UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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MULTIDISCIPLINARY RESEARCH LEADING TO UTILIZATION OF EXTRATERRESTRIAL RESOURCES

Annual Status Report
Fiscal Year 1971

TWIN CITIES MINING RESEARCH CENTER

Thomas C. Atchison, Research Director

NASA Contract R-09-040-001

MULTIDISCIPLINARY RESEARCH LEADING TO UTILIZATION OF EXTRATERRESTRIAL RESOURCES

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U. S. Bureau of Mines NASA Program of Multidisciplinary Research
Leading to Utilization of Extraterrestrial Resources

ANNUAL STATUS REPORT FISCAL YEAR 1971

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U. S. Bureau of Mines NASA Program of Multidisciplinary Research Leading to Utilization of Extraterrestrial Resources

July 1, 1971

Task title: Background analysis and coordination
Investigator: David E. Fogelson, Acting Program Manager
Location: Twin Cities Mining Research Center
Minneapolis, Minnesota

Date begun: April 1965 To be completed: Continuing

Personnel: David E. Fogelson, Supervisory Geophysicist
Other Bureau personnel, as assigned

PROGRESS REPORT

Objective

The objective of the program is to help provide basic scientific and engineering knowledge needed to use extraterrestrial mineral resources in support of future space missions. Under this component, background and supporting studies and coordinating and liaison activities for the program are carried out.

Summary

During the year the five research tasks at the three research centers making up the Bureau's extraterrestrial resource utilization program were monitored. We continued to obtain, evaluate, and distribute information applicable to the program by literature search and direct contact with groups conducting related research. We also continued to extract and organize material from Bureau reports to provide periodic status reports to NASA and prepared special information related to the program when requested by NASA.

Progress During the Year

The past year's effort was concentrated on five tasks with the primary emphasis on basic studies of material properties and behavior in a simulated lunar environment. During the year technical information and guidance were provided to the task investigators. (D. P. Lindroth, Physicist, assisted in the review and analysis of the literature.) A particular effort was made to review the status of current knowledge concerning the nature of the lunar surface as derived from analyses of the lunar surface experiments and the returned lunar samples from Apollo's 11, 12, and 14. D. E. Fogelson presented a talk on "The Lunar Surface" to task investigators at the TCMRC and at the Spring Meeting of the AIME in Houghton, Michigan.

Arrangements have been made with Dr. Jack Green to study the casting of powdered tholeiitic basalt and to prepare a report of the results. The powdered basalt has been prepared and forwarded to Dr. Green. Physical property tests will be made on the cast basalt specimens by the Bureau of Mines.

A proposal was prepared and submitted to NASA for continuing the Bureau's program through its seventh and eighth years. The proposal was accepted; however, the level of funding for fiscal year 1972 will be reduced to $200,000.

Status of Manuscripts

Proposal for Continuing Bureau Extraterrestrial Resource Utilization Program by D. E. Fogelson and NASA project leaders was submitted to NASA in November.

Electrowinning of Oxygen From Silicate Rocks by Donald G. Kesterke is in press as a Bureau of Mines Report of Investigations.

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Bureau of Mines NASA Program of Multidisciplinary Research

Task title: Surface properties of rock in simulated lunar environment
Investigator: Wallace W. Roepke, Project Leader
Location: Twin Cities Mining Research Center
Minneapolis, Minnesota
Date begun: April 1966 To be completed: June 1972

Personnel: William H. Engelmann, Supervisory Research Chemist
Wallace W. Roepke, Principal Vacuum Specialist
Kelly C. Strebig, Mining Engineer
James R. Blair, Physical Science Technician
Bradley V. Johnson, Physical Science Technician
Darlene L. Nelson, Secretary

PROGRESS REPORT

Objective

The objective of this project is to study the surface properties of rocks and minerals in a simulated lunar environment. The study of friction on clean surfaces, drilling of rock in UHV, and particulate shearing will be continued.

Summary

Major emphasis has been placed on completion of vane-shear testing this fiscal year. Several vane-shear tests of basalt powder have been completed in both atmospheric and ultrahigh vacuum. Final experiments are now in progress.

