ different basic operating principles. The writer recently learned that the two IBM 2281's have been cannibalized to provide components for the new equipment.

The writer feels that the IBM 2281 is potentially the most important of the three scanners investigated because provision for computer linkage is built into the system and also because the scanning unit generates results that are already in digital form. Thus the digital output of the scanning system is readily amenable to computer analysis. At the present time the IBM corporation is in the developmental stage with respect to optical scanners, as noted by the fact that the two prototypes have been dismantled and the components used for other scanners. The information now available regarding the success of the two prototypes indicates that IBM will soon make available a self-contained optical scanner that will enable rapid and accurate analyses of all types of geologic data, including coarse clastic sediments, thin sections of sedimentary, metamorphic and igneous rocks of all types, contour maps, aerial photographs showing joint patterns, and many others.

THE AMEDA SYSTEM

The Ameda System is an automated microscope electronic data accumulator used for point counting and particle size determination. It was designed initially for determining the percentages of microconstituents in metallographic specimens. However, the system is quite versatile in its application and can be used to scan and digitize photographs of many different types of data, such as polished sections of coal, counting of blood cells on a glass slide, size analysis of minerals in a rock thin section, and many others.

Preliminary testing showed that a negative photograph of a coarse clastic sediment could not be analyzed because there was not enough light contrast between the matrix and the clasts. To overcome this problem, the photograph was enlarged and printed on photographic paper and the clasts were inked over with india ink. Then the photographic emulsion was bleached out, leaving black silhouettes on a white background. This print was then photographed to reduce the large print and to produce a negative with white clasts on a black background. With photographs prepared in this manner the system can readily discriminate between the area occupied by matrix and the area occupied by the large grains of the coarse clastic.

Textural data recorded on the film in the above manner are placed on the stage of a microscope which allows focusing on a small part of the film (Text-fig. 1B). Scanning is then accomplished by the automatic stage drive which controls the motion of the microscope stage while the textural data recorded on the film are scanned through the optics of the microscope.

The microscope stage is driven past the objective at a constant rate, for example one millimeter per second. The length of the scanning travel is controlled by adjustable limit switches in the stage-drive mechanism. At the end of the scan, the table is moved in a transverse direction a preset distance. Then the microscope stage reverses direction, thus passing the sample under the objective again. Once initiated, the sequence of stage movements will continue automatically until the entire sample has been scanned and analyzed.

Light transmitted through a photograph of a coarse clastic sediment is picked up by a photomultiplier tube and converted to an electric impulse. The signal from the photomultiplier tube is an electrical analog representation of the sample passing under the microscope. This signal is chopped at constant rate (for example, 1,000 pulses per second) by an electronic chopper, thus converting the analog signal to a digital signal. Inasmuch as the traverse speed of the stage is constant, the interval of time that the instrument would record a light value above the predetermined level can be converted to microns and be recorded in the proper size category. The Ameda System is capable of making one million point counts on a sample in twenty minutes; each point count is a one-micron diameter field (Femco Inc., 1967).

Six photographs were processed by the Ameda System during February and March 1968. The photographs were scanned in both an east-west and north-south direction. Results were returned as a percentage of total area covered by each size class.

Coarse clastic sediments are usually analyzed texturally by counting and measuring the weight percentage or size frequency from a given sample. This results in a size frequency distribution which is then analyzed by the standard statistical measures used in sedimentology, such as sorting, mean, standard deviation, etc. These analyses tend to give misleading results inasmuch as most size-frequency curves of conglomerates are bimodal with the strongest mode located in the smaller size classes. In actual numbers the small clasts far outnumber the larger ones, but in terms of the volume in the deposit which is occupied by the larger clasts they are much more significant.

As stated before, scan results obtained from the tests made with the Ameda System show the percentage of the total area which is covered by each size class. We are thus able to determine how each size class affects the nature of the deposit from the standpoint of the area it covers in a two-dimensional outcrop rather than just a determination of the number of particles or weight of a grain-size range in the sample. It is also possible to determine size frequence using the Ameda, but because the writer did not have personal access to the equipment only area percentage determinations were made.

Text-figure 2A shows two area percentage curves created by scanning a photograph of a conglomerate in both an east-west and north-south direction. Note that the two curves are rather different in general form, although the high point on each curve falls at minus 7 phi, and both are skewed strongly to the right, showing only the mode produced by the large grains. The east-west curve has a higher mode and a smaller standard deviation than does the north-south curve. It is thought that this difference may be an expression of stratification displayed by the deposit, but further testing is needed to substantiate this inference.

Text-figure 2B shows curves produced by Ameda analysis of a coarse clastic deposit which displays a higher degree of sorting than does Text-figure 2A. The difference in the degree of sorting is shown very well by the curves. Both modes in Text-figure 2B are higher than those in Text-figure 2A. The standard deviations in Text-figure 2B are smaller than in Text-figure 2A, thus showing that Text-figure 2B is sorted much better than Text-figure 2A, inasmuch as standard deviation expresses sorting. It should be noted at this point that the fine-grained matrix it not analyzed with the Ameda System. Only those particles large enough to be recognized as separate entities have been inked over and preserved in the negative which was analyzed by the Ameda System.

