UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

TECHNICAL LETTER NASA-6

ULTRAVIOLET ABSORPTION AND LUMINESCENCE INVESTIGATIONS

PROGRESS REPORT *

by

William R. Hemphill **

Samuel U. Carnahan ***

These data are preliminary and should not be quoted without permission.

* Work performed under NASA Contract No. R-146
** U. S. Geological Survey, Washington, D. C.
*** Westinghouse Electric Corporation, Baltimore, Maryland

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for the National Aeronautics and
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UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Technical Letter
NASA - 6
August 16, 1965

Dr. Peter C. Badgley
Chief, Advanced Missions
Manned Space Science Division
NASA Headquarters
Washington, D. C. 20546

Dear Peter:

Transmitted herewith are 25 copies of:

TECHNICAL LETTER NASA-6

ULTRAVIOLET ABSORPTION AND LUMINESCENCE INVESTIGATIONS

PROGRESS REPORT *

by

William R. Hemphill**
Samuel U. Carnahan ***

Sincerely yours,

R. M. Moxham

R. M. Moxham
Chief
Branch of Theoretical Geophysics

*Work performed under NASA Contract No. R-146
**U. S. Geological Survey, Washington, D. C.
***Westinghouse Electric Corporation, Baltimore, Maryland

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SUMMARY

An ultraviolet imaging system, developed by the Westinghouse Electric Corporation, is being investigated for remote detection of luminescent minerals and rocks as well as for discriminating among non-luminescing materials on the basis of absorption of ultraviolet energy between 3300Å and 4100Å wavelengths. Basic operational components of the system include an ultraviolet transmitter employing a flying spot scanner, and an image dissector receiver so designed that its field of view is limited to an area slightly larger than the transmitter spot; the scan of the transmitter spot and the receiver field are synchronized. The receiver output is connected to both a CRT (A-scope) and a video monitor for simultaneous observation and measurement of intensity of luminescence and/or reflectance.

In order to evaluate the system's performance under outdoor conditions, the equipment was mounted in a delivery-type van and transported to quarries and outcrops in the Baltimore area. Luminescing minerals including deweylite, talc, dolomite, and calcite, were imaged at distances as great as 200 feet. Also, outcrops and terrain features were imaged

*Work performed under NASA Contract No. R-146
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by means of reflected ultraviolet light at distances as great as 75 feet. This work was done at night in order to avoid solar radiation in the ultraviolet. It was noted that some features, such as rock fractures and mineralized veins, seem to display more image contrast when imaged by reflected ultraviolet light than in natural light.

The present system, having been originally designed for another purpose, is not very efficient for our application. Because of the limited success of these field tests of less-than optimum instruments, an improved ultraviolet imaging system utilizing a transmitter peaking at 2600Å, improved optics and circuitry will be constructed. Appreciable solar energy at wavelengths shorter than 2900Å is absent at or near the earth's surface. Thus, an active system, such as the one to be built, would provide the only mechanism for remotely stimulating luminescence and for imaging terrain features at these wavelengths. Moreover, in this region where solar radiation is minimal, imaging of terrain features by means of reflected ultraviolet light could be conducted during daylight hours, thus facilitating field operations.

INTRODUCTION

Purpose and scope. -- The ultraviolet video imaging system, developed by Westinghouse Electric Corporation, was initially designed as an imaging device for use in low flying aircraft. The objective of the present study, described herein, is to appraise the suitability of this system for remote detection of luminescent minerals and rocks as well as for discriminating among non-luminescing rocks on the basis of absorption of electromagnetic energy between 3300Å and 4100Å wavelengths. General operation of the ultraviolet imaging system is described by Hemphill and Gawarecki (1964).

The study is divided into three phases. Phase I involved indoor tests using the equipment to image handspecimens of various luminescing and non-luminescing minerals. These tests were completed October 27, 1964 (Hemphill and Gawarecki, 1964). Phase II is similar to Phase I except that the tests were conducted outdoors, bulk samples were used, and meteorological conditions were recorded. In Phase III, the equipment was mounted in a vehicle and tests were performed in the field where luminescing minerals occur.

Phase II and Phase III tests have been completed and the results are described in this report.

ACKNOWLEDGMENTS

The cooperation of officials of Harry T. Campbell and Son, and the Arundel Corporation, both of Baltimore, Maryland, is gratefully acknowledged. Both of these organizations permitted repeated day and night visits to their quarries in the Baltimore area.

PHASE II

<u>Procedure</u>.-- In order to evaluate some of the critical limitations in an out-door operation, the imaging system was installed in a roof-top test room on one of the hangars at the Westinghouse plant, Friendship Airport, Baltimore (fig. 1). The equipment was positioned in the room so that the transmitter-receiver could be inclined and directed through an open window downward toward the ground where six trays, containing bulk samples of luminescing minerals, were arranged (fig. 2). The distance between the trays and the transmitter-receiver was 45 feet. Layout of the trays and the identification of the minerals occupying each tray is shown in Appendix A.

Stencils, prepared from posterboard painted flat black, were used to simulate 50 percent, 75 percent, and 88 percent contamination of the samples by non-luminescing materials. The stencils were constructed slightly smaller in overall size than the inside dimensions of the sample trays; in this way the stencil could be placed inside the tray directly on top of the sample.

Filters (Appendix B) were introduced in the receiver to limit the bandpass to discrete parts of the visible spectrum. This work was similar to that conducted in Phase I; it was undertaken in order to determine the suitability of the imaging device in determining the luminescence signature of specific minerals.

Throughout the Phase II study, the transmitter was filtered with a Corning 7-54. Use of this filter was necessary because the transmitter's P-16 phosphor peaks at 3700 Å (Appendix C) near the visible spectrum; thus, the Corning 7-54 restricted the transmitter output to wavelengths shorter than 4000 Å (Appendix B). Unfortunately, however, this filter also reduced the transmitter's peak output by about 30 percent.

During five evenings in mid-November, the samples were imaged using the contamination stencils and transmitter and receiver filters noted above. In addition, air temperature and relative humidity were observed. The results of the tests are noted in terms of temperature and relative humidity, moonlight, efficiency of the transmitter tube, as well as the effect of contaminants on the imaging ability of the system.

<u>Transmitter tube</u>.-- One of the most important factors affecting the overall performance of the imaging system is the rate of reduction of output efficiency and short life of the P-16 transmitter tube. Power output of a new unfiltered transmitter tube is about 10 milliwatts. Appendix D shows that the output of the tube is reduced by 50 percent after only 10 hours of operation. Many tubes appeared to lose their efficiency at an even faster rate; most tubes shattered after less than five hours use. An exception is the tube used throughout Phase I and reinstalled on November 19, during Phase II.

It is estimated that this tube was operated for more than 100 hours. However, the tube was unique in that, inadvertently, no binder was used to adhere the phosphor to the glass; apparently, this manufacturing technique greatly lengthened the tube life and reduced the rate at which the output efficiency depreciated.

Figure 4 shows the video monitor image when an old P-16 tube was being used in the transmitter; the receiver was filtered with a Corning 3-73. By comparison, figure 5 shows the video monitor less than one hour later when a new P-16 tube has been substituted. Not only is the phosphate more strongly imaged, but, in addition, images of the calcite, colemanite, and fluorite samples can also be seen. Figures 6 and 7 show a similar comparison with a Kodak 8(K-2) filter installed in the receiver.

Relative humidity.-- Cursory studies of the effect of relative humidity strongly suggests that this factor has surprisingly little, if any, effect on the ability of the system to image reflected ultraviolet light or to detect luminescence, at least at the subject distances involved in the Phase II tests.

On the evenings of November 17, 19, and 20, relative humity was 55 percent, 93 percent, and 62 percent, respectively; similarly, air temperature was 48 degrees, 51 degrees, and 40 degrees each evening when the tests were made. The moon was either obscured by clouds or shaded from the samples by nearby buildings. Although the transmitter tube used on November 17 had been operated for about nine hours, several times less than the tube used on November 19 and 20, the output efficiency of both tubes appeared to be about the same, despite deterioration of output with age shown in

Appendix D. This may be due to unique techniques used in the manufacture of the older tube (see page 6).

Figures 8, 9, and 10 show the A-scope peaks of the willemite (with calcite) sample and the phosphate sample on each of the three evenings. On November 17 and 19, the impulse recorded for the willemite and the phosphate was about 50 mv and 150 mv respectively. A slightly higher impulse was recorded on November 20 for both samples; however, this was attributed to adjustments of both the transmitter and receiver which increased the sensitivity of the system. On November 19, during the time that measurements were made, visibility at Friendship Airport, less than one mile away, was less than 1/8 mile, according to the U. S. Weather Bureau. Despite this low visibility and high humidity on November 19, both A-scope traces (figs. 8, 9, and 10) and video monitor images (figs. 11, 12, and 13) for all three evenings compare favorably.

Moonlight.-- Moonlight shining directly on the samples adds background noise to the image, thereby obscuring weak signals and reducing background contrast with stronger signals.

Figure 14 shows the video monitor images of five of the six samples taken with a Kodak 8(K-2) filter installed in the receiver; the full moon is obscured by a cloud. Figure 15 was taken five minutes later when the moon had emerged and was shining directly on the upper part of the field of view, including the sample trays in the top row. Although both samples can be distinguished, the calcite with sulfur, on the left, is nearly obscured by background noise.

Similarly, automobile headlights, building lights, and other sources of ambient light increased background noise and reduced image contrast.

Filters.-- In order to evaluate the suitability of the imaging system in determining the luminescence signature of specific minerals, various filters were introduced in the receiver to limit the bandpass to discrete parts of the visible spectrum beyond 4000 Å. These tests were repeated on each of the five evenings that the Phase II tests were conducted; however, the best results were obtained on November 13 when a new P-16 transmitter tube had been installed. These results are discussed below.

Figure 16 shows the video monitor image of the six bulk samples used in the Phase II tests. Because the receiver was not filtered, the images show reflected ultraviolet light as well as any luminescence that the specimens may be exhibiting. The two samples in the top row are darker in tone than the other four samples imaged in figure 16. However, this tonal distinction is due to a vignetting effect dependent upon the adjustment of the raster sweep of the receiver, rather than to any difference in ultraviolet absorption between the samples.

Figure 17 shows the video monitor images after a Corning 3-73 filter was installed in the receiver; this filter restricts the bandpass to wavelengths longer than 4000 Å. Gain has been increased to maximum. Luminescence of phosphate at the middle right and fluorite at the lower left are strongly imaged. Colemanite and calcite may be clearly seen at the lower right and upper right respectively. Calcite with limestone is weakly visible at the upper left; willemite is faintly imaged to the left in the middle row.

Figure 18 shows the video monitor image after a Corning 3-72 filter was installed; this filter restricts the bandpass to wavelengths longer than 4300 Å. Luminescence of the phosphate is the most strongly imaged, followed by fluorite. The colemanite and calcite are about equal in image brightness. The calcite in limestone is weakly visible. Willemite cannot be seen. Although luminescence of willemite peaks at 5250 Å (excitation wavelength: 3650 Å, Fischer and Daniels, 1964, Appendix II) well within the bandpass of the Corning 3-72 filter (Appendix B), its disappearance here is due to fact that luminescence of this bulk sample is limited to about 20 percent of the surface area of the sample tray.

Figure 19 shows the video monitor image after a Kodak K-4 filter has been installed in the receiver; this filter restricts the bandpass to wavelengths longer than 4500 Å. Phosphate continues to show strongly, followed by fluorite, colemanite, calcite, and calcite in limestone.

Figure 20 shows the video monitor image after a Kodak 8(K-2) filter has been installed in the receiver; this filter restricts the bandpass to wavelengths longer than 4700 Å. Phosphate, though the strongest mineral imaged, is significantly weaker than before. Fluorite is weaker than the phosphate, followed by colemanite and calcite, about equal in intensity. Weakest image is the calcite in limestone.

Figure 21 shows the video monitor image after a Kodak 15G filter has been installed in the receiver; this filter restricts the bandpass to wavelengths longer than 5100 Å. Phosphate continues to image the strongest; fluorite, colemanite, calcite, and calcite in limestone are about equal in image brightness.

Figure 22 shows the video monitor image after a Kodak 16 filter has been installed in the receiver; this filter restricts the bandpass to wavelengths longer than 5200 Å. Image intensity of all the samples is about the same as described above for figure 21.

Figure 23 shows the video monitor image after a Kodak 22 filter has been installed in the receiver; this filter restricts the bandpass to wavelengths longer than 5450 Å. Phosphate, though clearly weaker than in figure 22, is still the brightest image. Fluorite, colemanite, and calcite are weakly visible and about equal in intensity. Sample containing calcite veins in limestone is not visible.

In comparison, images of both the phosphate and the colemanite samples are considerably less bright than the hand specimens of these same minerals used in the Phase I tests (Hemphill and Gawarecki, 1964, p. I 15-16a). This is probably due to the fact that in the Phase I tests, hand specimens were selected individually on the basis of their intensity of luminescence, whereas in Phase II tests unselected bulk samples were used.

Distinguishing the minerals on the basis of luminescence signature was inconclusive, in part, because of the similarity in spectral characteristics of luminescence between the minerals studied and, in part, because of limitations in spectral response of the receiver in the visible region. Appendix A shows the estimated percentage of surface area in each bulk sample tray that luminesces under a longwave (3660Å) mineral light; samples in the order (decreasing) of their area of luminescence are as follows: calcite, phosphate, fluorite, colemanite, willemite, and calcite veins in limestone. This order of relative brightness is generally retained in figures 17-23 as filters are introduced which limit bandpass to progressively longer wavelengths (an exception, the calcite sample, luminesces comparatively weakly, despite its extensive area). Thus, progressive reduction in image intensity appears to be due to the attenuating effect of the filters rather than to any spectral difference in luminescence between the samples. This possibility is reaffirmed by the fact that all the samples, except willemite, luminesce white. Moreover, response of the S-13 CBS image dissector is reduced at wavelengths longer than 4500 Å (Appendix C).

