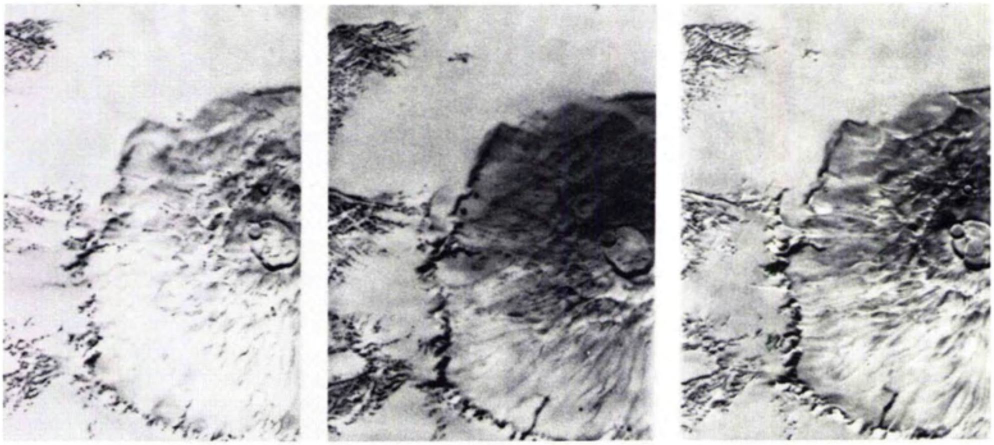

(a) (b) (c)

FRONTISPIECE. Progressive stages in the portrayal of relief using airbrush and eraser techniques.

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Applied Photo Interpretation for Airbrush Cartography

An airbrush portrayal technique has been developed for the interpretation of satellite television imagery of the moon and planets.

(Abstract on next page)

INTRODUCTION

LUNAR AND PLANETARY EXPLORATION has required the development of new techniques of cartographic portrayal. Whereas in conventional photogrammetric mapping, original map data (i.e., stereoscopic aerial photographs) frequently contain more information than can be shown legibly on a map, lunar and planetary data have had much lower resolution, requiring intensive interpretation and utilization of all available material. Data for the maps have consisted largely of telescopic photographs or satellite television images taken under a wide variety of conditions. These pictures provide planimetric and morphologic information, but are usually unsuited to conventional photogrammetric treatment. As a result, the use of shaded relief portrayal of photo interpretations has been greatly expanded. These techniques, as they are now applied, are far more complex than the conventional shading of contour maps and have required illustrators to become skilled photo interpreters. Relief illustration is accomplished using a unique airbrush technique in which highlights are accentuated with an electric eraser. Extensive production controls are instituted throughout the preparation of a map to insure consistency.

The cartographic methods now used allow a versatile approach to the mapping of all planets and a form of map portrayal in which details of surface mottling and structure are presented to the map user with a clarity not often found in more conventional maps.

ABSTRACT: *New techniques of cartographic portrayal have been developed for compilation of maps of lunar and plentary surfaces. Conventional photo interpretive methods utilizing size, shape, shadow, tone, pattern, and texture are applied to computer processed satellite television images. The variety of the image data allows the illustrator to interpret image details by inter-comparison and intra-comparison of photographs. Comparative judgements are affected by illumination, resolution, variations in surface coloration, and transmission or processing artifacts. The validity of the interpretation process is tested by making a representational drawing by a unique airbrush portrayal technique. Production controls insure the consistency of a map series. Photo interpretive cartographic portrayal skills are used to prepare two kinds of map series and are adptable to map products of different kinds and purposes.*

HISTORY

Systematic mapping of the moon, begun early in the last decade by the Aeronautical Chart and Information Center of the U.S. Air Force, provided the first base materials utilizing photo interpretation by shaded relief illustrators. Methods have been developed for obtaining lunar topographic contour data (Kopal and Carder, 1974), but the data lacked sufficient detail for mapping at large scales. Shaded relief illustrators had to rely solely upon small scale photography taken through Earth-based telescopes. Because the photographic resolution was adversely affected by the Earth's atmosphere, illustrators learned to employ many procedures used in traditional photo interpretation to provide maximum detail representation. Since contour maps were limited or non-existent, slopes were shown using different density values of tone. A mid-grey density implied a flat surface and increasingly dark or light densities delineated slopes, as would be the case in a photograph of a relief model. The apparent light source was always assumed to be from the west. For clarity only surface relief was shown, and surface coloration was suppressed by careful interpretation of the photography during illustration. Later, telescopic observation of the mapping area by the illustrator provided further refinement of mapping detail. Increasing skill soon allowed illustrators to infer detail from apparently analogous but poorly resolved relief. In the latter part of the last decade photographic information returned by artificial satellites resulted in a surplus of high resolution photography of the lunar surface. The level of detail in the photography seemed to end the need for further development of the photo interpretive and airbrush techniques because a large scale map series was not instituted using these data at their resolution limits.

