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SOME METHODS TO EXTRACT GEOLOGICAL INFORMATION FROM REMOTE SENSING DATA: A BRIEF REVIEW

by

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INTRODUCTION

The large amount of information usually recorded in remote sensing data is not always completely evaluated during the interpretation phase of a project: a rigourous interpretation of a single piece of imagery or photography by human interpreters takes relatively a great deal of time. In all cases, the user obtains from remote sensing data more information than desired or required. This additional output sometimes helps during the interpretation but in some cases, it becomes a problem when it obscures the main features.

INTERPRETATION OF REMOTE SENSING DATA

Interpretation of remote sensing data, either photographs or imagery, has been defined in several ways which stress a given interpretation method or application. References have been made in the literature about the difference between "identification" or "reading", defined as the recognition of specific features, and "interpretation" itself which is the understanding of the significance and relationship among these features as seen by an expert.

Interpretation of this type of data however always implies searching for answers to specific or general questions about the area recorded in images. Interpretation therefore, as pointed out by Guy (1967), is the process of trying to increase the amount of information available about the area being studied.

The image interpretation process is based on the act of visual perception and a careful understanding of this phenomenon is basic when analysing interpretation problems. DeHaas, Hempenius and Vink (1967) made an interdisciplinary attempt to discuss the psychology of photo-interpretation and concluded that the whole process is not a passive acquisition of information but an active evaluation of incoming signals. Visual perception seems to depend to a great extent on the knowledge and experience of the interpreter. This dependency is explained because visual perception manifests itself as a set of expectations which act as hypotheses which are the reference frame to check the information. The interpretation process is therefore, since the beginning, biased because of the expectations for a suitable type of information. Fortunately this physiological and mental filtering of information may be reduced by training. Interpretation may be considered then as divided in steps, where conclusions undergo tests by formulating new hypotheses of more specific or refined nature. The initial bias may be minimized as a consequence of this procedure and hopefully, expectations may become certainties. In general, if the interpreter has additional information about the region where the images come from or a strong general knowledge, it is possible to decrease the probability of uncertain classifications.

The whole interpretation process, as a general rule, is time consuming, consequently expensive, and in practice image interpretation is done intuitively (Guy, 1967).

DISCRIMINANT ANALYSIS IN REMOTE SENSING

Before presenting the two most promising data processing methods, an overall idea of the discrimination problem in remote sensing is presented here.

Discrimination may be defined as the sequence of operations starting with the recognition that different materials are, indeed, different and is followed by the identification of these materials.

Remote sensing data have at least four principal characteristics which can be used to effect discrimination namely: 1) spectral variations, 2) spatial variations, 3) polarization variations, and 4) time variations (Holter, 1970). Only the first two of these characteristics will be discussed here because of their importance, but, if necessary in a later stage of this study, the two remaining ones may be considered.

Spectral discrimination is based on the variations in the sensed electromagnetic radiations as a function of wavelength. The spectral characteristic or spectral signature of a given material is not completely deterministic but has a statistical character. This is the single most important factor to be considered when selecting methods for spectral discrimination.

One analysis technique used requires the calculation of a <u>maximum likelihood ratio</u> based on a Gaussian assumption. This procedure indicates the probability or likelihood that a given material is identified based on the distribution of previous spectral measurements of typical materials in "sample" or "training" areas. The entire image is classified into the types which were selected for the "training" areas.

<u>Cluster analysis</u> is a technique used in discrimination which does not require "training" areas. The whole set of data is divided into a number of groups or clusters, each containing points with similar spectral characteristics. Identification of the materials included in the clusters become necessary after completing the analysis and sometimes reveal that the classification does not suit the purposes of the interpretation study (fig. 1).

