FRACTURE ANALYSIS: APPLICATIONS IN HAZARDOUS WASTE MANAGEMENT

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ABSTRACT

Hazardous wastes can be transported from their original depositional site into the environment through subsurface fractures. A method has been devised which allows for the characterization of fractures. A photograph of the fractured sidewall of a trench excavated into the subsurface was digitized and analyzed with imaging software. Geometricx variables, such as the number of fractures, their length, orientation, roughness, and width, were calculated on the entire population.

INTRODUCTION

The ability to characterize subsurface fractures is important for selecting sites to contain hazardous wastes. The environmental implications are that hazardous wastes can be transported through fractures and fissures in the subsurface from their original depositional site into the surrounding area or possibly even long distances from the original site.

Fractures have been analyzed in a variety of ways and on a variety of scales. Fracturing has been observed from rock thin sections, from lineament analysis of Landsat data, from bore hole televiewer data, from outcrops, and from borehole core material. While scale differences from microfracturing observed on thin sections to the regional proportions from Landsat data are significant, the analysis of fractures at all scales usually begins with an analyst counting the fractures by eye. Automation of this process has focused on the use of digitizing equipment to enter fracture data into a computer. Digitizing photographs of fractured rock or using lineaments from Landsat data is useful for counting fractures and describing orientation. There are other variables that may be important for the management and containment of hazardous wastes. Variables other than the number of fractures and orientation that are important are surface roughness, width, and length. These variables are important for the following reasons:

- The greater the number of fractures, the more likely they are to be interconnected. Also, the more fractures there are, the greater the possible throughput of potential contaminants.
- Fracture orientation determines the direction in which the contaminants will migrate.
- Fracture width determines the volume of fluid present and how easily fluid will migrate through the fractures.
- The surface roughness of a fracture determines how fast fluid will move through a fracture system and how much hydrologic pressure will be required.
- The longer a fracture is, the more likely that it will intersect other fractures. Fracture length also determines the distance that hazardous wastes can potentially migrate.

We decided to apply image processing and image analysis techniques to the problem of automated fracture analysis. A technique was needed that would make it easy and objective to measure these variables at any scale. To determine if image quantification could be applied to the problem of mapping fractures there were three specific goals:

- Capture a computer image of a fractured rock. Create an objective procedure by which the computer could locate all fractures in the image.
- Subdivide the complete set of fractures into subsets based on 5 geometric variables.
- Create maps of fracture subsets on which to base a hydrologic model.

Procedure

Figure 1 schematically represents the image collection and processing procedure as described below. A photograph of the sidewall of a trench excavated into a subsoil zone was digitized using a camera with a linear array of 4096 silicon detectors. The sidewall contained numerous fractures which cut across the clay-rich subsoil.

A computer image of the photograph (Fig. 2) was created by sequentially exposing the row of detectors on the camera, moving the row, and exposing the detectors again. The detectors traverse across the photograph in 4096 steps, and can create an image with 4096 columns and 4096 rows. In the present study, only the central 1024 detectors were enabled, producing an image 1024 x 1024.

The resulting image was analyzed using a software procedure which permits the fractures to be identified by their sharp edges and darker color. After the fractures are picked out, a file is created which contains only the boundaries of the fractures, not the surrounding rock (Fig. 3). This file, or boundary map, contains the perimeter, and location of every fracture in the original image. Geometric variables, such as the number of fractures, their length, orientation,

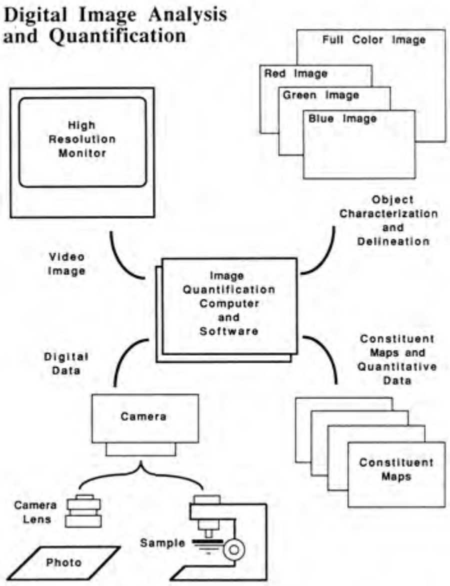

Fig. 1. Image Collection and Processing Procedure.

