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NEW USES OF SHADOW ENHANCEMENT

Don L. Sawatzky and Keenan Lee

Remote Sensing Report 74-5

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ABSTRACT

Shadow enhancement of topographic linears in photographic or scanner images is a valuable tool for interpretation of geologic structures. Whether linears will be enhanced or subdued depends on sun angle and azimuth. The relationship of the sun's attitude to topographic slopes determines which trends are available for interpretation in existing imagery, and it can be used to select the time of day, surface properties, and film and filter characteristics in planning aircraft flights or satellite orbital passes. The technique of selective shadow enhancement can be applied to all photographic or imaging experiments, but is best for snow-covered scenes, side-looking radar images, and painted relief models.

INTRODUCTION

D.U. Wise (1969) discussed the enhancement of topographic linears produced by low-angle illumination of relief maps from various directions. The technique reveals sets of linears often noticeably aligned within 30 degrees of the illumination direction. Many of these linears are anomalous in that they are unrelated to obvious geologic structural trends and transect major features of different tectonic style.

This paper attempts to explain selective shadow enhancement by developing and extending the ideas of Wise. The theory of selective shadow enhancement is shown to be useful in the interpretation of linear trends on imagery and photographs, and useful in planning experiments that selectively enhance certain trends.

Shadow enhancement is defined as the exaggeration of topographic linears or alignments of such linears by shadows formed within or along them. The topographic linears may or may not be obvious. Enhancement can be produced by a linear shadow margin or by an elongated shaded area.

The shadow is the result of low irradiance on the area, and is distinguished from illuminated areas of low reflectance. In much imagery and photography the distinction between the two is not always obvious. While both types of dark areas may have strong geologic controls, the shape of a shadow is strongly controlled by the illumination attitude (elevation and direction).

Numerous techniques have been developed to exaggerate linears in imagery and photographs. On the spectrum of enhancement techniques, image enhancement techniques are ternary. Shadow enhancement is secondary, and geomorphic processes, while not under our control, are primary. Image enhancement operates only on the linears available in the image, which are only a subset of all the linears in the object scene. Shadow enhancement is the result of topography and illumination at the time of exposure or scanning. However, it operates variably upon topographic linears, depending on slope attitudes, and may subdue them as well as enhance them (Fig. 1, [A]). Therefore, there will always be some linear features unavailable for enhancement.

Alignment of several linear segments is a puzzling phenomenon that may have psychophysical aspects to it. Little seems to be known about it, and long-winded speculations will not be made here. The phenomenon is puzzling for two reasons. First, very long linear features are often composed of