Reapplication of the technique became necessary with receipt of Mariner 9 television images of Mars, beginning in 1971. Unlike other orbiting spacecraft pictures, Mariner 9 images were taken under a wide variety of atmospheric, illumination, and surface conditions. Because the Mariner 9 data underwent computer image processing, artifacts often seriously complicated interpretation of the data. Different kinds of image processing of single frames produced large and often unwieldy data sets. Elevation information was not sufficiently dense to provide shading control. Photo interpretive mapping of Mars was therefore essential for synthesizing the data set into a comprehensible cartographic format. The return of television pictures of Mercury by Mariner 10 in 1974 and 1975 further expanded the need for planetary photo interpretive mapping.

METHODS

Certain initial steps in planetary photo interpretive mapping are similar to photo interpretive methods outlined by Colwell (1952) and Rabben and others (1960). However, departure from traditional photo interpretation methods occurs when the illustrator justifies an interpretation by actually drawing the feature under study. The drawing, in effect, is a double check of the interpretation. In performing the transfer of data to a drawing, the illustrator is affected by several considerations.

SIZE AND SHAPE

Unlike other methods of satellite photo interpretation, which require high resolution and are not sensitive to image size and shape (Carter and Stone, 1974), these two elements are vital in planetary photo interpretation. The highly representational detail in a planetary map demands awareness of size and shape of physiographic features. Size is of additional importance during the interpretation and portrayal because indistinct features must be related to distinct ones to insure the correct size and position of both. Because the planetary maps describe form, careful evaluation of shape and size is a tool for the comparative classification of features seen in photographic images. An initial breakdown of features into craters and noncraters simplifies much of the interpretive task. The predominantly circular shape of the craters allows the illustrator to classify and analyze the features at the limits of photographic resolution.

SHADOW

Images affected by extremely low sun angles are usually avoided during planetary mapping. Cast shadows obscure detail and very fine details are excessively exaggerated (Kopal and Carder, 1974). High sun angle images are similarly avoided since the absence of shadow makes the shape and size of forms difficult to perceive. In fortunate circumstances the illustrator selects an image data set which has sun angles only slightly lower than the average slope angles of the features. In practice, however, such ideal images are difficult to obtain, so the illustrator must utilize his judgment and experience in the selection of optimum data.

TONE, PATTERN, AND TEXTURE

When dealing with shaded relief maps, the illustrator must remain concerned with the slope and form of surfaces, not the apparent brightness of those surfaces. The factors which affect the surface coloration of a planet are complex and not completely understood. The inclusion of surface coloration in a planetary relief maps would require the use of tonal densities that would conflict with those reserved to show slope elevations and angles. Photo interpretation is therefore used to exclude surface coloration from most planetary relief map drawings and to include patterns and textures that are discernible as discrete relief features.

Data

The logic and experience used in map il-

Fig. 1a. Horizontally high-pass filtered version of Mariner 9 picture (DAS 09378154) of high frequency contrast data.