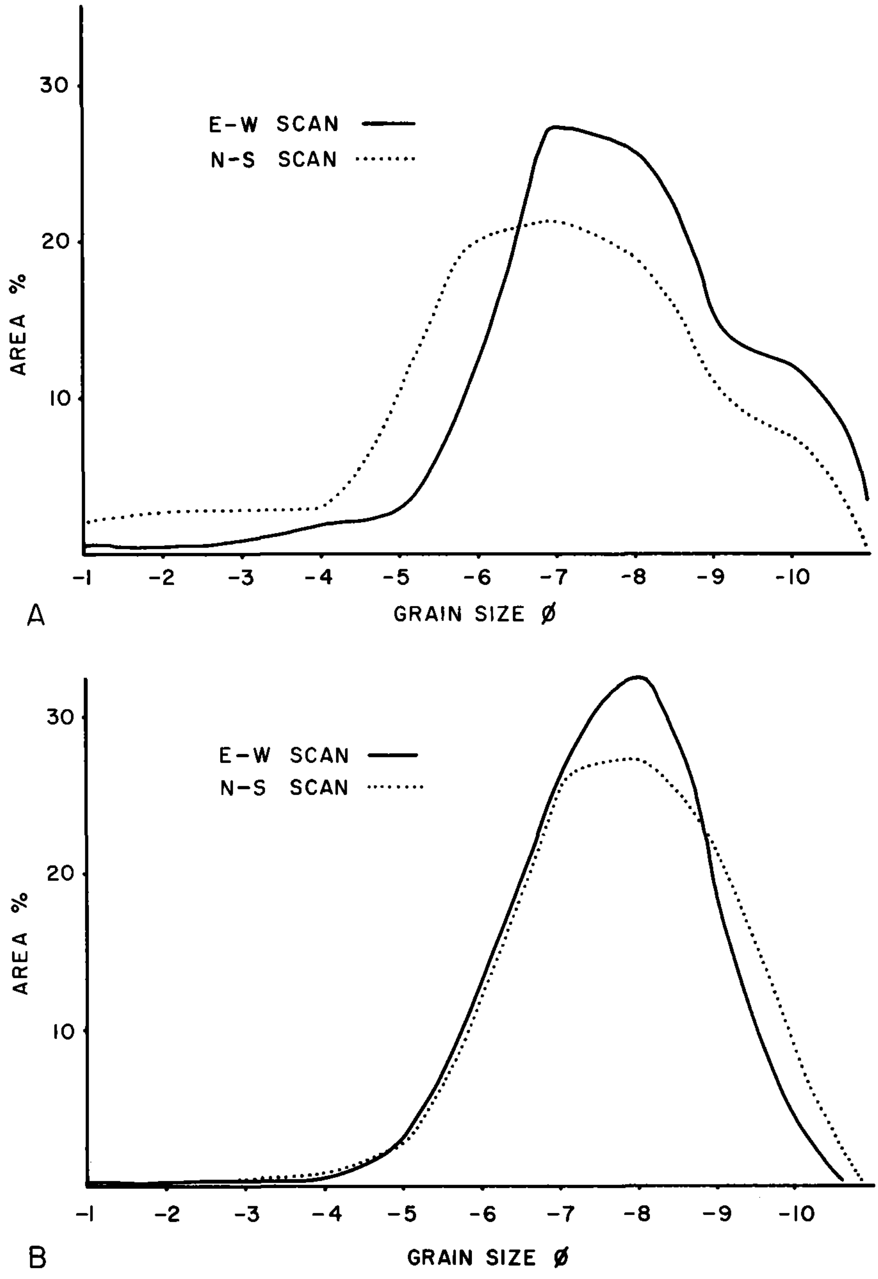
Relating the curves resulting from Ameda scanning to the original photograph is difficult because of the following factors:

1. Adjacent scan lines were spaced too closely to enable determination of size frequency from the output. The distance between adjacent scan lines is determined by a variable stage index control. The stage index used for these analyses was only 300 microns, so adjacent east-west or north-south scan lines would traverse each of the large particles many times during the analysis. This difficulty could easily be overcome by setting the stage index so that the distance between adjacent scan lines would be at least as great as the diameter of the largest grains.

2. Because of the problem stated above, the output gave an expression of the percentage of total area occupied by each size class. Though this may be a more significant measure than the size frequency, it is difficult at present to evaluate because of the limited number of samples that have been processed.

Neither of the above difficulties are serious enough to prohibit future testing with the Ameda System. The writer is confident that both of these difficulties could have been eliminated had he been present when the photographs were scanned.