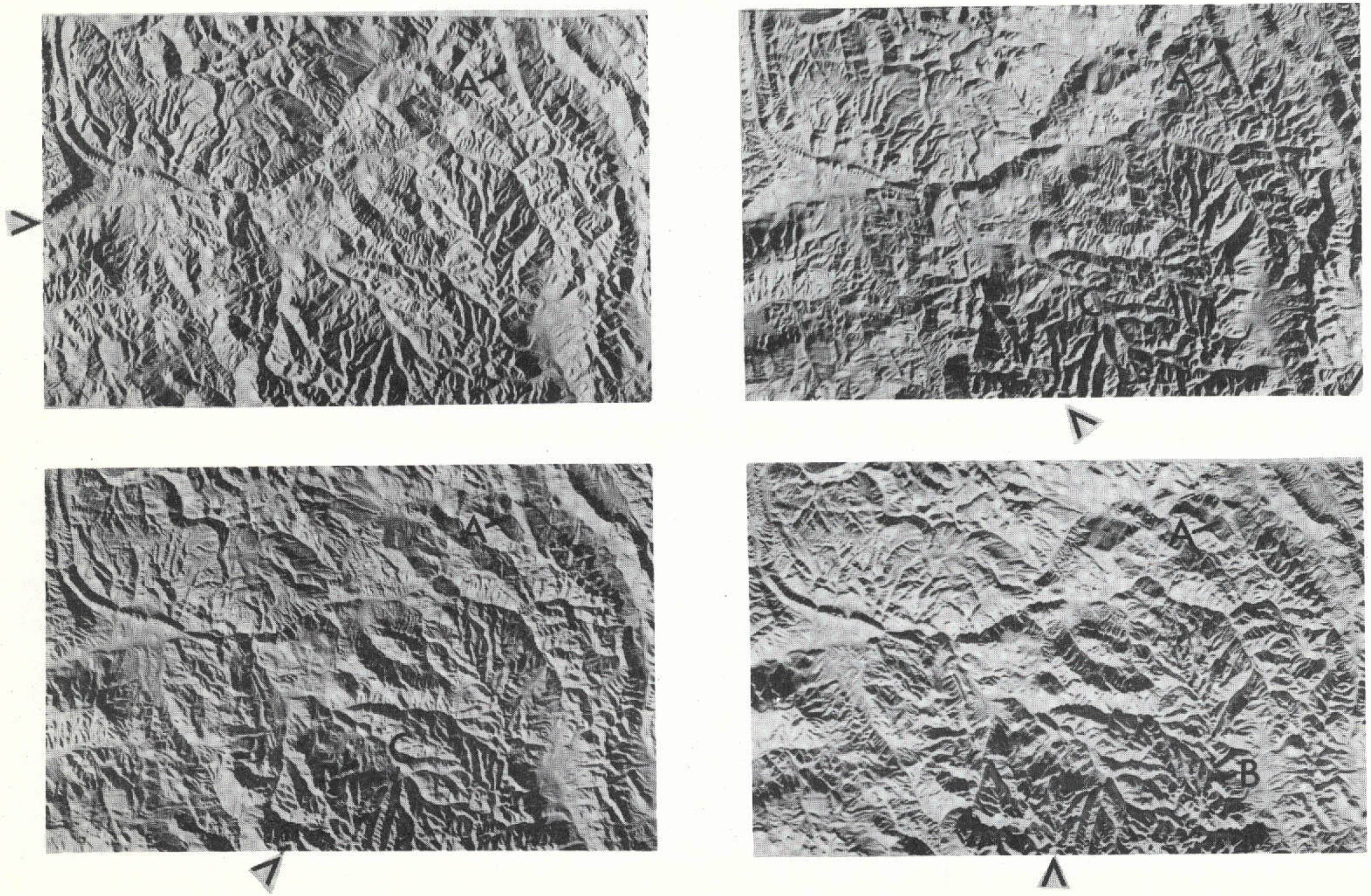

Figure 1: High contrast photographs of a relief model of the Leadville, Colorado, map (original scale = 1:250,000). Arrows indicate the illumination direction. The elevation is 27 degrees.

several segments. They cross major tectonic features without apparent relationship to the tectonic trends. Second, the alignments are near perfect at some illumination directions, but become angular or even non-existent at other directions (Fig. 1, [B]). In our experience, the physical origin of short linears or individual segments can be determined with great probability, but the origin of many of the long alignments cannot be. Some preliminary results of plots of random linears indicate that apparent trends will exist (Fig. 2).

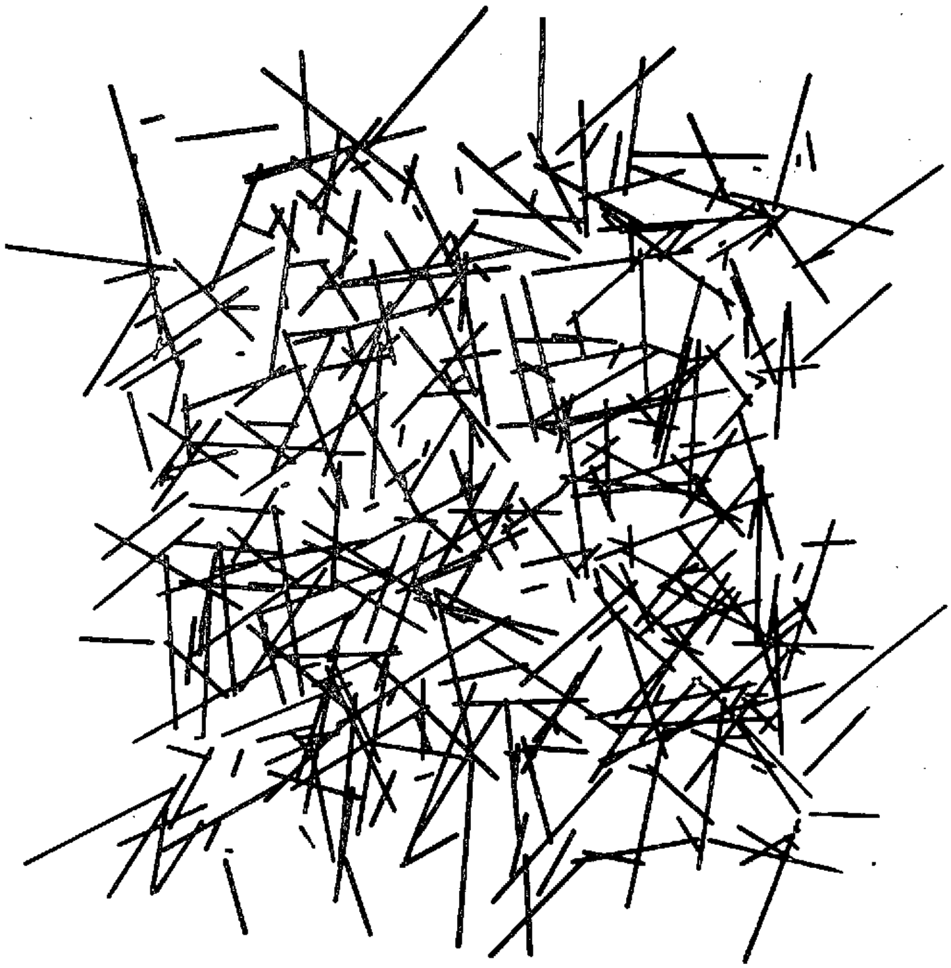

Figure 2: Plot of lines whose position, azimuth, and length have been generated randomly.

NEW USES OF SHADOW ENHANCEMENT

Unless such alignments can be identified, they should be considered seriously to be <u>fortuitous</u> alignments.