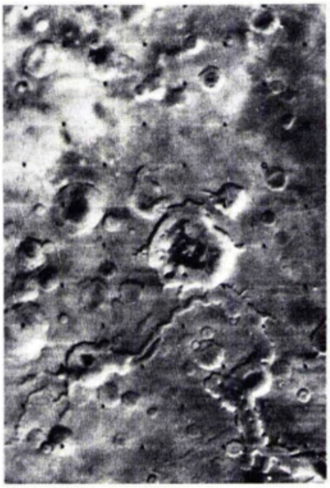
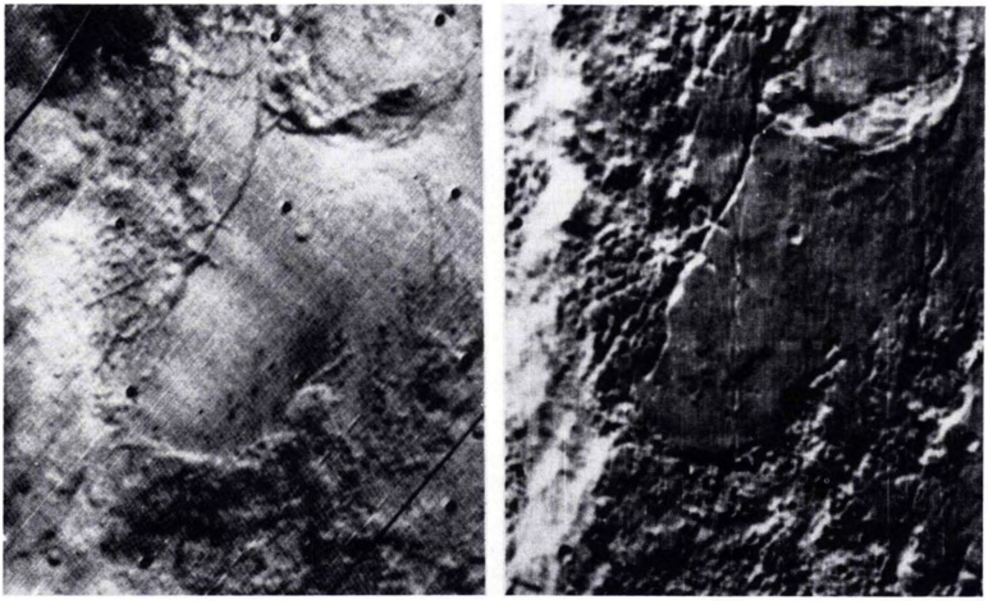


Fig. 1b. Vertically high-pass filtered version of figure 1a picture showing similar enhancement of high frequency contrasts but suppressing surface coloration.

Fig. 1c. Shading corrected version of figure 1a picture presenting a more "natural" appearance of the Martian surface. The picture has been corrected for known electronic shading, and the contrast has been enhanced, but no other processing has been done.

lustration depends on a number of value judgements made over a long period of time. The opportunity to accumulate this experience is augmented by the extensive data comparisons necessary to use limited sets of planetary photographs. Most often, only one or two pictures are available for studying a particular area. The illustrator must apply interpretive methods to their limits and rely heavily upon the use of analogy to infer the nature of alien topography. The preparation of a map is thus strongly affected by the photographic data available to the illustrator and by the comparative methods employed to use the data.

Image data sets contain several versions of an image that has been subjected to some form of computer image processing (Levinthal and others, 1973). The image data set becomes quite extensive when subjected to



(a) (b)

FIG. 2. Mariner 9 pictures taken with different illumination clarify slope and form (DAS 07686248, Figure 2a, DAS 12186067, Figure 2b).

