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A LUNAR AND PLANETARY PETROGRAPHIC MICROSCOPE[1]

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ABSTRACT

An engineering prototype model of a petrographic microscope for lunar and planetary missions has been designed and fabricated. It is designed primarily for remote operation on soft-landing spacecraft, but it could be adapted for support of a manned mission. An aggregate of crushed rock particles is thermally encapsulated between two opposing sheets of a clear isotropic thermoplastic which has a refractive index of 1.54. The images are projected through refracting lenses and an eyepiece onto the faceplate of a television camera. A television picture is taken both below and above the place of correct focus as well as in that plane for each field of view in order to change the Becke line positions. Each particle is viewed in both plane-polarized and cross-polarized light; the spectral width through an interference filter is small enough to provide light and dark interference rings on a black-and-white television.

NATURE OF A PETROGRAPHY EXPERIMENT

Perhaps the most commonly used technique to investigate the general nature of rocks on Earth is petrography. Petrographic data should be obtained at an early opportunity from rocks on other planets. Data on the coarseness of crystal size and bulk mineralogy are important in considerations of the tectonic and thermal history of the planet in question. Such data suggest the extent of processes of internal melting, depth of erosion, extent and type of rock differentiation, *etc.* Accordingly, a lunar and planetary petrography experiment has been envisioned for several years. The objectives of such an experiment are as follows:

(1) observation of rock textures, (2) determination of the gross mineralogy of the sample and identification of phases which occur in small amounts, (3) detection of glass and an estimation of its composition, and (4) determination of the size and shape distribution of particulate surface materials.

The microscope employed for such an experiment must operate remotely, and must be able to process rocks for viewing even under hostile physical conditions. Three separate models have been designed and fabricated during the years 1962–1966.

The main problem was processing samples at the surface of the Moon, where the ambient temperature varies between about −180° and +130°C, and the atmospheric pressure is probably less than about 10^{-13} mm Hg. Moreover, the physical state of the surficial material was unknown, and the material had unknown cohesion and adhesive strength

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for foreign surfaces. It was therefore considered desirable to handle all samples positively—that is, move them about by force, rather than depend on gravity.

The experiment was designed to process a particulate sample according to the following reasoning: A remotely operating petrography experiment on a distant planetary surface will not have access to selected hand specimens, but must make use of nearby surficial or shallow subsurface material. One would expect a particulate rather than a solid rock in a majority of cases. Also, it is easier in many ways to crush solid rocks or drill small particles from them than it is to impregnate a loose sample in order to make it solid; this is especially true for the surface of the Moon, where the vapor pressures of common impregnating materials are considerably higher than the atmospheric pressure. Moreover, making a good thin section is difficult on Earth, let alone with a remote mechanical device.

Although more information can be gained from observation of thin sections than from crushed particles, much of it is of a very sophisticated nature, *e.g.* zoning of mineral compositions, orientation of crystals, *etc.* The basic data concerning average crystal size and bulk mineralogy are available from a crushed grain mount. More information is available from particles with diameters of 50μ to about 300μ than from finer or coarser particles. Particles finer than 50μ may be of interest from size distribution or mineralogical considerations, but they do not show overall rock textures well. Also, very fine particles tend to interfere optically with the coarser grains. Coarser particles tend to be opaque.

A series of mechanisms were designed to carry out the main functions required: acceptance of a particulate sample from a separate sampler; crushing; size fractionation of particles; immersion in an isotropic medium of known refractive index; transport of immersed samples to the optical train of a microscope; display of a correctly focused image on film or the faceplate of a television camera.

