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Digital Data From Shuttle Photography: The Effects of Platform Variables

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ABSTRACT

Two major criticisms of using Shuttle hand-held photography as an Earth science sensor are that it is non-digital/ non-quantitative and that it has inconsistent platform characteristics, e.g., variable look-angles, especially as compared to remote sensing satellites such as Landsat and SPOT. However, these criticisms are assumptions and have not been systematically investigated. This project focusses on the spectral effects of off-nadir views of hand-held photography from the Shuttle and their role in interpretation of lava flow morphology on the island of Hawaii. The first stages of the research are discussed--digitization of photography at JSC and use of LIPS image analysis software in obtaining data. Preliminary interpretative results of one flow are given. Most of the time was spent in developing procedures and overcoming equipment problems. Preliminary data are satisfactory for detailed analysis.

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Since 1972, Landsat has provided the standard for Earth science remote sensing from space, while hand-held photography from manned spacecraft has been relegated to an inferior subsidiary role of illustration. Despite the provision of some 37,000 hand-held photographs from the Space Transportation System Shuttle program in the past five years, there have been very few scientific reports using the imagery as a major data source (see e.g., Kaltenbach, Helfert, and Wells, 1984; Gallegos, et al., 1984; Nerem and Holz, 1984). The fundamental reason for diversity of scientific acceptance between the two sensors is a perception of technological performance differences: Landsat is seen as state-of-the-art but photography is deemed deficient and largely second-rate. For example, whereas Landsat is a digital scanner system which renders data computer compatible, photography is film based--visually analog and not intrinsically amenable to computer analysis techniques. Hand-held photography (herein referred to as HHP) also has variable platform characteristics, such as a diversity of viewing-angles (also called look angles and usually referred to as off-nadir when non-vertical angles are considered) and different solar illumination conditions. Landsat, to its supposed advantage, is very consistent in platform attributes (especially the nadir view), thereby offering a standard format of imagery. Believing that HHP can be a more useful scientific data resource, the differences in platform performance were called to questions with the hypothesis that non-vertical viewing angles and attendant illumination changes are not debilitating in terms of image quality and utility, and in fact, may be advantageous in some earth science research. This study investigates the nature of off-nadir viewing from HHP and its role in analysis of lava flow morphology on the island of Hawaii.

The basic objective of this project was to develope a methodology to analyze spectral (tonal) differences of given features on HHP frames having variable look angles. Three phases of the project were perceived: digitization of photography (the processing stage), development of data extraction techniques, and analysis of selected features (applications stage). Most of the summer period involved the first two steps and preliminary analysis of data was initiated. This report discusses the theoretical and practical considerations of digitally processing photography and the means to extract useful information. Preliminary results of one research site are presented as a demonstration of the methodology.

THEORY

A Lambertian surface is a perfectly diffusing target that reflects energy equally in all directions (e.g., Slater, 1983). The physics of such perfection are calculable but terrestrial surfaces are not Lambertian, so there is interest in the interactions of electromagnetic energy with various types and conditions of targets. Off-nadir sensing has been investigated, but primarily for vegetated surfaces (e.g., Bartlett, Johnson, Hardisky, Klemas, 1986; Daughtry and Ranson, 1986; Gerstl and Simmer, 1986; Goel and Deering, 1985; Holben, Kimes, Fraser, 1986; Kimes, Newcomb, Nelson, Schutt, 1986; Li and Strahler, 1985; Lord, Desjardines, Dubé, Brach, 1985; Norman, Welles, Walter, 1985; Simmer and Gerstl, 1985). No research on the effects of different look angles to spectral response of lava flow (or any volcanic landscapes) could be found. Further, emphasis has been on the derivation of mathematical models of off-nadir viewing but this investigation concentrates initially on detection of changes on a new medium and their role in analysis of lava flow morphology.

Basic theory of digital imagery processing and analysis forms the framework of this project (see Jensen, 1986, for the best single reference) and details of its application, i.e., specific procedures, are discussed in the next section. The literature on digital remote sensing is vast but will be mentioned only when directly relevant; no literature review is offered here. As prescribed above, digitization is considered first, followed by data extraction and data analysis.

Photography, a film-based image, is a visual product and analog by nature. Conversion to a digital format, necessary for computer analysis, is a theoretically simple process of re-imaging with a vidicon camera (in this case, but a scanning densitometer also can be used) and transformation of picture elements (pixels) into discrete values representing tone or density. Specifically, light of a known intensity is transmitted through a transparency and the reduction in intensity received by the vidicon, on a pixel by pixel basis, is translated as film density. Pixels, having specific X-Y locations, are restructured into a digital image of the photographed scene. Color photographs are reduced to three distinct bands (usually red, green and blue) by the use of filters in the re-imaging process, making a three-band digital image, ready for computer manipulation.

Digitization of photography is not a new technique (e.g., Hoffer, Anuta, Phillips, 1971; Jensen, Estes, Tinney, 1978;

LeSchack, 1971; McDowell, 1974; Scarpace, Quirk, Kiefer, Wynn, 1981; Smedes, Linnerud, Woolaver, Hawks, 1971), but it is not a popular technique for quantitative analysis, primarily due to the many vagaries inherent in photography and difficulty in control and repeatibility of the digitizing process. Despite high quaility control, the chemical processes in manufacturing, storing, development, and reproduction of films are not quantitatively known or maintained, and thereby are subject to latitudes of variance. Because of these factors, precise analytical controls are very difficult to attain and derivation of absolute spectral signatures, for example, is seldom attempted. In fact, Scarpace (1978, p. 1287) maintains that "film density is not the parameter to be correlated with the reflected energy from the ground. The dye densities formed in films depend in a non-linear way on not only the amount of energy and its spectral distribution striking the unexposed film, but also on the processing of the imagery." Radiometric calibration derives the relationship between film density and light energy (making D-log E curves of exposure and film response) but the process is too complex to include here (involving photo technicians and detailed dye measurements) (also see McDowell and Specht, 1974).

The result of these difficulties is that while digitization is a relatively simple process, as described, great care must be taken in maintaining data that are comparative. A major aim of this project (and most of the work expended) was in development of procedures for producing quantitatively standard data so that features on different frames could be compared effectively and accurately.