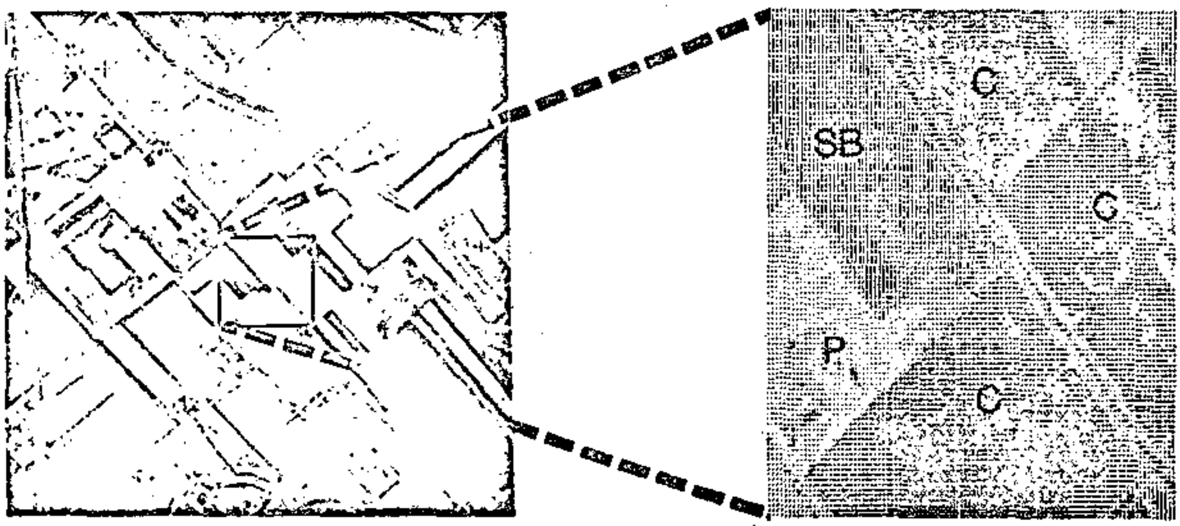


Figure 1. Results of automatic classification of data in multiband photographs. Left: digital display image (.59 - .71 μm band). Right: computer printout of crop species classified. P: pasture, SB: soybean, C: corn. (From Hoffer, *et al*, 1971).

Both techniques require a large amount of calculations and computer programs are available to some extent to process the information.

Spatial discrimination is based on the variations of shape and textural characteristics of materials. Viewing angle and shadowing have a strong influence in shape and texture. Some of the techniques which have been tried in spatial discrimination are spatial density evaluation (Rosenfeld, 1962) and the analysis of the frequency content of the spatial distribution of density by Fourier methods. Both are described in more detail later in this paper.

COMPUTER DATA PROCESSING

The task of digital computers in the image-interpretation (or pattern recognition) problem consists of recognizing the class which will contain any given sample from a set of data. This is a problem that requires testing statistical hypotheses such as those mentioned in the preceeding section.

The published works in data processing with computers mentioned in this paper have been classified in two groups according to the type of sensor output. If cameras were used photographic film is the output, however, if nonphotographic sensors were used the data collected may be recorded on magnetic tape. In both cases the information is digitized before being processed and may be displayed for visual analysis either by its presentation on a cathode ray tube (CRT) or in a printout (fig. 2).