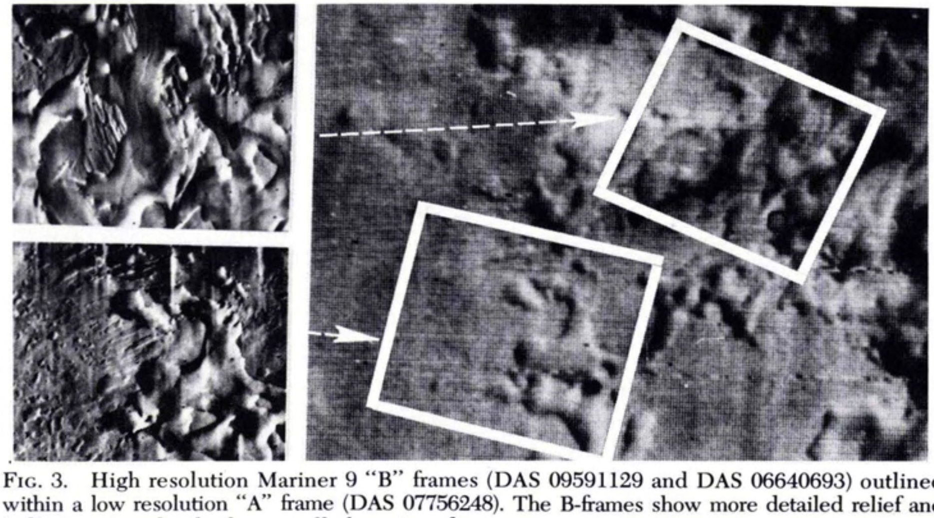
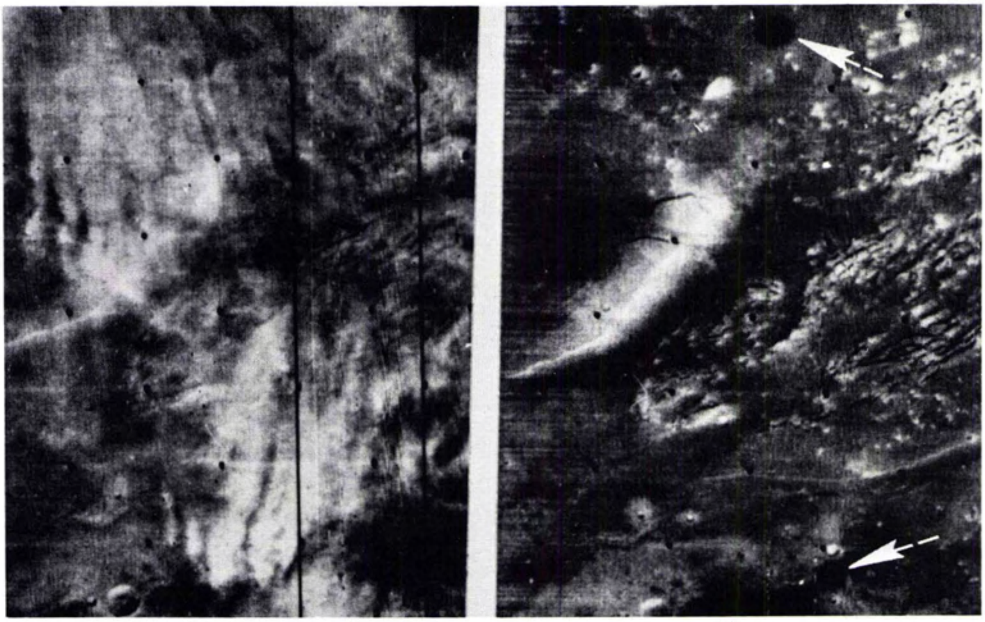


FIG. 3. High resolution Mariner 9 "B" frames (DAS 09591129 and DAS 06640693) outlined within a low resolution "A" frame (DAS 07756248). The B-frames show more detailed relief and indicate more clearly the overall character of an area.

computer image processing. For Mars mapping, photographs are often categorized by resolution, date of spacecraft acquisition, and by the kind of computer processing provided. Of nearly 20 such categories, all may be subjected to high-pass filtration in the computer which accentuates high frequency detail while suppressing broad tonal varia-



(a) (b)

FIG. 4. Cloud obscuration of relief on Mariner 9 pictures is evident by comparison of Figure 4a (DAS 07615128) with Figure 4b (DAS 09089824). Blemishes on the television vidicon tube are indicated by arrows in Figure 4b.