INSTRUMENT DESCRIPTION

Since 1961, when the project was initiated, two bread-board instruments were constructed prior to design of the present engineering prototype model. The first was made by the Armour Research Foundation of the Illinois Institute of Technology on contract from JPL. The second was designed and built at JPL. The prototype instrument assembly is shown in Figures 1 and 2. It was designed at JPL by Mr. Allen G. Ford, and fabricated in the Space Sciences Division Model Shop by Mr. Kenneth C. LaBau in 1966–1967. The instrument as shown, without external electronic controls, weighs about 6 lb. A television assembly and

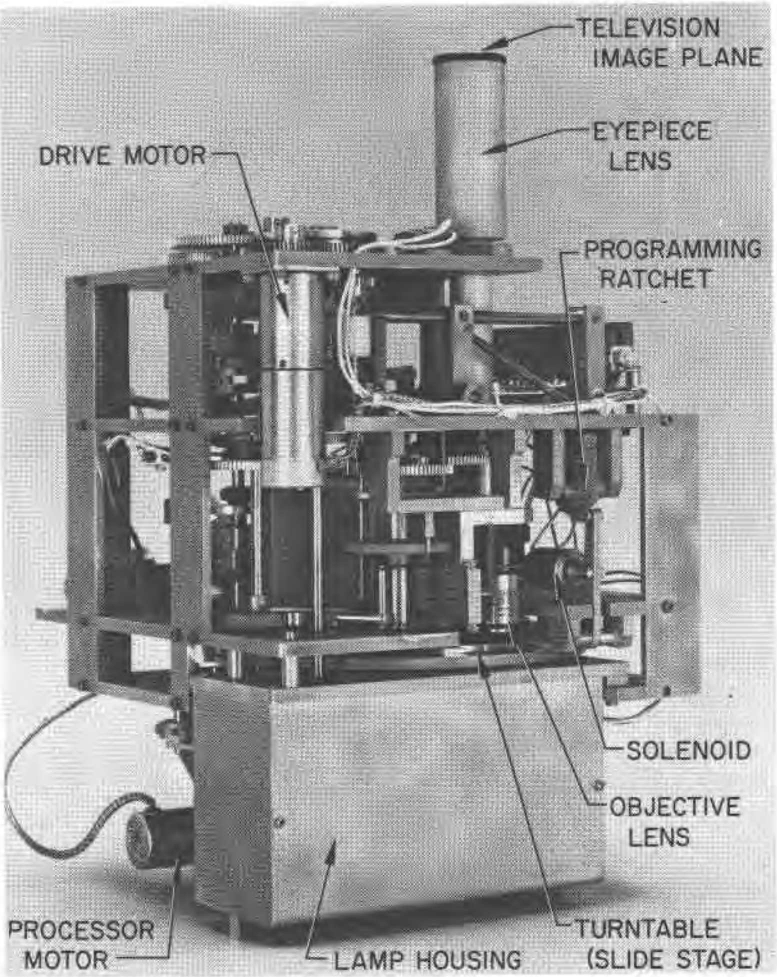

FIG. 1. Engineering prototype assembly, side view. Instrument is about 8 inches square and 12 inches high.

ancillary electronics would weigh about 9 lb; thus, a complete flight instrument would weigh about 15 lb.

The microscope includes the following three functional subsystems.

1. The sample-handling subsystem consisting of a particle size separator, a particle-encapsulation mechanism, and a rotating slide stage.
2. The optical subsystem consisting of a light source, a narrow-band (10 mμ) filter at about 550 mμ (set to match peak spectral response of television camera), a polarizer, a substage condensing lens, two refracting