Of the three scanners investigated during this study the Ameda System is at present readily accessible and produces scanning results that lend themselves conveniently to mathematical and and statistical analysis. The initial cost



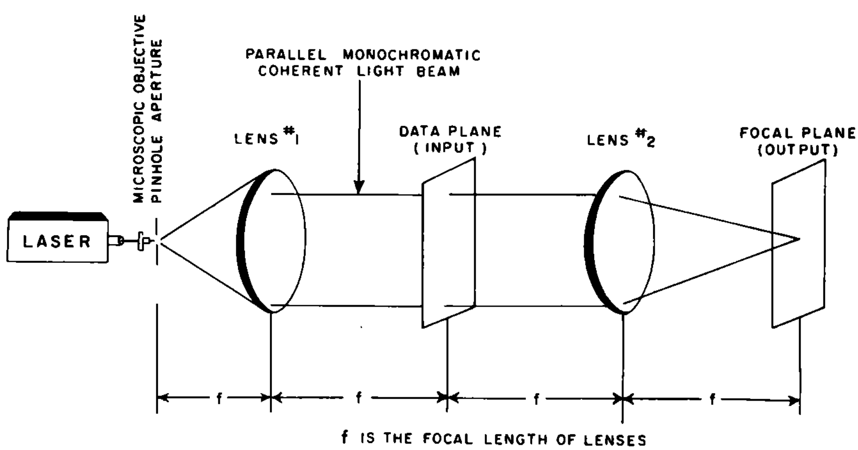
TEXT-FIGURE 2.—A and B. Area percentage curves obtained by plotting Ameda System scan results of a coarse clastic sediment.

is considerably less than that of the IBM 2281 but more than the cost required to set up an optical data-processing system. Though the Ameda System is not designed to be used in conjunction with a computer, as is the IBM film scanner, it does provide scan results that may be manipulated with computer programs to interpret the nature of the photograph; whereas the diffraction patterns produced by the optical data processing system are presently difficult to interpret with any degree of reliability. Inasmuch as the Ameda System is readily available and is presently capable of producing workable results, the writer feels that it is the best system yet devised for the type of analysis desired in sedimentological studies.

OPTICAL DATA PROCESSING

Fundamental principles of optical data processing have been known for many years (Born and Wolf, 1964; and Jennison, 1961). Recent development of laser light sources has stimulated new interest and applications. Applications of optical data processing to geological studies are still in an early stage of development. However, analysis of variable-density seismograms by this method is widely used for practical problems and has experienced considerable refinement. Some of the geologic applications now being investigated include analysis of vectorial rock fabric data, fault and joint patterns recorded on aerial photographs, black-line lineament maps, contour maps and photomicrographs of rock thin-sections (Pincus, 1966; Pincus and Dobrin, 1966).

The basic arrangement of optical components for obtaining two-dimensional diffraction patterns is described in Cutrona, *et al.,* (1965) and is shown schematically in Text-figure 3. The light source is provided by a Perkin-Elmer 5300 helium-neon gas laser with a 10 milliwatt output. The light is monochromatic and coherent with a wave length of 6,328 angstroms. The light beam is spread with a 8 mm 0.50, 21x microscope objective and a pinhole aperture. Two double convex, spherical lenses are placed a distance equal to twice their focal length apart and one focal length away from the pinhole aperture. The lenses are three inches in diameter, having a focal length of twenty inches and



TEXT-FIGURE 3.—Schematic diagram of an optical data processing system.

are coated to minimize unwanted reflection. Lens No. 1 is placed between the pinhole aperture and the data plane. Its purpose is to collimate the light coming from the pinhole aperture and provide planar light which strikes the photograph positioned in the data plane. The second lens is on the opposite side of the data plane from lens No. 1. The purpose of lens No. 2 is to focus the collimated light to a point in a plane at the focus of the lens.

Apertures in the photograph create interference of the planar light known as Fraunhofer Diffraction Patterns and may be viewed on a screen or photographed in the focal plane of lens No. 2. These patterns consist of alternating dark and light fringes whose configuration is determined by the type of data being processed.

Optical data processing techniques are used to scan the entire photograph and resolve the image on the film into directional and frequency components which describe direction and size of particles in the deposit. Diffraction patterns are cumulative expressions of all the directional and frequency components present in the deposit and can be used to determine a preferred orientation of the elongate grains if it exists, as well as the relative size-frequency distribution expressing the distribution of particle sizes in the deposit.

To visualize how images on film affect the form of their diffraction patterns it is convenient to consider diffraction patterns of some simple geometric forms. Knowledge gained from these analyses can then be used to interpret diffraction patterns of natural phenomena such as pebbles in a conglomerate or sand grains in a sandstone.

To illustrate the theoretical basis of fabric analysis by optical scanning techniques, consider the diffraction patterns produced by the following examples.

The simplest case of diffraction is that produced by a long slit aperture. Plate 1, figs. 1 and 2, show diffraction produced by two slits, one of which is twice as wide as the other. In each pattern diffraction of the planar light by the slit produces alternating dark and light fringes called orders of diffraction which decrease in intensity as they move away from the slit. Spacing of the successive orders of diffraction is a function of the size of the aperture. This is clearly illustrated by Plate 1, fig. 1, wherein orders of diffraction produced by the narrowest slit have wider spacing than do those produced by the wider slit (Plate 1, fig. 2).