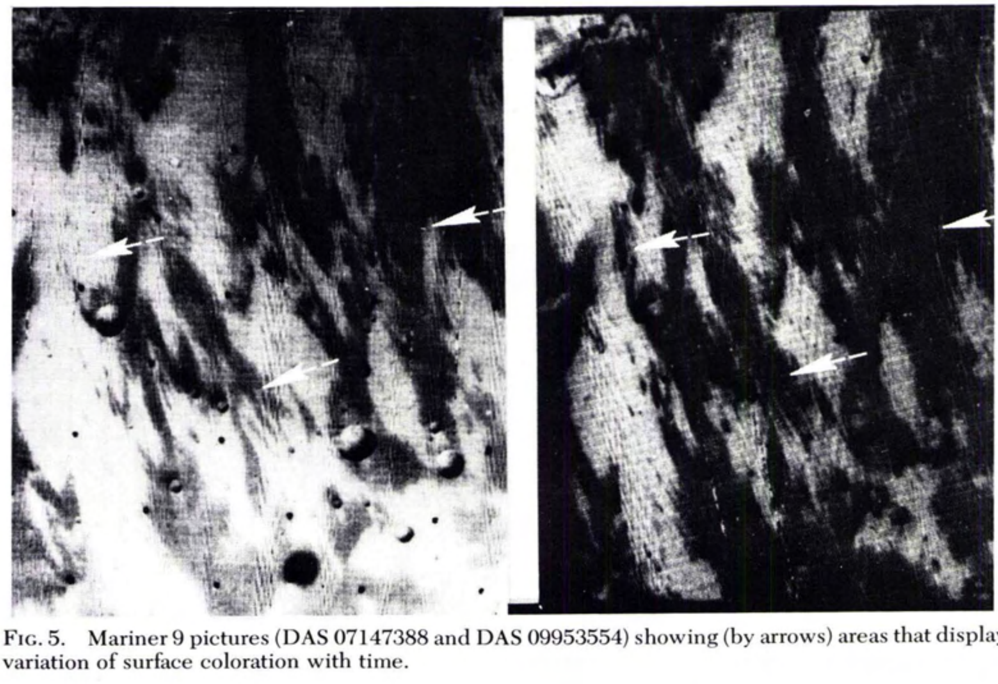
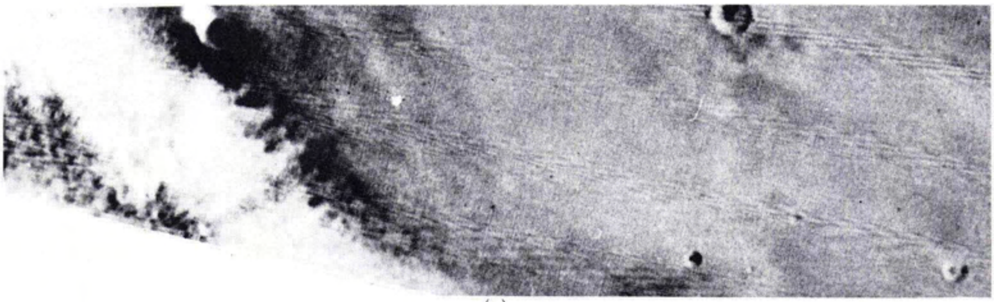


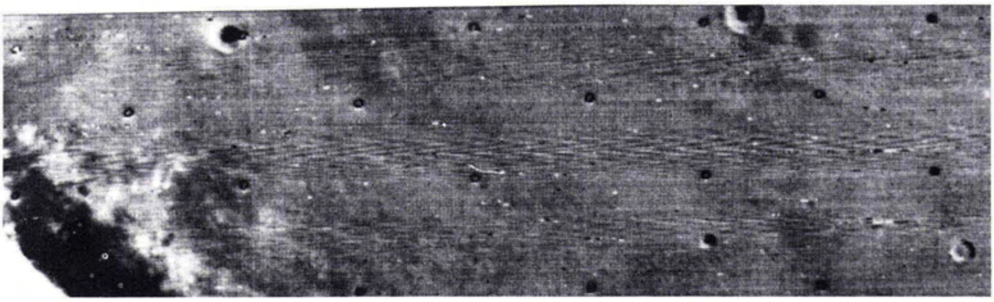
FIG. 5. Mariner 9 pictures (DAS 07147388 and DAS 09953554) showing (by arrows) areas that display variation of surface coloration with time.

tions. The enhancement of different features is shown in Figure 1 by three versions of a single frame subjected to image processing. The horizontally high-pass filtered version (Figure 1b) depresses surface coloration and enhances high frequency contrast. Figure 1c more closely simulates the "natural" appearance of the Martian surface, because known shading characteristics of the camera have been employed. In this version, relief tends to be subdued.

Computer image processing has provided



(a)



(b)

FIG. 6. Mariner 9 picture (DAS 11482114) in which the presence of frost gives a false impression of detail as compared to Figure 6b (DAS 12502275).

FIG. 7a. Mariner 9 high-resolution picture (DAS 09305179), outlined in Figure 7b. A feature that looks like a scarp on Figure 7b is shown to be surface coloration by Figure 7a.