Applications of shadow enhancement can be made to many types of imagery and photography and relief models. The latter are most effective when painted a uniform light color. Side-looking radar imagery is also effective because of the high contrasts between the illuminated and shaded areas. Photography that has high contrasts can also be effective, for example, a black-and-white positive of a snow-covered scene (Fig. 3). Black-and-white ERTS images or Skylab photographs display abundant linears, many of which are shadow enhanced. In such images, areas of low reflectance are as abundant as shadows and may compete with or enhance shadow trends.

BASIS OF SHADOW ENHANCEMENT

Wise (1969, Fig. 4) reasoned that effective enhancement of linears occurs when the angle between the normal to the slope and the illumination vector is 90 degrees (Fig. 4). Under this condition the slope is shaded, and the distal margin of the shadow (the margin away from the source) lies at the foot of the slope, which could be a valley floor. If the valley floor is a linear feature, it is enhanced by the shadow margin. Thus the condition defined by Wise can account for the enhancement of linears. However, a study of shadows on relief maps reveals that this condition occurs for only a small percentage of shadows, and, under other conditions of shadowing, sets of linears also appear (Fig. 1, [C]).

The equation of Wise can be extended to include all conditions of shadowing. In this general case, the angle between the unit source vector $\overline{S}$ and the unit slope normal $\overline{N}$ is equal to or greater than 90 degrees or, in vector notation, the vector scalar product

Figure 3: ERTS image (Band 6) of a snow-covered scene in central Colorado. The sun elevation is 23 degrees, azimuth is 150 degrees.

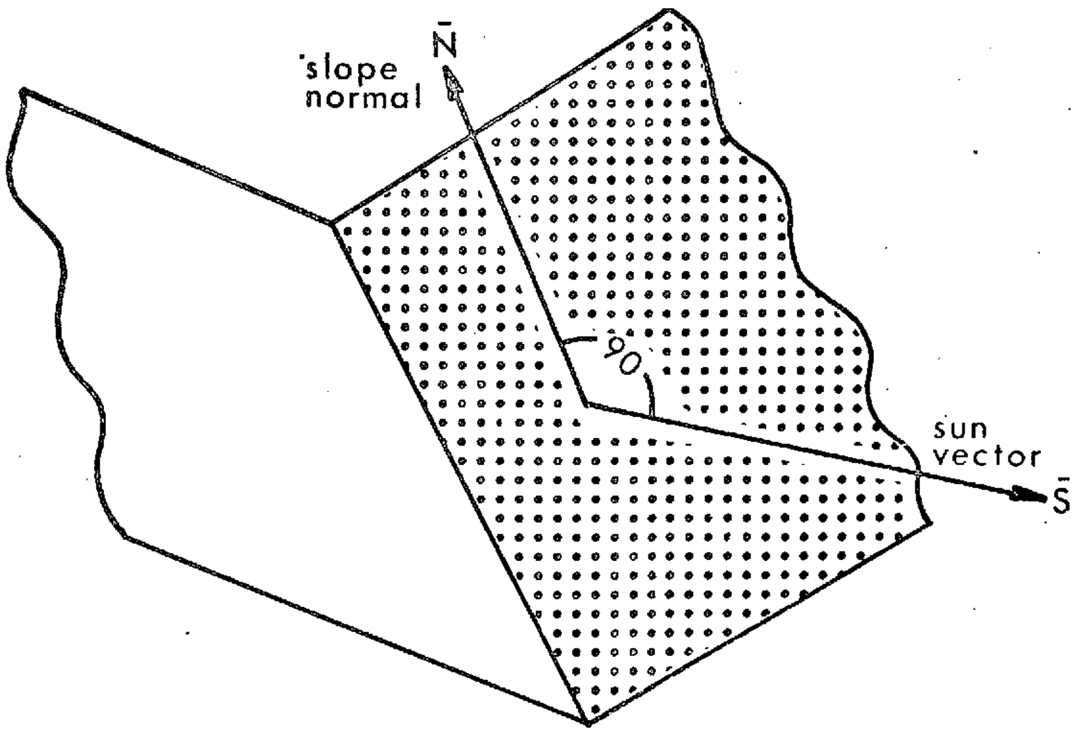

Figure 4: Diagram of Wise's condition of shadow enhancement.

$$\bar{S} \cdot \bar{N} \leq 0. \qquad (1)$$

This inequality reduces to

$$\mathrm{SIN(deviation) \cdot TAN(slope\ angle) \geq TAN(elevation)}, \qquad (2)$$

where deviation is the acute angle between the illumination direction (e.g., sun azimuth) and the strike of the slope, the slope angle is the true dip of the slope, and the elevation is the vertical angle of the source above the horizon (e.g., sun elevation). See Appendix for details.

Under all conditions of the extended formula (2) are included not only enhancement of the foot of a slope (or a valley bottom) but also enhancement of a ridge line or escarpment rim at the proximal margin of a shadow (nearest the source) (Fig. 5). Parallelism of ridge lines and valley bottoms is a common situation.