Contaminants.-- In order to evaluate the effect of nonluminescing contaminants, cardboard stencils were introduced in the trays directly on top of the mineral samples. Three sets of stencils were used representing 50 percent, 75 percent, and 88 percent contamination. The 50 percent set consisted of half-inch strips of cardboard, painted flat black, alternating with half-inch spaces. The 75 percent set consisted of three-fourths inch cardboard strips and quarter-inch spaces. The 88 percent set consisted of seven-eights inch strips and eight-inch spaces. Spaces were oriented in a direction perpendicular to the direction of the raster scan. Figure 24 shows the video monitor with the 50 percent stencils covering the samples; images of the half-inch strips of the cardboard stencil may be seen across the short dimension of two of the trays in the lower left. Because the receiver is not filtered, images shown in figure 24 represent reflected ultra-violet light as well as any luminescence that the minerals may be exhibiting. This photograph was taken November 13, less than one hour after a new transmitter had been installed.

Figures 25 through 28 were taken November 20 and show the video monitor images of the six samples under various degrees of contamination. Relative humidity was about 65 percent; although the moon was out during part of the evening, the samples lay in the shadow of the hangar. The transmitter tube had been used more than 75 hours.

Figure 25 shows the video monitor images of five of the samples after a Corning 3-73 filter was installed on the receiver, thus restricting the bandpass to visible light or luminescence. The phosphate sample is strongly imaged; only the willemite sample is not visible.

Figure 26 is similar to figure 25, except that a cardboard stencil, simulating 50 percent contamination, has been introduced on top of the samples. All images visible in figure 25 are also visible here, but more weakly, particularly the calcite in limestone sample in the upper left.

Figure 27 and 28 show the video monitor images of the samples after 75 percent and 88 percent contamination stencils, respectively, have been introduced. All images visible in figure 26 are weakly imaged in figure 27. However, only the phosphate sample is visible in figure 28 demonstracting that with power output capabilities of the equipment, only very strongly luminescing minerals can be detected where surface contamination or cover is excessive.

Nevertheless, the ability of the system to image highly contaminated samples is surprisingly good when a new transmitter tube is used. Figure 29 (Transmitter tube, p. 5) is similar to figure 28 except that a new transmitter tube has been installed. In figure 29 the image of phosphate, as well as fluorite, colemanite, and calcite, can be seen in spite of the 88 percent contamination stencil. That the colemanite is visible is particularly surprising inasmuch as only 40 percent of the surface area of the sample luminesces (Appendix A).

PHASE III

<u>Procedure</u>.-- In order to evaluate some of the critical limitations in imaging luminescence of rock outcrops under field conditions, the imaging equipment was installed in a delivery-type van (fig. 30-A). The transmitter-receiver was positioned in the van so that it could be directed through the rear doors toward the rock exposures to be imaged. A video monitor was used for image display as in Phases II and III. Power for the system was provided by a portable gasoline generator.

The equipment was used to image rock in quarries and outcrops, most of which are located in the Baltimore-Washington area.

Five localities, where luminescing minerals were detected, are discussed below.

Cavetown Quarry.-- The Cavetown Quarry is located in the village of Cavetown, four miles east of Hagerstown, Maryland, on State Highway 64 (fig. 30). The quarry, now inactive, exposes thick-bedded and massive gray limestones of Early Paleozoic age. The rocks dip generally westward and are strongly jointed. Two caves open into the quarry; one is located at the extreme southern end of the quarry and the other is in the west face of the north-central part. Calcite ($CaCO_3$), derived from cave deposits and fracture fillings, is abundant in the boulder and cobble debris along the base of parts of the west face. Some of this calcite luminesces under a longwave (3600 Å) ultraviolet mineral lamp.

Tests were conducted in the quarry during the evening of December 7, 1964. Air temperature ranged between 19° F and 21° F; the moon did not appear during the tests. The vehicle was parked in the central part of the quarry on a level about six feet above the quarry floor. The rear door opened toward the debris at the base of the west face.

The image at the center of figure 31 is a luminescing calcite boulder, 56 feet from the transmitter-receiver. That part which luminesces is a moderately fresh surface about 8 by 18 inches in area; although the boulder is larger, its weathered surface luminesced very weakly, if at all, when exposed to a longwave mineral lamp. The image, in the lower right, represents a cobble, of which an area of only 2 by 4 inches is exposed to the transmitter-receiver more than 50 feet away.

Figure 32 shows the same area as in figure 31 but without filters on either the transmitter or receiver; thus the receiver is registering reflected ultraviolet light as well as any luminescence that may be present. Comparison with figure 31 shows that those areas which luminesced in figure 31 are among the brightest in figure 32; this illustrates a possible application of an ultraviolet imaging system in enhancing image contrast and facilitating the mapping of some rock units that contain luminescing minerals.

Figure 33 shows a conventional photograph of the same area. Corner marks on the photograph delimit the area covered in figures 31 and 32. A shoulder bag, included for scale, lies immediately left of the photograph center on top of the same brightly imaged boulder seen in figures 31 and 32. Although this boulder is a well-defined, light-toned image in the photograph, other features that luminesced under ultraviolet light are not strongly contrasted in the photograph; for example, the image indicating luminescence to the left of the large boulder in figure 31 is not clearly seen in figure 33.

Comparison of figures 32 and 33 illustrate the marked lack of image detail in the ultraviolet imagery; however, design refinements and circuitry modifications are expected to significantly improve the resolution and image quality of the ultraviolet imaging system.

Figure 34 is the video monitor image seen when the transmitter-receiver is directed toward the quarry face above the debris imaged in figures 31 and 32. The transmitter is filtered with a Corning 7-54 and the receiver with a Corning 3-73. The luminescence imaged in figure 34 is apparently due to secondary calcite deposited in fractures in the limestone, although this could not be verified because the cliff face was not readily accessible. Distance from transmitter-receiver to the face is 110 feet.

Figure 35 shows the same area as in figure 34 but with only the transmitter filtered with Corning 7-54; figure 35 shows features imaged with the aid of reflected ultraviolet light as well as any luminescence that may be present. Image quality is reduced, compared with figure 32, because of the greater distance.

Figure 36 shows a conventional photograph of the same area; corner marks on the photograph delimit the area covered in figures 34 and 35. Detail visible in the conventional photograph is not readily identified in figure 35; this shortcoming is due to the equipment's limitation in resolution; it is expected that circuitry modifications now planned will greatly improve image quality and resolution of the ultraviolet imaging system.

Barehills Quarry.-- The Barehills Quarry is located about one mile north of the Baltimore city limits on Falls Road near its junction with Old Pimlico Road (fig. 30). The quarry, now abandoned, once produced serpentine ($3\ Mg\ O \cdot 2S \cdot O_2 \cdot 2H_2O$) for use as a building stone.

Tests were conducted in the quarry during the evening of December 8, 1964; during the tests no moon appeared and air temperature was 35° F. The rear door of the vehicle opened toward an area of the north face of the quarry about 70 feet west of Falls Road.

Figure 37 shows the video monitor image of luminescing dolomite deposited in fractures in the serpentine. The brightest image represents an area of about 3 by 5 inches on the quarry face. The less bright area surrounding this image represents thin discontinuous veins and loose fragments of dolomite $CaMg(CO_3)_2$ as well as a small amount of decayed vegetal material. The rock face is 23 feet from the transmitter-receiver.

In figure 38, the receiver filter has been removed so that luminescence as well as reflected ultraviolet light is being imaged. The bright area in figure 37 is one of the brighter areas in figure 38, suggesting that luminescence may exaggerate or enhance image brightness. This suggestion is supported in figure 39, a conventional photograph of the same area; for example, detail at a in figure 39 is dark-toned and generally poorly defined. Any luminescence that may be present is overwhelmed by sunlight. Same area in figure 38 is brightly imaged and luminescence is indicated in figure 37.

Figures 40 and 41 are similar to figures 37 and 38 except that the distance from the transmitter-receiver to the face is 50 feet. Spot with poorly defined image surrounding it can be seen in figure 40, but less brightly than in figure 38. Signals recorded in the margins of the monitor screen in figure 40 represent background noise. Detail in figure 41 is poorly defined because of inadequate power density and resolution at this distance.

Similarly, figure 42 is the same as figure 38 except that the distance from the rock face has been increased to 75 feet. Spot, slightly brighter than the background noise level in figure 42, indicates luminescence of the same area seen in figures 37 and 40; however, area around the central spot, noted in figures 37 and 40, cannot be distinguished from background noise in figure 42.

Delight Quarry.-- The Delight Quarry is located in Baltimore County on Nicodemus Road, one mile west of Delight, Maryland (fig. 30). The quarry is in a serpentine dike intruded in the Wissahickon Schist.

Tests were conducted on the east face of the upper level on the evening of December 10, 1964. Air temperature was 26° F. In figure 43 the video monitor image indicates luminescence of a mineral of the serpentine group, probably deweylite ($4MgO.3SiO_2.6H_2O$), which is exposed in reticulating veins of magnesite as much as six inches thick in the rock face. Distance of the transmitter-receiver from the face is 64 feet. A linear pattern is suggested by the configuration of the luminescing areas.

In figure 44, the receiver filter has been removed so that luminescence as well as reflected light is being imaged. Brighter areas, indicating luminescence in figure 43, are shown at a. As at Barehills and at Cavetown quarries, among the brightest images are those areas which contain luminescing minerals.

In figure 45, a conventional photograph, a shows areas indicating luminescence in figure 43. Fractures or joints, which appear as very dark-toned images in figure 44, are shown at b; vertical joint to right of center and right-angle joint intersection to the left of center are not boldly imaged in this photograph. It is not understood why these features are imaged so strongly in figure 44.

Figure 46 is the same as figure 43 except that the distance from the rock face has been increased to 100 feet.

Tests were conducted on the inaccessible east face of the lower level on the evenings of January 5 and 6, 1965; temperatures ranged between 32°F and 27°F; moonlight was not significant. In figure 47 the video monitor image indicates luminescence of an unidentified mineral, probably of the serpentine group, which is exposed in reticulating veins of magnesite ($MgCO_3$) throughout the rock face. Distance from the face is 75 feet. Figure 48 is a photograph of the video monitor image of the same area, but with the receiver filter removed so that reflected ultraviolet light is being received as well as luminescence. A sinuous feature, concave upward, extends from near the left margin through the center of photograph; this feature is interpreted to be one of the larger veins of magnesite, perhaps 10 inches in width. Luminescence in figure 47 is shown in a poorly defined area that overlaps this vein; this is probably due to luminescent material in smaller veins throughout the area as well as to luminescent detrital material. No evidence of this feature is visible in figure 49, a conventional photograph which includes the same area.

Figure 50 is the video image of the same area shown in figure 47, 48, and 49; however, in figure 50, the distance from the rock face has been increased to 200 feet. Luminescence, seen in the lower right center of figure 50, is from the same area as the luminescence shown in figure 47. That luminescence was detected is surprising considering the increased distance of the rock face from the transmitter-receiver.

Area shown in figure 51 corresponds to figure 50; however, here the receiver filter was removed so that the video monitor is exhibiting reflected ultraviolet light as well as luminescence. As previously noted in similar comparisons, the brightest image in figure 51 is in the area of maximum luminescence as indicated in figure 50. Detail is poorly defined, however, because of the low resolution at distances greater than 75 feet. Dark-toned area in lower left part of figure is due to spring water which emerges from the rock face along a fracture at the upper margin of the dark-toned area.

Marriottsville Quarry.-- The Marriottsville Quarry is located in Baltimore County at the intersection of Wards Chapel and Marriottsville Roads, about two miles northeast of the village of Marriottsville (fig. 30). The quarry is in the Cockeysville Marble of Precambrian age.

Tests were conducted on the north face of the quarry during the evening of January 7, 1965; air temperature was 33°F and the moon was obscured by low clouds. Figure 52 shows the video monitor image of a luminescing mineral, tentatively identified as talc, $H_2Mg3(SiO_4)$, which was observed in the debris at the base of the north face. The mineral is apparently derived from a serpentine dike which intrudes the Cockeysville Marble and which is exposed on the inaccessible north face of the quarry. Attempts to observe luminescence of the mineral *in situ*, by directing the transmitter-receiver upward toward the rock face, was not successful. The transmitter-receiver was 56 feet from the base of the cliff.

Figure 53 is a photograph of the video monitor image of the same area, but with the receiver filter removed so that reflected ultraviolet light is being received as well as luminescence. The bright spot in the upper center of photograph is a boulder in the debris below the face; the luminescing pieces of talc in figure 52 are located just below and to the left of this boulder. However, they are not discernible in this photograph.

CONCLUSION

Favorable conclusions indicated by the tests are as follows:

1. Luminescing minerals may be detected at distances as great as 200 feet using the ultraviolet imaging system described above. By modifying the circuitry, substituting critical component parts, and increasing the transmitter output, it may be possible to image strongly luminescing minerals at distances greater than 500 feet from the outcrop.

2. The ultraviolet imaging system was used to image outcrops and terrain features on the basis of reflected ultraviolet light. Luminescing minerals are among the brightest features in this type of imagery, thus illustrating an advantage of an ultraviolet imaging system in enhancing and facilitating the mapping of such features as mineralized veins which contain luminescing materials.