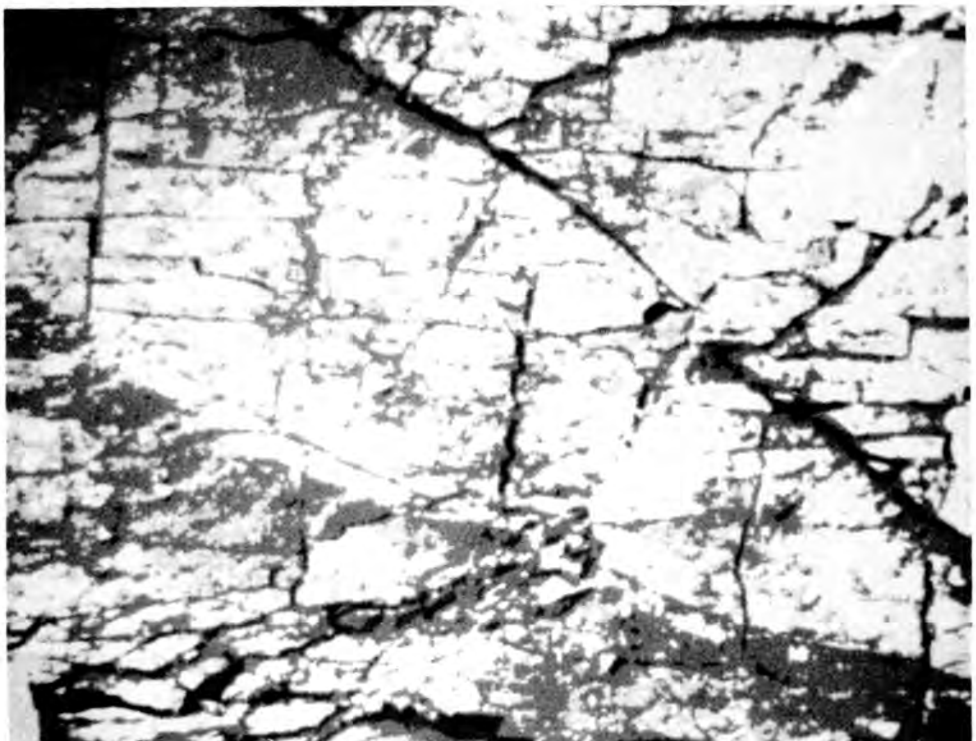

Fig. 2. Computer Image of the Fractured Sidewall of a Trench. Area = 60 cm x 60 cm.

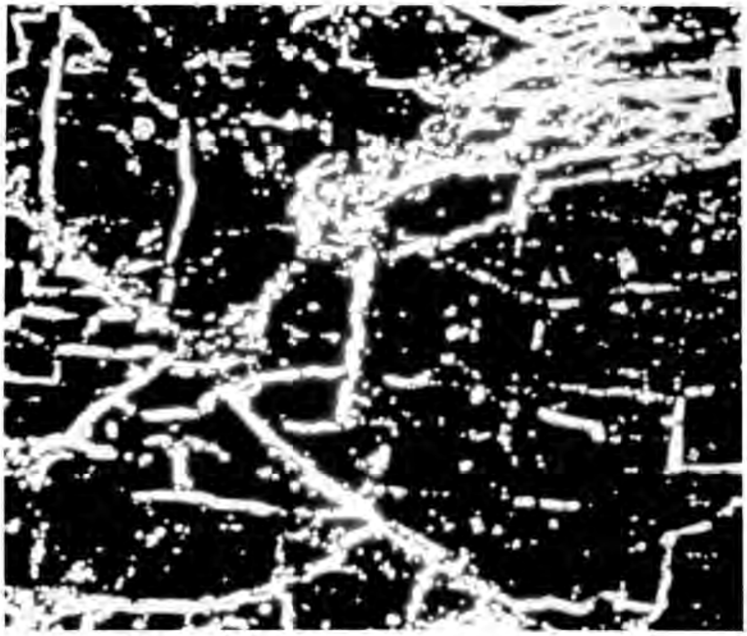

Fig. 3. Boundary Map of Fractures Extracted From Image in Fig. 2.

roughness and width, were calculated on the entire fracture population in a matter of minutes.

The computer image which was generated from the original photograph represents a rather small area, 60 cm by 60 cm, but the same procedure just described could also have been used on Landsat data, thin sections, borehole televiewer data, or core photographs.