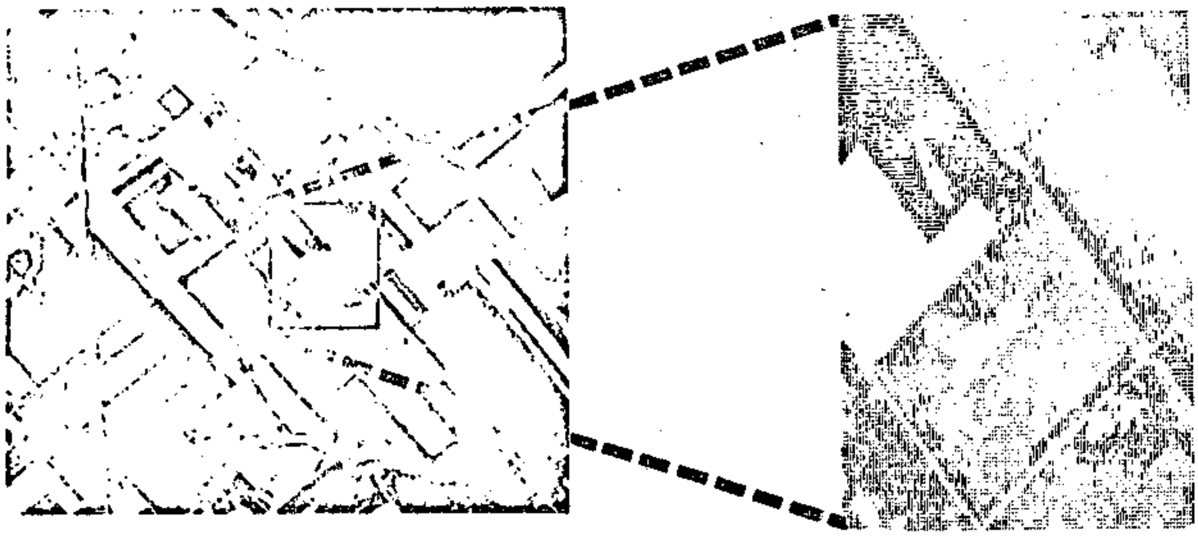


Figure 2. Left: digital display image in a TV screen representing variations in tone with 16 levels of grey. Right: computer line printer display of part of the area shown on the left. Different density levels are shown by different computer symbols. (From Hoffer, et al, 1971).

1. Taped output - then digitized

Automatic terrain mapping based on multispectral imagery has been tried with relative success. Smedes, et al (1970) used information acquired with a 12-channel scanner covering the 0.4 to 1.0 um range where all 12 channels were recorded separately on magnetic tape. A digitized copy of the original magnetic tape was then made in order to allow digital processing of the data. The shades of gray observed in the CRT also can be represented by symbols in the computer output, each one of the characters corresponding to one gray level within the full range of tones of gray present in the original data.

Computer processing as presented by Smedes et al, is useful when statistical parameters for small areas are to be calculated and compared. The discrimination method used to classify the unknown data points into previously selected categories was the Gaussian maximum-likelihood decision scheme. These computations require a large computer memory especially if the area studied is large and there is a large number of channels to be analysed. The area mapped in the referred study covered 12 square miles and contained 127,600 data points, each corresponding to a 20 ft by 20 ft ground cell, 20 feet apart, along the scan lines. With such large amounts of data to be processed, the computer time was further reduced by using only data from the four "best" channels. Even then, the cost of computer time was quite high (about US$7,400) considering that only nine terrain types were mapped. The cost of the entire multispectral survey including the area mapped but excluding salaries (approximately US$26,000) was not very attractive either (Smedes et al, 1970).

Stingelin (1969) mentions that automatic processing of thermal infrared imagery has been developed by Eliason et al (1968) using the taped output from an infrared detector. Computer generated displays of contoured radiation levels were produced and if desired, altered during processing in order to enhance specific features. This technique however, requires ground control data obtained at the time the survey flight is carried out to produce displays with quantitative value.

2. Film output - then digitized.

Another approach to the computer processing of imagery was tried by Barr (1969), Dalke (1966) and Tisdale (1971) among others. Here, the imagery was recorded originally on film transparencies (or transferred to transparencies) and the photographic densities of the points in the imagery were measured with a densitometer. A gray level value was assigned to the density of each point in the imagery. These density measurements are fed into a computer for processing.

The number of gray levels which should be used for the greatest probability of correct classification has not been established yet. Dalke (1966) studied the variation of the probability of correct classification with number of signal levels (and number of input images) and concluded that this probability is relatively independent of changes in the number of gray level. Tisdale (1971) used relatively few gray levels, only 16, in his automatic processing study. Other researchers such as Barr (1969) however, have divided the range of density values from the films into 400 discrete levels. McCardle (1971) suggested that the greater the number of gray levels used (>13) for discriminating a given target, the more characteristic are the density curves therefore better are the chances of correct classification.

As a general rule it seems that the probability of correct classification of a given target becomes greater when increasing the number of non-redundant input images of the area containing the target (Dalke, 1966). High cost of computer time however, is a factor limiting this number as already observed (Smedes et al, 1969).

The characteristics and objectives of computer programs used for automatic data processing vary widely as can be expected. Some programs are used only to classify terrain features. Smedes et al (1969) "mapped" with an over 80 percent accuracy the following terrain units: bedrock exposures, talus, vegetated rock rubble, glacial kame terrace, glacial till, forest, bog, water, and shadows. This is not a geological map but some features of geological importance were mapped. A very useful feature for geological mapping was incorporated in Tisdale's (1971) program, namely the indication in the output display of gradient direction, i.e. symbols indicate increase in density values along given direction. This program characteristic could be used to locate structural lineaments.