Since the lunar drill frame is shared by both the drilling task and vane-shear task, the drilling has been recessed. The drilling task will be restarted during the first quarter of the next fiscal year.

The friction work has advanced very well, even though both the CO_2 laser and a data acquisition system were unavailable during the past year. The CO_2 laser was used by another project which precluded any friction measurements of laser-cleaned surfaces. Friction system reproducibility has been increased to $\pm$ 2.5 percent and as a result several hundred tests have been run using a variety of mineral/mineral and mineral/metal pairs.

The experimental expertise gained from the friction studies has led to further direct applications of these techniques. A new concept in experimental friction apparatus has been utilized to provide a proposed system for Health and Safety work this next fiscal year. The new design concept will allow direct observation of the actual area of contact during dynamic

friction testing. This past year we have also adapted friction probe techniques to the ARPA Adhesion in Rock studies by G. A. Savanick. The design of a bench-top friction system for this purpose has been completed and will soon be ready for use.

Progress During the Year

Ultrahigh Vacuum Vane-Shear Studies

The vane-shear test apparatus and associated instrumentation has been installed in the UHV chamber and calibration and testing were initiated this year. Since the UHV vane-shear work must be correlated with the atmospheric vane-shear studies of D. E. Nicholson at the Spokane Mining Research Center (SMRC), several atmospheric pressure tests were run while checking the apparatus to compare it with the equipment and results at SMRC. It was found that our data agreed very well with that obtained by SMRC under similar atmospheric conditions.

A 200-gram sample of impact-milled basalt, carefully preconditioned for UHV use, was evacuated to mid-10^{-11} torr to establish a baseline pumpdown curve for the powder. Preliminary tests have been run during the second pumpdown of the total system with no significant changes observed in the shear strength of the powder in a minimally outgassed condition over the pressure range from atmospheric to 10^{-10} torr. Table 1 shows the results of these pumpdown tests.

TABLE 1. - Pumpdown vane-shear test results

Chamber pressure, torr	Consolidation load, g	Normal load, g	Ultimate shear strength, g
5×10^{-8}	6,000	6,000	5,800
3×10^{-8}	3,000	3,000	3,300
3×10^{-8}	4,600	3,600	3,700
4×10^{-9}	4,600	3,600	3,600
6×10^{-10}	6,000	6,000	6,000

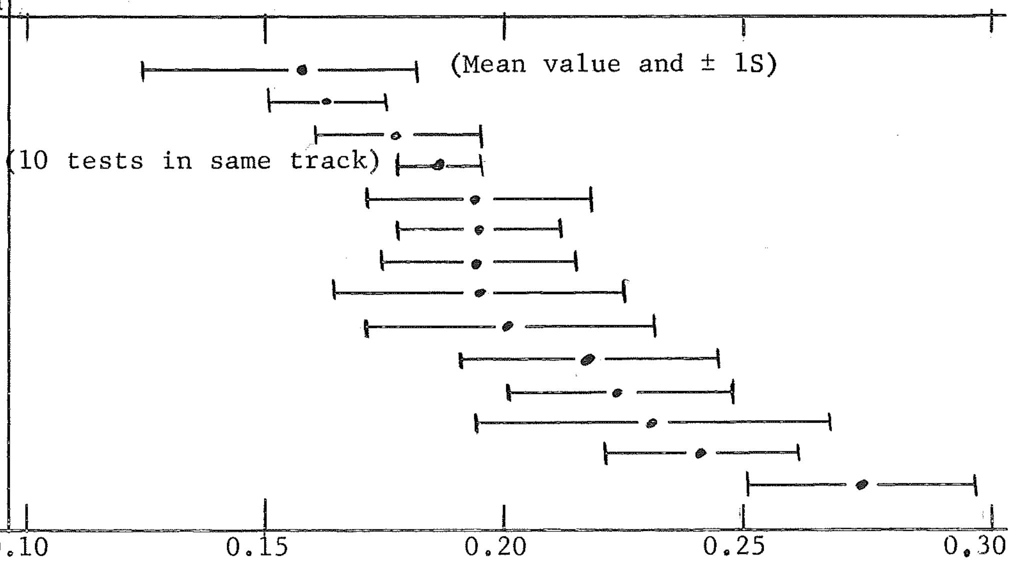
It must be stressed that although the sample material has been preconditioned to eliminate moisture, an extremely long bakeout in UHV to maximize outgassing of the material would be needed to approach an ultraclean surface condition. If significant changes in shear strength were to occur in the lunar environment, this ultraclean condition may be needed before any changes become apparent.