There is no practical way to determine film chemistry processes and their quantitative meaning for HHP. The best approach is to use reproductions as close as possible to first generation images (keeping data degradation to a minimum) and to select frames on the same roll (to ensure reasonably identical processing). Fortunately, two four-frame sequential series of second generation images of the desired study area were available, minimizing extraneous factors of variability.

The initial aim of data analysis was to spectrally characterize lava flows at various viewing angles and to evaluate the signature differences.[1] Spectral signatures of changing linear features are best represented as a chain

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1. As noted, absolute spectral signatures are not attempted here and only relative responses are used. The term "spectral signature" is used for convenience and does not imply establishment of pure signatures; actually, the proper term to use would be film response.

of tonal values along their paths. That is, pixel values from each band are collected at locations along the lava flows and compiled into sets of value curves. Various statistical methods are available that determine differences and relationships of curves and points within a set of data. Analysis of single frame information may be useful in terms of lava flow morphology, but when all frames are combined and compared, synergetic interpretation may be possible.

One of the major problems of multi-frame image analysis is obtaining data that are truly and purely comparative. Under perfect (unrealistic) conditions, all pixel values reflect ground variables only and photographic or digitizing factors do not induce tonal corruption. However, practical conditions contribute both noise and potentially invalid values. For example, Jensen (1986, p. 16) states that vignetting is one of the most serious problems in video digitizing--fall-off of intensity from the center of output to the edges, usually in a circular pattern. Also, Jensen, Estes, Tinney (1978) found vignetting to be a critical component preventing consistent measurements of agricultural fields.

If such intrinsic "antagonists" can be identified and measured, their dilutions can be subtracted from data. The aim, then, is to "normalize" data to some common base or measure so that only the ground effects contribute to tonal change. From there, changes wrought by different look angles and slant ranges can be deduced. There are numerous methods of normalization, but a fairly simple approach was used that identifies and compensates for extraneous influence, i.e., light table variances were identified and removed. Once extrinsic factors have been eliminated and a satisfactory set of densities values gathered, analysis of data can proceed.

DATA

As stated, two ideal sequences of images of Hawaii were located: visual 65A-50-056 to 059 and color infrared 65A-55-105 to 108. Table 1 presents their viewing geometries of the visual color frames. Initially, three lava flows were examined--Keamuku (about 300 years old), 1859, and 1880 (Map 1). To maximize resolution and spectral information, enlarged subimages of each flow were produced from each of the frames above. Further, in that each band of the images requires individual analysis, there was a total of 72 data images (8 frames x 3 bands each x 3 study flows).

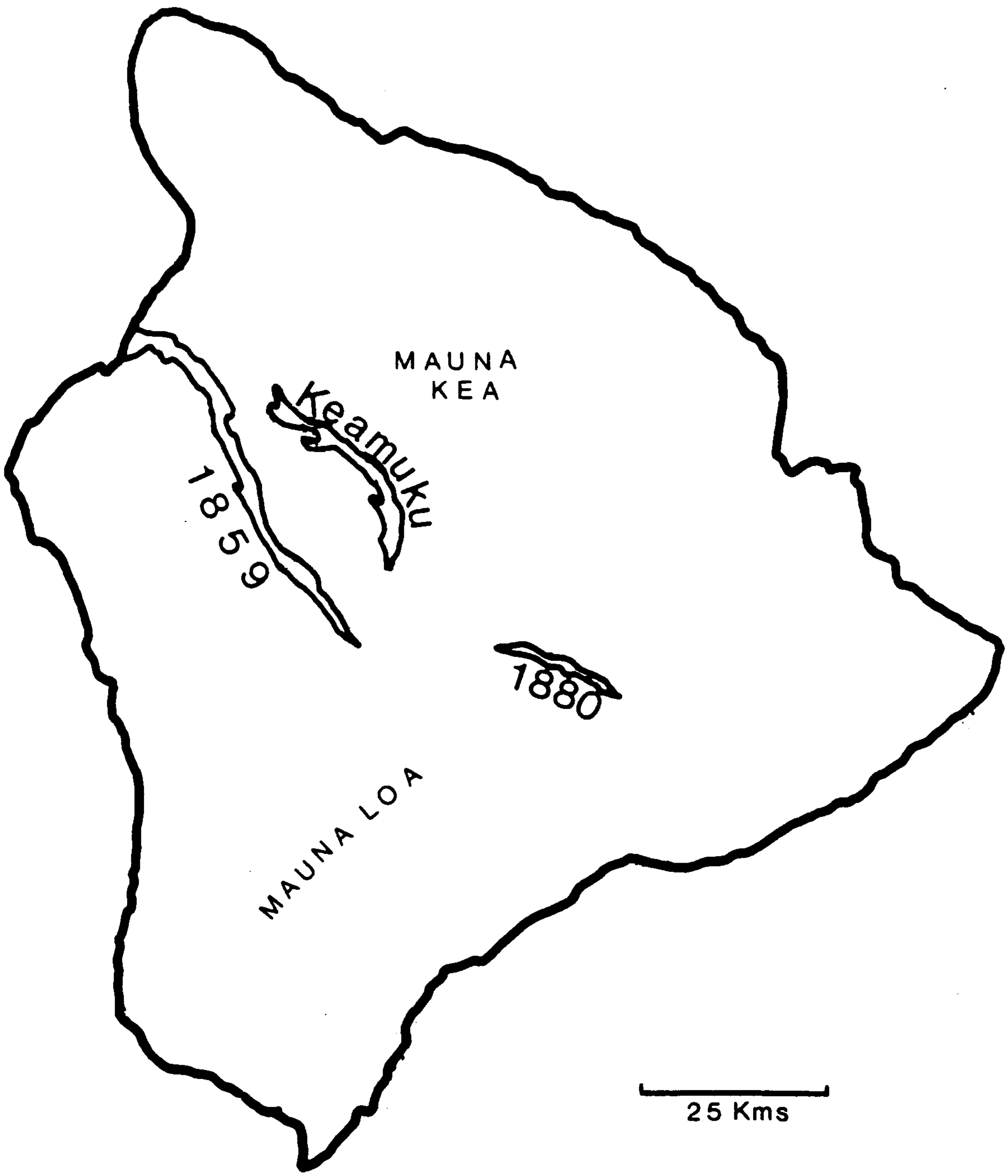
The photographs were digitized on JSC's new Gould Eikonix

TABLE 1: IMAGE GEOMETRY

Based on Shuttle to Keamuku flow
Altitude: 176 n.m.