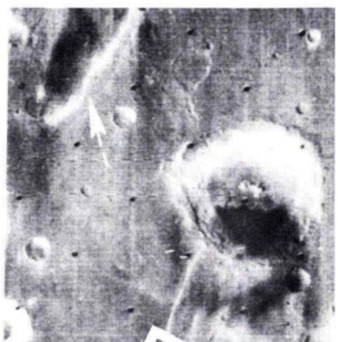


FIG. 7b. Mariner 9 picture (DAS 07902618), showing location of Figure 7a. A second scarp-like feature, not covered by any high-resolution image is shown by an arrow. It is probably surface coloration also.

the illustrator with a remarkable range of data that allows both inter-comparison of different photographs and intra-comparison of a photograph's different variations. In addition to the clarification of detail information, the elimination of artifacts and variable non-relief features is affected by the methods of data utilization during comparative study of the photography given below.

ILUMINATION

Efficient study of a relief feature is achieved by examination and comparison of images taken at different times and with different sun angles of illumination. When light source varies, the appearance of some relief changes relative to other relief. For example, steeper slopes are affected less by small changes in illumination than are subtle slopes. This study of interrelated slope angles through use of varying illumination is similar in practice to early telescopic observation of lunar features. Comparison of differently processed versions of a given image can reveal false enhancement of relief by other phenomena. Although it is convenient to examine images with a western light source, similar to the map, images with an eastern light source are nevertheless useful. Such opposite illumination (Figure 2) clarifies slopes and reveals subtle forms which may have tone values obscured by photo-mechanical problems such as print density. In addition, the character of non-relief phenomena is altered, allowing clearer visibility of form and slope.

RESOLUTION

There are a number of isolated high resolution images within a set of planetary images. Although the area portrayed is often too small to be included in a map, such images can provide a clue or clarification of the relief character of a region. As shown in Figure 3, high resolution images convey detailed structure obscured by low resolution. Through examination of the high resolution pictures, the illustrator can infer the nature of the surrounding areas.

Detail can be resolved more clearly in some versions of an image than in others. Figures 1a and 1b compared with Figure 1c are examples.

FIG. 8a. Mariner 9 picture (DAS 07255188), showing a faint residual image from Figure 8b.

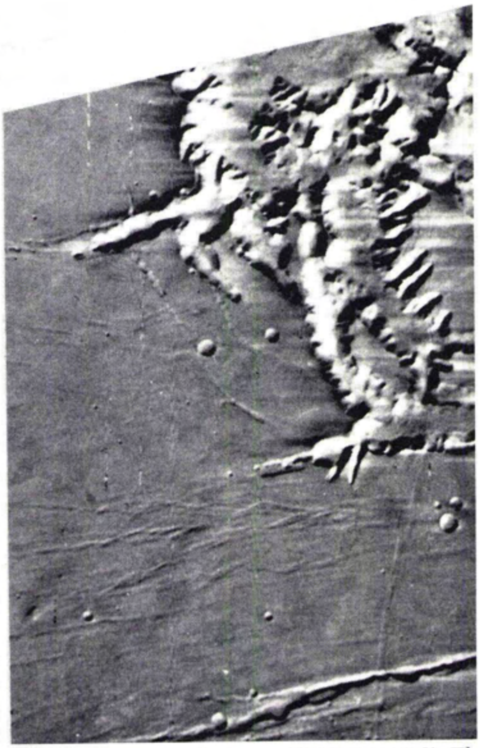


FIG. 8b. Mariner 9 picture (DAS 0725438). The high contrast image "burned" the picture tube and affected subsequent pictures.

NON-RELIEF PHENOMENA

By comparing different processed images the illustrator can find evidence of detail obscuration by clouds or frost. These phenomena, not always readily apparent in horizontally high-pass filtered images, are usually quite evident in shading-corrected or vertically high-pass filtered versions. Having found evidence of cloud or frost obscuration, the illustrator can confirm their presence by inter-comparison with images taken at different times. This can reveal changes in these phenomena, since relief is assumed not to vary with time. Examples of the variability of clouds, surface coloration, and frost are shown in Figures 4, 5, and 6 respectively.

Comparative study is additionally vital since variable features can be misconstrued as relief. For example, frost in Figure 6a might be seen as relief without comparison to an image taken later in time. High resolution images can also be similarly used. The light streak outlined in the low resolution picture (Figure 7b) is shown to be surface coloration in the adjacent high resolution frame (Figure 7a). The illustrator would assume that the white streak, noted by the arrow in Figure 7b, is also surface coloration and not relief.