Ultrahigh Vacuum Friction Studies

Results of several hundred tests that have been run this past year using 100-gram normal loads on the materials are listed in table 2, together

TABLE 2. - Kinetic coefficient of friction between various probe tip/test material combinations

Test Material	Probe composition
Stainless steel, polished	WC
Basalt, 37 μm finish	Al_2O_3
Magnetite, 37 μm finish	Al_2O_3
Quartz, 37 μm finish	Al_2O_3
Andesine, 37 μm finish	Al_2O_3
Quartz, 37 μm finish	Al_2O_3
Dacite, 37 μm finish	Al_2O_3
Pyroxene, 37 μm finish	Al_2O_3
Stainless steel, polished	Al_2O_3
Feldspar (white), 37 μm finish	Al_2O_3
Feldspar (pink), 37 μm finish	Al_2O_3
Stainless steel, 37 μm finish	WC
Stainless steel, 37 μm finish	Al_2O_3
Laboradorite, 37 μm finish	Al_2O_3



Kinetic coefficient of friction (μk)

with the probe materials used (tungsten carbide or sapphire). The average kinetic coefficient of friction (μk) for several runs is shown with the value of one standard deviation. All of the tests shown have been run in atmospheric pressures, since constant deadweight loading has been used to check and improve the electronic package associated with the new one-piece friction-probe load cell assembly. Shielding and electronic design changes have reduced total system noise to less than 5 μv. Some uncontrolled thermal drift in the electronic divider circuit limits system reproducibility to ± 2.5 percent. Since no computer-compatible data acquisition system was available this past year, we utilized a multichannel Beckman recorder which would allow the use of an electronic integrator on the divider output. Therefore, all friction forces and normal forces are electronically divided yielding the instantaneous coefficient of friction value. These values are then fed through the integrator providing an easily handled result. At this time we do not have the capability of recording peak and valley levels and the slopes of the same for automatic data reduction. This capability has become of vital interest to us because our past years' results show a need to correlate peak to valley (P/V) ratios with the kinetic coefficient of friction (μk) values. Additionally, we have found that the surface roughness must be given more serious consideration. Microscopic examination of the moving probe sample interface during tests on dacite and quartz, shows that for dacite visual comparison can be made between surface pits and friction output, whereas no such visual comparison was discernible for quartz. Accordingly, the dacite and quartz surface textures (profiles) were obtained. Although the surface preparation was identical (37 μm aluminum oxide) for both samples, the dacite has a center line average (CLA) roughness of 192 microinches, while the quartz has a CLA of 21 microinches. Table 2 shows almost identical μk values for dacite and for quartz, which is to be expected. The P/V ratio is 2.37 for dacite and 1.39 for quartz, but the statistical spread of the μk value is approximately 60 percent greater for dacite over that for quartz. This greater P/V ratio for dacite is attributable to pits in the surface and to wear debris, which is generated at both edges of these pits by the probe. The wear debris has been seen accumulating under the leading edge of the friction probe, when microscopy is used during sliding.

In anticipation of obtaining another laser in the first quarter of the next fiscal year, an external laser-alignment system has been developed which will allow the laser beam to traverse a larger area of the sample surface. This will permit more tests on fresh areas of the sample with the laser cleaning technique during any single pumpdown to UHV conditions.