Frame	Ground Range (n.m.)	Slant Range (n.m.)	Look Angle (degrees)	Solar[1] Az	Solar[1] Elev
56	315	372	59	141.0	53.0
57	229	293	51	143.6	52.5
58	210	278	49	144.2	52.3
59	160	241	42	146.1	51.8

1. Solar Az: Solar Azimuth from Shuttle to Sun, measured cw from north.
   Solar Elev: Solar elevation angle at Shuttle nadir.



MAP 1 HAWAII

850 digitizing system in Building 17. It offers digitizing formats of 512 x 512 pixels, 1024 x 1024, and 2048 x 2048, each with center or upper left corner (0,0) origins. Additionally, either transparencies or prints may be used, though the former usually present best results. Computer processing and analysis were performed with LIPS--Library of Image Processing Software.

METHODS AND PROCEDURES

Indicated above were the contrasts between theory and practice in digitization and analysis of imagery. Discussed here are the specific procedures used (as guided by basic theory) and the problems encountered. Practical considerations are addressed as a means for developing insight and furthering project evolution. The format employed is representative of a digitizing task and subsequent preparation for image analysis. Specific LIPS commands and responses are given for JSC operator convenience.

Digitizing System:

Light Table: Consisting of floodlights for opaque prints and a small table window with lighting from underneath for transparencies (the format used here), the light table provides illumination for the images. It is this component which created intransigent problems and seriously delayed progress. Illumination must be strong so that other variablesin the total system can be exercised. However, because of unsuspected power supply wiring problems, light intensity was a fraction of its design, therefore necessitating maximum conditions of other controls just to attain minimum illumination. Consequently, poor and unacceptable image data resulted, causing much waste in time and effort. The problem was finally rectified in week nine of the ten week program, so data are preliminary, incomplete, and essentially unanalyzed.

Another major (and continuing) problems of the lighting system is that it is a condenser type, resulting in uneven illumination across viewing area. A "hot spot" is particularly evident (though always present) at camera positions outside the narrow focus position--apparently inherent in condenser systems. A diffusing light system (more expensive) retards such conditions and offers more even lighting. Perhaps this also is inherent in Eikonix instrumentation, as other users have complained of similar limitations. The applied aspects of such problems is that standardization of pixel values is not ensured, forcing development of means to remove the variance. Further delays were encountered because of mathematical limitations in LIPS (to be discussed). In essence, the illumination component is a critical weakness to spectral analysis work in this digitizing system.

Camera: the vidicon camera digitizes with the use of a linear array of 2048 photoelectric detectors that scan the image in a vertical manner. Exterior controls consist of f-stop, focus, framing, and lens. Framing is accomplished by vertical racking of the camera on its support, but as mentioned, best results are attained at the condenser system's focus point, which greatly limits framing and scaling. The only reasonable option is to use different lens--normally available are a 50mm, 105 mm, and extension tube, although these too must be positioned at the lighting system's focus. Also included in the camera is a filter wheel which introduces red, green, and blue filters in the light path (after the lens) in order to reduce a color photo into three primary colors.

A major problem in the camera is the presence of numerous dead or deficient detectors, which causes streaking and erroneous data on the image. A column of four or five dead detectors in the center creates a wide dark band that is visually distracting and quantitatively distorting in data analysis. For example, a pixel value histogram of a central bright area will show values of 0 (dark), which obviously do not belong and also create erroneous frequency statistics. Designing images that fit into the limited framing and that avoid most of the dead detectors is unnecessarily time consuming and can cause potentially undesirable compromises.

Control Box: Other major exterior controls for digitizing are contained on an instrument beside the light table. Light intensity is monitored with an oscilloscope atop the box and controlled with an incremented lever. Filters (or clear) are selectable, as are several other non-critical exposure variables that are usually controlled with computer inputs. Fine focussing is aided with a contrast reading on the oscilloscope.

Software: Primary regulation of digitizing is in the software, using IDTST, CALIBRATION and DIGIT programs. IDTST establishes detector exposure time (dwell time) and scan rate. CALIBRATION sets the range of detector response from the darkest input (to 0) to the brightest (to 255). DIGIT prepares the system for digitizing and within are selections for exposure and scan framing. Image size can be dictated by choosing one of three scan outputs (512 x 512 lines and pixels [columns], 1024 x 1024, or 2048 x 2048) and selecting a center or upper left origin. Once digitizing has been accomplished, entry into LIPS begins the image manipulation and analysis phases.

The newly digitized scene is transferred from the primary operating system (VMS) to LIPS by a DEFIMG (DEFine IMaGe) routine. For scan outputs over 512 x 512, a screen cursor can be positioned anywhere on the scene to define a 512 x 512 subimage. Once the desired images have been saved, normal LIPS operations can begin, e.g., enhancements, algebraic renditions, signature analysis, etc.

Under ideal conditions, the process for signature analysis would include digitizing as described above, saving the image in LIPS, and using one of several pixel value collection routines--point value, box histogram, or profile, all manually controlled. Organization and statistical analysis of resulting data would then round out the task. The process is fairly straightforward and seemingly easy, but as indicated, numerous barriers were encountered, the first of which was inadequate light table intensity.

There simply is no solution to insufficient lighting for images. A normal image's wide range of values are compressed at the lower end of the brightness range and spectral resolution and contrast are lost. Contrast stretching offers visual relief but doesn't change the relationships of original data. Therefore, satisfactory illumination is the first crucial criterion for progress.

While awaiting solution of the light intensity problem, the uneven illumination was investigated. A fundamental premise of this research is that pixel values in a scene represent ground features and that different values within a feature indicate inhomogeneity of surface appearance or atmospheric effect, which in turn stimulates investigation into the reasons for these differences. Hence, one has to be assured that pixel values are results of factors inherent in the feature or in the sensing (atmospheric conditions, solar angles, etc.) and are not the product of treatment of the image in the laboratory. Thus, distortion induced by image analysis equipment must be removed.