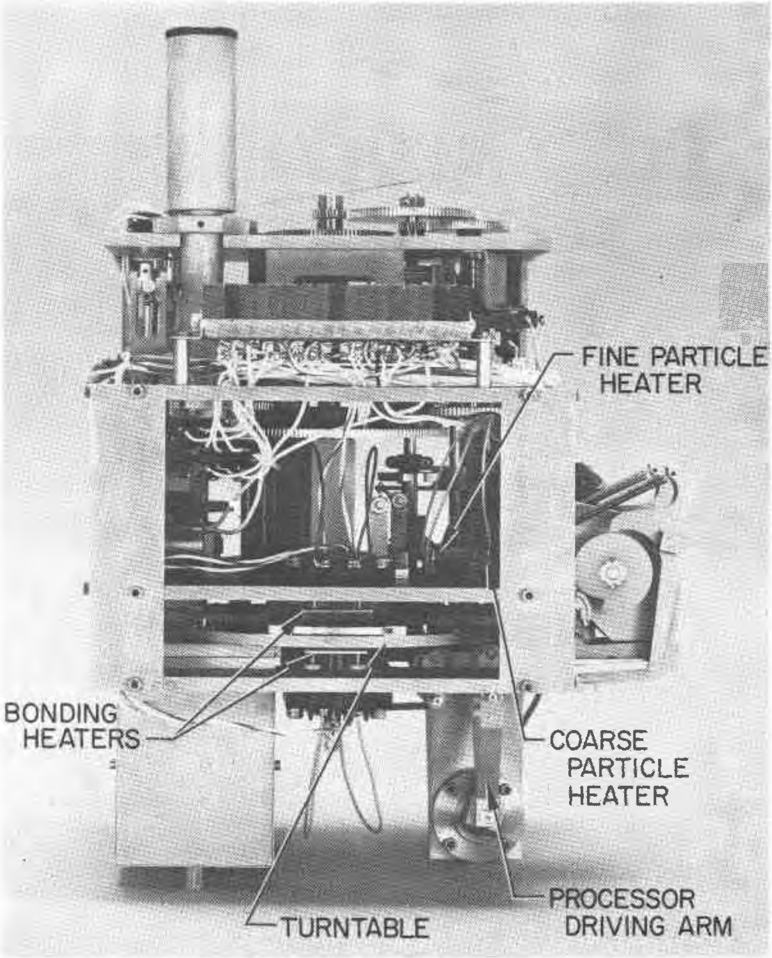

FIG. 2. Engineering prototype assembly, front view.

objective lenses, a step-focusing mechanism, and an eyepiece lens.

3. Imaging subsystem consisting of analyzer, neutral-density filters, and a television camera.

The instrument is mechanically preprogrammed in three phases of operation. The first phase processes the sample particles, the second encapsulates them, and the third passes them through the field of view of the objective lens.

Sample processing and encapsulation. A particulate sample produced by an independent sampling system is pumped into a metering cup which has a capacity of 1 cm^3. The instrument operation starts with the rotation of the cup 180 degrees to drop the sample into the

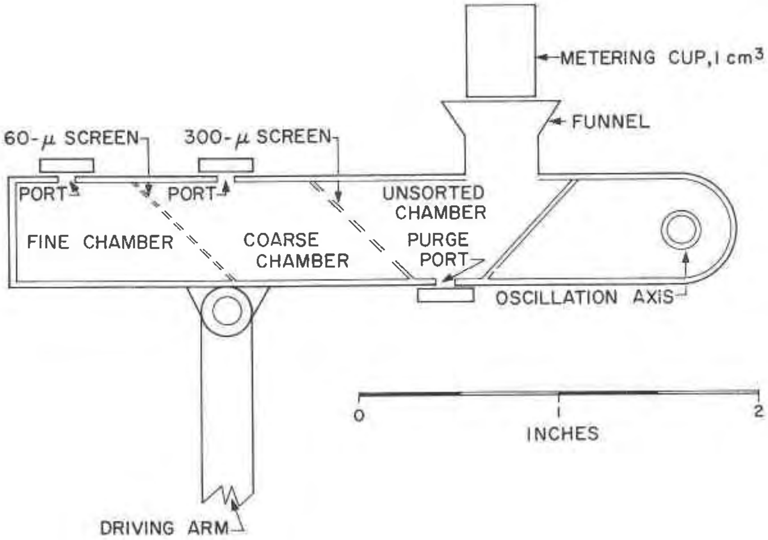

FIG. 3. Diagram of processor.

processor through the funnel; in a flight model the sample would be shoved into the processor to make the operation independent of gravity. The processor is a three-chambered enclosure oscillated by a $\frac{1}{4}$-inch crank, which is driven by the processor motor at 1600 rpm. A diagram of the processor is shown in Figure 3.