ARTIFACTS

Computer processing of images is a complex task. The conversion of millions of bits of information from one form to another can accentuate anomalies in the data returned by satellite. Typical problems often encountered in photo interpretation involve residual images and noise in the data. For example, images with excessive contrast can "burn" the television picture tube and affect subsequent images as in Figure 8. Exceptionally bright images will not only produce residual images as shown by the arrow in Figure 9a but are of such high contrast that the bright crater in Figures 9a and 9b suffers from a loss of resolution from "smearing" in the TV picture tube. Residual images may also be created during processing as in Figure 10 or, in some instances, surface coloration is actually embellished and will look like relief (Figure 11). Transmission difficulties produce slightly "noisy" images (Figure 12) and force the illustrator to interpret de-

FIG. 9a. Mariner 9 picture (DAS 12188937). The faint residual image indicated by an arrow originates from an earlier picture.

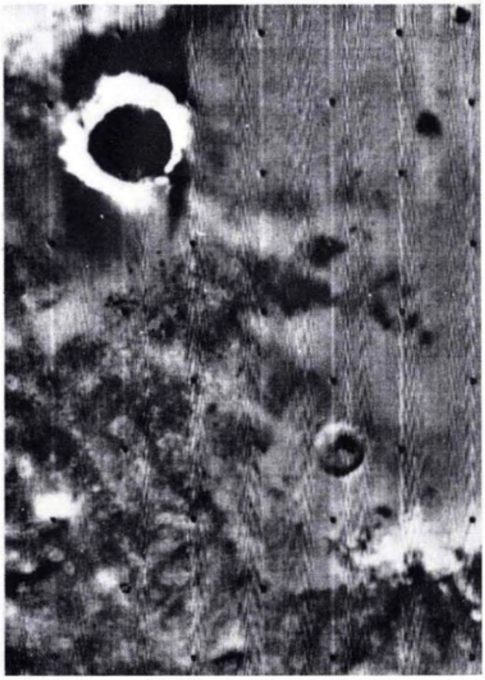


FIG. 9b. Mariner 9 picture (DAS 12188797). This frame covers part of the area of Figure 9a. The high contrast image "burned" the picture tube and obscured surrounding detail.

tail through streaks and patterns. Blemishes on the television vidicon tube (Figure 4b) are often recurrent and can be identified easily, though detail is obscured.

PORTRAYAL

The portrayal of tonal densities in a relief illustration is accomplished using a unique airbrush technique derived from "hill-shading" of contour maps. The methods of contour shading described by Means (1958) have undergone considerable refinement during application to planetary shading relief maps. These methods have been discussed elsewhere (Inge, 1972) and are demonstrated in the Frontispiece. The features are first lightly drawn (Frontispiece (a)) as the illustrator refines detail position and becomes familiar with the photographic data. Because the illustrator must interpret several images and portray his interpretation in a map drawing, considerable practice is necessary to master the capabilities of an airbrush. The atomized spray of ink from the airbrush can be made to produce broad tones as well as extremely fine lines. The control of tone and line quality is essential in order to achieve a stage in the drawing process as shown in the Frontispiece (b). This is because the mid-grey to dark tone densities must be finalized prior to the addition of highlights to the drawing. This is done with an electric eraser. Detail is refined by erasure until the drawing is completed as shown in the Frontispiece (c). The drawing density is controlled with a reflectance-reading densitometer to meet certain density guidelines. In this way, sample-to-sample variations in a map series are reduced and continuity of slope information is insured. All map manuscripts are reviewed by geologists and other photo interpreters prior to publication.

The versatility of planetary photo interpretive methods used in airbrushed map portrayals is demonstrated by the application of

FIG. 10a. Mariner 9 picture (DAS 07111198), shows false detail created during computer image processing (arrow).

FIG. 10b. Mariner 9 picture (DAS 07111198), vertical high-pass filtered version. The feature indicated by an arrow on Figure 10a is not visible.