In the simplest sense, irregularities can be compensated for by adding or subtracting the difference between observed and the desired. However, care must be taken in that simple addition or subtraction can change the relationship of values, particularly when two different exposure intensities are used in measuring. More precisely, the problem is that the bare light table's illumination is far brighter than when covered with an image--the photo reduces light intensity so much that identical camera or exposure setting are incompatible with the level of the bare light table. So, to measure the initial intensity and accompanying irregularities, exposure must be reduced as compared to image digitizing intensity. Exposure differences present problems in standardizing pixel values because of the wholely changed nature of the illumination. By computing on a ratio basis, however, most of the difference and variance can be managed. Using the maximum intensity of the light table as the standard (to which variances must be increased to) Formula 1 was used to produce a "mask" for each band (red, green, and blue). This and other formulae are applied to each color band of the image. LIPS commands are given in brackets where appropriate.

Formula 1:
[RATIO]

$$Mxy = \frac{Hc}{Vxy} \times 100$$

Where

M = Mask
xy = Coordinates of a given pixel
H = Maximum intensity value in entire scene
V = Intensity value

The mask then could be applied to the image for "normalization" of each band using the idealized formula:

Formula 2:

$$N = \frac{(Mxy)(Ixy)}{100}$$

Where

N = Normalized image
M = Mask value
I = Image

These formulae correct light table illumination variances but LIPS presents difficulties in their application. The first problem is minor: LIPS can output only integers. Understandably, pixel values must be integers and at the end of any calculation of two images, LIPS is prepared to depict results in the form of an image. Consequently, rounding occurs; LIPS has no way of knowing that Mask, for example, is an intervening calculation where image output is not necessary. Therefore, resulting pixel values are plus or minus one DN (density number), an acceptable error for this project.

Mathematically, these formulae can be reduced to:

Formula 3: $$N = \frac{H(Ixy)}{Vxy}$$

A second problem is that LIPS does not accept designed formulae but uses only established routines. As in Formula 1, RATIO can manage A/B but not (AxB)/C; thus, the numerator must be constructed appropriately. A third intrinsic problem is introduced: output is limited to the range 0-255. Again, because LIPS is prepared to produce an image from any algebraic routine and because the tonal range is restricted, any calculation performed must result in integers between (and including) 0-255. Multiplying H x I surely will exceed this limit, so LIPS has scaling subroutines to keep results within its boundaries. The user, then, cannot have confidence that each pixel has the desired (or same) relationship with all other pixels. The simple illumination rectification formula cannot be applied directly.

With some tenacity the problem can be overcome. Using one of LIPS' multiplication routines the modified (scaled) product of two images can be produced. In this case, the mask (Formula 1) is multiplied by the image, i.e., the numerator operation in Formula 2. To find the scaling number (transformation number) approximately a dozen sample pixel values are taken, using a floating cursor point value routine (PIxel). If a particular class of features is under study, pixel values should be taken from them. These values are compared to hand-calculated values of the Formula 2--the desired output. Once the ratio of LIPS product to desired output is derived, its integer value (ratio percentage x 100) is stored as a single-value image (using the CONSTANT routine in LIPS). Finally, the normalized image is achieved by ratioing the product image and transformation number x 100. These steps are:

1. Formula 4: $P_{xy} = (M_{xy})(I_{xy})$
[MUL8 or MULI]

Where
P = Intermediate product

2. Obtain pixel value of selected sites (V_{xy}) using PI in LIPS.

3. Using sample pixel values, calculate output of the desired formula (Formula 2).

4. Calculate the Transformation number for each band (T) by:

Formula 5: $$T = \frac{P_{xy}}{N_{xy}} \times 100$$

[The Nxy here is from Formula 2]

5. Store T as a single-value image.

6. Normalize by:

Formula 6: $$N = \frac{P_{xy}}{T}$$

7. Save Pxy as the final, normalized image to use in signature analysis. Combine the color bands of each frame into a three-band color image.

These procedures can be applied to full frames, but the features under study here (lava flows) are too small on each frame to present sufficient size for pixel value sampling. As discussed, subimages can be produced at the DEFIMG stage, thereby making an enlarged image for each flow. A total of 72 images serves as the data base.

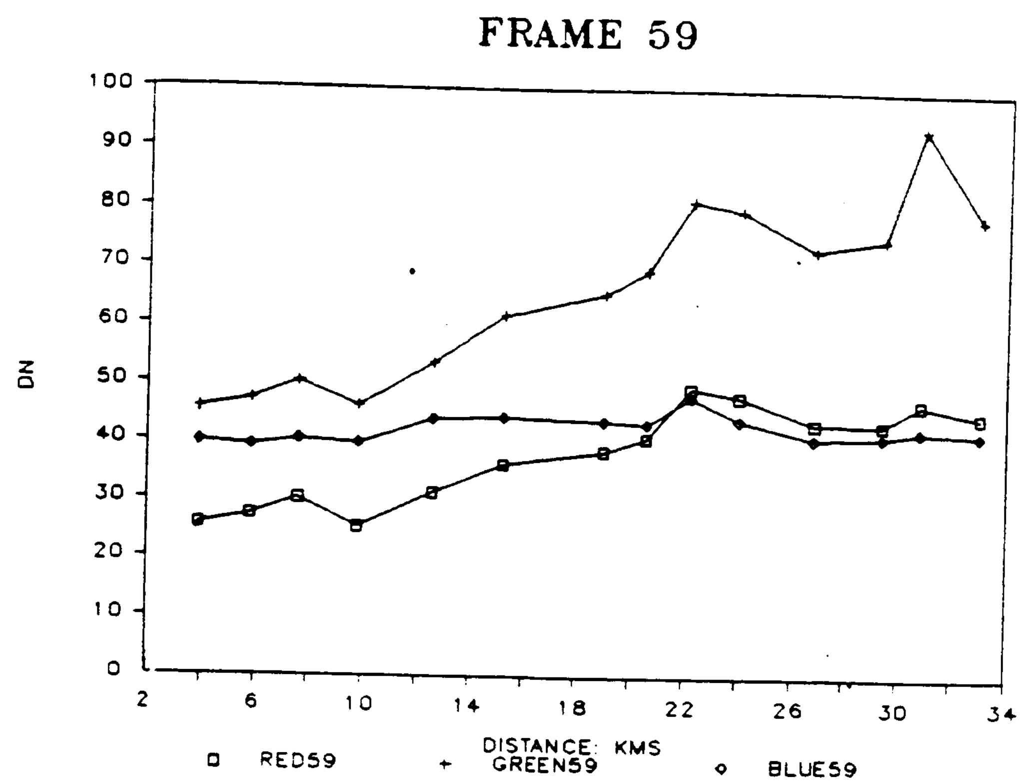
Unfortunately, the above procedure must be applied to each subimage for normalization. Although some short-cuts could be performed, there is no assurance that standardization of images will result, primarily because the variances in illumination is spatially unique and one site's of numbers will not work for another site. For example, the transformation numbers for frame 059 was applied unsuccessfully to 056. The method is time-consuming, but serves as the only reasonable technique for overcoming inherent problems in the Eikonix hardware and in LIPS.