Analysis Results

On the 60 cm by 60 cm digitized sidewall section, there were 3161 fractures delineated by the analysis software. The analysis software also produced histograms illustrating the distribution of fracture width, length, and roughness, and a rose diagram (Fig. 4) indicating the orientation of the long axis. Fracture width, in this case, means the point of closest approach, or the point at which the fracture opening is the narrowest (Fig. 5). Fracture length is the measurement of the longest axis of a fracture (Fig. 6). Fracture roughness is the measurement of the smoothness or roughness of the fracture wall *(Fig.* 7).

By selecting bars on the distribution histogram, maps of subpopulations of fracture width, fracture length, and fracture roughness were created. The three resulting maps showed that there were three fracture subpopulations with characteristic width, length, and surface roughness that could be differentiated. Using the rose diagram initially, three directions of fracture orientation were highlighted and displayed on a map. Later, when orientation was plotted against fracture length as a scatter plot (Fig. 8) four subpopulations were observed. Polygons were drawn around clusters of dots on the scatter plot to differentiate the subpopulations. A map was made of the four subpopulations revealing that there are sets of fractures oriented Southwest-Northeast that are short to medium-length, East-West fractures that are medium to long, North-South fractures that are medium to long,, and Northwest-Southeast fractures that are longest (Fig. 9). The original photograph of the map was in color, with each subpopulation displayed in a different color.

CONCLUSIONS

- Fracture analysis can be performed from photographs using image quantification.
- Individual variables, such as length or orientation, can be used separately to subdivide a population of fractures.
- Subpopulations of fractures can be identified by combining variables and delineating areas in scatter plots.
- The predictive capability of a hydrologic model may be increased if the geometry and interconnectedness of the fracture system is included in the simulation.

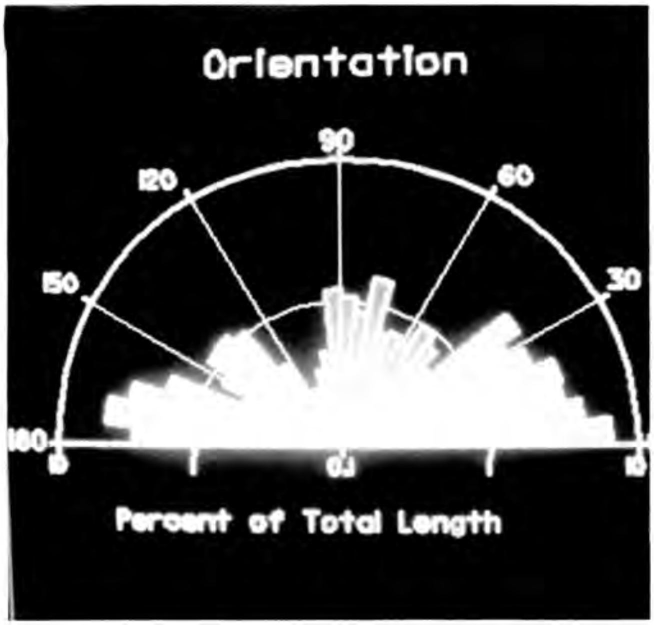

Fig. 4. Rose Diagram of Fracture Orientation.

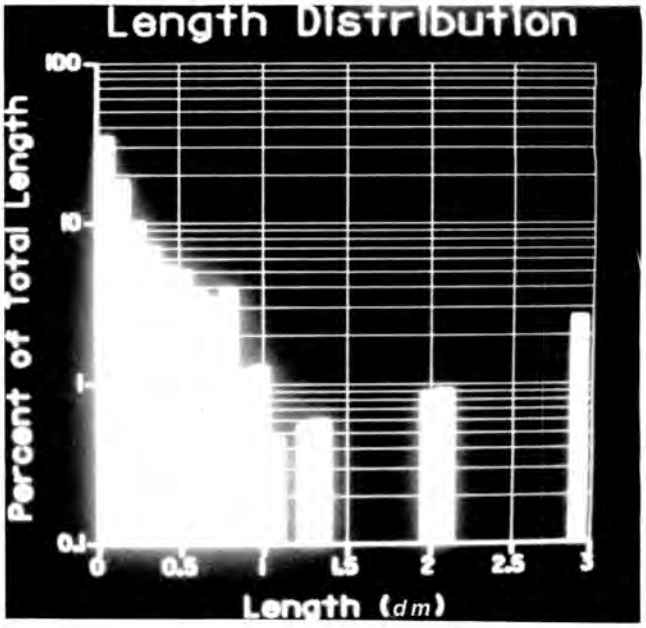

Fig. 6. Fracture Length Histogram.