The sample is introduced to the chamber nearest the fixed axis of oscillation and migrates toward a 300-μ screen separating the second chamber from the first. Because the screen is installed at a 45-degree angle, the oscillations cause violent impingement of the particles on the screen, forcing the particles smaller than 300μ through it. In a similar manner, particles less than 60μ are forced through the fine screen separating the third chamber from the second. Particles are accelerated at several Earth g's, so that operation in a low-gravity field, or at some tilt angle, will not be affected.

Each chamber has a rectangular port with an elastomerfaced cover which seals the port during the sorting operation. After two minutes of sorting, the port of the fine-grained chamber is opened by a toggle linkage which first releases the spring pressure sealing the cover, then pulls the cover back clear of the port. The oscillating motion propels the specimen particles upward through the port to impinge on a glass slide The slide is coated with a thin film of thermoplastic (Zerlon), which has been preheated to its softening point. Zerlon is a methyl-methacrylate styrene copolymer made by the Dow Chemical Company. The impinging material sticks to the slide in a single layer, all excess material falling away. At the same time, the port at the bottom of the first chamber opens discarding all material larger than 300μ. After another two minutes, the port of the coarse-grained chamber opens, coating a second slide in a similar manner.

The material which was retained by the 300-μ screen is then purged from the chamber, and a second sample is delivered to the hopper. Two more slides are made from the second sample in the manner described above. The method by which the particles are encapsulated is shown in Figure 4.

The slides are mounted on the turntable shown in Figure 5 at four stations, 90 degrees

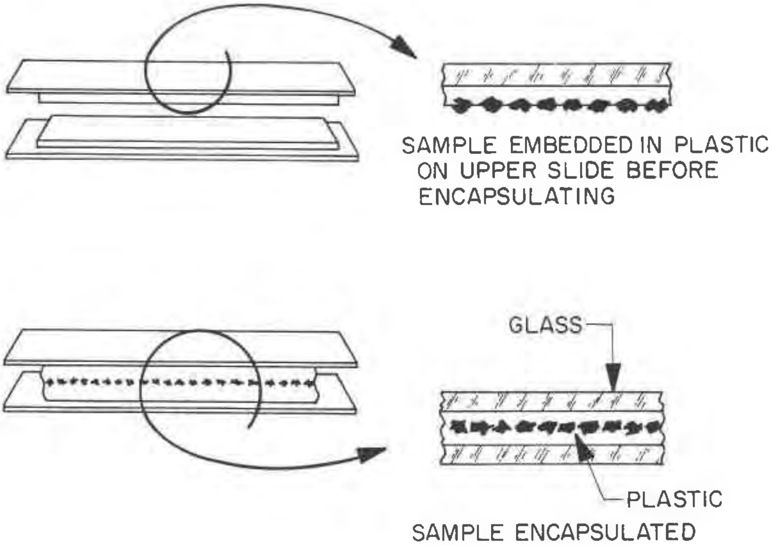

FIG. 4. Schematic diagram of encapsulation procedure.