DATA ANALYSIS

By the time the problems were solved, little time remained for generation of complete data. The Keamuku flow was subimaged and pixel values were taken. Procedures of digitizing, normalization, and preliminary data collection were verified. No analysis of consequence has been completed but demonstration results are given and discussed. Because this report concentrates primarily on procedures and because complete discussion of data and analysis normally is lengthly (site and feature characteristics, literature history, tables of data, details of analysis, consideration of results, etc.), only brief remarks of results and preliminary thoughts of meaning (no conclusions) are presented.

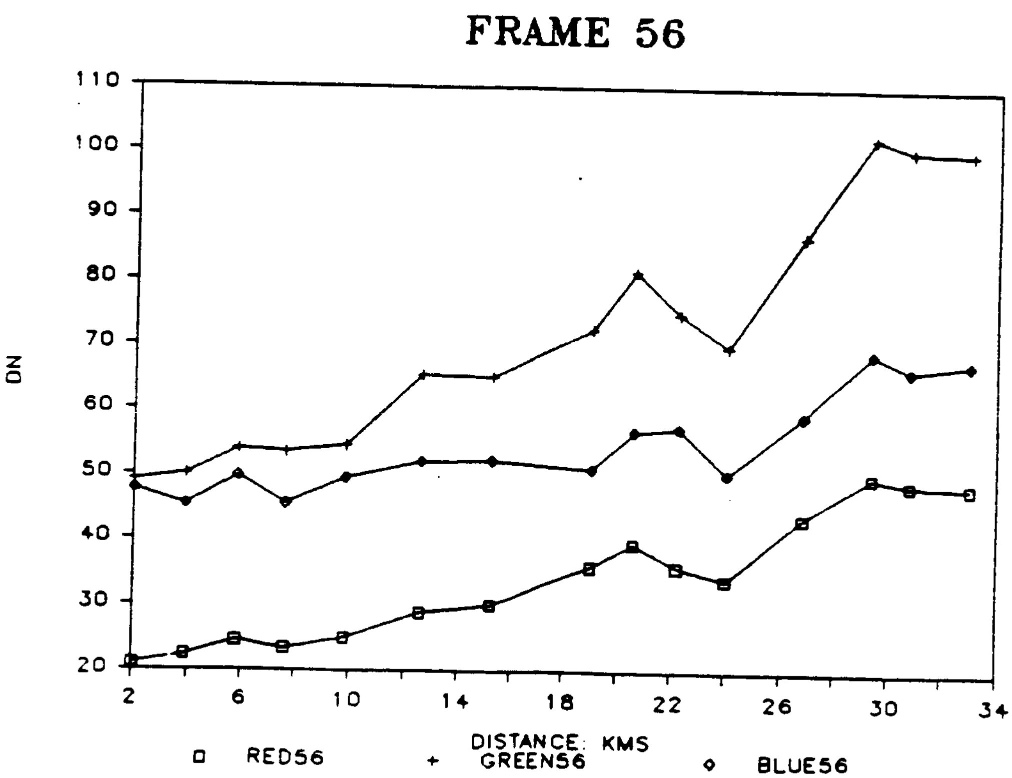
Contrast normally decreases with increased viewing angle and with decreasing solar angle. Distance is not a major determinant but the increased atmosphere between sensor and target also tends to reduce contrast (e.g., Slater, 1983). Detail and features within lava flows are naturally very low contrast and the effects of look angle and solar illumination may be critical in lava morphology interpretation. The first stage of data analysis compares the spectral effects of the visual frames (056 to 059).

Figure 1 shows tonal response (DN) of the three color of frame 59 (the highest viewing angle--least off-nadir) to distance from the main vent. Although there is practically no vegetation (lichen) on the Keamuku flow, green has the brightest response. A comparison with frame 56 (lowest viewing angle) in Figure 2 shows the effect of changing look angle. Green retains the highest values in 56, but the difference between blue and red is more pronounced. Table 2 presents a selected set of correlations for further and quantitative comparison. All colors of frame 56 have good correlations with distance, as does red and green in 59, but blue in the latter image has almost no correlation. This is surprising given that blue should be scattered much more on 56 because of the greater viewing angle and slant range atmosphere and thus should exhibit



FRAME 59
DN
100
90
80
70
60
50
40
30
20
10
0
2
6
10
14
18
22
26
30
34
DISTANCE: KMS
RED59
GREEN59
BLUE59

Fig. 1



FRAME 56
DN
110
100
90
80
70
60
50
40
30
20
2
6
10
14
18
22
26
30
34
DISTANCE: KMS
RED56
GREEN56
BLUE56

Fig. 2

TABLE 2: SELECTED CORRELATIONS

1.

Frame	Distance	Elevation
Red 56	.97	.96
Green 56	.96	.96
Blue 56	.87	.91
Red 59	.90	-.82
Green 59	.94	-.88
Blue 59	.21	-.12

2.

Red 56	.97	-.96
Red 57	.98	-.95
Red 58	.98	-.95
Red 59	.90	-.82
Blue 56	.87	-.91
Blue 57	.98	-.97
Blue 58	.97	-.99
Blue 59	.21	-.12

3.

Red to Red:

Frame 56-57:	.98
Frame 56-58:	.97
Frame 56-59:	.87

Blue to Blue:

Frame 56-57:	.90
Frame 56-58:	.89
Frame 56-59:	.17

4.

Red 56 - Red 59:	.87
Green 56 - Green 59	.91
Blue 56 - Blue 59	.17

less substantive information. Obviously, this is an important question which subsequent research should address.