3. High relative humidity (between 92 and 100 percent) and low visibility (less than one-eighth mile) had surprisingly little or no effect on imaging capabilities of either luminescence or reflected ultraviolet light, at least at subject distances of 45 feet (P-16 Phosphor).

4. Imaging system was responsive to luminescence of bulk mineral samples at 45 feet subject distance despite contamination by as much as 88 percent of the surface area of the samples by non-luminescing material.

Unfavorable conclusions include the following:

1. Circuitry and power limitations reduced the range of the receiver, and restricted the distance at which a reasonably good reflected light image could be received to less than 75 feet from the outcrop. However, it is expected that redesign of certain critical components will significantly increase the output power, improve both image gray scale, and increase effective operational distance.

2. Deterioration in efficiency of the P-16 transmitter tube within short operational periods significantly reduced the sensitivity of the system. Some of this deterioration is apparently due to tube manufacturing techniques which probably can be eliminated when new tubes are built. Other causes are related to the P-16 phosphor specifically and would not be significant factor if other phosphors were used.

3. Moonlight, building lights, and other sources of ambient light increased background noise and tended to obscure imagery of both luminescence and reflected ultraviolet light.

Distinguishing the samples on the basis of luminescence signature was inconclusive, partly because the visible emission of the mineral samples studied were too similar for significant differences in luminescence to be detected, and partly because circuitry and component design of receiver provided only limited sensitivity at wavelengths longer than 4500 Å.

FUTURE WORK

An improved ultraviolet imaging system featuring a transmitter operable either in continuous wave or pulsed power modes is under study. Both the transmitter and the receiver of the newer system will use reflective optics, thus facilitating use of a variety of phosphors emitting at varying wavelengths in the ultraviolet spectrum. These and other changes in the design of the ultraviolet imaging system should significantly increase the range, improve gray scale, and generally improve system versatility.

It is expected that modification of components and circuitry in the receiver will permit remote measurement of decay time or phosphorescence, and hopefully, some correlation can be established between decay characteristics and specific minerals or groups of minerals. It is also expected that improved equipment will be capable of remotely detecting spectral differences in luminescence between minerals; however, direct identification of specific minerals in terms of their luminescence characteristics remains to be demonstrated, the kinds and amounts of impurities or activators causing luminescence in natural substances are extremely variable, not readily defined, and commonly cause wide variation in luminescence properties. even in the same mineral.

In addition, the upgraded system will use a short wavelength (2600 Å) phosphor, recently developed by Westinghouse; this phosphor will make possible studies in the deep ultraviolet similar to studies described above at longer wavelengths. Operation in this part of the ultraviolet spectrum is indicated by the following:

1. Some minerals, for example scheelite ($CaWO_4$), luminesce under short wavelength ultraviolet light only.
2. Eliminating the visible "tail" from the transmitter (and associated problems in removing this visible component with filters) will be facilitated by using phosphors whose peak wavelengths are far removed from the visible spectrum.
3. Appreciable solar radiance at wavelengths shorter than 2900 Å is absent at or near the earth's surface; thus, imaging of terrain features at shorter wavelengths could be conducted during daylight hours, thereby facilitating field operations.
4. Reflected ultraviolet light between 2200 Å and 3000 Å may reveal diagnostic criteria, pertinent to mapping the distribution of rock units and other geologic features not visible at longer wavelengths. Although nearly all energy is absorbed in this region, preliminary work by Fischer and Gerharz (1964) suggests that such small amounts of reflected energy may be utilized through image enhancing devices and through special photographic developing techniques.

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Hemphill, William R., and Gawarecki, Stephen J., 1964, Interim report, Part I, Ultraviolet video imaging system: unpublished U. S. Geol. Survey Technical Letter, NASA-3.

Pfahnl, A., 1963, Fast decay phosphor: Bell System Tech. Jour., p. 193-194.

Westinghouse Electric Corporation, 1965, A performance comparison of two lunar surface remote sensing systems: unpublished report, Aero Space Division, Baltimore, p. 2.

APPENDICES

Appendix A. Sketch showing the layout and dimensions of sample trays, identification of minerals in each tray, source area of the mineral or minerals, as well as the estimated percentage of surface area of each sample that luminesces under a longwave (3660 Å) ultraviolet mineral light. All samples luminesce white or cream, except willemite which luminesces green.

Appendix B. Curves showing the spectral transmission characteristics of the Corning 7-54, 3-73, and 3-72 filters as well as the following Kodak filters: 4, 8, 15G, 16 and 22.

Appendix C. Curves showing spectral characteristics of the Westinghouse P-16 Phosphor and the CBS S-13 image dissector tube.

Appendix D. Curve showing output efficiency of the P-16 phosphor at 30 watts beam power (Pfahnl, 1963).

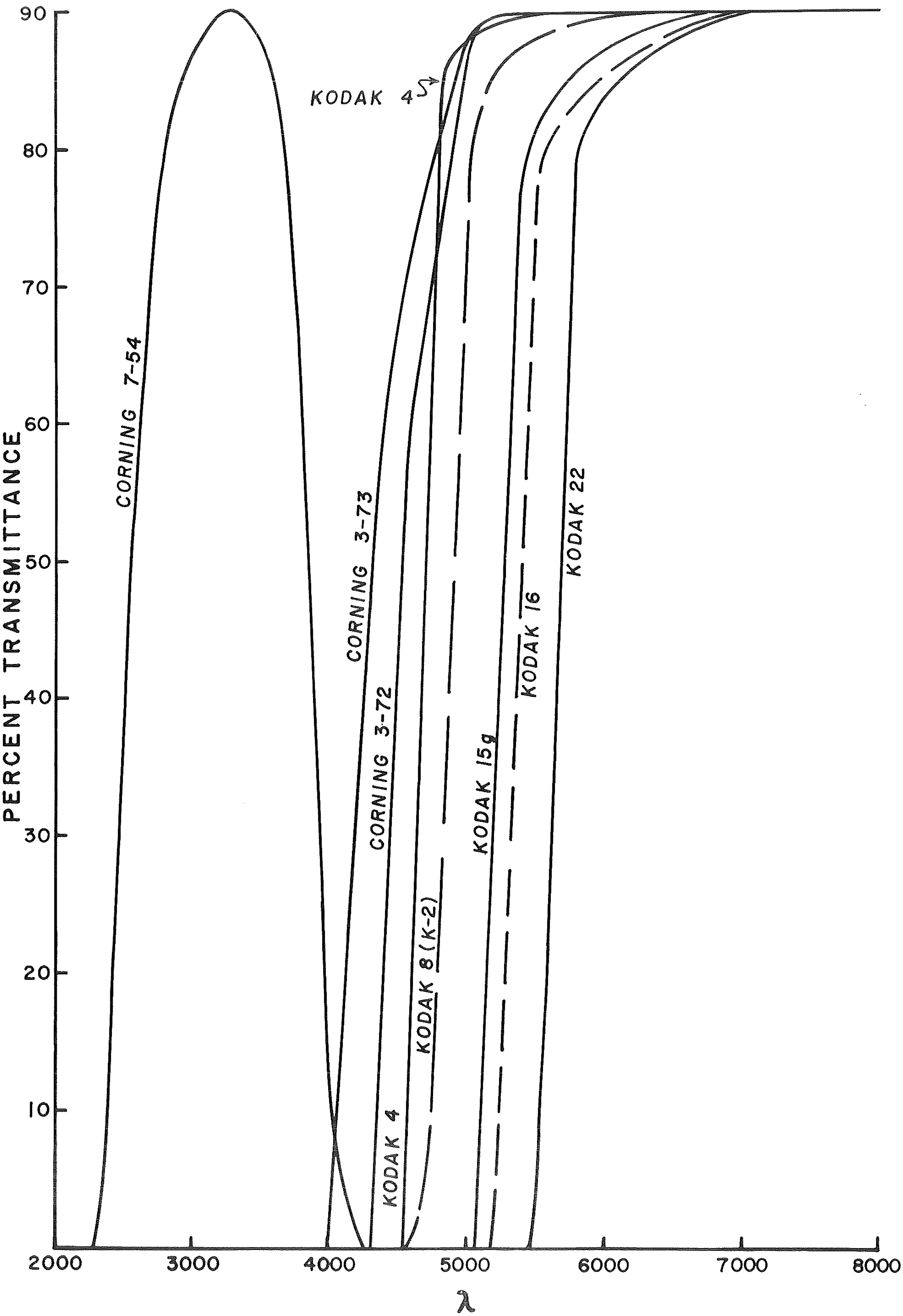
APPENDIX A

3'

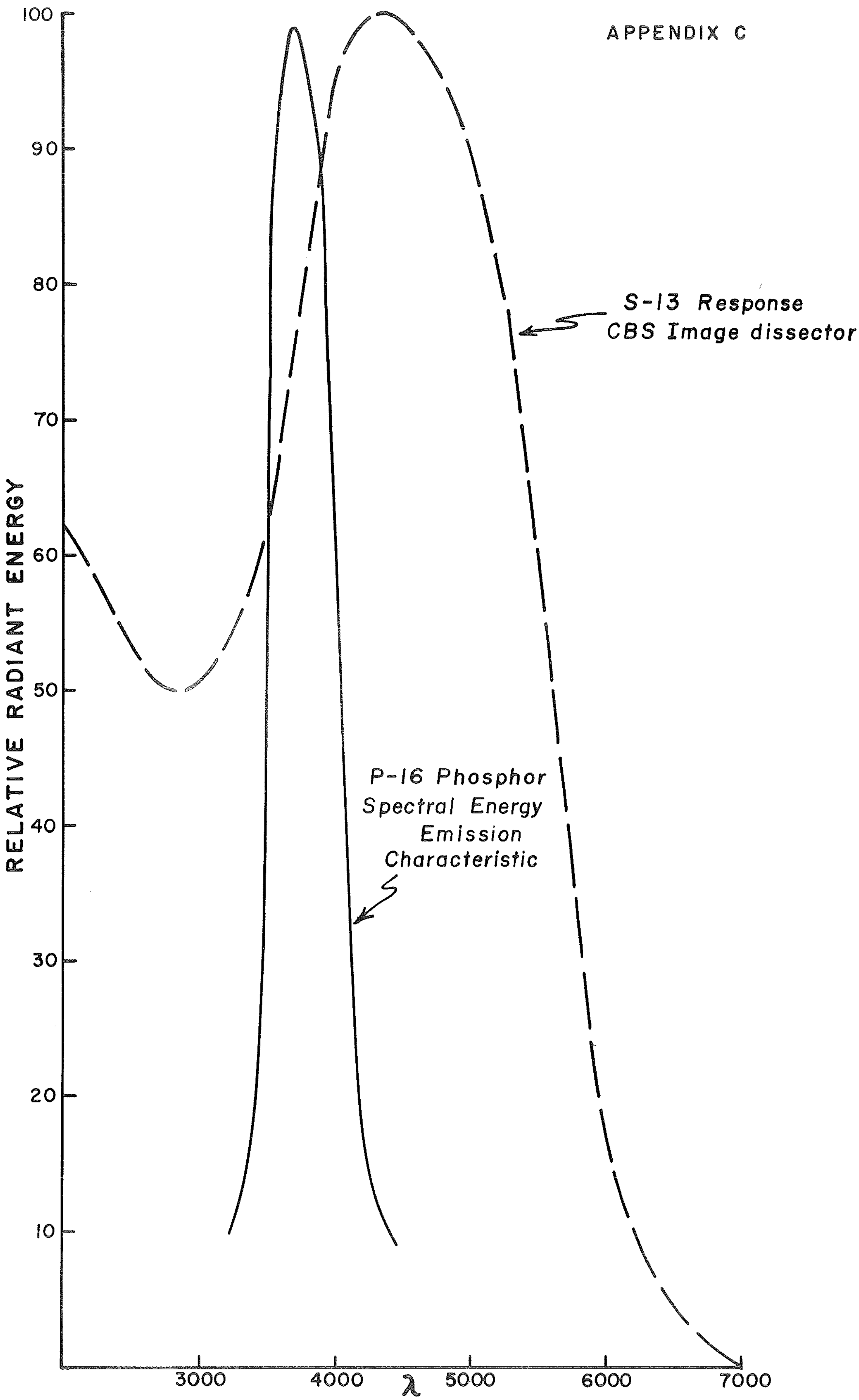
1'

CALCITE ($CaCO_3$) (with limestone) Italy 10%	CALCITE ($CaCO_3$) Moorefield, West Virginia 85%
WILLEMITE (Zn_2SiO_4) (with calcite and franklinite) Franklin, New Jersey 20%	PHOSPHATE ROCK Florida 70%
FLUORITE (CaF_2) Illinois 60%	COLEMANITE ($Ca_2B_6O_{11} \cdot 5H_2O$) Turkey 40%