Several courses have been attended in support of these tasks during the past year. J. R. Blair completed the following courses: "Laser Systems and Laser Safety" (1 week), "Research Instrumentation" (1 week), a 3-day course on "Vacuum Techniques," "Vacuum Technology" (1 week), and on his own time and expense, "Digital Logic Circuits - Fundamentals" (1 semester) and "Digital Logic Circuits - Applications" (1 semester). W. W. Roepke attended the American Vacuum Society Symposium in October, completed a course in mathematics (1 semester), and also made several short trips to support a Health and Safety proposal effort. W. H. Engelmann completed the 1-week course, "Vacuum Technology." An invention report, "Anion Supressor Grid for Mass Spectrometers," by W. W. Roepke and K. G. Pung has been assigned a serial number (#86,870).

Status of Manuscripts

None in progress.

ANNUAL STATUS REPORT FISCAL YEAR 1971

Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Rock failure processes and strength and elastic properties in simulated lunar environment
Investigator:	John O. Atkins, Project Leader
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	June 1966 To be completed: June 1972
Personnel:	Egons R. Podnieks, Supervisory Mechanical Engineer Robert J. Willard, Geologist Thomas R. Bur, Geophysicist John O. Atkins, Physicist Kenneth G. Pung, Physical Science Technician Stephen D. Anderson, Physical Science Technician

PROGRESS REPORT

Objective

The objective of this project is to study the effect of simulated lunar environment on rock deformation and failure processes at the mesostructural and the microstructural level. The engineering data obtained from simulated lunar rocks under these environmental conditions will assist advance planning of lunar resource utilization.

Summary

Modifications were made on the ultrahigh vacuum system and additional apparatus including heating elements and a cantilever beam strain sensor were designed, fabricated, and installed in the ultrahigh vacuum system to extend the capability of the system to ultrahigh vacuum compression testing of rock specimens at lunar "day" temperatures. The servocontrol for the hydraulic compression testing machine was recalibrated and reprogrammed to be compatible with the new cantilever beam strain sensor.

Cooperative studies were carried out with Dr. H. J. Pincus at the University of Wisconsin-Milwaukee to establish correlation between information obtained by optical data processing (ODP) and rock fabric measured microscopically in thin sections. Brazilian and point load tests on disk samples of Duluth Gabbro were performed and it was determined that a common plane of weakness exists parallel to the low velocity direction. Thin sections of selected rocks were prepared for universal stage microscopic study which has been rescheduled for FY 1972.

Preparation of rock specimens and acoustic velocity measurements for lunar "day" compression studies in ultrahigh vacuum have been completed. Preparation of rock specimens for mechanical anisotropy studies has begun.

Two journal articles were published during the year: one in Space Simulation, NBS Special Publication 336 and the other in Icarus (Internat. J. Solar System Studies).

Progress During the Year

Elevated Temperature Compression Tests in Ultrahigh Vacuum

Elements for heating rock specimens to lunar "day" temperatures were designed, fabricated and installed in the ultrahigh vacuum system. Special heating elements were made that are compatible with the ultrahigh vacuum, capable of heating the rock specimens without excessively increasing the chamber wall temperature, and able to allow passage to outgassing particles from the specimen to the vacuum chamber. The elements consist of a 1-in hardened tool steel cylinder with a spiral groove cut on the cylinder wall for accepting a Nichrome V heating wire. Prior to winding the wire on the cylinder, an Al_2O_3 coating was applied to that portion of the wall to provide electrical insulation. A second Al_2O_3 coating was applied, after winding the wire in place, to secure the wire and also to reduce radiation from the element to the chamber walls. Near one end of the cylinder a groove was cut around the cylinder circumference for fastening of the strain sensor with set screws (fig. 1). The heating elements were tested in the ultrahigh vacuum system with specimens of dacite, basalt, and gabbro. Measurements of temperature gradients in these specimens heated to the lunar "day" temperature (135° C) were made with four thermocouples mounted in each specimen. A small radiant energy heating element is being fabricated to minimize the thermal gradients in the specimens.

A special cantilever beam strain sensor was designed, fabricated, calibrated, and installed in the ultrahigh vacuum system. The output from this strain sensor is used to plot the strain coordinate of a stress versus strain curve during each compression test and also to control the deformation rate of the hydraulic compression machine.