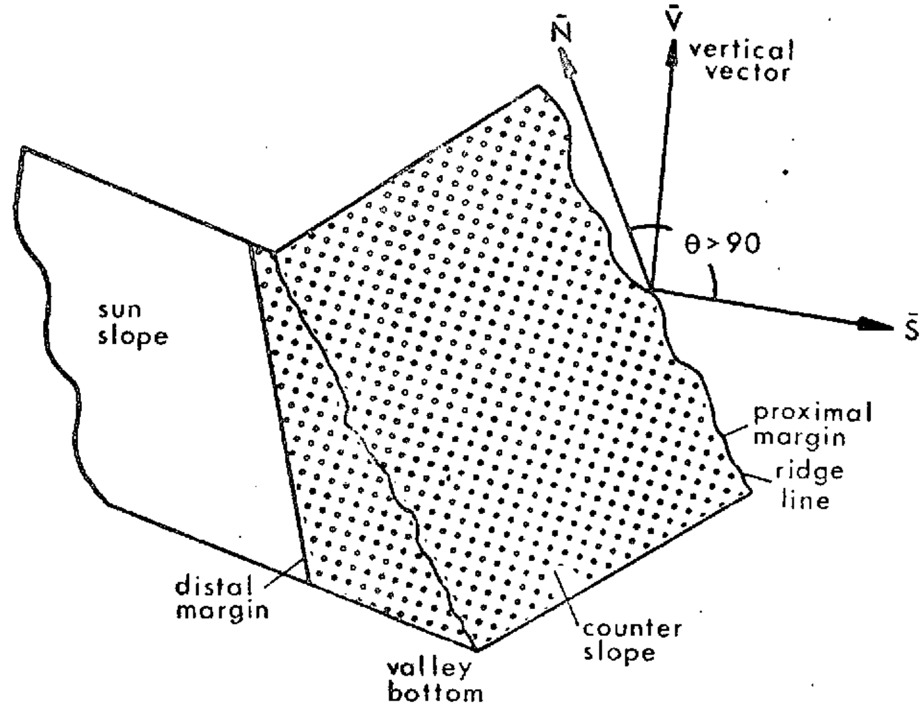

Figure 5: Diagram of extended conditions of shadow enhancement. The symbols are defined in the Appendix.

SELECTIVE ENHANCEMENT

Under the broader definition, shadow enhancement can be thought of as a two-dimensional filter that "cuts on" when the formula (2) is satisfied equally and "passes" information (shade is present) on those combinations of slope angle, deviation, and elevation that satisfy the inequality of (2). These combinations define the pass band of the filter (Fig. 6). In other words, for a given elevation, the cut-on slope angle is inversely proportional to deviation, but always greater than the elevation. It is this last characteristic that provides an explanation of the enhancement of some anomalous linears.

For a wide range of elevations, and in the range of deviations from about 45 to 90 degrees, information is passed (counter slopes are shaded) for nearly the whole range of available slopes (from the illumination elevation through 90

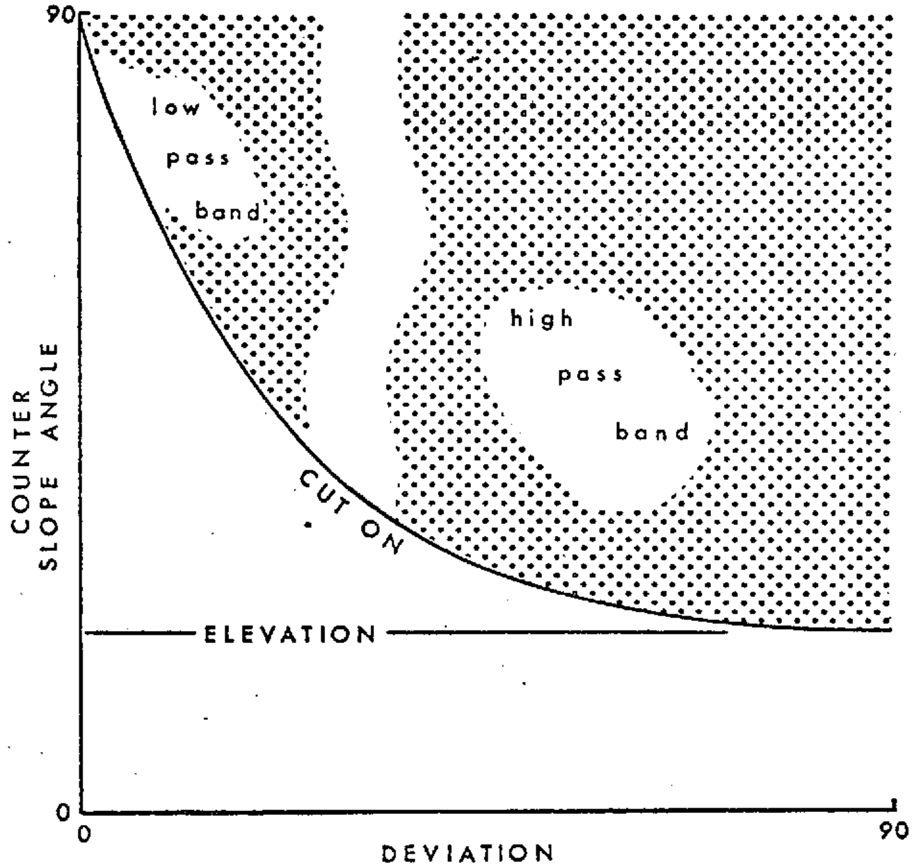

Figure 6: Graph of shadow enhancement filter. The pass band is above the cut-on curve. The cut-on curve is defined by a unique value of elevation.

degrees). These slope angles and deviations are in the high pass band of the filter. In other words, slopes within broad ranges of slope angle and deviation are all shaded. However, for deviations in the range from 0 to about 20 degrees, only slope angles in the range from approximately 20 to 90 degrees are shaded. This is in the low pass band of the filter. Therefore, while shadow enhancement as a filter passes all slopes greater than the elevation at larger deviations, it passes only the steeper slopes at low deviations. This is an important aspect of shadow enhancement, since steepsloped topographic features commonly produce the straightest patterns. This is especially important in interpretation of high-angle geologic faults and associated fault-line scarps.