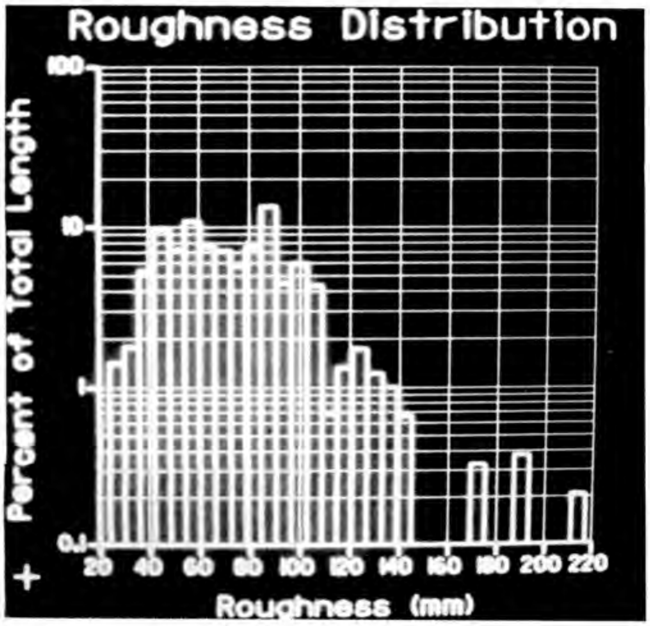

Fig. 5. Fracture Width (Neck Distribution) Histogram.

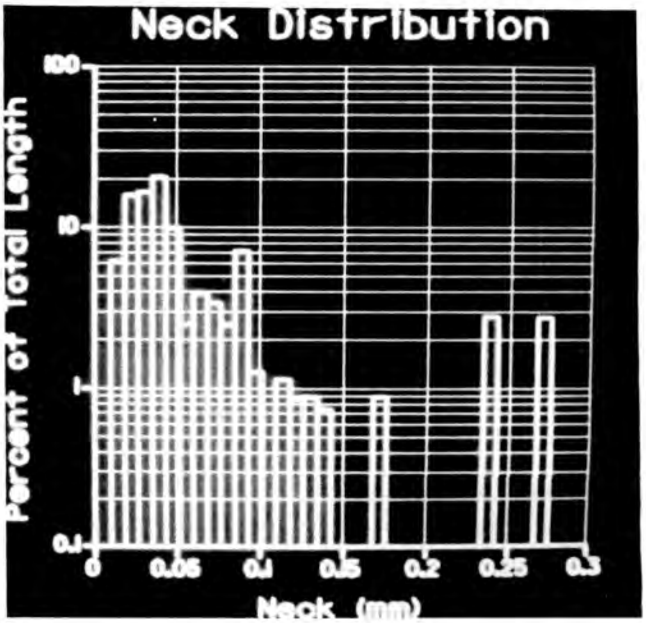

Fig. 7. Fracture Roughness Histogram.

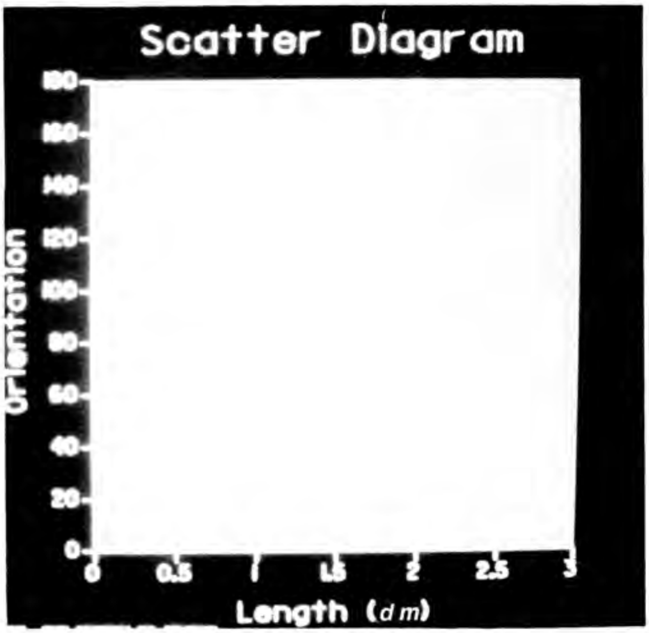

Fig. 8. Scatter Plot of Fracture Length Versus Orientation.

Fig. 9. Map of Sub-Populations Generated by Enclosing Regions in Fig. 8 (Original in Color).