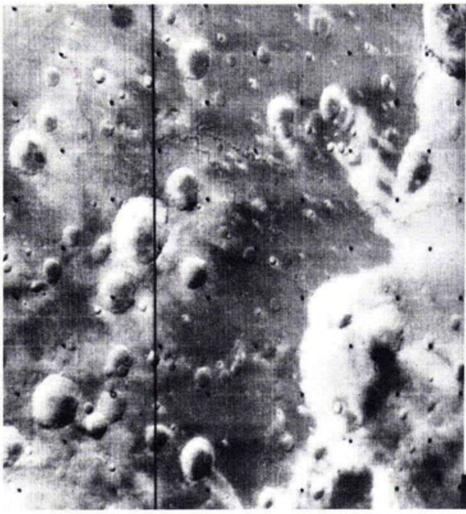


FIG. 11a. Mariner 9 picture (DAS 07543448), shading corrected version.

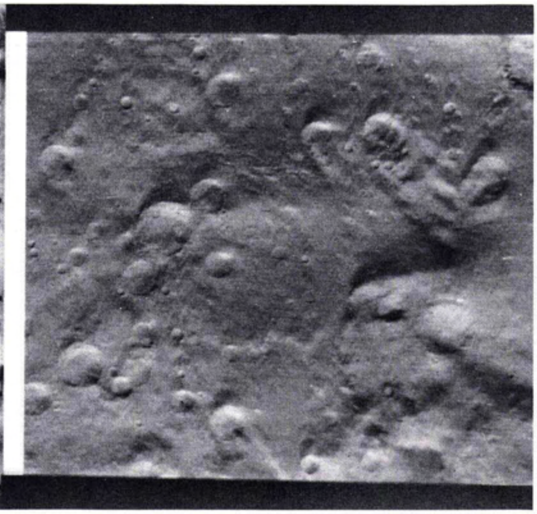


FIG. 11b. Mariner 9 picture (DAS 07543448), high-pass filtered version. the filter made albedo variations look like relief.

FIG. 12. Mariner 9 picture (DAS 11445784), electronic interference noise patterns obscure or distort image.

these techniques to the synthesis of non-relief data. Of the planetary map series compiled to date, one shows relief and one has relief combined with surface coloration. The latter series depends on the ability of the illustrator to perceive surface coloration as a discrete unit. For example, a comparison of Figure 13 and Figure 14 will show the differences between a typical photomosaic and a completed shaded relief drawing. The adaptability of planetary photo interpretation to all forms of mapping is shown in Figure 15, which combined the surface coloration and relief in a form clearer than the original photomosaic.

CONCLUSIONS

The methods utilized to interpret satellite pictures of planets and to prepare representational maps using those interpretations is a unique kind of cartography. The techniques have been developed because preliminary elevation data are insufficient for detailed mapping of the surface. To indirectly paraphrase Colwell (1968), the shaded relief of Mars, Mercury, or the Moon should not be considered a substitute for, or a copy of, photographs. The final map synthesizes several hundred photographs and clarifies dramatically the alien topographic structure

Fig. 13. Part of a typical mosaic used for horizontal control during the drawing process (MC-13 Syrtis Major).

Fig. 14. Shaded relief drawing of the area of Figure 13. The improvement of relief presentation when compared to the photomosaic of the area of Figure 13 is typical.

Fig. 15. The areas of Figures 13 and 14, in which surface coloration is combined with relief to provide additional information for map users.

of a planet. Because these photo interpretive techniques allow the maximum utilization of limited data sets, they will be invaluable in interpreting data acquired in future spacecraft missions. It is possible that these methods could be employed in certain smaller-scaled maps of the Earth, condensing a huge amount of photographic data into a usable format. This kind of cartography is a form of data processing that is impartial, rapid, and highly adaptable.

Acknowledgments

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The Symposium will examine Remote Sensing as a vital and mature technology which embodies conceptual problem definition, technologica development, and proven application. It hopes to demonstrate the wide applicability of particular sensors and interpretation algorithms in a way which enhances our appreciation of the interdependence of processes on the earth's surface, its water bodies and in the atmosphere.

Those wishing to present a paper at the 4th Canadian Remote Sensing Symposium are asked to send a detailed, comprehensive summary of 250 words (in English or French) no later than *September 30, 1976,* to the address given below. Since selection of papers to be presented at the meeting will be based upon this summary, it must include an outline of the problem, methods used in its solution, and results obtained. Papers accepted for presentation will be refereed prior to publication in the Symposium Proceedings. Papers may be presented in either English or French.

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