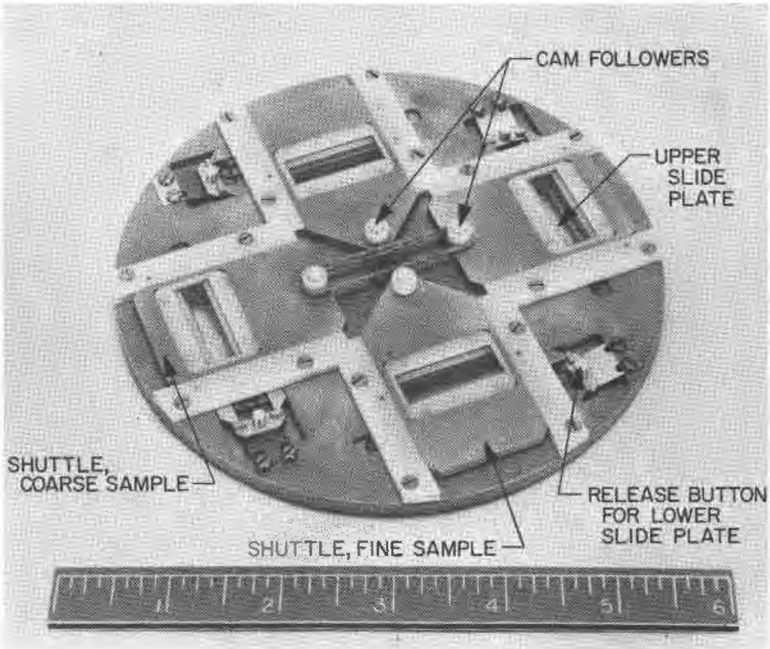

FIG. 5. Rotating slide stage. Scale in inches.

apart. The upper glass plates are mounted on shuttles which shift them radially between a filling position and a viewing position. The filling positions align the slides with the ports of the processor; the slides for the fine samples are filled at a 1.45-inch radius, and the slides for the coarse samples are filled at 2.25-inch radius. The viewing position for all slides is at 1.85-inch radius. Fixed cams at the center of the turntable shift the slides to the filling position when they are moved to the processor, and to the viewing position when moved to the objective lens, which is 180 degrees from the filling position.

The lower glass plates are retained in pockets in the turntable at the viewing radius. Each plate has a 0.030-inch layer of Zerlon bonded to the upper side and is spring-loaded against a pair of retaining bars which position it flush with the upper surface of the turntable.

Heaters which soften the Zerlon are nichrome wire encapsulated in a block of RTV 108 Silicone potting compound which is molded to the shape of the slides. The upper heaters are spring-loaded against the upper glass plates when they are at the filling position and provide heat to the appropriate plate during each two-minute processing period. The lower heaters are mounted at a station 90 degrees beyond the viewing station and provide the heat for bonding the lower slides to the upper ones.

Each two and one-half minutes, an indexing sequence is initiated, in which the following events take place: (1) Open the processor port and eject particles, (2) lift heater from contact with upper plate, (3) close processor port, (4) index turntable 90 degrees to viewing position, (5) take one TV picture, and (6) drop heaters to contact next upper plate. This sequence is executed in 20 seconds.

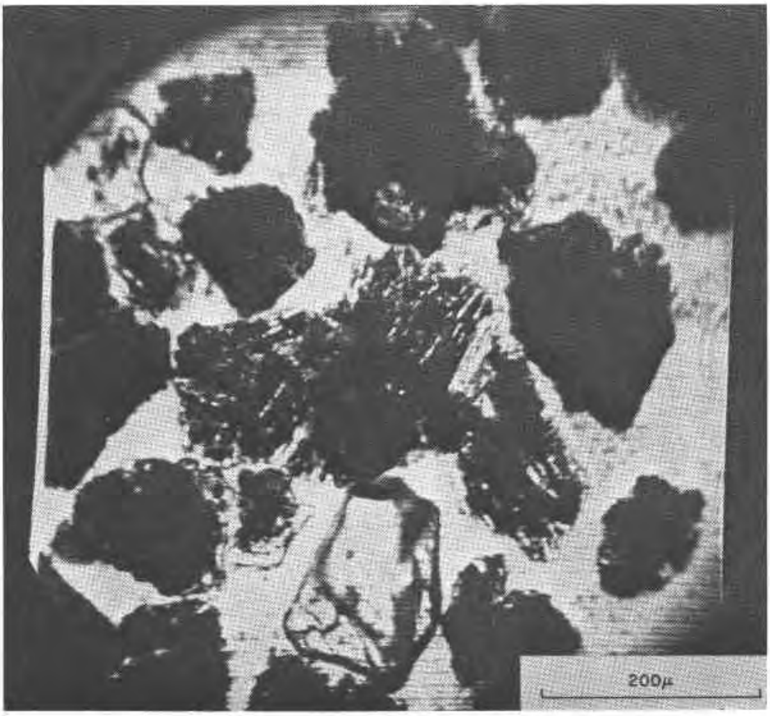

Fig. 6. Little Lake State basalt, plane-polarized light.