Figures 3-5 depict the color bands of each image based on distance. Considering red, Figure 3, frame 56 should show either the brightest or dimmest values (depending on the atmospheric effects) because of the extreme geometry. However, it's position beneath red and partially mixed with 57 cannot be explained. A general pattern of curves is evident, however (with 57 having some deviations), which is indicative of the flow's basic tonal configuration. There is good correlation between each frame's red and distance (subset #2 on Table 2) and good red-red relationships (#3), suggesting that a fairly consistent pattern of response in the red occurs under different viewing angle even when density values change. The same is true for blue except for frame 59, as evidenced above. Green reacts similar to red (not shown).

A second surprise results: the model of lava flow is to erupt in its most fluid state (lowest viscosity), cool as it travels downslope, and eventually becoming so viscous that it breaks into a jumbled jagged pile; i.e., from smooth, relatively reflective pahoehoe to broken, darker aa lava. Figures 3-5 show the opposite effect.

RED BANDS

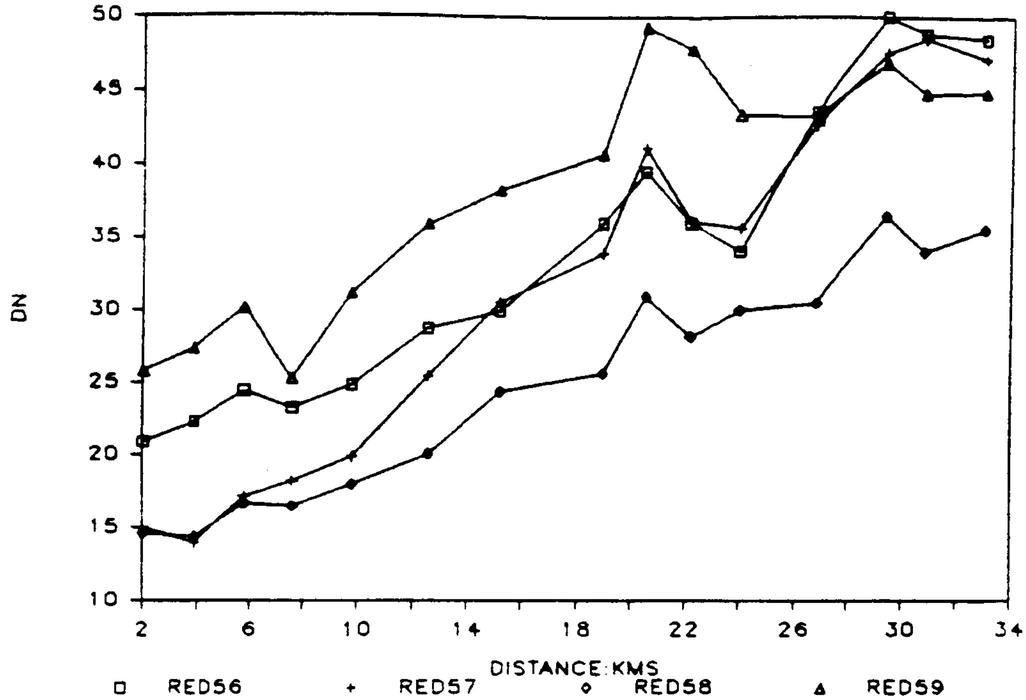


Fig. 3

GREEN BANDS

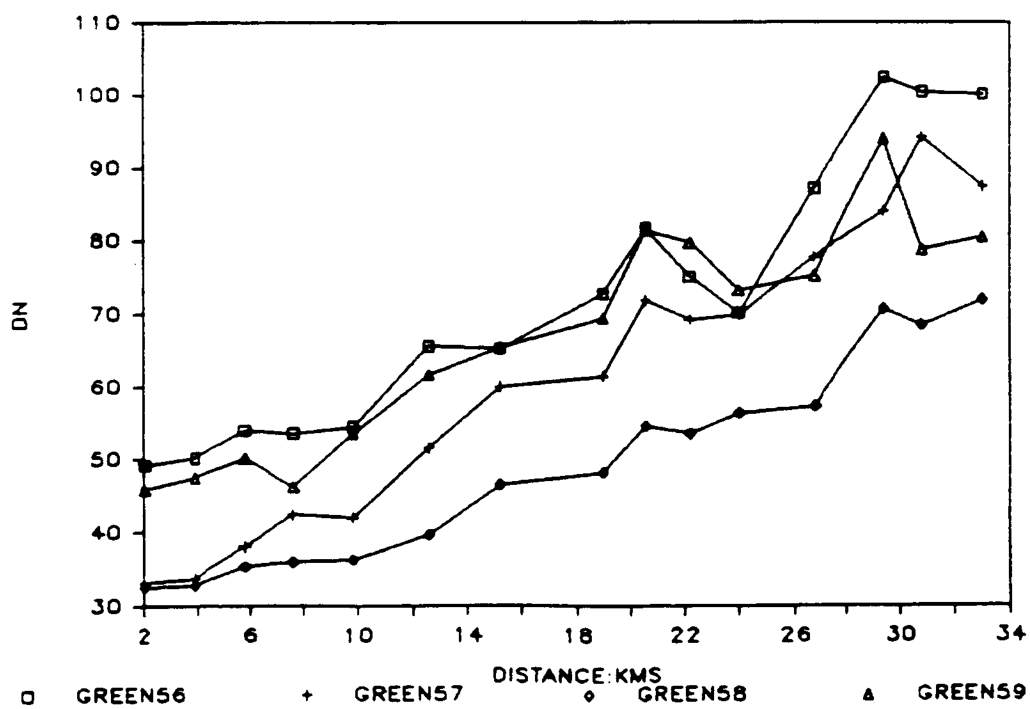


Fig. 4

BLUE BANDS

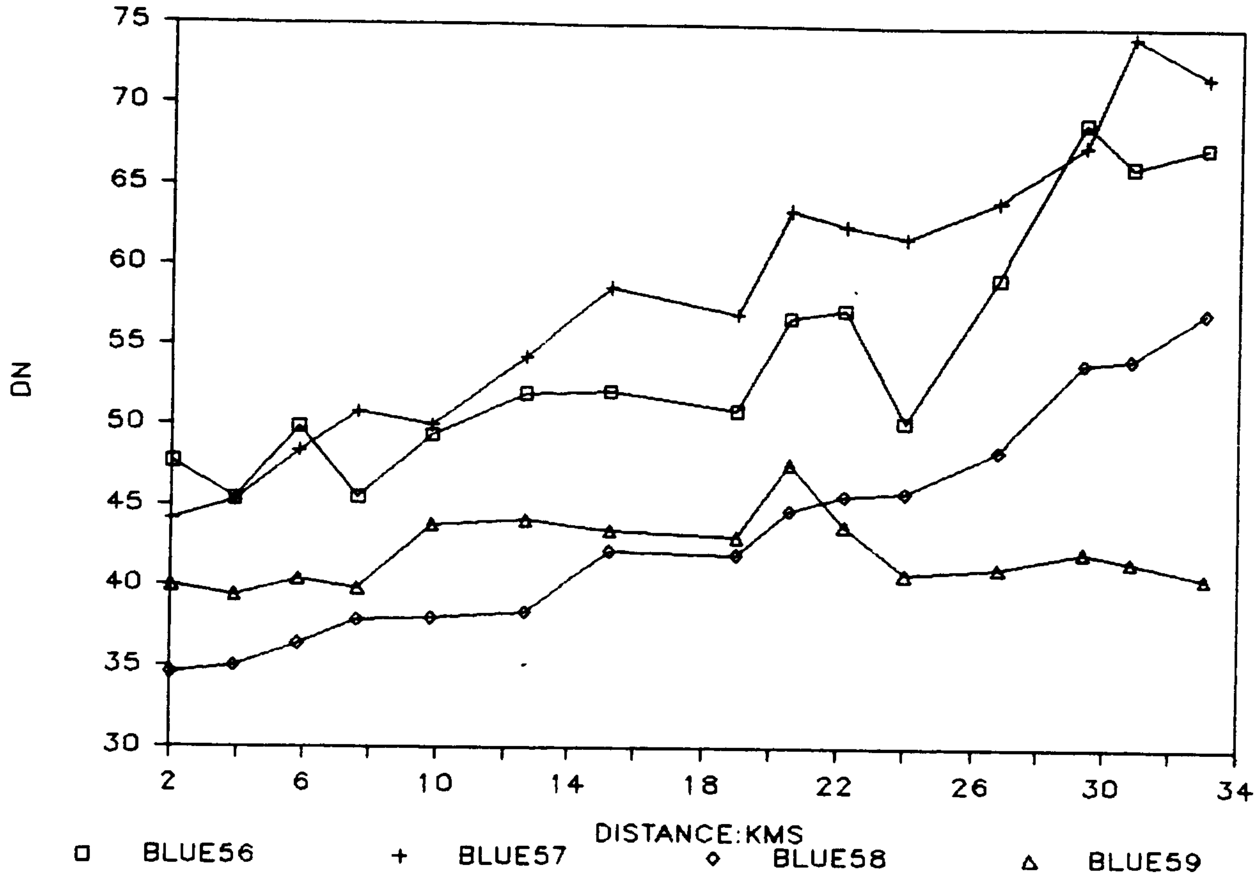