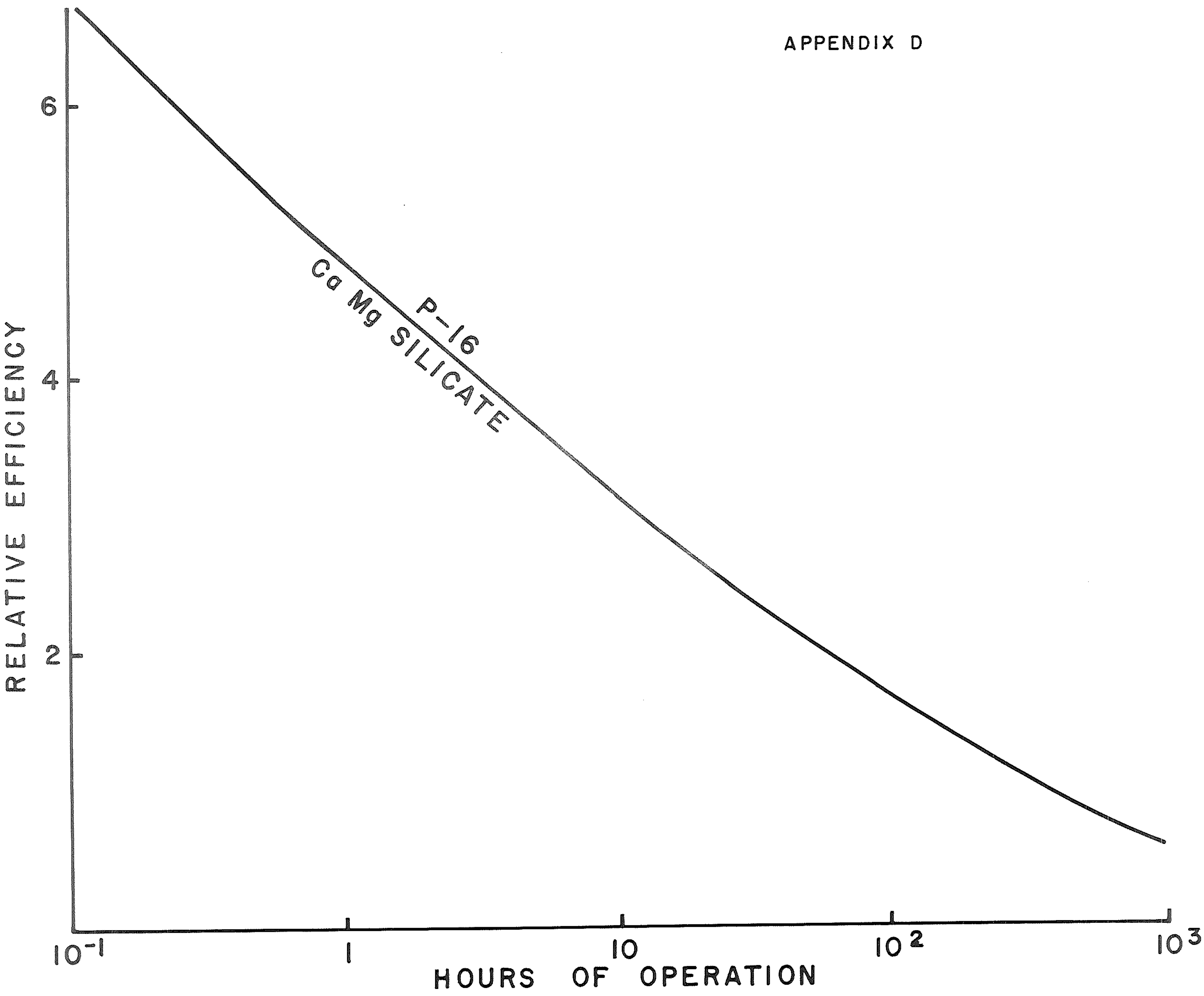
APPENDIX B


90
80
70
60
50
40
30
20
10
PERCENT TRANSMITTANCE
2000
3000
4000
5000
6000
7000
8000
λ
CORNING 7-54
CORNING 3-73
CORNING 3-72
KODAK 4
KODAK 4
KODAK 8 (K-2)
KODAK 15g
KODAK 16
KODAK 22

APPENDIX C


100
90
80
70
60
50
40
30
20
10
RELATIVE RADIANT ENERGY
3000
4000
λ
5000
6000
7000
S-13 Response
CBS Image dissector
P-16 Phosphor
Spectral Energy
Emission
Characteristic

APPENDIX D



RELATIVE EFFICIENCY
6
4
2
P-16
Ca Mg SILICATE
10-1
1
10
10 2
10 3
HOURS OF OPERATION

ILLUSTRATIONS

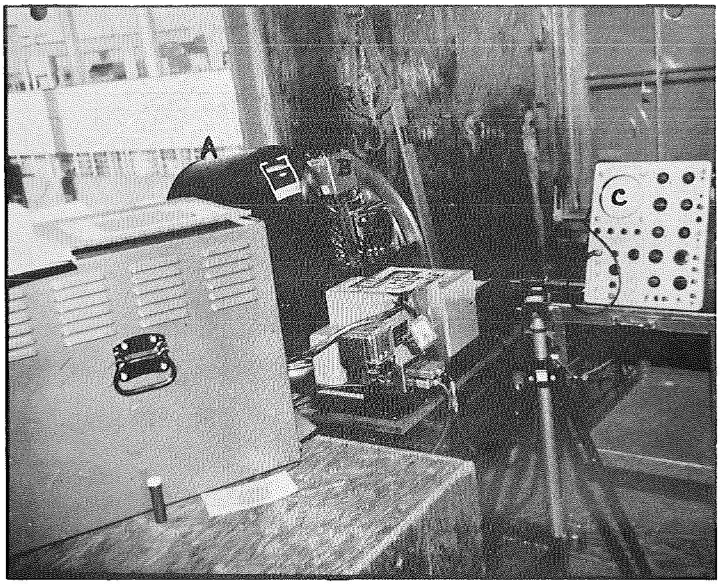


Fig. 1

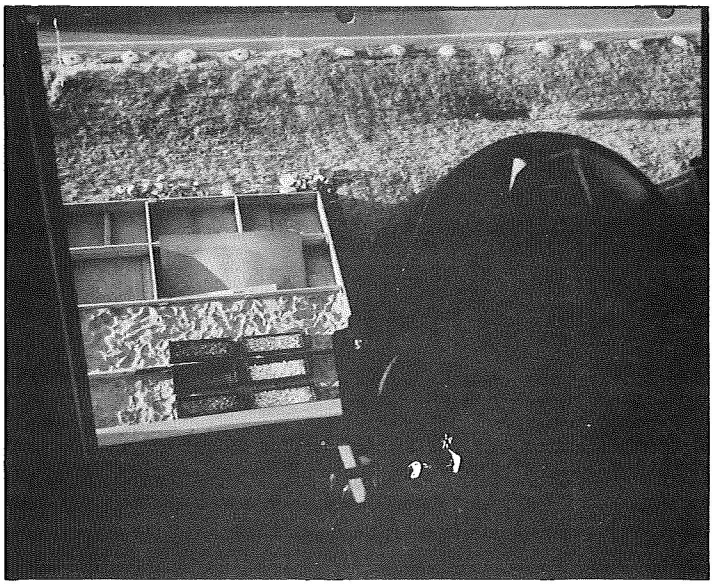


Fig. 2

Figure 4. Video monitor image showing luminescence of the phosphate rock sample when an old P-16 transmitter tube is being used. The receiver is filtered with a Corning 3-73. The other five samples are not visible.

Figure 5. Video monitor less than one hour later. Same as figure 4 except that a new P-16 tube has been installed in the transmitter. Not only does the phosphate rock image appear more brightly, but images of the calcite, fluorite, and colemanite samples can also be seen.

Figure 6. Video monitor. Same as figure 4 except that the receiver is filtered with a Kodak 8(K-2) filter. The phosphate rock sample is very weakly imaged in the right center.

Figure 7. Video monitor. Same as figure 6 except that a new P-16 transmitter tube has been installed. The phosphate rock sample is strongly imaged.

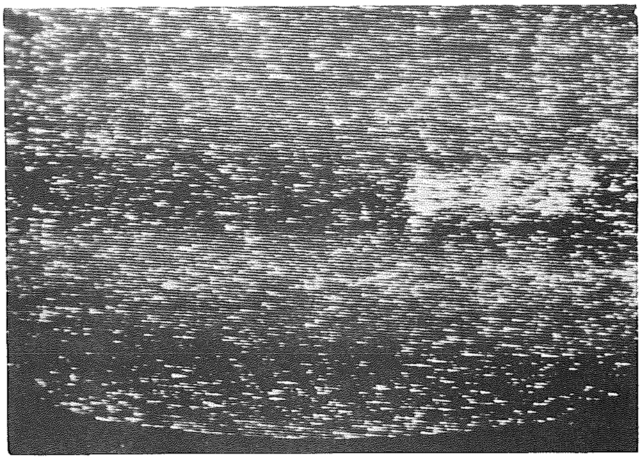


Fig. 4

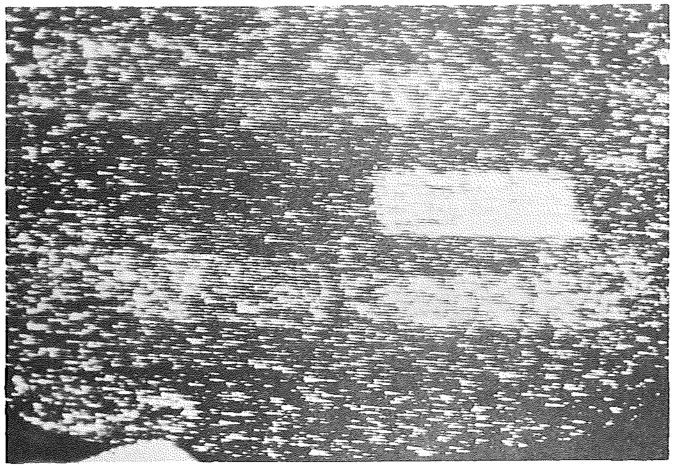


Fig. 5

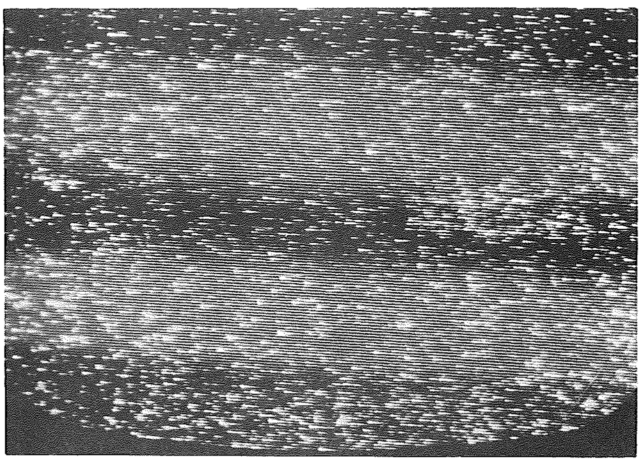


Fig. 6

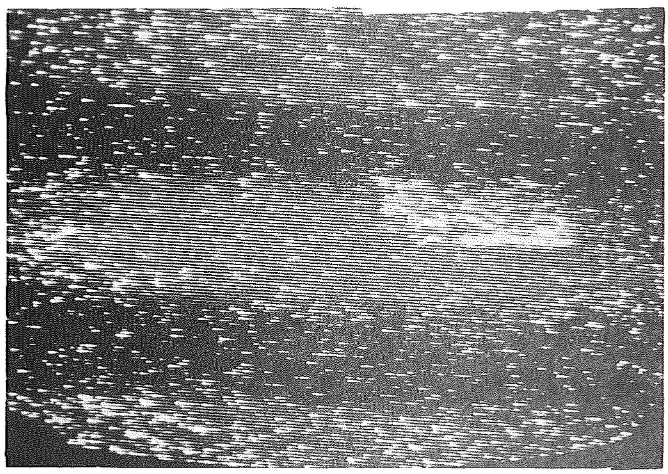


Fig.7

Figure 8. A-scope trace at 50 mv/cm, November 17. Peaks represent reflected ultraviolet light from the willemite (with calcite) sample (left) and phosphate rock sample (right). Despite general homogeneity of the two samples, trace tends to peak near the center; this is due to a vignetting effect of the system which results in a weaker signal near the margins of the field of view. When this trace was made, relative humidity was 55 percent, air temperature was 48°F, and the sky was clear.

Figure 9. A-scope trace at 50 mv/cm, November 19. Generally, the same conditions prevail here as in figure 8 except that visibility is restricted to less than 1/8 mile due to fog.

Figure 10. A-scope trace at 50 mv/cm, November 20. Weather conditions when this trace was made were similar to November 17 (figure 8).

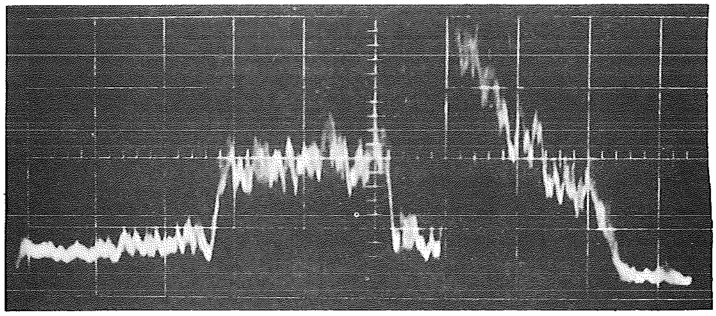


Fig. 8

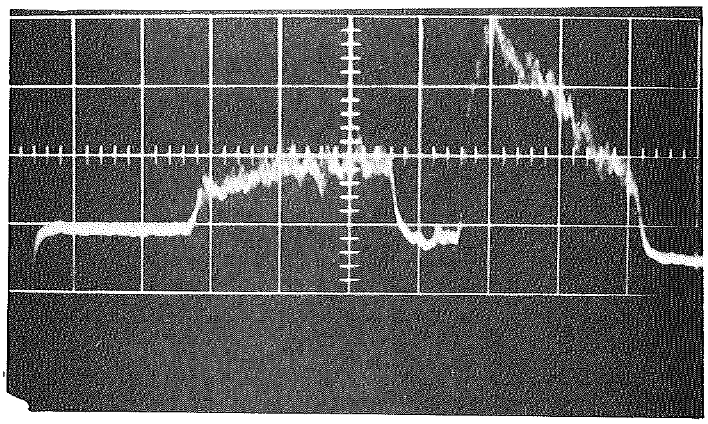


Fig. 9

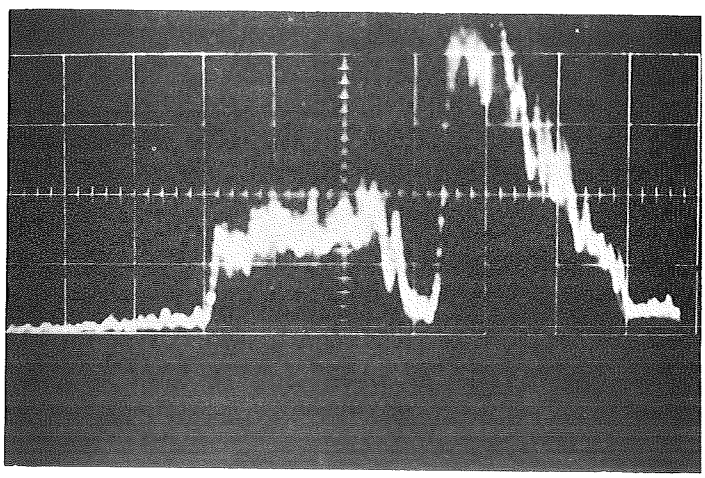


Fig. 10

Figure 11. Video monitor image showing reflected ultraviolet light, November 17, 1964. This image was made at essentially the same time and under the same conditions as the A-scope trace in figure 8.