A single rectangular aperture is nothing more than a specialized slit. Plate 1, fig. 3, shows a diffraction pattern produced by a rectangular aperture, with the sides differing by a ratio of 3:2. Orders of diffraction form with wide spacing as a result of diffraction of light by the narrow dimension of the rectangle. Conversely, orders of diffraction form with narrow spacing as a result of diffraction by the long dimension of the rectangle. Enlargement of the pattern as shown in Plate 1, fig. 3, illustrates some important features: The center is rectangular with the long side oriented perpendicular to the orientation of the aperture as positioned in the data plane of the system. Spacing of orders of diffraction along the north-south ray is different than along the east-west ray and differs by a ratio of 3:2, which is the ratio of the length of the sides of the rectangular aperture. For a detailed discussion of diffraction by a rectangular aperture, refer to Lemon and Ference (1943) and Rossi (1957).

Diffraction by curved apertures, such as that produced by photographs of coarse clastic sediments, follows the same pattern as that of rectangular apertures. Plate 1, fig. 4, shows diffraction by an elliptical aperture with concentric, dark and light elliptical fringes oriented perpendicular to the orientation of the ellipses in the data plane. These dark and light fringes again represent the orders of diffraction. Note that the configuration of the pattern is determined by the aperture which produces it.

Diffraction patterns of a random distribution of similarly oriented rectangles or ellipses show more intense patterns which extend farther from the center than do those produced by single apertures (Plate 2, figs. 1, 2, 3, and 4). This is true because different beams of light which have equal angular relationship with a line through the center of the lens are focused at the same point in the focal plane. Because the apertures in Plate 2, figs. 1 and 3, are of the same size, shape, and orientation, their respective diffraction patterns will be superimposed on each other in the focal plane (Plate 2, figs. 2 and 4).

In sedimentary fabric studies we are concerned with the spatial arrangement and orientation of aggregates of grains in a given deposit. To enable analysis of aggregates of grains as found in sediments, thirty idealized models were tested with optical data processing techniques. The objective of the model testing is to establish some criteria which may be used to help interpret diffraction patterns obtained from actual rock samples.

Plate 2, fig. 1, shows a sedimentary fabric model wherein 300 rectangles with a length to width ratio of 3:2 are distributed randomly with all of the

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EXPLANATION OF PLATE 1

DIFFRACTION PATTERNS OF SOME SIMPLE GEOMETRIC FORMS

FIG. 1.—Diffraction pattern produced by a slit aperture 0.015 inch wide, oriented horizontal in the optical system, 4x.

FIG. 2.—Diffraction pattern produced by a slit aperture 0.030 inch wide, oriented horizontal in the optical system, 4x.

FIG. 3.—Diffraction pattern produced by a rectangular aperture 0.030 inch by 0.020 inch with the long side oriented north-south in the optical system, 4x.

FIG. 4.—Diffraction pattern produced by an elliptical aperture whose axes measure 0.030 inch by 0.020 inch. The long axis was oriented north-south in the optical system, 4x.

EXPLANATION OF PLATE 2

DIFFRACTION PATTERNS OF SEDIMENTARY FABRIC MODELS

FIG. 1.—*Sedimentary fabric model consisting of 300 rectangles 0.030 inch by 0.020 inch,* 100 percent of which are oriented north-south, 4x.

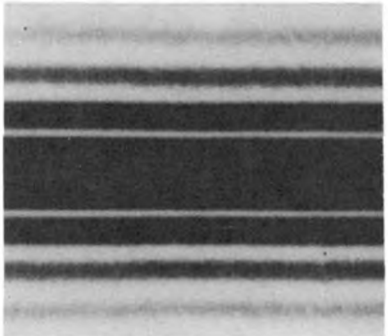
FIG. 2.—Diffraction pattern produced by optical processing a film negative of Plate 2, fig. 1, 1x.

FIG. 3.—Sedimentary fabric model consisting of 300 ellipses whose axes measure 0.030 inch by 0.020 inch. 100 percent of the ellipses are oriented north-south, 4x.

FIG. 4.—Diffraction pattern produced by optical processing a film negative of Plate 2, fig. 3, 1x.

FIG. 5.—Sedimentary fabric model consisting of 300 rectangles 0.030 inch by 0.020 inch, 50 percent (150) of which are oriented north-south and 50 percent (150) are randomly oriented, 4x.

FIG. 6.—Diffraction pattern produced by optical processing a film negative of Plate 2, fig. 5, 1x.