Most of the attempts to analyse quantitatively geological data have taken into consideration only the tonal characteristics of the area photographed or imaged. In other words, only areas which are shown in the recorded data as having different gray tones are being differentiated.

Another photographic characteristics of geological features closely associated to tone and not easily described is texture. Miller and Miller (1961) define texture as the quality of a feature or an area "which distinguishes it from some other feature or area having the same photographic tone." Some of the qualitative and somewhat subjective terms which have been used to describe texture are smooth, rippled, mottled, irregular, and lineated (Miller and Miller, 1961, p. 87).

Realizing the need for an identification of these textural characteristics, Rosenfeld (1962) carried out an experiment to identify automatically what he called "basic terrain types" such as urban residential areas, cultivated fields, industrial zones, woods and water bodies. The identification process was performed for assorted portions of aerial photographs having approximately the same exposures and ground shadows, characterized by "uniformly textured" areas. The chosen areas were scanned 18 times by a flying spot scanner and the density information was displayed as a time varying video signal. If these measurements are averaged for a large number of scans it is suggested that the result measures the mean contrast frequency of a given area. Rosenfeld (1962) concluded that some terrain types such as those mentioned above could be identified in aerial photographs regarding their textural characteristics. Morain and Simonett (1967) and Barr (1969) have indicated that probability/density curves might be a useful measure of photographic texture. Barr (1969) obtained representative probability/density curves scanning each image study area by a densitometer and displaying the results in an oscilloscope. Some of the conclusions from this work are that the shape of these curves (also called histograms of tone elements) is a quantitative measure of image texture (fig. 3) and that the ratio of the base width to peak height of these curves is not significantly dependent on absolute tone values (Barr, 1969).