The strain sensor consists of three cantilever beams, a beam holder and a reference collar (fig. 1). Three beams were used in order to minimize any errors in strain measurement caused by nonparallel platen, heating element, or rock specimen surfaces. The beam holder fastens to the lower heating element with set screws and is secured to a clamp on the lower platen with springs to provide stability and prevent beam damage during specimen fracture. The reference collar is similarly secured to the upper heating element and upper platen.

The control system for the hydraulic compression machine has been recalibrated and programmed to provide the same strain rate (1×10^{-5} sec) with the new strain sensor as was used in previous tests. The flanges of one platen and one bellows on the ultrahigh vacuum system were modified so that a more positive seal could be achieved.

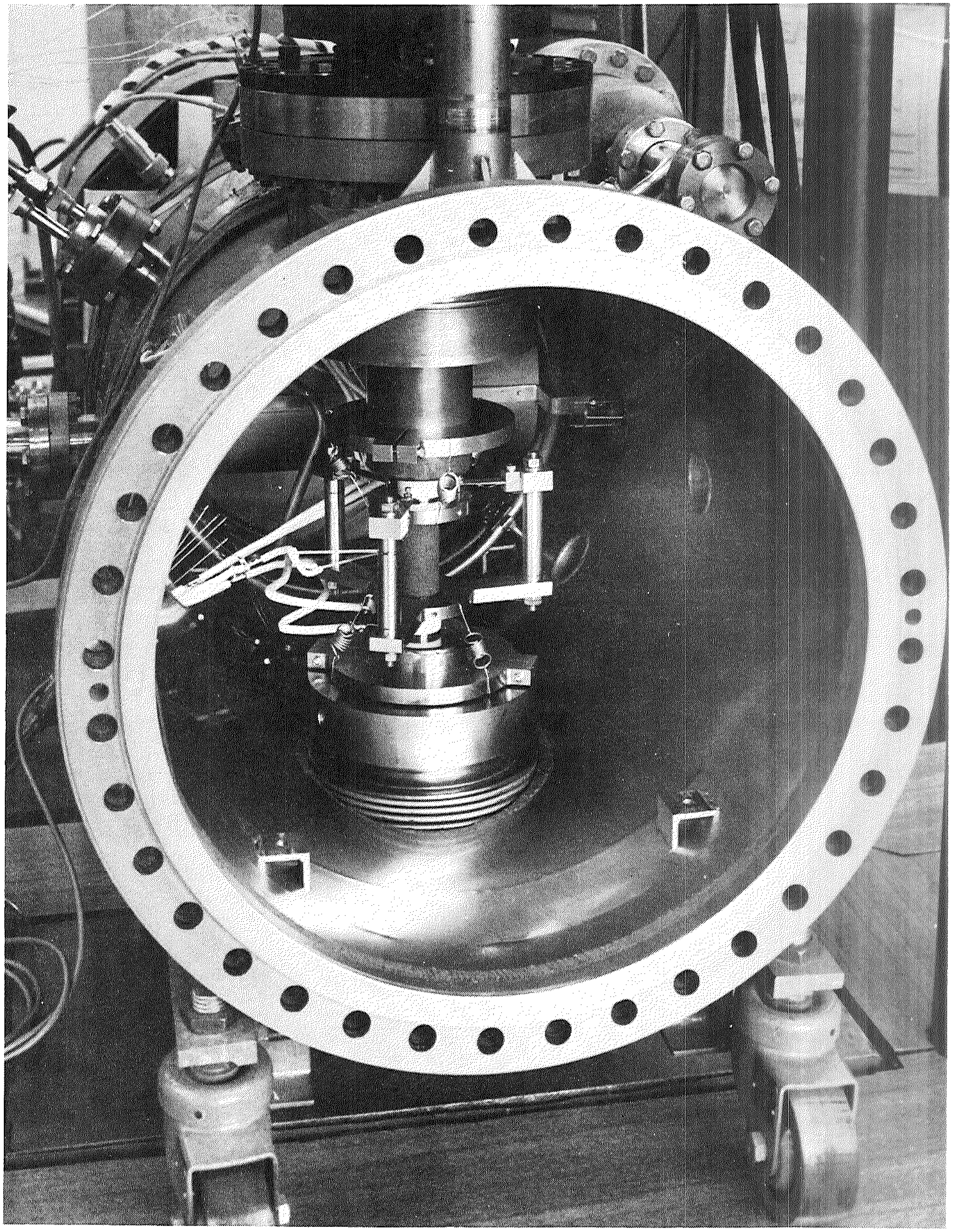


FIGURE 1. - Heating Elements and Strain Sensor Mounted in Ultrahigh Vacuum System.