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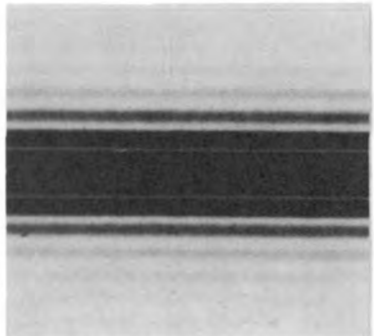

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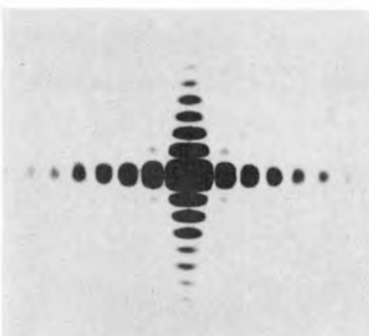

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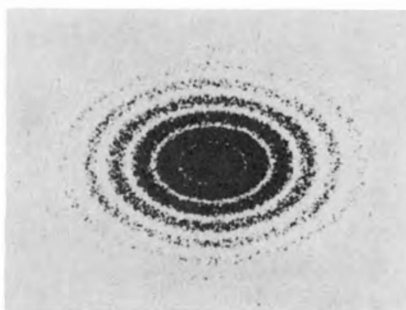

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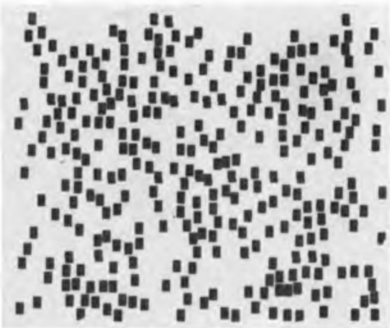
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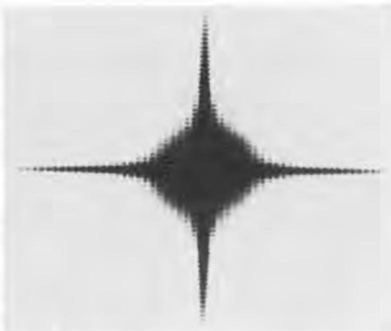
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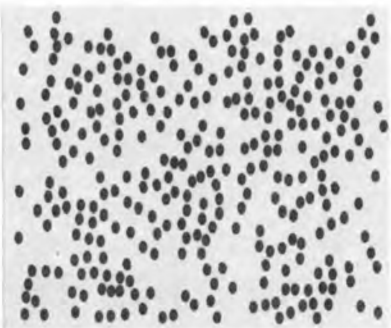
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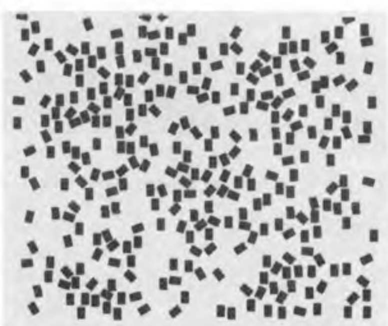
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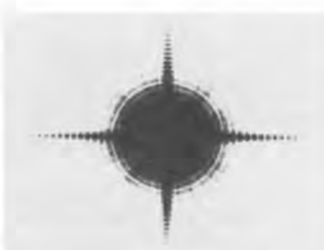
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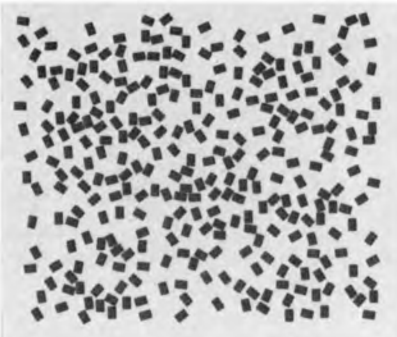
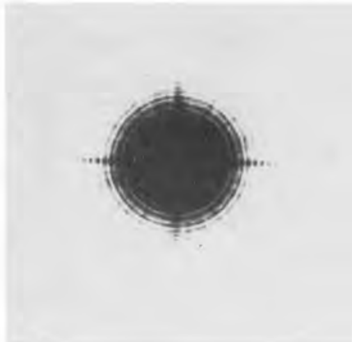


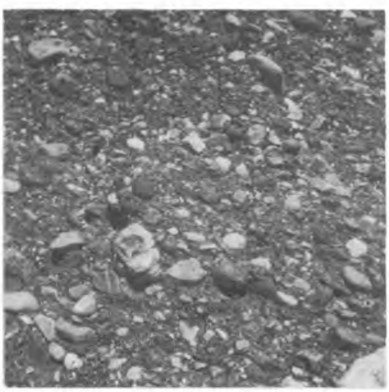
1



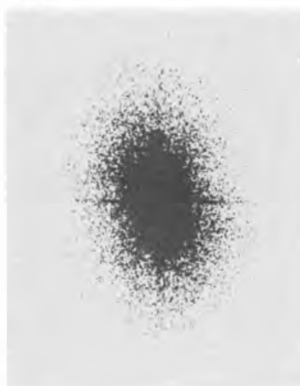
2

3

4



5



6

1

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6

long sides oriented north-south. The diffraction pattern (Plate 2, fig. 2) produced by this model shows the strong north-south and east-west rays which result from the superposition of the individual diffraction patterns of 300 rectangles. It is a simple task to infer the nature of the original data from this pattern by noting the orientation of the rays of diffraction and the spacing of the orders of diffraction along those rays. If the rectangles were all oriented with the long axes aligned N 45° E then the rays of light diffraction would be similarly oriented in the diffraction pattern. By close inspection one can see that the orders of diffraction along the north-south ray are spaced more closely than along the east-west ray. Since the long dimension of the rectangle produces the closer spaced orders of diffraction, one can determine from the diffraction pattern that the rectangular apertures on the film in the data plane are oriented north-south.