Figure 12. Video monitor image showing reflected ultraviolet light, November 19, 1964. This image was made at essentially the same time and under the same conditions as the A-scope trace in figure 9.

Figure 13. Video monitor image showing reflected ultraviolet light, November 20, 1964. This image was made at essentially the same time and under the same conditions as the A-scope trace in figure 10.

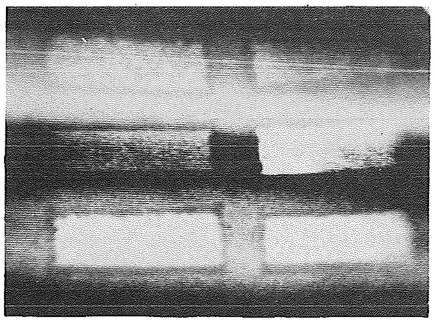


Fig. 11

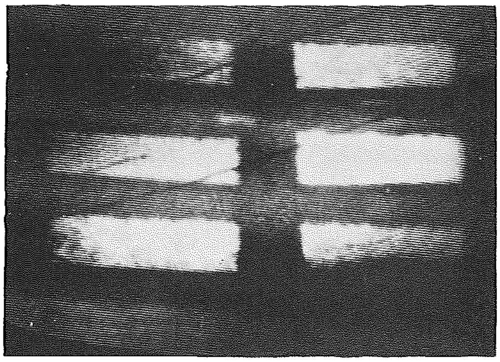


Fig. 12

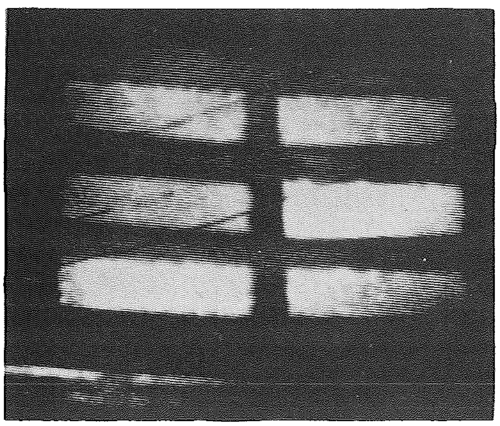


Fig. 13

Figure 14. Video monitor. Images indicate luminescence of all the mineral samples except the willemite sample. Full moon is behind a cloud. The receiver is filtered with a Kodak 8 (K-2) filter.

Figure 15. Video monitor. Same as figure 14 except that photograph was taken five minutes later when the moon had emerged and was shining directly on the two sample trays in the upper part of the field of view. Moonlight adds noise to the image and may obscure weaker signals.

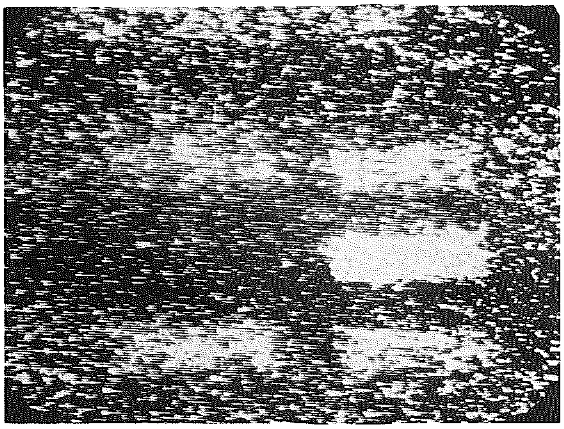


Fig. 14

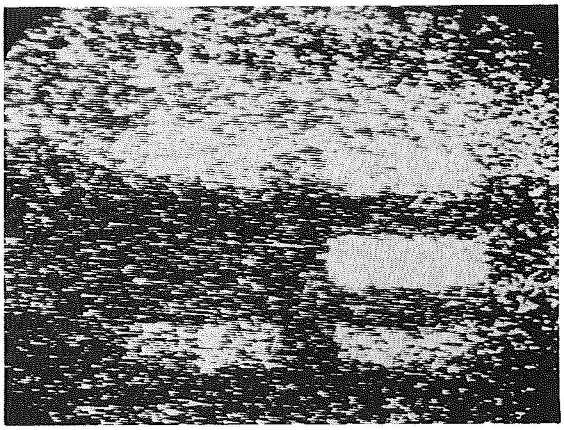


Fig. 15

Figure 16. Video monitor showing all six samples imaged November 13, 1964, with the aid of reflected ultraviolet light as well as any luminescence that the specimens may be exhibiting.

Figure 17. Video monitor. Generally same as figure 16 except that a Corning 3-73 filter has been installed on the receiver; thus, only luminescence is being imaged. All six samples may be seen, although the willemite at the middle left and the calcite in limestone at the upper left are very weakly imaged. Tests using various receiver filters were repeated during five evenings in November; however, the most consistent results were obtained November 13, when a new P-16 tube had been installed in the transmitter. These results are shown in figures 17-23.

Figure 18. Video monitor. Generally the same as figure 16 except that a Corning 3-72 filter has been installed in the receiver. Images, indicating luminescence, may be seen for all samples except willemite.

Figure 19. Video monitor. Generally the same as figure 16 except that a Kodak K-4 filter has been installed in the receiver. Images, indicating luminescence, may be seen for all samples except willemite.

Figure 20. Video monitor. Generally the same as figure 16 except that a Kodak 8(K-2) filter has been installed in the receiver. Same images visible in figure 19 are seen here, but more weakly.

Figure 21. Video monitor. Generally the same as figure 16 except that a Kodak 15-G filter has been installed in the receiver. Samples seen with filters used previously are more weakly visible here.

Figure 22. Video monitor. Generally the same as figure 16 except that a Kodak 16 filter has been installed in the receiver.

Figure 23. Video monitor. Generally the same as figure 16 except that a Kodak 22 filter has been installed in the receiver. Phosphate rock sample is imaged the most brightly; in addition, calcite, colemanite, and fluorite samples are very weakly visible.

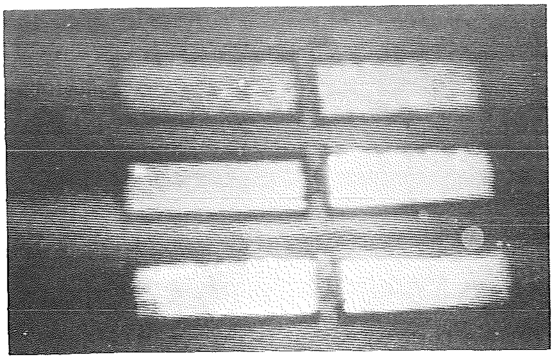


Fig. 16

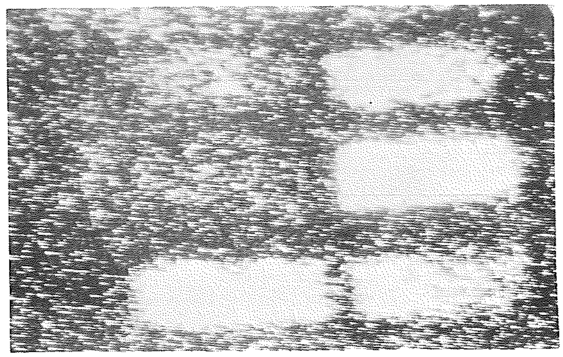


Fig. 17

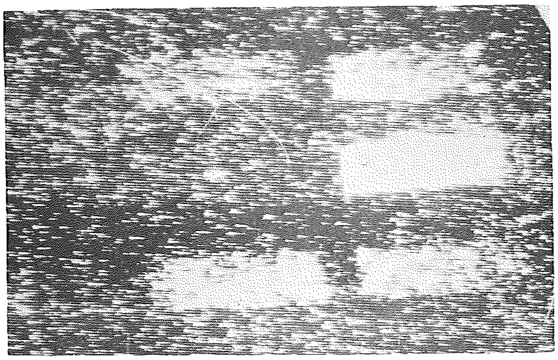


Fig. 18

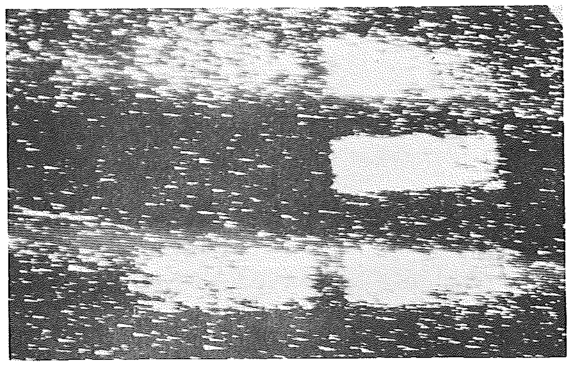


Fig. 19

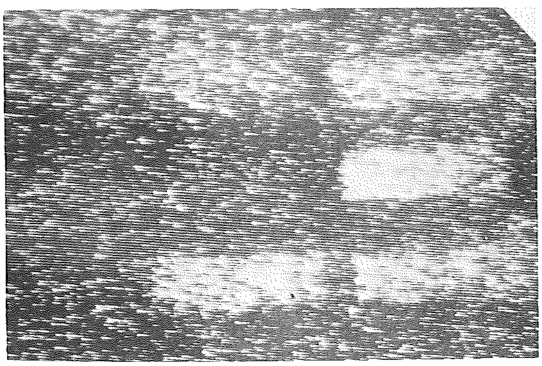


Fig. 20

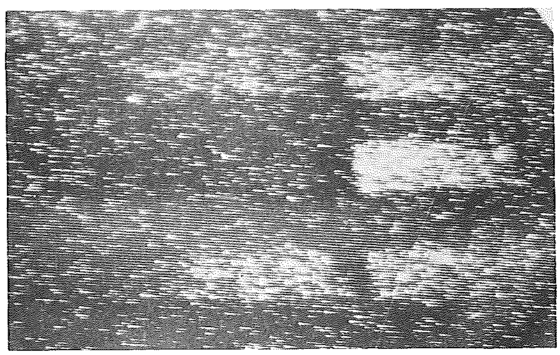


Fig. 21


Fig. 22

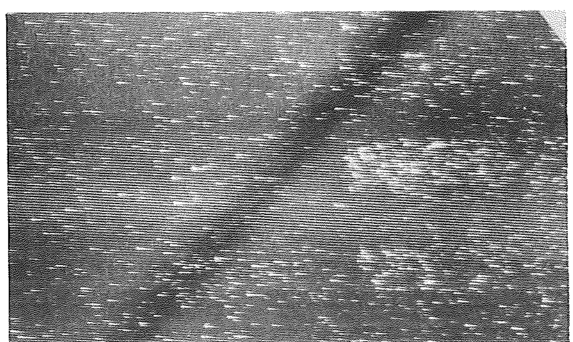


Fig. 23

Figure 24. Video monitor. Samples were imaged with the aid of reflected ultraviolet light as well as any luminescence that the minerals may be exhibiting. Stencil, simulating 50 percent contamination, is covering the sample; note images of the half-inch strips of cardboard across the short dimension of the middle and lower left trays.

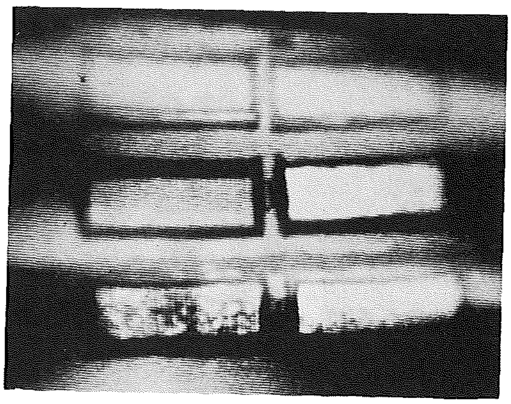


Fig.24

Figure 25. Video monitor. A Corning 3-73 filter has been installed on the receiver, thus restricting the bandpass to luminescence. Only the willemite is not visible.

Figure 26. Video monitor. Same as figure 25 except that a cardboard stencil simulating 50 percent contamination is covering the samples. Images visible in figure 25 are more weakly imaged here.