EFFECT OF IRRADIANCE

Another cut-on characteristic of the filter can be defined. In reality there are slopes, outside the pass band, but near the cut-on curve, whose irradiance is low enough so that they can be considered effectively to be shaded. Therefore, the sharpness of the cut-on must be considered.

For the cut-off region of the filter, the irradiance of a slope is a function of the angle of incidence of illumination. (See Appendix.) For near grazing illumination, which usually occurs at low elevations less than about 15 degrees, tonal contrasts between shaded and illuminated slopes may be sufficiently small to make discrimination difficult. The problem will be greater if reflectances are low. If it is desirable to have shadow enhancement at low sun elevations, then it is also desirable to have the reflectances at a uniform and high value. This can be achieved by painting relief models white (Fig. 1) or by photographing snow-covered scenes (Fig. 3). If the photographic process is included in the method of shadow enhancement, the cut-on sharpness can be selectively modified by increasing the gamma of the film. This increases the contrast between shadowed and illuminated slopes. Further increase in contrast is possible by making shadows darker with respect to illuminated areas at the time of exposure. This can be done by using black-and-white infrared film with a Wratten 25 filter (Fig. 7).

APPLICATIONS

Many useful and potentially useful applications of selective shadow enhancement exist. It can be

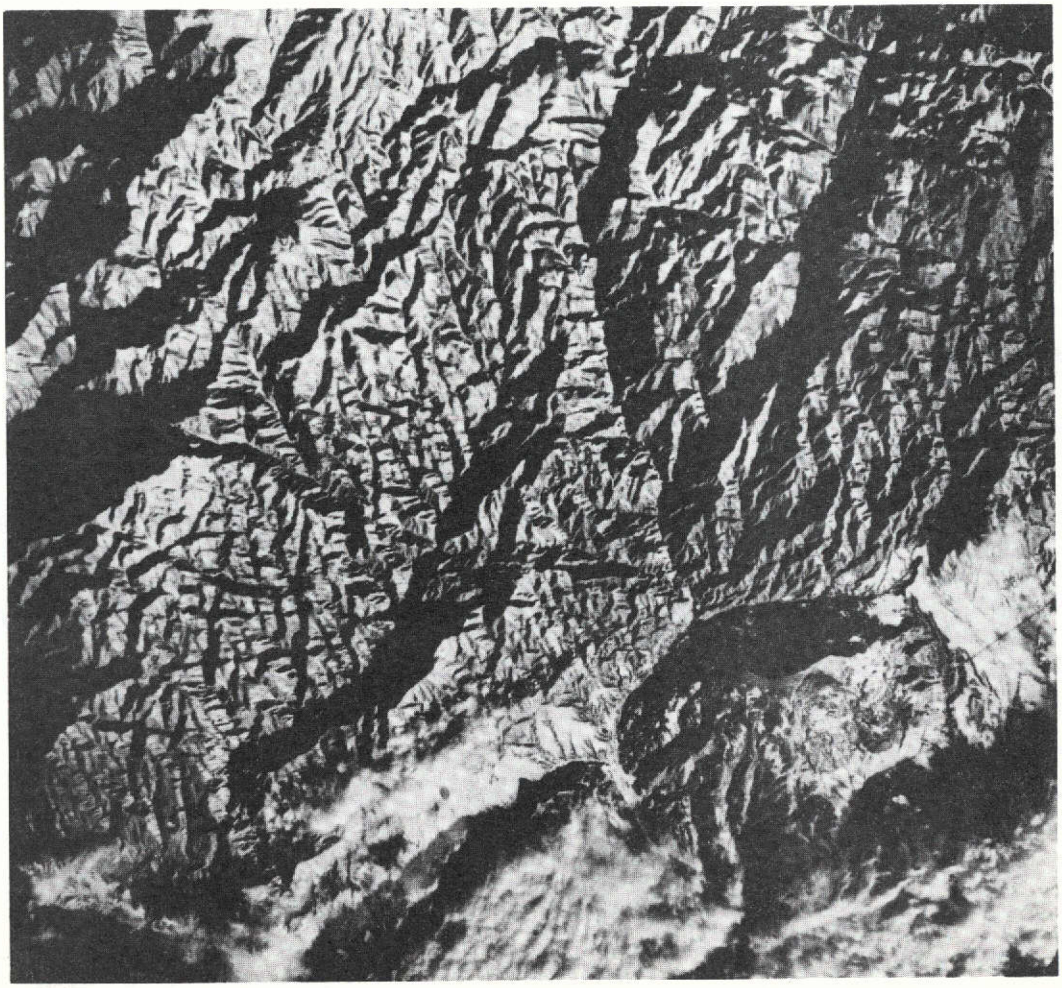

Figure 7: High-altitude, low sun-angle photography of a snow-covered scene in southern Front Range, Colorado. Sun elevation is 10 degrees and sun azimuth is 128 degrees. Black-and-white infrared film was exposed through a Wratten 25 filter and developed for high contrast.