Plate 2, fig. 5, shows a model where 50 percent of the rectangles have a preferred orientation and 50 percent are randomly oriented. Note that light

EXPLANATION OF PLATE 3

DIFFRACTION PATTERNS OF A SEDIMENTARY FABRIC MODEL AND TWO COARSE CLASTIC SEDIMENTS

FIG. 1.—Sedimentary fabric model consisting of 300 rectangles 0.030 inch by 0.020 inch, 10 percent (30) of which are oriented north-south and 90 percent (270) are randomly oriented, 4x.

FIG. 2.—Diffraction pattern produced by optical processing a film negative of Plate 3, fig. 1, 1x.

FIG. 3.—Outcrop of Lake Bonneville gravels exposed in a gravel pit at the mouth of American Fork Canyon, Utah County, Utah. The photograph shows an area of the outcrop 20 inches by 20 inches.

FIG. 4.—Diffraction pattern produced by optical processing a film negative of Plate 3, fig. 3, 1x.

FIG. 5.—Outcrop of Lake Bonneville gravels exposed in a gravel pit at the mouth of American Fork Canyon, Utah County, Utah. The photograph shows an area of the outcrop 30 inches by 30 inches.

FIG. 6.—Diffraction pattern produced by optical processing a film negative of Plate 3, fig. 5, 1x.

EXPLANATION OF PLATE 4

DIFFRACTION PATTERNS OF COARSE CLASTIC SEDIMENTS

FIG. 1.—Outcrop of Lake Bonneville gravels exposed at the mouth of American Fork Canyon, Utah County, Utah. The photograph shows an area of the outcrop 30 inches by 30 inches.

FIG. 2.—Diffraction pattern produced by optical processing a film negative of Plate 4, fig. 1, 1x.

FIG. 3.—Outcrop of Lake Bonneville gravels exposed at the mouth of American Fork Canyon, Utah County, Utah. The photograph shows an area 30 inches by 30 inches.

FIG. 4.—Diffraction pattern produced by optical processing a film negative of Plate 4, fig. 3, 1x.

FIG. 5.—Outcrop of Lake Bonneville gravels exposed at the mouth of American Fork Canyon, Utah County, Utah. The photograph shows an area 30 inches by 30 inches.

FIG. 6.—Diffraction pattern produced by optical processing a film negative of Plate 4, fig. 5, 1x.

diffraction in the quadrants between the two major light rays now makes up a significant portion of the diffraction pattern (Plate 2, fig. 6). This diffraction is produced by the 150 rectangles which are randomly oriented.

As indicated previously, the intensity of a given diffraction element is dependent upon the number of aperatures which contribute to the diffraction element. Thus we see (Plate 2, fig. 6) east-west and north-south rays which are longer and brighter than any others in the diffraction pattern. This is true because 150 rectangles oriented in the same direction are contributing their individual diffraction patterns to those two dominant rays. The diffraction patterns produced by the other 150 rectangles are oriented per the random orientation of the rectangles and are thus spread over a greater area, producing diffraction which is much less in total intensity than the rays produced by diffraction of light by the 150 like-oriented rectangles.

Plate 2, fig. 6, shows another important feature related to random-oriented rectangles. Concentric rings of dark and light fringes may be seen which give a bull's-eye appearance to the diffraction pattern. When rectangles are oriented in directions other than the preferred direction, the diffraction pattern which coincides with each rectangle is also reoriented to conform to the orientation of the rectangle. Since the orders of diffraction of each diffraction pattern produced by a rectangle are the same distance apart along like axes, the rotation of diffraction patterns to coincide with the rotation of rectangles causes concentric dark and light rings to form.

Plate 3, fig. 1, shows a model wherein only 10 percent of the rectangles have a preferred orientation and 90 percent are randomly oriented. Even when only 10 percent of the rectangles have a preferred orientation, the north-south and east-west rays produced by the like-oriented rectangles can be easily discriminated from the diffraction produced by the other 90 percent of the rectangles (Plate 3, fig. 2) (Smith, 1967).

Of course, in nature the clastic particles found in sedimentary rocks are not well-defined rectangles or ellipses. However, the observations made of the idealized sedimentary fabric models prove to be very useful in recognizing similar relationships found in sediments.

While employed by Gulf Research and Development Company during the summer of 1967, the writer had the opportunity to analyze with the optical data processing system twenty photographs of coarse clastic sediments. Results of these analyses show some important characteristics not readily discernible without optical processing. Interpretation of the diffraction patterns is commonly done qualitatively; however, equipment exists which will create isodensity contour maps of the diffraction patterns, thus allowing quantitative analysis of the patterns.