Figure 27. Video monitor. Same as figure 25 except that a stencil simulating 75 percent contamination is covering the sample. Despite contamination, all images visible in figure 26 are very weakly visible here.

Figure 28. Video monitor. Same as figure 25 except that a stencil simulating 88 percent contamination is covering the sample. Only the phosphate rock sample is imaged.

Figure 29. Video monitor. Same as figure 28 except that a new P-16 transmitter tube has been installed. In addition to the phosphate rock sample, fluorite, colemanite, and the calcite samples are imaged.

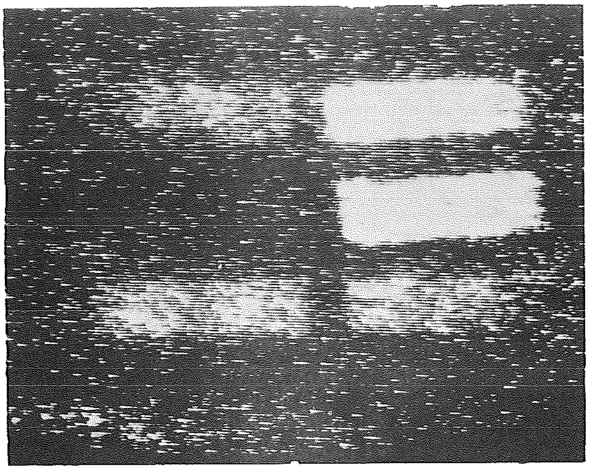


Fig.25

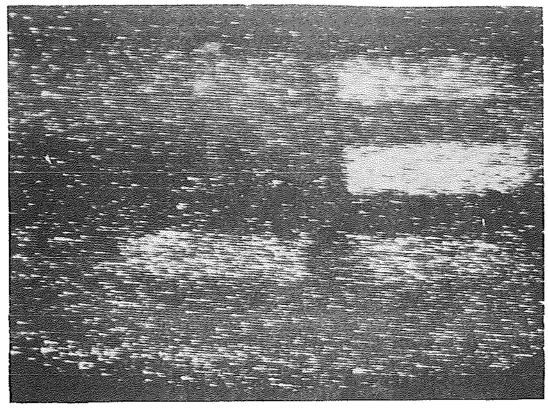


Fig. 26

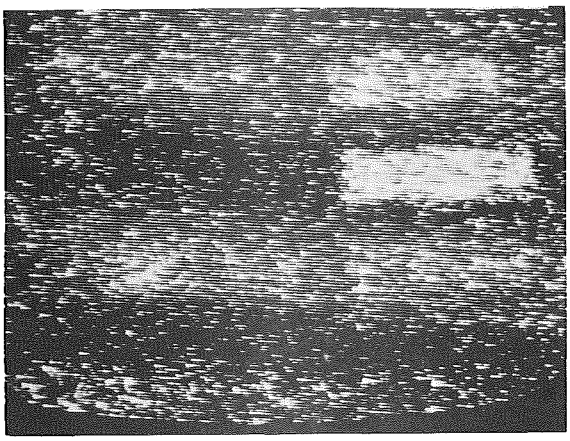


Fig.27

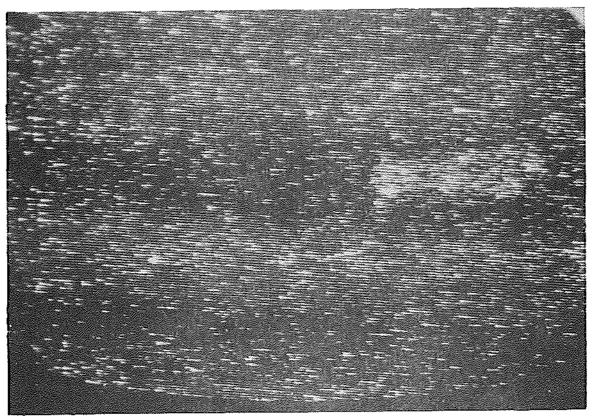


Fig. 28

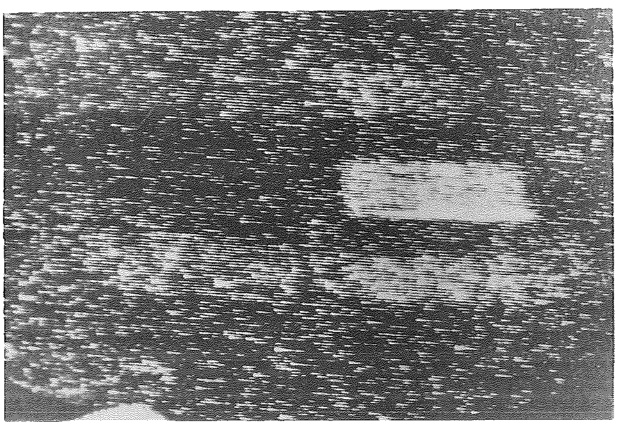


Fig.29

Figure 30. Index map showing the location of quarries visited during the Phase III tests.

a. Cavetown Quarry

b. Bare Hills, Delight, and Marriottsville Quarries.

Figure 30A. Ultraviolet imagery system installed in a delivery-type van. The transmitter-receiver may be directed through the rear doors toward the rock exposures to be imaged. Electrical power is provided by a portable gasoline generator.

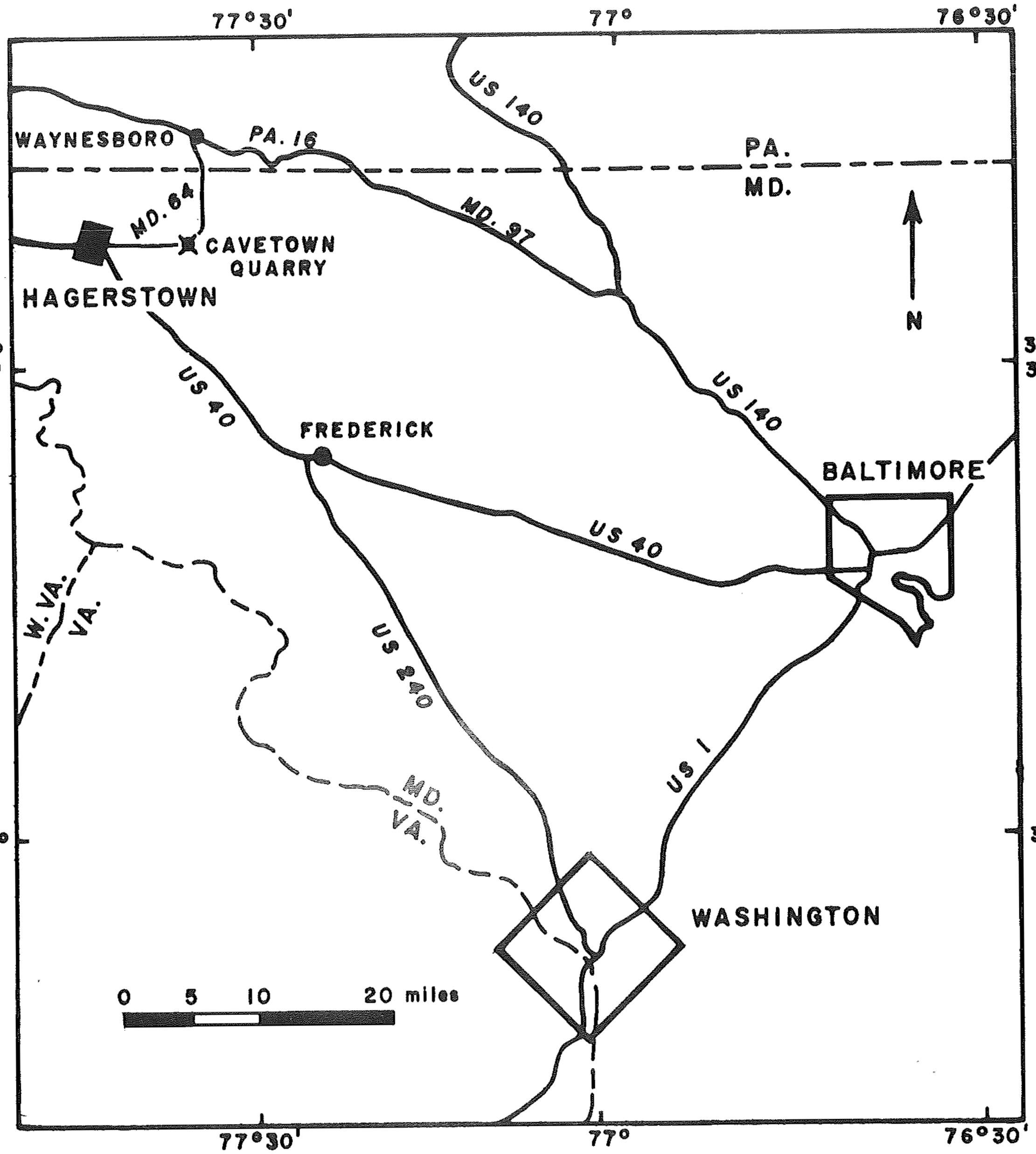

77°30'
77°
76°30'
US 140
WAYNESBORO
PA. 16
PA.
MD.
MD. 64
MD. 97
CAVETOWN
QUARRY
HAGERSTOWN
N
39°
30'
US 40
FREDERICK
US 140
BALTIMORE
US 40
W.VA.
VA.
US 240
US 1
MD.
VA.
39°
WASHINGTON
0 5 10 20 miles

Fig. 30a

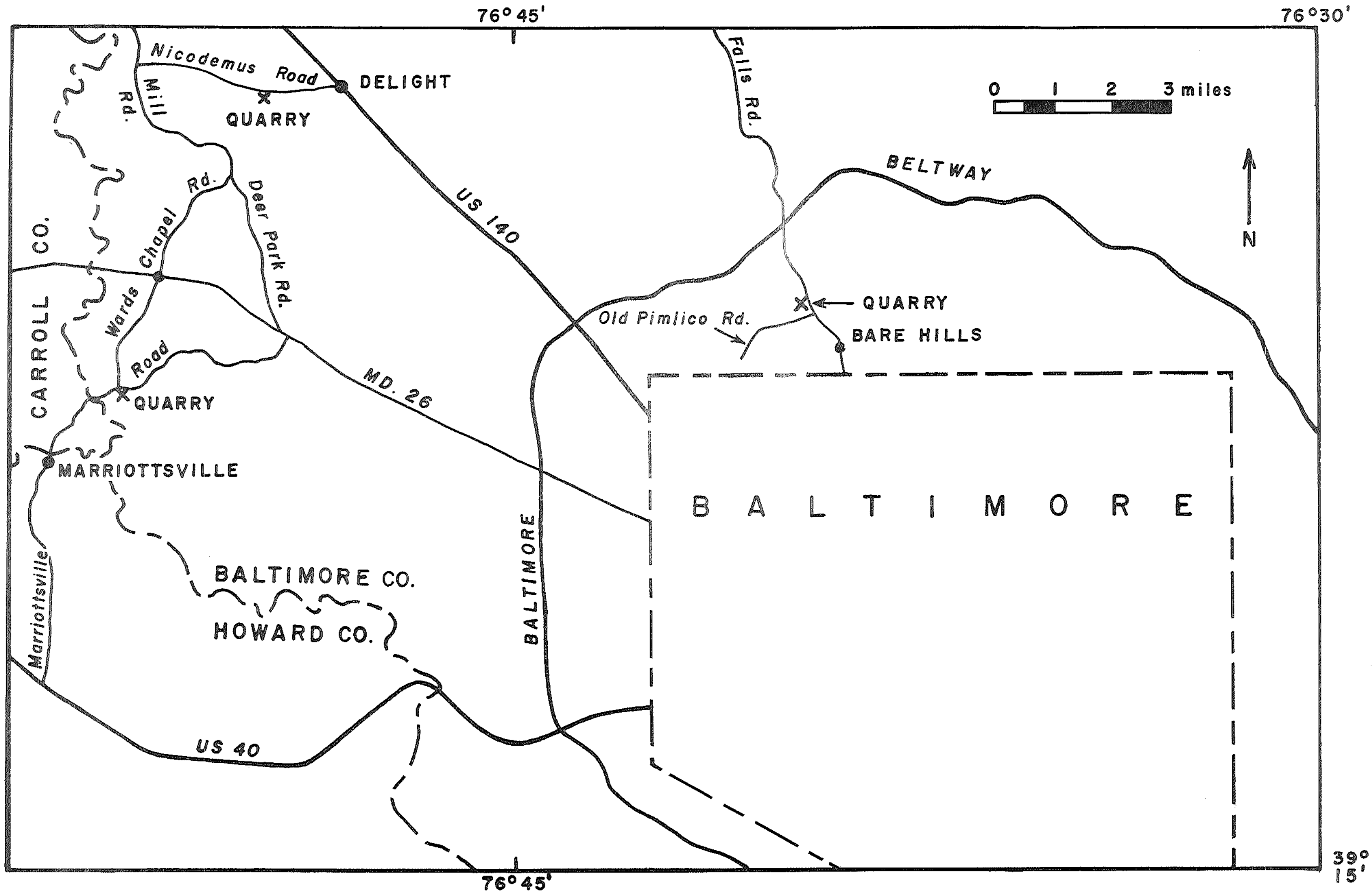

76°45'
76°30'
Nicodemus Road
DELIGHT
Mill Rd.
QUARRY
Falls Rd.
0 1 2 3 miles
BELTWAY
N
US 140
Chapel Rd.
Deer Park Rd.
CARROLL CO.
Wards Road
QUARRY
Old Pimlico Rd.
BARE HILLS
MD. 26
QUARRY
MARRIOTTSVILLE
BALTIMORE
BALTIMORE
BALTIMORE CO.
HOWARD CO.
Marriottsville
US 40
76°45'
39° 15'

Fig. 30b

Fig. 30 A

Figure 31. Video monitor showing images obtained from luminescing calcite in talus in a limestone quarry near Hagerstown, Maryland. Transmitter-receiver is more than 50 feet away.