applied in the study of relief maps and in designing aircraft photography flights and satellite orbital passes. The simplest experiment, designed for illumination at fixed elevation and azimuth, cuts off all slopes less than the elevation and selectively cuts off slopes of smaller angle at smaller deviations (Figs. 1,3,7). It is possible to look for linear trends at low deviations to the sun azimuth. These trends will be the straightest ones associated with the steepest slopes. Several experiments could be planned that would enhance trends at several ranges of azimuth.

Low sun-angle photography is included is this simple experiment. The low sun elevation defines a broad pass band for slopes, and therefore, most structurally controlled topography is enhanced (Fig. 7). The low angle also defines a broad pass band for all deviations, and selective passing of very steep slopes occurs at only very small deviations. Low sun elevation also produces broader shadows, which aid discrimination. On the other hand, high sun-angle photography has a narrower, and more selective, slope pass band, but shadows are narrower and discrimination is decreased. This could be overcome by changing the vertical look direction to a high-oblique look direction directly toward the source of illumination.

More complicated experiments involve two illumination directions (Fig. 8). By the following formula,

$$\mathrm{TAN(elevation)} \cdot \mathrm{CTN(slope\ angle)} = \mathrm{SIN(deviation)}, \quad (5)$$

combinations of azimuth and elevation can be determined to selectively shadow enhance slopes in any desired ranges of slope angle and deviation. Desired deviation and slope-angle cut-ons are determined by inspection of Fig. 9, and the optimum sun elevation is calculated from (5). The result is a filter combination as shown in Fig. 10. The band of deviations between the peaks is a slope-