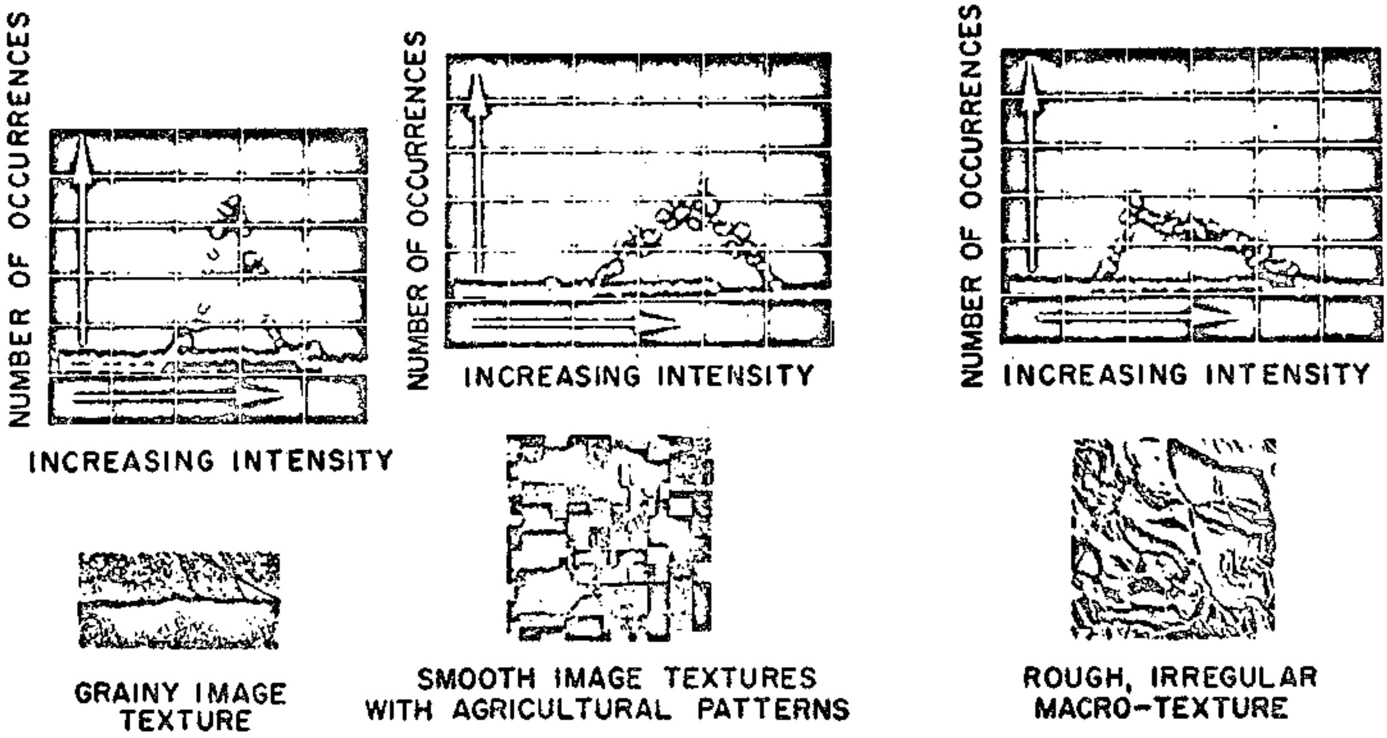


Figure 3. Probability/density (histograms of tone values) for selected areas on K-band SLAR imagery obtained with a densitometer (From Barr, 1969).

One should mention the fact that colors may be assigned to the density levels (or shades of gray) in an input image and a color enhanced image is displayed on a TV screen. This is the so-called false color density slicing technique used in some commercial color densitometers (Kilinc and Lyon, 1970; Helgeson and Ross, 1970).

OPTICAL DATA PROCESSING

One way to use optical principles to enhance structural lineaments in remote sensing data recorded in photographic film is through the use of moiré patterns (fig. 4) as described by Cummings and Pohn (1966). This technique is based on the observation of patterns

(Moiré patterns) formed when two similar screens or sets of rulings which act as diffraction gratings are nearly superimposed (Nishijima and Oster, 1964). Small relative displacements of two transparencies of combinations of figures having parallel lines, radial lines and concentric circles are associated with large movement of moire fringes which are most evident at some positions which can be precisely described by the mathematical solution of moire patterns (Oster et al, 1964).