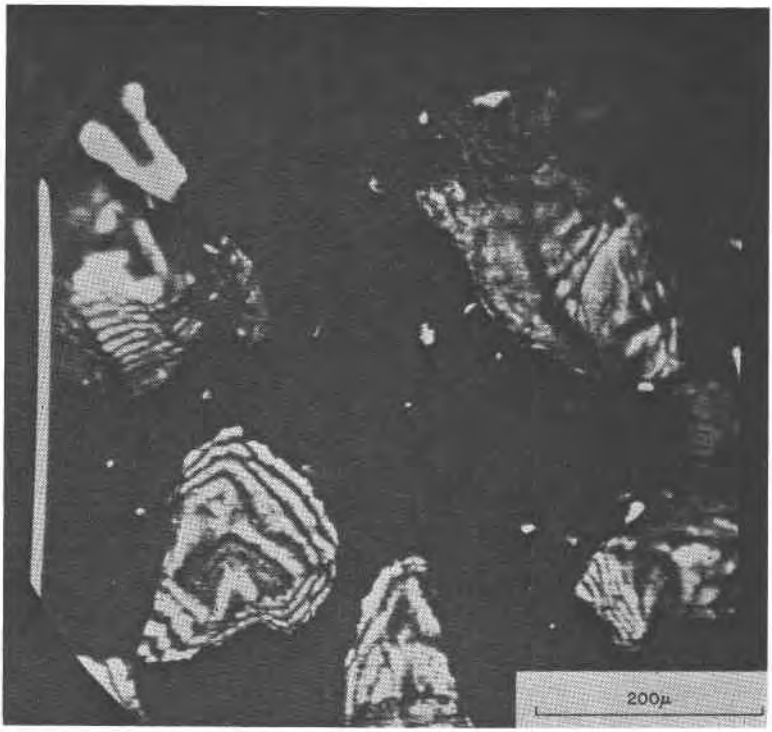

FIG. 7. Twin Sisters Oregon dunite, cross-polarized light.

A picture is taken in order to determine whether a satisfactory specimen has been deposited on the slide. If the slide is satisfactory, a pulse is initiated by ground control to accept the slide by actuating a solenoid, which releases a lower glass plate, permitting it to bear against the upper plate and thereby locking the shuttle in the viewing position. If the specimen is unsatisfactory, the acceptance pulse is not sent, and the upper plate is returned to the filling position on the next turn of the turntable for another attempt.

Each time the solenoid is actuated, it advances the programming ratchet one notch. After the fourth actuation (when all of the specimens have been accepted), the system is shifted to the phase in which the four samples are finally encapsulated by bonding the lower and upper plates to one another.

Imaging procedure. The substage optical subsystem contains a light source, a narrow-band filter, and a condensing lens. An incandescent bulb is being used with a Baird-Atomic interference filter centered at 530 mμ. An interference filter must have a half-width of less than about 14 mμ in order to produce sharp interference bands on a black and white TV. The wave-length desired from the scientific point of view can be anything which is shorter than about 600 mμ and which is compatible with the peak response of the imaging system employed. The General Electrodynamics Corporation vidicon which has been used in testing has a peak spectral response at 550 mμ.

The polarizer has been made of Polaroid Corporation's KN-36, a neutral linear polarizer on a polyvinyl alcohol base. Sheets of KN-36 have been treated and cooled in moderate