Plate 3, figs. 3 and 4, show a photograph of a coarse clastic sediment and the diffraction pattern created by processing that photograph with optical data processing methods. Most of the clasts in this deposit are generally elliptical, so the diffraction pattern is similar in nature to Plate 2, fig. 4. The pattern in Plate 3, fig. 4, is elliptical as are most of the grains in the deposit, and the pattern is oriented perpendicular to the apparent horizontal preferred orientation of the grains.

In Plate 2, fig. 3, all of the ellipses are the same size, and as a result, the diffraction pattern is made up of concentric dark and light fringes or orders of diffraction which decrease in intensity as the distance from the center increases. The distinct elliptical orders of diffraction do not appear on the diffraction pattern in Plate 3, fig. 4, because the clasts making up the deposit cover a wide range of sizes. This is true because the distance from the center to one of the orders of diffraction is dependent upon the size of the aperture creating the diffraction. Intensification of the diffraction pattern in Plate 2, fig. 4, is caused by superposition of many diffraction patterns of like size. Since the particles in Plate 3, fig. 3, are of many different sizes, coincidence of the orders of diffraction does not occur, and a homogeneous, elliptical-shaped pattern is produced whose intensity decreases as the distance from the center of the pattern increases.

Thin rays of diffraction running north-south and east-west through the diffraction pattern were produced by diffraction of the large rectangle which encloses the photograph of the coarse clastic sediment. These thin north-south and east-west rays occur on all the diffraction patterns of coarse clastic sediments and serve as guides to enable proper orientation of the patterns.

The diffraction pattern shown in Plate 3, fig. 6, has the same form as the one shown in Plate 3, fig. 4. However, the elliptical shape, which is a reflection of grain shape, is rotated counterclockwise 15 degrees. This is a response produced by imbrication or preferred orientation of the long axes of the grains. Interpretations of the nature of this deposit, based upon the diffraction pattern, state that most of the grains are generally elliptical and the long axes dip 15 degrees to the west.

Plate 4, fig. 2, shows a diffraction pattern which is characteristic of many of those produced by processing photographs of coarse clastic sediments. The pattern is elliptical and oriented about north 40° east, which indicates that most of the grains are generally elliptical and have a preferred orientation perpendicular to the orientation of the ellipse in the diffraction pattern. Or, in other words, the long axes of most grains dip 40° to the right. Inspection of the photograph of the outcrop does not verify this interpretation, indicating that additional testing must be done before reliable interpretations can be made (Plate 4, fig. 1).

Another siginficant feature is present on this diffraction pattern in the form of a well-defined line oriented N 45° W, extending through the pattern, which is barren of diffracted light points. This indicates that the photograph processed by the optical system has few if any linear elements oriented perpendicular to the barren zone because no light diffraction occurs. The writer feels that this line may be an effect produced by shadows on the outcrop which are recorded by the photograph. Not enough tests have been made to determine the validity of this hypothesis.

The diffraction pattern shown in Plate 4, fig. 4, is quite unique in that it seems to indicate a bimodal fabric. Unlike the other patterns this one is not a simple elliptical shape. The diffracted light points around the outer margin show a general elliptical form, but by more careful inspection we note that the central portion of the pattern shows a somewhat indistinct cross of concentrated light points with the elements of the cross aligned north-south and east-west. This may indicate that the coarse clastic deposit has two directions of preferred orientation of the long axes of the clasts. However, visual inspection of the photograph of the deposit does not verify this interpretation (Plate 4, fig. 3).

Plate 4, figs. 5 and 6, show a photograph and resulting diffraction pattern of a coarse clastic deposit made up of much larger clasts than the preceding examples. As previously noted, the size of the apertures, or in this case clastic particles, determines the distance from the center of the pattern that the diffracted light will occur on the diffraction pattern. By comparing the diffraction pattern shown in Plate 4, fig. 6, with the preceding diffraction patterns of coarse clastic sediments, it will be readily apparent that a coarse clastic sediment made up of large boulders produces a diffraction pattern which has most of the diffracted light points concentrated very close to the center. On the other hand, patterns produced by coarse clastic sediments made up of smaller boulders or cobbles show light diffraction distributed over a much greater area and a greater distance away from the center of the pattern.

Interpretations enumerated above are based on qualitative criteria alone. Although quantification of the diffraction patterns is possible through the use of microdensitometers, the writer did not have access to this type of equipment. Microdensitometer analysis of the diffraction patterns must be developed before accurate determinations of preferred orientation and size frequency distribution can be made.

Problems now exist which must be solved before optical data processing can be utilized as a tool in sedimentological studies. One problem is quantification of the diffraction pattern as noted above. Another is to determine the extent to which shadows on the outcrop, which are recorded on the photograph, affect the form of the diffraction pattern after the photograph has been processed by optical methods. To solve this difficulty it is proposed that an outcrop be photographed at various times of the day and also with a flash attachment to record shadows at various angles and with no shadows at all. After optical processing of these photographs has been accomplished it would be a simple task to compare the resulting diffraction patterns, noting that any variations in the patterns would be produced by the migration or absence of shadows on the outcrop.