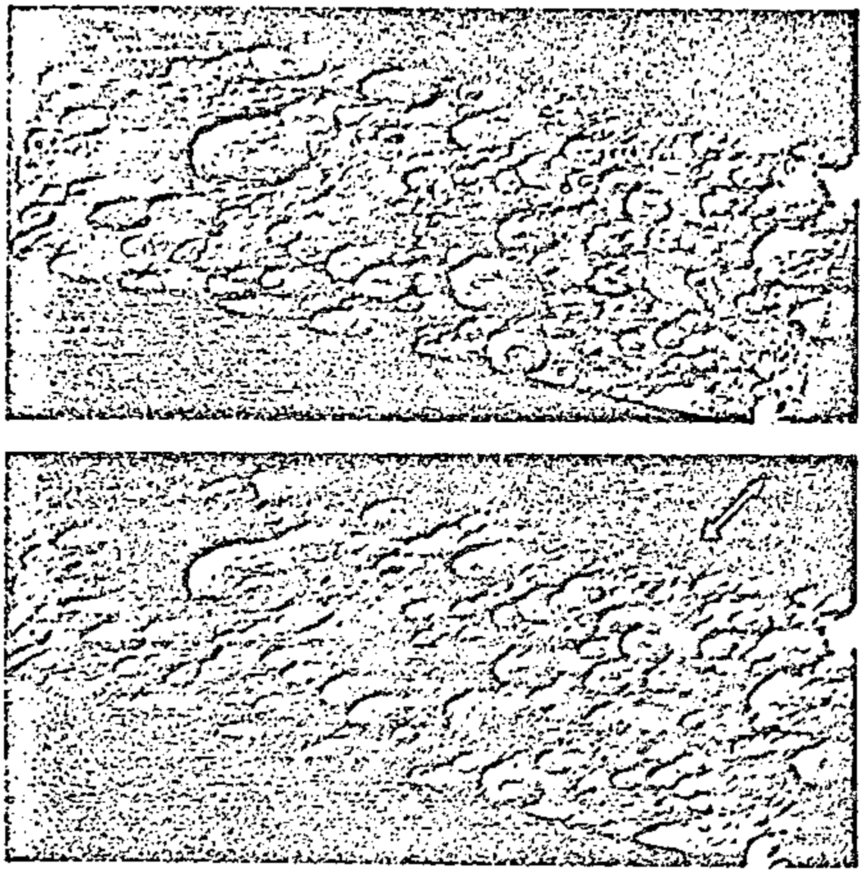


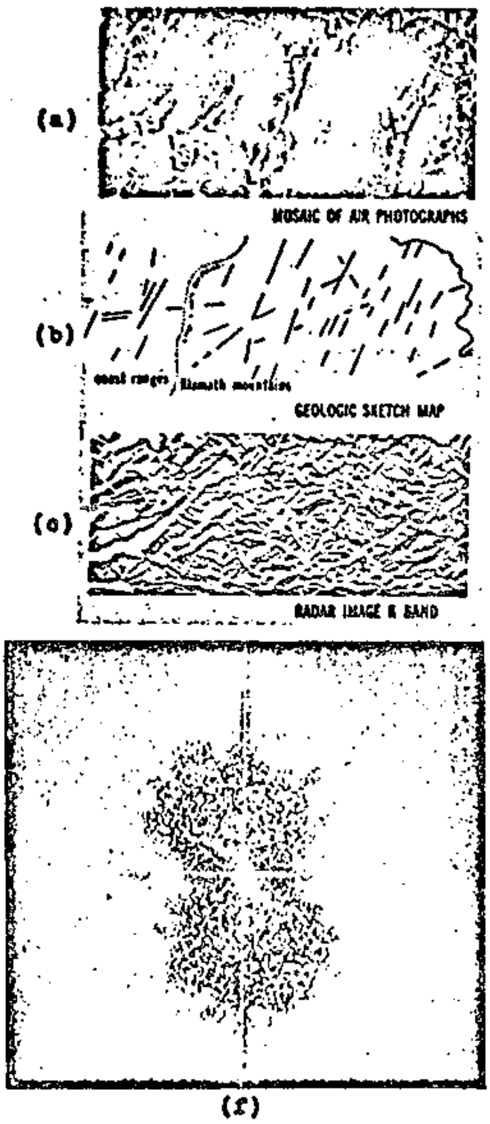
Figure 4. Enhancement of lineaments by superposition of transparent screens. Top: photograph (Lick Observatory) without overlay. Bottom: line screen superimposed on photograph. The orientation of the line screen enhances a family of lineaments parallel to the direction of the arrow. (From Cummings and Pohn, 1966).

Another optical processing technique which has been used to analyse geological data is based on the relationship between the Fraunhofer diffraction patterns and the Fourier transforms. The light distribution at a distance from the object approaching infinity due to Fresnel diffraction is referred to as Fraunhofer diffraction. This phenomenon may be observed when an objective lens is placed behind the object diffracting the light. A Fraunhofer diffraction pattern is then formed in the focal plane, also called "Fourier" or "transform" plane of the lens. When spatially coherent monochromatic light is being diffracted, then the Fraunhofer diffraction pattern is very similar to the Fourier transform of the object causing diffraction.

The earliest application of this processing technique to geoscience was carried out by Jackson (1965) and Dobrin et al (1965) to extract information from variable-density and variable-area seismograms. After this pioneer work, Pincus and Dobrin (1966) published experimental results which indicated that the technique could be applied also to several types of geological data such as fractures, cleavages, grain orientation, drainage patterns, structural lineaments in aerial photographs and others. Pincus and Ali (1968), Dobrin (1968), Pincus (1969a,b,c) and Nyberg et al (1971) among others, have also used optical data processing for geological applications (fig. 5).

The optical and mathematical principles on which this technique is based were described in detail by Dobrin et al (1965) and only a very brief description of these principles is presented here. The pictorial information to be processed is transferred to a photographic transparency. A beam of coherent, monochromatic light, such as from a laser, is passed through the transparency and a lens, situated a focal length beyond the film, will convert the information into a diffraction pattern that is the two-dimensional Fourier transform of the input data (fig. 6). An important feature of this technique is that another lens beyond the transform or Fourier plane will convert the diffraction pattern into a second Fourier transform. This second transform is comparable to the original image.