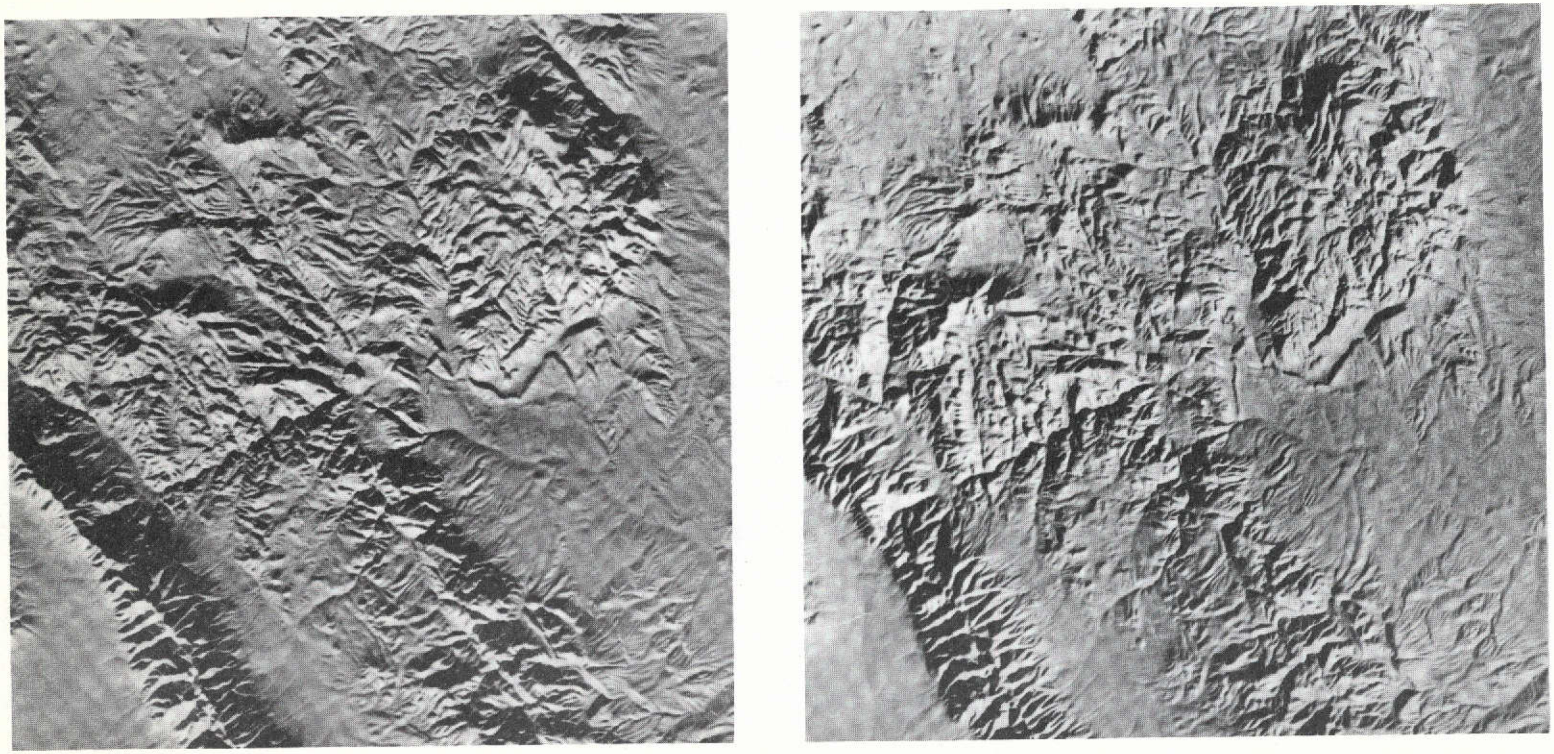

Figure 8: Images of painted relief model taken at two illumination azimuths, shown by arrows. Single filter effect is evidenced in each. The two-filter effect is observed by pseudostereoscopic viewing of the two images. The double pass band is centered on N22½W azimuth.

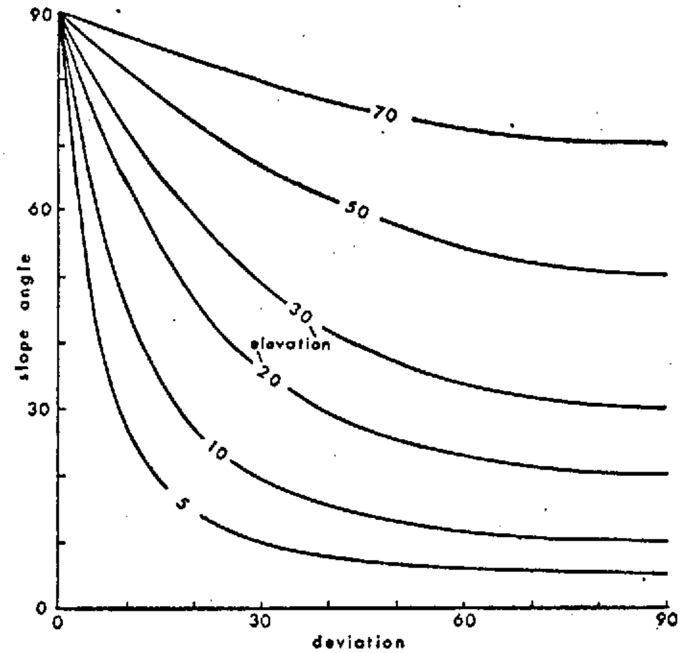

Figure 9: Graph of cut-on curves for various illumination elevations.

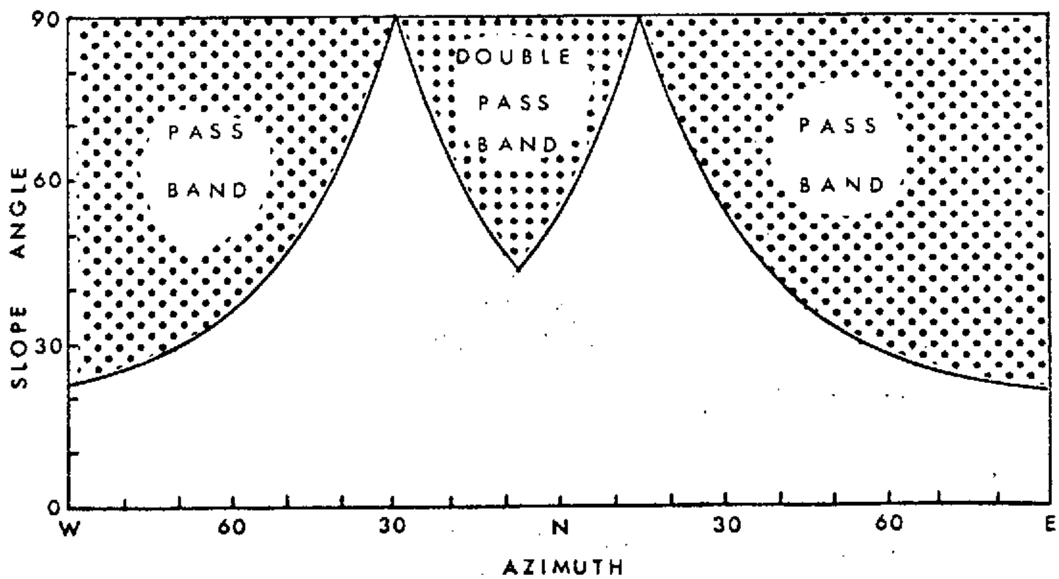

Figure 10: Shadow enhancement pass band for illumination at two azimuths.

angle pass band double that of a single filter. Thus, the selective pass band can be increased by filter combinations. Multiple double pass bands can be used by simply extending the technique to several filters at several azimuths.

A further extension is to have continuous illumination over a band of azimuths. The resulting filter is shown in Fig. 11. The pass band of this filter is just the selective pass band of a double filter. This experiment would be difficult to realize for the earth's surface because of limitations of the sun's attitude. However, the experiment could be set up for relief models or side-looking radar.