Another problem arises as a result of the orientation of a given outcrop. The preferred orientation determined by optical processing may in fact be only a reflection of an apparent preferred orientation as shown by the photograph. The photograph is a two-dimensional expression of the outcrop, and thus the boulders which are three dimensional in nature may not be represented on the photograph by the longest axis, but rather the apparent long dimension recorded on the photograph may in fact be the intermediate axis. To solve this problem extensive testing of a highly dissected deposit of conglomerate should be conducted. This would allow photographing outcrops oriented in many directions and one could determine to what extent the orientation of the outcrop would affect the diffraction patterns and thus interpretaion.

Optical processing of data is a relatively new technique and is thus still in the early developmental stage, so it is difficult to accurately predict its future potential in terms of application to analysis of coarse clastic sediments. However, the preliminary testing carried out during this study has indicated that the technique has a bright future. Analysis of the diffraction patterns is the most pressing current problem which if solved will make this technique very popular among researchers, inasmuch as an optical system is relatively inexpensive and results may be obtained instantaneously after the photograph is placed in the data plane. The optical data processing system is the least expensive and the fastest of the three scanners investigated on this study.

CONCLUSIONS

Preliminary investigations outlined in this paper indicate that it is possible to digitize and process pictorial data by computer techniques. However, it is not possible at present to make routine analyses of coarse clastic sediments because sophisticated optical scanning equipment is relatively inaccessible and very expensive. Many optical scanning techniques have evolved as a result of research related to the United States Space Program, but because of security regulations they are not presently available.

Time and materials for the tests made by the three optical scanners were donated by the industrial firms mentioned in the text of this paper. Since the writer did not have control of the scanning processes, a complete and accurate evaluation of each scanner is difficult. Preliminary testing indicates that minor modifications in the scanning techniques would greatly improve their applicability to geologic problems. However, the nature of this project prohibited the investigator from making any changes in the scanning procedures as testing progressed. Scanning results contained in this paper are products of single trial tests made by operators with no geologic background.

It appears that the IBM 2281 and the Ameda System could both be modified to obtain rapid and accurate determinations of the size distribution of a coarse clastic deposit. No information is presently available that indicates whether the IBM 2281 or the Ameda could be altered in such a manner that preferred orientation of elongate grains could be determined.

In addition to equipment modification, a photographic process is needed that will simplify preparation of a photograph of a coarse clastic sediment and eliminate the need to black out the boulders with ink before scanning. One avenue of investigation in this respect is the possible use of infrared film, which would allow discrimination of the cool matrix and the warmer boulders, or the other way around, depending upon the nature of the deposit and the thermal conditions prevailing at the outcrop.

Optical data processing techniques are ideally suited for determination of preferred orientation of the elongate grains, but present methods do not allow accurate determination of the size-frequency distribution expressed by a given deposit. Optical filtering techniques exist which may help solve this difficulty (Pincus and Dobrin, 1966). Improvement of photographic techniques allowing for better quality negative or positive photographs of the coarse clastic deposit would aid greatly in minimizing or eliminating unwanted and/or indistinguishable optical noise.

Development of a routine, making possible rapid and accurate analyses of coarse clastics, is shown by this study to be conceptually feasible. This will be accomplished by linking an optical scanner with a digital computer. With such an arrangement, the photograph will be digitized by the scanning equipment and the digitized data fed directly into the computer for calculating of statistical and mathematical expressions which describe the deposit and allow the investigator to discriminate between deposits of various origins. Prerequisites to a project of this nature would be a ready access to the optical scanning equipment described in this report as well as any other equipment that might be made available in the future. Resolution of pictorial and graphic data by optical scanners is receiving considerable emphasis by research organizations at the present time, so it is logical to assume that rapid developments in this area are likely in the future.

The writer concludes from the results of this investigation that any one of the three scanners could potentially be used to scan and digitize textural data of coarse clastics as recorded on a photograph of the outcrop. With a few changes these scanners could also be applied to analysis of thin sections of sandstones, carbonates and other sedimentary rocks. Of the three scanners investigated the IBM 2281 film scanner is the most expensive to purchase, but it represents greater potential because it is designed to be used in conjunction with the IBM 360 computer. The optical data processing system is the least expensive of the three. Data may also be processed faster with an optical system, but present techniques of analyzing the results need considerable refinement before they will be considered reliable. At the present time the Ameda System seems to be the best compromise in terms of expense as well as functional application.

If the writer had to decide now on which of the scanners he would choose in a far-reaching study to develop a method of analyzing coarse clastics and then applying that method to many hundreds or thousands of samples, he would choose the Ameda System because of its versatility of application and also because it is the only one that can now provide a digitized scan of a photograph. Future refinement of technology will bring about a change in optical-scanner availability and application.

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