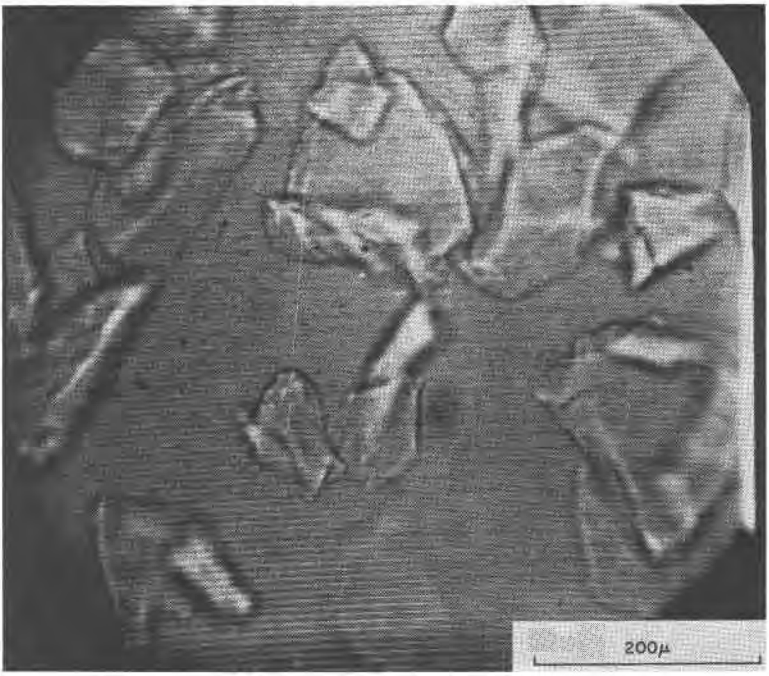

FIG. 8a. Glass particles, plane-polarized light.

vacuum ($\sim 10^{-6}$ torr) in partial lunar environmental tests. The KN-36 sheets in a cross-polarizing position polarize very effectively in the 500- to 550-mμ range but not nearly as effectively in blue or red wavelengths.

The condensing lens produces an apical angle of about 20 degrees. This convergence is not meant for conoscopic observation; it is only to increase the surface relief of transparent particles in the sample and to enhance the Becke line effect. Objective lenses of 16× and 40× are employed with a low-power eyepiece to view the coarse-grained and the fine-grained slides, respectively.

Six pictures are obtained of each field of view. Pictures are taken both below and above the plane of correct focus, as well as in that plane, in order to change the positions of Becke lines, and to insure that one picture is taken while most of the grains are in focus. Each picture is taken in both plane-polarized and cross-polarized light. A maximum number of fields of view is made available by shifting the turntable radially, thereby obtaining four fields of view across the width of the slide. The turntable is indexed tangentially at the end of each radial scan. Eighty-eight fields of view will be available on each slide, providing 528 pictures for each.

If a vidicon is used as the television camera, the electron optics in the vidicon system determine the resolution of the final images. The diameter of the scanning spot in the vidicon tube is about 25μ and probably cannot be made smaller. The desired final resolution therefore determines the total optical magnification to be used before the image is displayed on the vidicon faceplate. As an example, in order to determine the shape of a grain as spherical, rectangular, hourglass, *etc.*, eight to ten separate scans across the grain must be made. Because the scanning spot is 25μ wide, the image on the faceplate must be