Figure 32. Video monitor showing combined luminescence and reflected ultraviolet light of same area imaged in figure 31. Some of the brightest images here are those which indicate luminescence in figure 31, thus illustrating a possible application of this type of imaging system in enhancing image contrast and facilitating the mapping of some rock units that contain luminescing minerals.

Figure 33. Conventional photograph. Corner marks indicate the area imaged in figures 31 and 32. Shoulder bag, just left of the center, is included for scale. Some features that luminesced and are strongly imaged in figures 31 and 32 are not strongly contrasted in this photograph. Although the image quality in figure 32 is greatly inferior to the conventional photograph, it is expected that design modifications of the ultraviolet system will improve resolution and image quality.

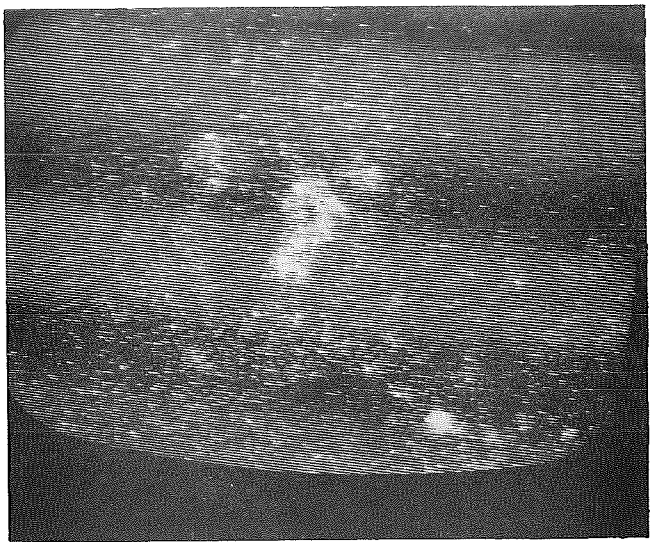


Fig. 31

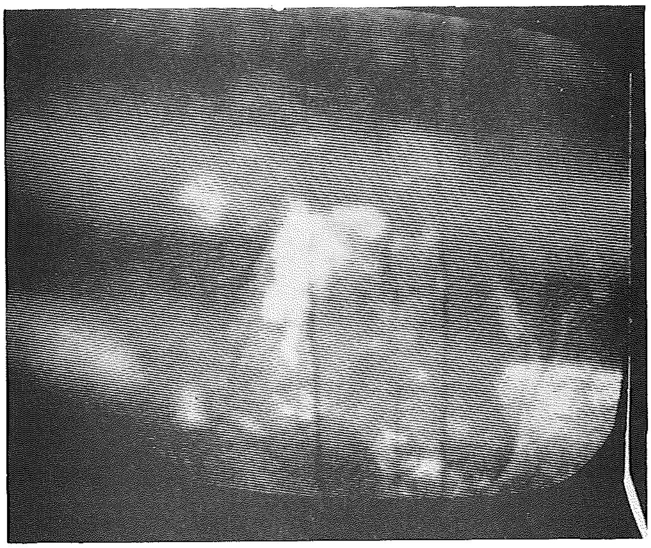


Fig. 32

Fig. 33

Figure 34. Video monitor showing images obtained from luminescing material, apparently calcite, deposited in fractures along the inaccessible limestone cliff above the debris imaged in figures 31 and 32. Transmitter-receiver is more than 110 feet away.

Figure 35. Video monitor showing combined luminescence and reflected ultraviolet light of the same area imaged in figure 34. Images are poorly resolved partly because of the distance from the transmitter, and partly because of shortcomings in the circuity of the ultraviolet imaging system. Vertical lines extending across the image are due to damage to the phosphor.

Figure 36. Conventional photograph. Corner marks indicate the area imaged in figures 34 and 35.

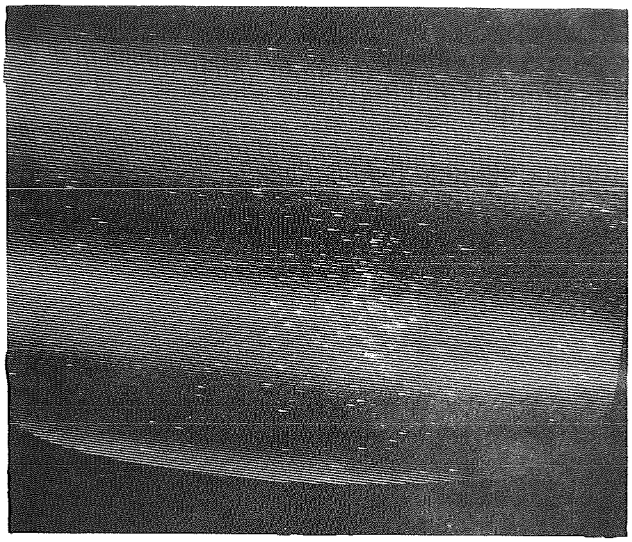


Fig. 34

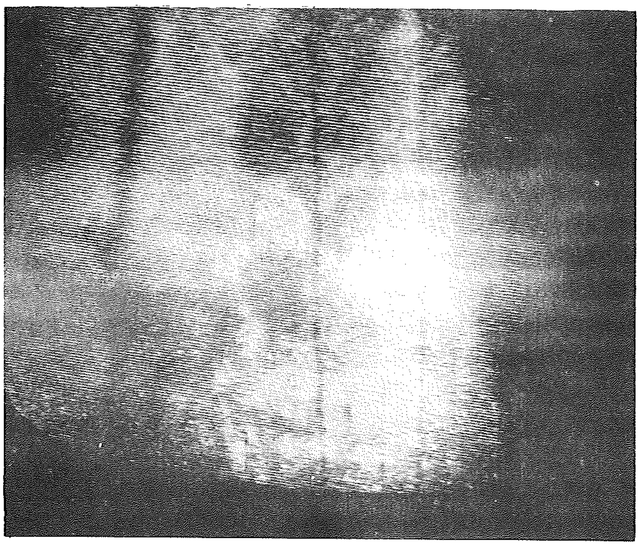


Fig. 35

Fig. 36

Figure 37. Video monitor showing images obtained from a luminescing dolomite, exposed in the north face of the Barehills Quarry, one mile north of the Baltimore city limits on Falls Road. Transmitter-receiver is 23 feet from the rock face.

Figure 38. Video monitor. Same as figure 37 except that the receiver filter has been removed; thus, luminescence as well as reflected ultraviolet light is being imaged. The bright area in figure 37 is one of the brighter areas in figure 38, suggesting that luminescence may exaggerate or enhance image brightness.

Figure 39. Conventional photograph of the same area seen in figures 37 and 38. Detail at a is dark-toned and generally poorly defined; however, same area is brightly imaged in figure 38, and luminescence is indicated for this area in figure 37. Any luminescence that may be present in the conventional photograph is overwhelmed by sunlight.

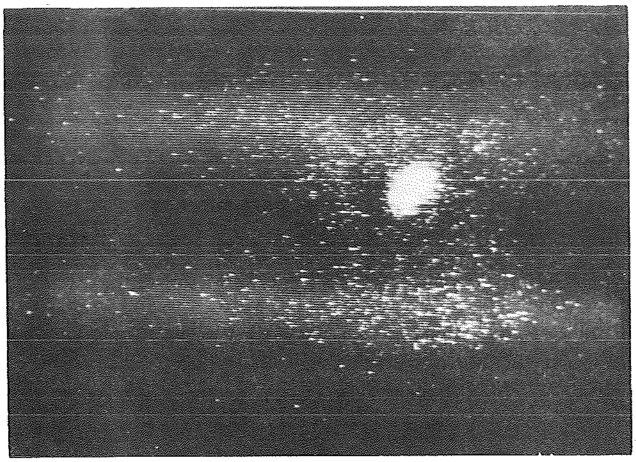


Fig. 37

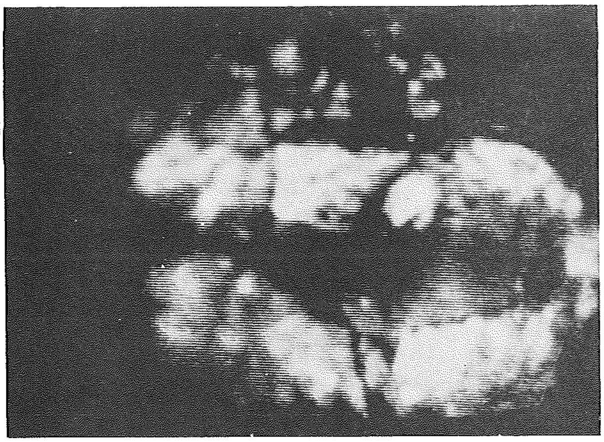


Fig. 38

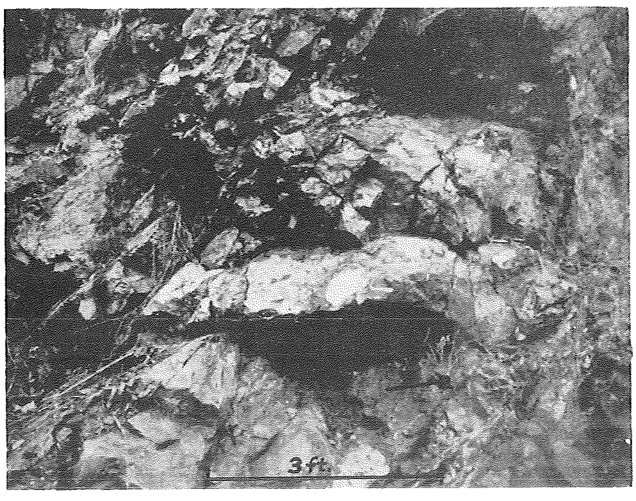


Fig. 39

Figure 40. Video monitor. Similar to figure 37 except that the transmitter-receiver has been moved to a distance of 50 feet from the rock face.

Figure 41. Video monitor. Same as figure 40, but with the receiver filter removed so that luminescence as well as reflected ultraviolet light is being imaged.

Figure 42. Video monitor. Same as figure 37 except that the transmitter-receiver has been moved to a distance of 75 feet from the rock face.

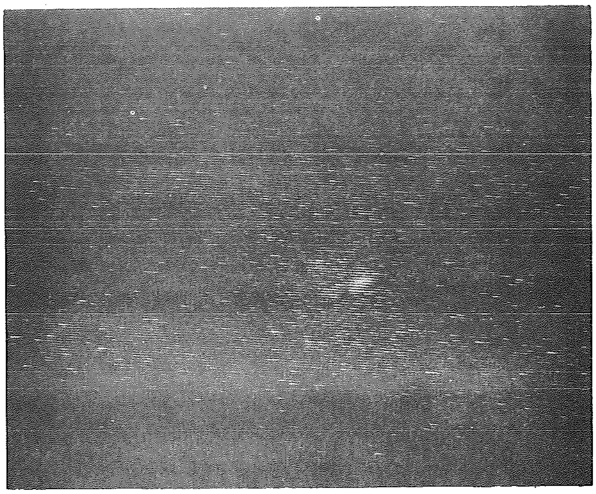


Fig. 40

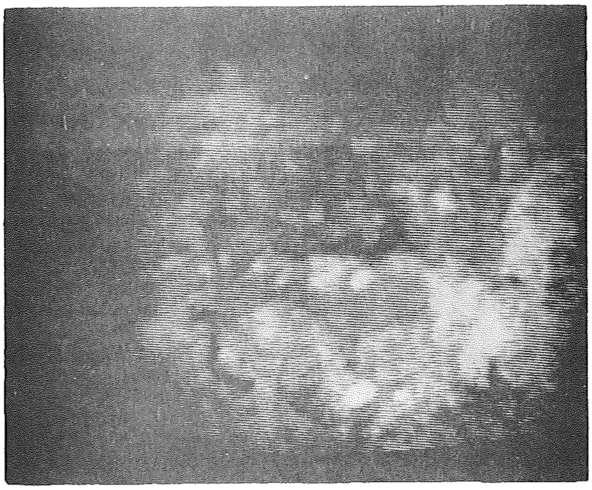


Fig. 41

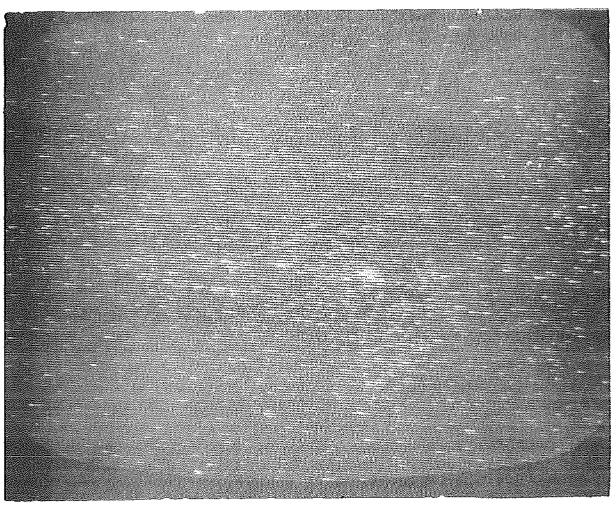


Fig. 42

Figure 43. Video monitor images indicating luminescence of deweylite which is exposed on the upper level of the Delight Quarry, one mile west of Delight, Maryland. Distance from the transmitter is 64 feet. Configuration of the luminescenct areas suggests a linear, and possibly intersecting, pattern of outcrop.