Fig. 5

Subset 4 in Table 2 presents a comparison between colors in the end frames. Red is a better penetrator of atmosphere than is blue, so a better correlation between is suggested. Analysis of residuals (deviations from regression lines) may offer further insight into the nature of the curves and comparisons of Figures 3-5.

Figures 6 and 7 display red and blue values as related to elevation. There is a -.98 correlation between distance and elevation, so the results are similar to those discussed above, except in an opposite direction. Specifically, darkest pixels are found in the upper elevations and get progressively brighter downslope. There is such a mix of lines in these graphs that consistency of viewing angle change responses is not apparent. However, note that there are similar tonal changes at particular elevations (e.g., a "bump" at 1600 meters), which can be useful for in-situ investigation, i.e., why is there a sudden change in the pattern of tones at a given elevation? Table 2 gives some band and elevation relationships, which, as expected, are very high except for frame 59's blue.

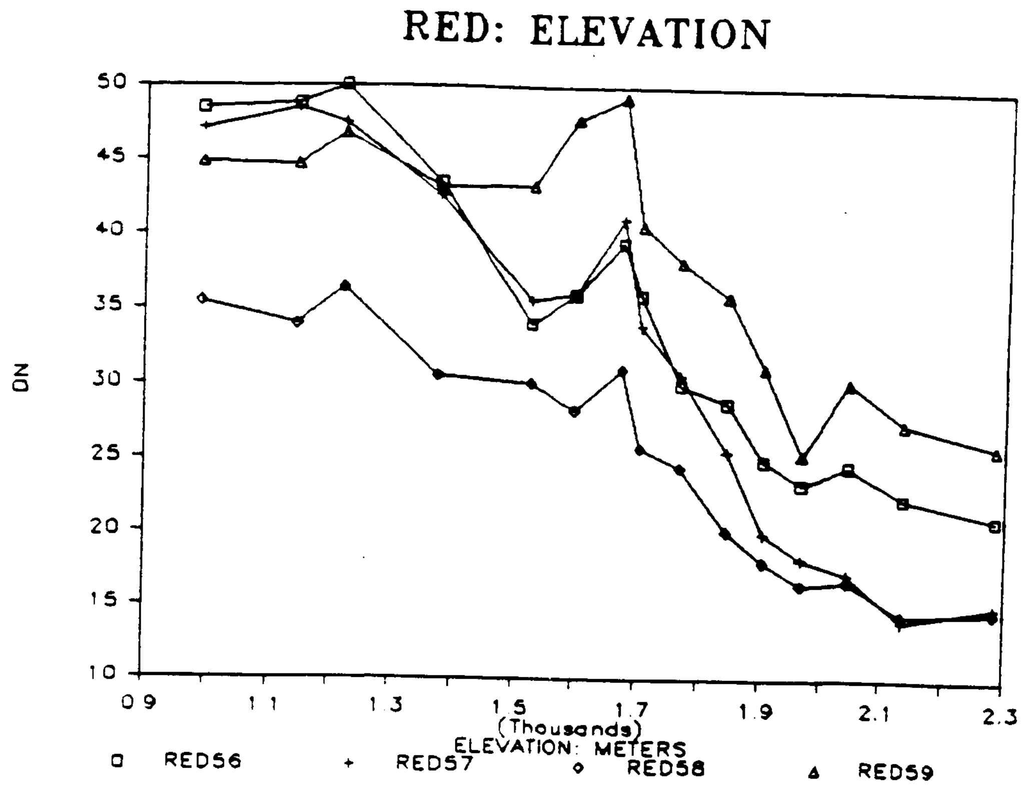

RED: ELEVATION
50
45
40
35
30
25
20
15
10
DN
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
(Thousands)
ELEVATION: METERS
RED56
RED57
RED58
RED59