Tholeiitic basalt and Devil's Hill dacite specimen preparation was completed and acoustic tests were completed under room conditions to compare the results with data on the same rock types obtained in earlier investigations. These specimens have been preconditioned and are ready for ultrahigh vacuum tests at lunar "day" temperatures. Duluth Gabbro specimen preparation has been completed also, and acoustic measurements made. These specimens are currently being preconditioned for the ultrahigh vacuum compression tests at lunar "day" temperatures.

Preparation of Duluth Gabbro specimens cored from the low, medium, and high velocity directions was completed. Acoustical anisotropy measurements have been completed on these specimens at room conditions. The specimens have been cut in half and surface ground and are currently being preconditioned for ultrahigh vacuum compression anisotropy studies. Preparation of vesicular basalt and pumice specimens cored from the low, medium, and high velocity directions for acoustic anisotropy studies is underway.

Fabric Analysis

Cooperative studies have been carried out this year with the optical data processing (ODP) group under Dr. Pincus at the University of Wisconsin-Milwaukee. Transforms have been produced and analyzed in order to establish correlation with rock fabric information measured microscopically in thin sections. Eight rocks were included in this analysis: pumice, rhyolite, two vesicular basalts, gabbro, tuff, serpentinite, and dunite. In every case, ODP transforms from photographic negative inputs were found to compare favorably with directional information obtained previously with a petrographic microscope. The negatives for ODP were prepared of sections chosen to coincide with an elastic symmetry plane containing the high and low elastic axes of the orthotropic rocks and the unique axis of the transversely isotropic rocks. Detailed results of these comparisons have been reported previously for the last four rocks above. For pumice and two vesicular basalts, the low spatial frequency direction (direction of the long axis of vesicles) was found to be parallel to the high elastic axis. For rhyolite the occurrence of the high spatial frequency of microfractures agreed with the location of the low elastic axis.

Additional studies were conducted on the gabbro. The studies involved Brazilian and point load tests on disk samples, and revealed that a common plane of weakness exists parallel to one of the principal (low) velocity directions. Thin sections of the tested samples were prepared for defect analysis and universal stage study to determine the extent to which preferred orientation of microdefects influences fracture orientation.

Several micrographs were made of a fracture surface of flood basalt and dacite, as part of a study aimed at a reexamination of their surfaces in the SEM, in order to identify microfeatures that may be responsible for their contrasting behavior in vacuum. The micrographs confirmed earlier findings that outgassing in dacite occurs rapidly through smooth-walled, interconnecting pores, and in flood basalt slowly through myriads of microcracks intersecting micropores.

Status of Manuscripts

Environmental Effects on Rock Properties by E. R. Podnieks, P. G. Chamberlain, and R. E. Thill has been submitted for publication in the Proceedings of the Tenth Symposium on Rock Mechanics held at the University of Texas in May 1968.

Method for Rock Property Determination in Ultrahigh Vacuum by E. R. Podnieks and P. G. Chamberlain was presented at the ASTM/IES/AIAA Space Simulation Conference at Gaithersburg, Md., September 1970 and has been published in Space Simulation, NBS Special Publication 336, October 1970.

Elastic and Attenuation Symmetries of Simulated Lunar Rocks by T. R. Bur and K. E. Hjelmstad was published in Icarus (Internat. J. Solar Systems Studies), v. 13, No. 3, November 1970.

Effect of Moisture and Temperature on the Fracture Morphology of Dacite by R. J. Willard and K. E. Hjelmstad has been accepted for publication in the Internat. J. of Rock Mech. and Min. Sci., v. 8, 197.