If the image causing diffraction contains only a single frequency such as equally spaced parallel lines, then the dots of light making up the diffraction pattern lie along a line perpendicular to the elements of the original image. The distance between the diffraction



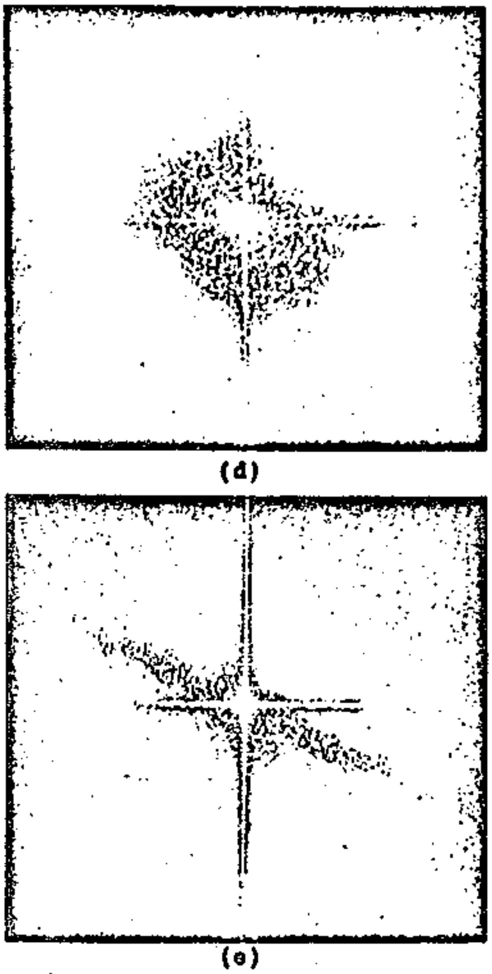


Figure 5. Diffraction patterns, d,e, and f of air photo mosaic, a, geologic sketch ma b, and K-band SLAR imagery, c, respectively Grants Pass area, Oregon. (From Pincus, 1969d).

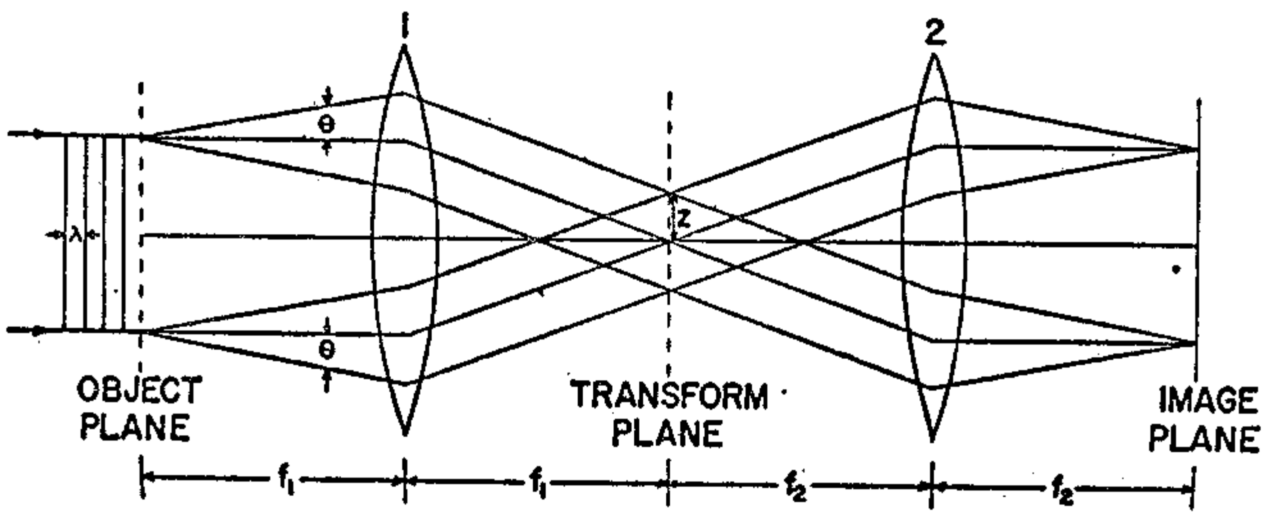


Figure 6. Relation between object, transform, and image for system containing two lenses. Diffraction pattern is focused in transform plane. (From Dobrin et al, 1965).

dots is proportional to the spatial frequency of the lines in the object plane.