Fig. 6

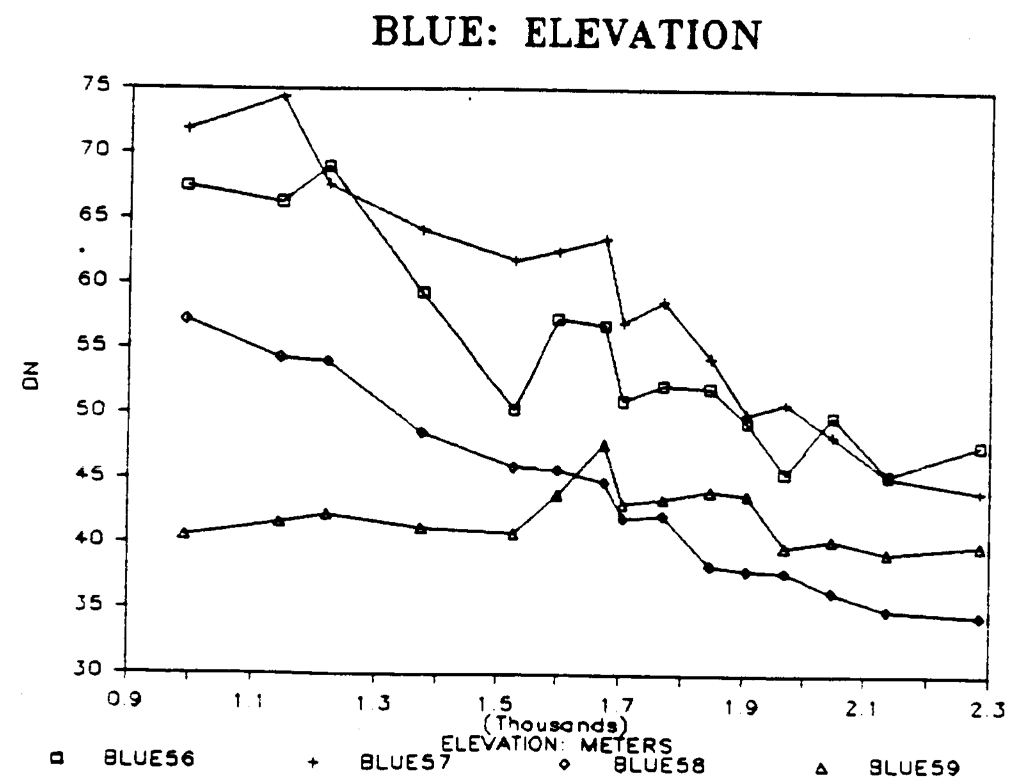

BLUE: ELEVATION
75
70
65
60
55
50
45
40
35
30
DN
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
(Thousands)
ELEVATION: METERS
BLUE56
BLUE57
BLUE58
BLUE59

Fig. 7

CONCLUSIONS

Conclusions primarily address procedures; data analysis statements are initial thoughts rather than pure results. For brevity, the major results are listed, with comments.

Procedures:

1. The procedures developed in this project are, for the most part, measures needed to overcome problems that shouldn't have been present in the first place. However, they are simplified and manageable techniques--qualities often missing in digital image analysis reports and publications. While they are tedious and time-consuming, results were satisfactory and useful.

2. With improved software (see Problems and Suggestions number 3 below), some steps can be combined, shortened, or even excluded, making the basic outline more efficient and convenient. For example, direct application of Formula 2 would reduce work time by a great margin. Therefore, the methods developed here are preliminary and subject to further development.

3. With improved hardware (see Problems and Suggestions number 2), several of these steps may be eliminated altogether. Most of this project was spent dealing with equipment problems but with a matured, developed system, spectral anlysis of photographic imagery can proceed efficiently. There is very little active research on the use of digitized photograph under way, and apparently NONE for Shuttle photography. With a few improvements, JSC will have the capacity to undertake a useful, needed, and unique direction in remote sensing.

DATA

1. Although data are preliminary, there seems to be adequate information for productive analysis in the effects of off-nadir remote sensing of lava flows. Questions arise in attempting to explain why the theoretically-worst image presents information better than some others. Also, why is blue so poor from the supposedly best frame? Is there a quantitative trend of change from one viewing angle to the next? Nonetheless, data seem satisfactory and can be used to address these questions.

2. Tonal information offers insight into the morphologic nature of lava flows. Seen here is that the Keamuku flow

exhibits non-linear and unexpected tonal change downslope, indicating that the simplified model of flowing lava and attendant darkening is not applicable here. Many questions are raised by initial interpretation of data, such as reasons for corruption of the flow model, why specific locations deviate from the general pattern, etc. More analysis and much ground investigation are needed.

3. There are many statistical techniques that can be applied to imagery. Only a very few of the most simple have been used here, but the data are convenient and amenable to almost any technique desired.

Problems and Suggestions:

1. Access to equipment: Despite perfect relations with personnel and good intentions all around, access to the digitizer and computer were limited to the convenience of all other users. The short period that summer faculty fellows have for research and reporting make higher priority desirable and necessary. Perhaps an equable scheduling arrangement will evolve as the system is matured (which includes a move to Building 31). Given the extreme time lost in dealing with equipment problems, access time was even more valuable than under ordinary circumstances.

2. Equipment problems: Obviously, this project was greatly impacted by equipment failures and problems, most of which seem to be rectified, or at least manageable, at present. As the system matures, minor difficulties will be controlled and more personnel will be able to use it. The single critical suggestion that can be made is to replace the condenser lighting system with a diffusing type. Had one been in place for this project, progress would be far beyond that which was possible under the current problematic light source.

3. Procedures: While LIPS is an excellent image analysis system, it retains some limitations that created difficulties in this research. Currently, only a few people (at best) in the JSC-LPI area have internal access to LIPS and can write codes to make individual changes. Rebecca McAllister at LIP, for example, has written several new and enhanced routines, greatly improving LIPS' capabilities. The inability for most users to enter individual formula hinders production. Either a general routine for emplacing formulae or a system for having a knowledgeable programmer accomplish the job is needed.

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