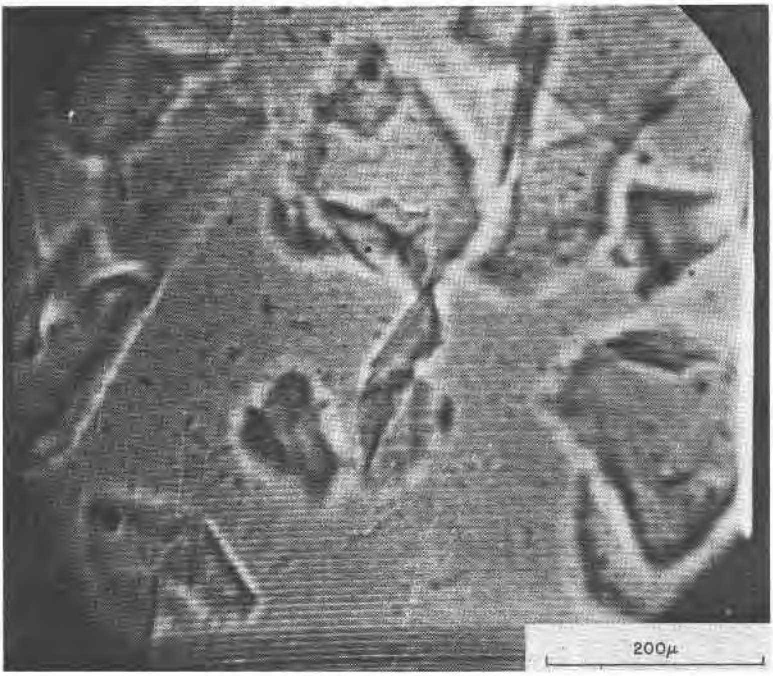

FIG. 8b. Same field of view as Figure 8a with Becke line shift.

200 to 250μ across. If the actual size of the grain is 10μ, the optical image magnification must be 20× to 25×.

Power and data-rate requirements. The processor motor and the heaters dissipate a total of about 12 w-hr during the processing and encapsulating phases. The viewing phase requires about 3 w-hr plus the television requirements. The peak power output required is 50 w in one-second pulses for the solenoid. The total power required to obtain TV images and read them out prior to transmission to Earth depends upon the type of mission; for the Moon it is about 12 w average power. The bandwidth available to a lunar mission might be about 250 kc, which is about enough to transmit one 600-line TV frame per second. The power required for transmission to Earth is about 50 w peak input power; images can be obtained about once every four seconds meaning that the average power required for transmission is about 13 w.

A lunar operation on an unmanned lunar soft-landing mission would entail encapsulating four samples and obtaining about 2200 TV pictures. A picture is transmitted in 1 sec; 2200 sec of transmitting time are required. The time between successive pictures depends upon the erase and readout times of the camera. During the erasure time for the microscope camera, data from other experiments could be transmitted. On these bases, the total operation time for an unmanned lunar microscopy experiment would be one to two hours plus whatever extra time might be dictated by the quality and interest of the data. The total power expenditure would be less than 40 w-hr.

An operation on Mars would be different because of the low power and bit-rate levels on planetary missions. Using Mariner IV TV as an example, a 200×200-element format is used; each of the 40,000 picture elements is assigned one of 64 discrete levels of luminance. A binary representation for numbers to 64 requires six bits of information per number. A digital signal of 240,000 bits is therefore required for each picture. At a bit rate of about 8 bits per sec, a picture could be transmitted in 8 to 9 hours, which is about two-thirds of a transmitting day from Mars. A surface capsule should have a lifetime of several weeks to months, so that 10 to 20 pictures might be obtained. In this event, a lens with a large depth of focus would be employed and only one picture taken per field of view.

EXAMPLES OF DATA

Examples of photographs obtained with crushed rock particles encapsulated in Zerlon are shown in Figures 6, 7, and 8. These mounts were all viewed through an earlier instrument model than the one described in this paper. The figures are photographs of a slow-scan television screen which is about 4 inches square. The horizontal scan-line traces are caused by electrical noise generated within the building where the apparatus was being tested; it is not an inherent imperfection in the system. The focus is sharper at the center of the field of view than around the edges not because of the microscope optics, but because of the characteristics of the television system, which was built in 1961; this problem would only occur during direct display.

Figure 6 shows clearly a volcanic texture with both phenocrysts and multicrystalline particles. Plagioclase laths are visible within a flow fabric in the center of the field of view. The large crystal in the lower center has a high refractive index, a poor cleavage, and is transparent although it is about 100μ thick; it is forsterite.

Figure 7 shows crushed forsterite grains from the Twin Sisters dunite in cross-polarized light. The smallest birefringent grains visible in the photograph are about 10μ across; details of their shapes are visible in plane-polarized light where the background is bright and the small grains are not over-exposed. The absence of multicrystalline particles suggests that it was a coarse-grained rock.

Figure 8 shows crushed glass fragments which have a refractive index of 1.51 (the mounting medium is 1.54). Strong Becke lines are visible within the edges of the particles in Figure 8a; movement of the lens away from the sample results in equally strong Becke lines outside the particles in the mounting medium, as in Figure 8b.

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