ANNUAL STATUS REPORT FISCAL YEAR 1971

Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Thermal fragmentation and thermophysical and optical properties in simulated lunar environment
Investigator:	David P. Lindroth, Project Leader
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	July 1969 To be completed: June 1972
Personnel:	Kuppusamy Thirumalai, Supervisory Mining Engineer David P. Lindroth, Research Physicist Richard A. Bestler, Physical Science Technician

PROGRESS REPORT

Objective

The objective of this work is to study the problems of thermal fragmentation in lunar environment. Through the use of nondestructive testing and remote sensing technology, the thermophysical properties of simulated lunar rocks are to be determined as a function of temperature and pressure over the lunar environment range. A study on the optical properties of absorptance, reflectance, and the absorption coefficient as a function of wavelength and temperature will be made.

Summary

During the year, work was completed on the design and setting up of an ultrahigh vacuum system for the thermal property measurements. A support frame and drive mechanism were constructed for rotating the multispecimen sample holder in the vacuum chamber. This new system for rapid thermophysical property measurements of simulated lunar rocks is now ready for operation.

Progress During the Year

A small ultrahigh vacuum system was custom-made to specifications for the thermal property determinations. The system consists of a 12-inch diameter sublimator well and a double flanged ion pump with a pumping capacity of 140 liters/sec. The system was delivered early in November and was put through a series of bakeout and pumpdown cycles. In the clean, dry, and empty condition, the system reaches 1×10^{-7} torr within 20 minutes and 3×10^{-10} torr within 24 hours. Other minor components obtained to complete the system were: (1) germanium windows, (2) magnetic coupled, rotary motion feedthrough, (3) liquid nitrogen feedthrough, (4) variacs and heater tapes and, (5) gears and bearings for the multispecimen sample holder drive assembly.

A new space for the laser and thermal property studies was prepared within the Thermal Fragmentation laboratory. A portable cart was designed and built to hold the vacuum system vertically. The ion pump, ion gauge, and thermocouple gauge power supplies were rack mounted to operate from a single control panel. The monitor system includes a Honeywell double pen, potentiometric recorder for monitoring chamber and pump pressure, and a Leeds and Northrup strip chart recorder for monitoring temperatures.

Antireflection-coated, plane-parallel germanium windows (1-inch diameter by 1/8 inch thick) were mounted in the 1-1/2-inch diameter nonrotatable flanges of the sublimator well. One window allows the passage of the 10.6-μm laser beam to the sample. The second window, mounted at 180 degrees from the first, permits temperature measurement of the rear of the sample with the infrared radiometer. Copper tubing (1/8-inch diameter) was coiled around each port and connected to a variable flow water supply for cooling the germanium windows. Thermocouples were positioned on each window flange and on the top and bottom of the sublimator well. These were connected to a multiposition switch and the Leeds and Northrup recorder to monitor the temperature of critical points during bakeout. Figure 1 shows an overall view of the test setup.

A support frame and drive assembly were designed and built to hold the multispecimen sample holder in the sublimator well. The magnetic-coupled, rotary-motion feedthrough drives the sample holder and allows the rotation of each sample for optical alignment with the windows, laser beam, and radiometer. Figure 2 shows a partial assembly of the sample holder and the drive assembly. A disk specimen of tholeiitic basalt is positioned in one of the 10 sample holders. The disk is supported at the edges by three stainless steel knife edges, each spaced 120 degrees apart.

The diffusivity measurements were initially planned to be carried out using the existing UHV system of the Chemical Fragmentation (NASA) group. Due to the trouble encountered with the drilling studies and the priority placed on the particulate shear study, this system became unavailable for the thermophysical property study. Some delay in the work was encountered because of the equipment assembly of a new system for the measurements. Considerable difficulty was also encountered in providing a good seal with the germanium windows for the operation. This problem is now being solved.

Specimen samples of tholeiitic basalt, Duluth Gabbro, rhyolite, dunite, obsidian, and granodiorite have been prepared for the measurements.

Status of Manuscripts

Effect of Reduced Pressure on Thermal Expansion Behavior of Rocks and Its Significance to Thermal Fragmentation by K. Thirumalai and S. G. Demou was published in The Journal of Applied Physics, v. 41, No. 13, December 1970, pp. 5147-5151.