If the light incident upon parts of the transform plane is blocked, the final image will show all the input information except for that which has been eliminated from the transform plane. This phenomenon is the base for both directional and spatial frequency filtering in optical processing (fig. 7).

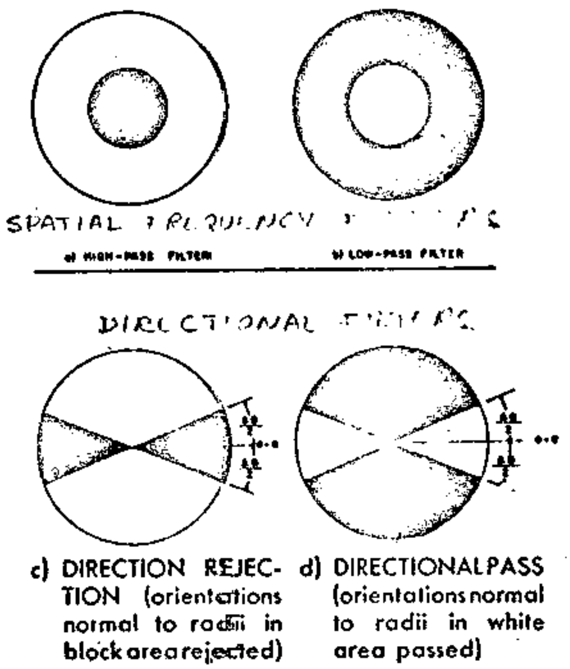


Figure 7. Masks used for spatial frequency directional filtering in transform plane. (Modified from Dobrin <u>et</u> <u>al</u>, 1965).

This type of optical processing has some advantages over other methods which were pointed out by Dobrin <u>et</u> <u>al</u> (1965):

a) economy: while other data processing techniques have costs increasing proportionally to the number of input information, this method may handle many hundreds of information channels in a single simple operation.

b) flexibility and speed: the output can be immediately analyzed and if not satisfactory can be changed through a modification of the input, or settings, or by filtering.

CONCLUSIONS

One cannot expect that either computer or optical data processing will provide the final answer for the perfect automatic geological data processing with available techniques. Both of these methods have advantages and disadvantages which have to be considered.

Digital computers may have large memories which can handle great parts of the tonal information contained in an image. Computer programs allow any change which could be necessary to perform a given type of processing however these alterations are time consuming. The high cost of computer time is a factor limiting the number of input data and the amount of operations performed therefore decreasing somehow the quality of the results. Most of the work with computers reported in the literature stresses the mapping of tonal and, to a lesser extent, textural characteristics of the pictorial information. The application of this technique to terrain mapping is therefore recommended.

Coherent optical systems are much more economical than computers and permit an easier monitoring of the processing operation. This technique permits a statistical analysis of lineation patterns in the whole input image, integrating all the information present in a simple operation. Optical filtering is particularly useful to enhance desired information which may be obscured by dominant elements in the input image. One should observe however, that the dynamic range available for optical processing is more limited than for digital work, because the transparency used in the first may lack density contrast or may have poor resolution. Even with this limitation it is possible to improve resolution of some pictures and to enhance features not readily observable in the input image (Dobrin et al, 1965; Dobrin, 1968).

The value of human interpreters in geology cannot be underestimated though. Geologic interpretation requires not only close attention to photographic tone or texture, and shapes or forms, but requires patience, judgement, and a not easily described ability to evaluate the significance of several types of information (Miller and Miller, 1961).

Research effort seems to be needed to evaluate carefully the presently available techniques of image-interpretation and to analyze the methodology used by photo-interpreters hoping to improve the growing field of automatic (or semi-automatic) data processing in geologic remote sensing.

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