Figure 44. Video monitor. Same as figure 43, but with the receiver filter removed so that luminescence as well as reflected light is being imaged. Brighter areas, indicating luminescence in figure 43, are shown at a. Strongly imaged fractures or mineralized veins are indicated at b.

Figure 45. Conventional photograph of same area shown in figures 43 and 44. Areas where luminescence is indicated in figure 43 are shown at a. Fractures which are strongly imaged in figure 44 are shown at b. Dark tone marking the near-horizontal fracture in the center of figure 45 is due to a rock overhang which creates a strong shadow when viewed in sunlight. Without the shadow of the overhang, image contrast in this part of the photograph would be less than is shown for this fracture in the video monitor image in figure 44.

Figure 46. Video monitor. Similar to figure 43 except that the distance of the transmitter-receiver from the rock face has been increased to 100 feet.

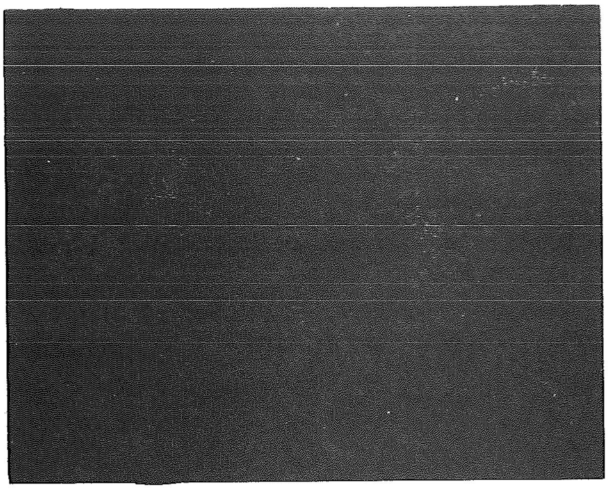


Fig. 43

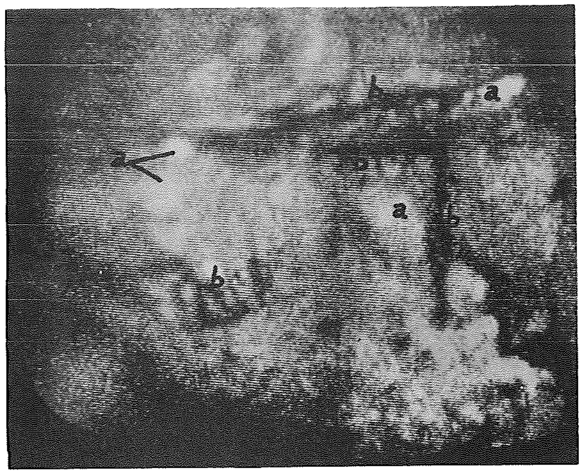


Fig. 44

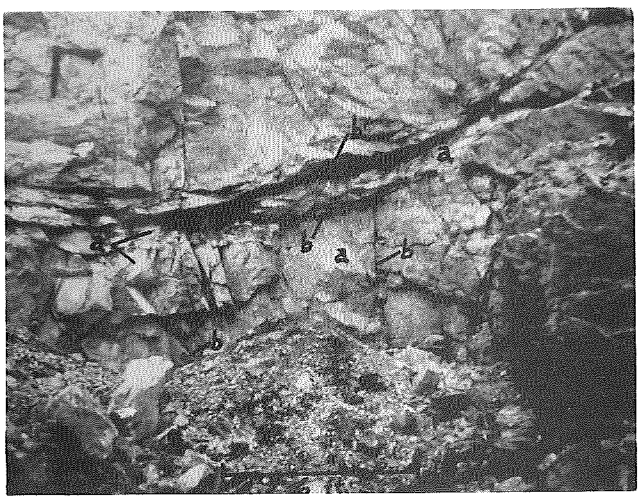


Fig. 45

Fig. 46

Figure 47. Video monitor images luminescence of an unidentified mineral of the serpentine group which is exposed on the east face of the lower level of the Delight Quarry near Delight, Maryland. Distance from the transmitter-receiver is 75 feet.

Figure 48. Video monitor. Same as figure 47 but with the receiver filter removed so that luminescence as well as reflected light is being imaged. Sinuous feature in center is interpreted to be a magnesite vein exposed on the rock face. Note the light-toned area at c.

Figure 49. Conventional photograph. Corner marks indicate the area shown in figures 47 and 48. Same light-toned area, observed in figure 48, may be seen at c. Sinuous feature shown in figure 48 is not readily observable here.

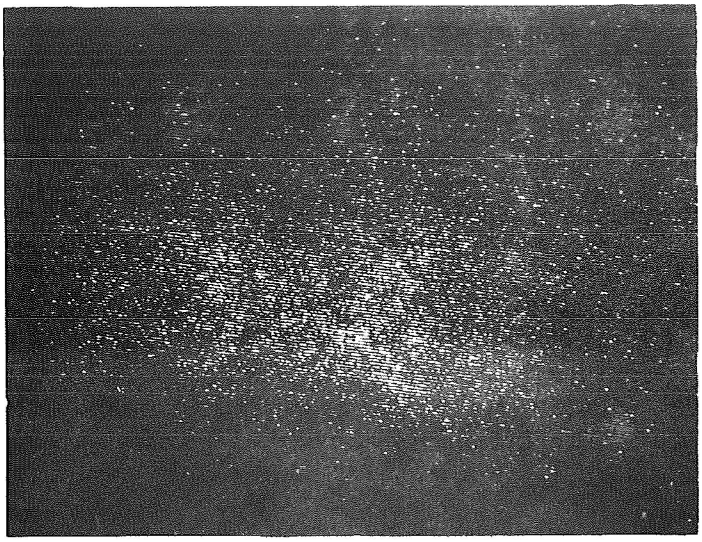


Fig. 47

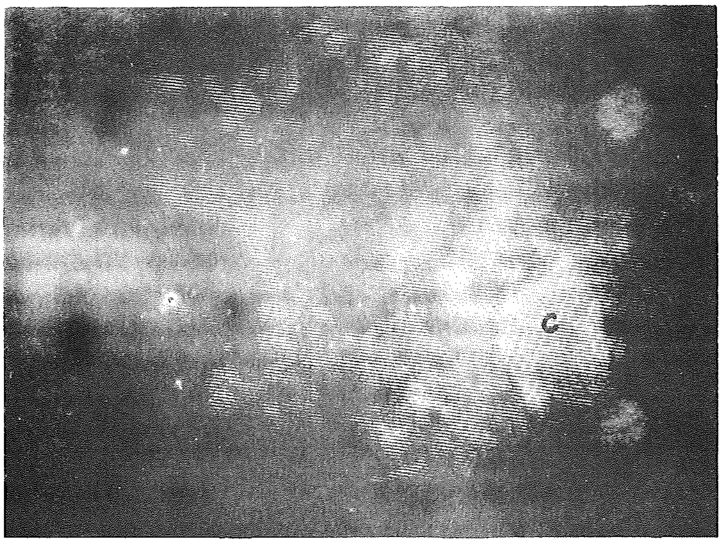


Fig. 48

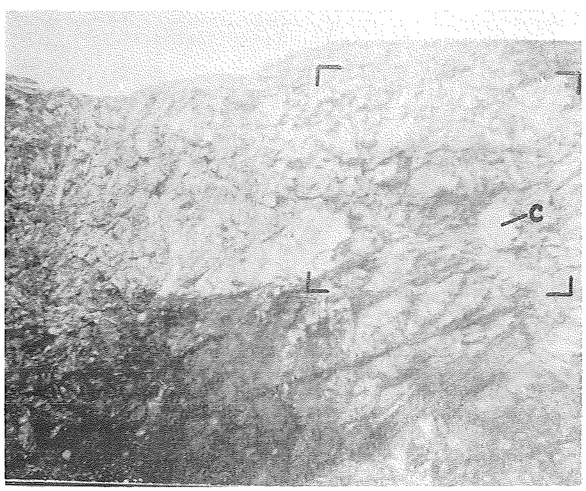


Fig. 49

Figure 50. Video monitor. Similar to figure 47 except that the distance of the transmitter-receiver from the rock face has been increased to 200 feet.

Figure 51. Video monitor. Same as figure 50 but with the receiver filter removed so that luminescence as well as reflected light is being imaged. Dark tone in the lower left is due to spring water which emerges from the rock face along a fracture at the upper margin of the dark-toned area.

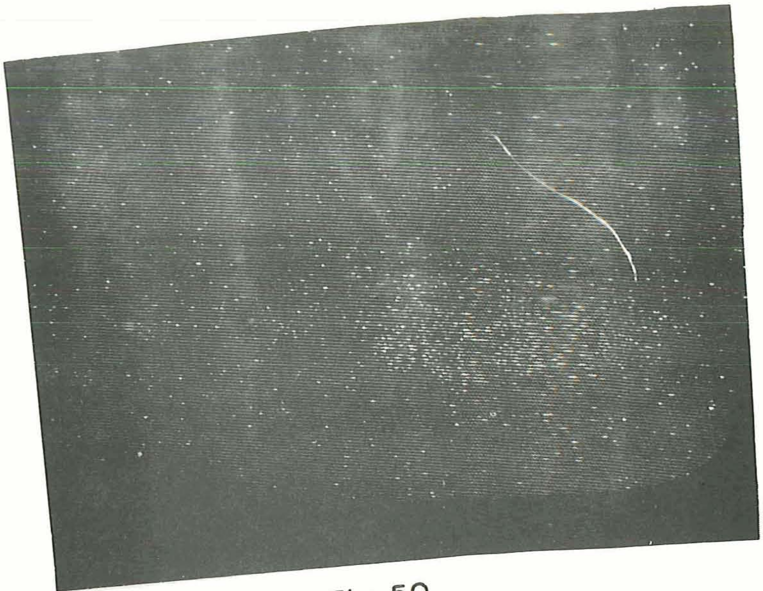


Fig. 50

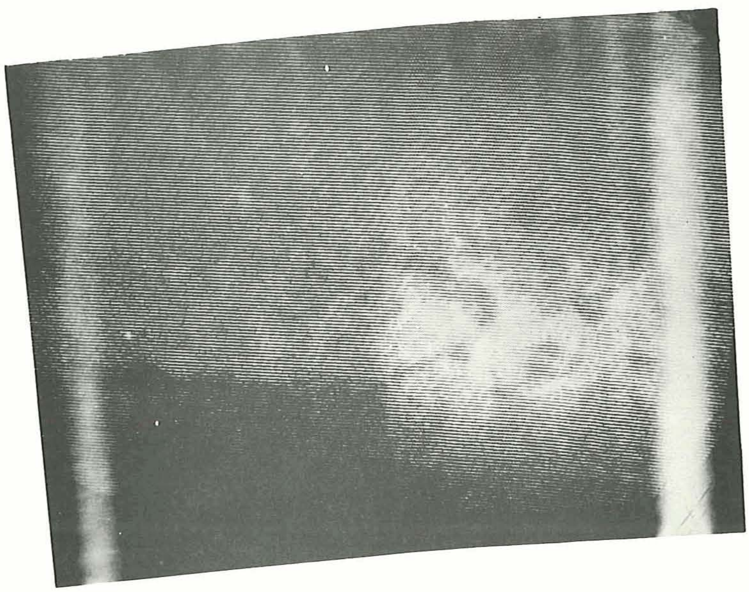


Fig. 51

Figure 52. Video monitor images indicating luminescence of talc in the debris at the base of the north face of the Marriottsville Quarry, near Marriottsville, Maryland. Distance from the transmitter-receiver is 56 feet.

Figure 53. Video monitor. Same as figure 52 but with the receiver filter removed so that luminescence as well as reflected light is imaged.

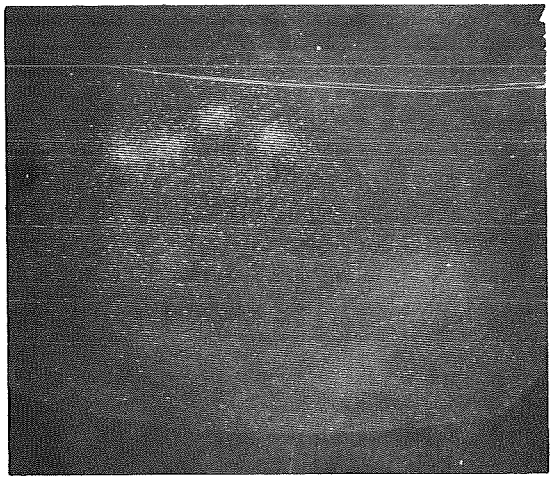


Fig.52

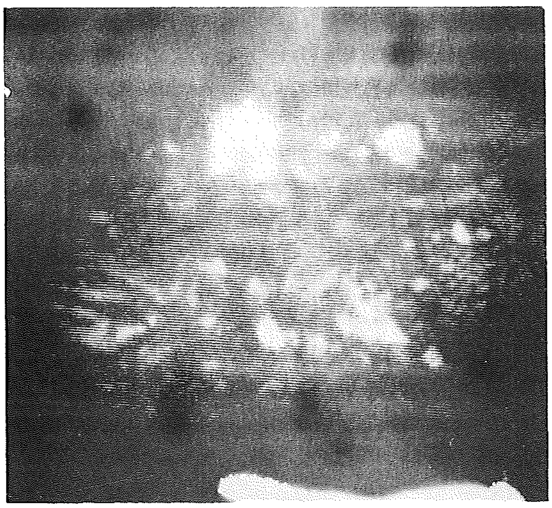


Fig.53