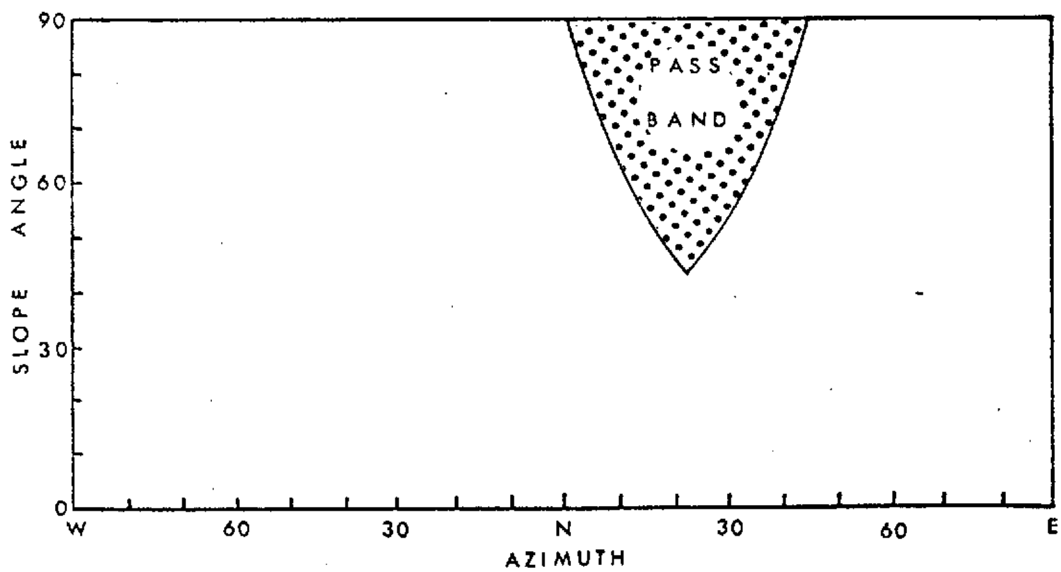

Figure 11: Shadow enhancement pass band for illumination over a continuous band of azimuths.

The ultimate extension is to have a constant illumination over an azimuth band of 180 degrees. The result is a gray level map or image free of deviation information. The gray levels represent different magnitudes of slope angle only. The results are confused when there is extreme shading of sun slopes, but, when most of the slopes are near the value of the sun elevation, the results are best.

CONCLUSIONS AND RECOMMENDATIONS

(1) Shadow enhancement is valuable for the study of geologic folds, faults, and regional fracture systems.

(2) Shadow enhancement is best where the scale of the imagery is small with respect to the size of the features studied.

(3) Painted relief maps, snow-covered scenes, radar imagery, and low sun-angle photography have the best shadow enhancement.

(4) Sun elevation and azimuth determine which trends are enhanced or subdued in images.

(5) Many techniques of image enhancement have been developed. A useful technique that enhances shadows in snow-free ERTS images, where they are confused with areas of low reflectance, involves color reconstitution. A color composite is made with Band 4 in green, Band 5 in red, and negative Band 6 in blue.

(6) It is possible to plan photography in which selective shadow enhancement is optimized to study one or more selected trends.

(7) Optimum enhancement is dependent on the topography. For low sun-angle photography, the sun elevation should be a few degrees less than the predominant slope angle. For mountainous areas, elevations of 10 to 15 degrees seem to be optimum,

while for gentler terrain approximately 5 degrees seems best. Elevations of 22 to 27 degrees seem to be optimum for relief models of mountainous terrain with a vertical exaggeration of 2. The optimum sun elevation should be increased as much as possible for surfaces with low reflectances.

ACKNOWLEDGEMENTS

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Wise, D.U., 1969, Pseudo-radar topographic shadowing for detection of sub-continental sized fracture systems: Proc. 6th Intl. Symp. Remote Sensing of Environment, U. Michigan, Ann Arbor, p. 603-615.

APPENDIX

The sun vector is the directed line taken in the sense toward the sun. The slope normal is the directed line perpendicular to the plane of the slope taken in the sense toward the atmosphere, whether in a model slope or a real one. Overturned slopes are a special case not considered in this discussion. Counter slopes are those whose normals have an angle greater than 90 degrees to the sun vector. Sun slopes have normals that form an angle less than 90 degrees to the sun vector. In the notation of formula (2) discussed earlier, if

$$-1 \leq N \cdot V \leq 1,$$

where $\overline{V}$ is the vertical vector,

then for counter slopes: $\overline{S} \cdot \overline{N} \leq 0$,

and for sun slopes: $\overline{S} \cdot \overline{N} \geq 0$.

The vector equation

$$\overline{S} \cdot \overline{N} = \cos\theta$$

relates two unit vectors to the angle between them. This forms the basis of formulas (1) and (2). The angle θ is the illumination angle of incidence (measured from slope normal) upon the slope surface. The equation can be reduced to a function of slope angle, deviation, and illumination elevation:

$$\overline{S} \cdot \overline{N} = \mathrm{SIN(elev)} \cdot \mathrm{COS(slope\ angle)} - \mathrm{COS(elev)} \cdot \mathrm{SIN(slope\ angle)} \cdot \mathrm{SIN(dev)}.$$

Irradiance E on an illuminated slope is expressed by

$$E = E_o \overline{S} \cdot \overline{N} = E_o \cos\theta,$$

where E_o is the irradiance on a surface perpendicular to the sun vector.