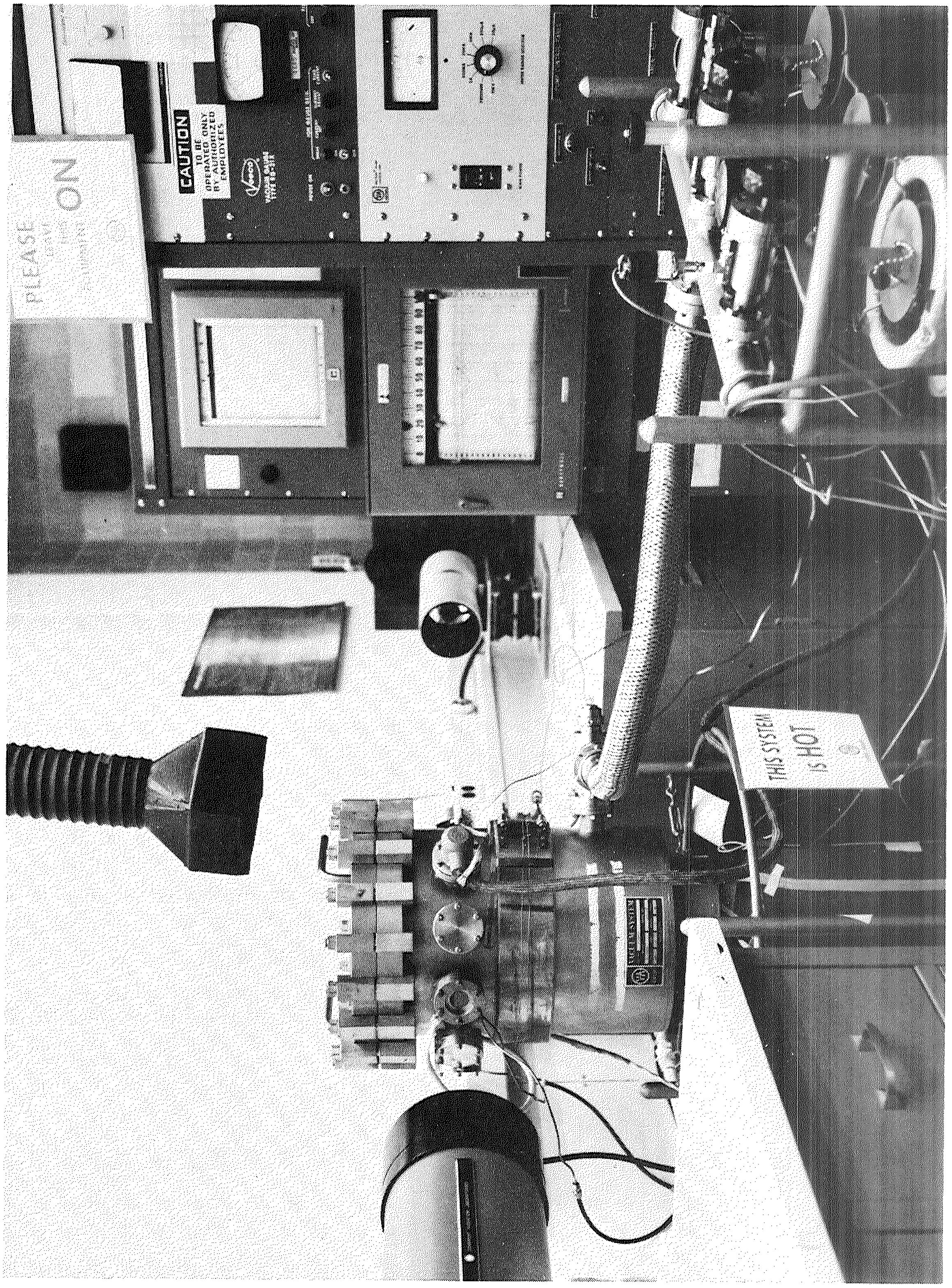


FIGURE 1. - A View of the Test Setup for Diffusivity Measurements in Ultrahigh Vacuum.

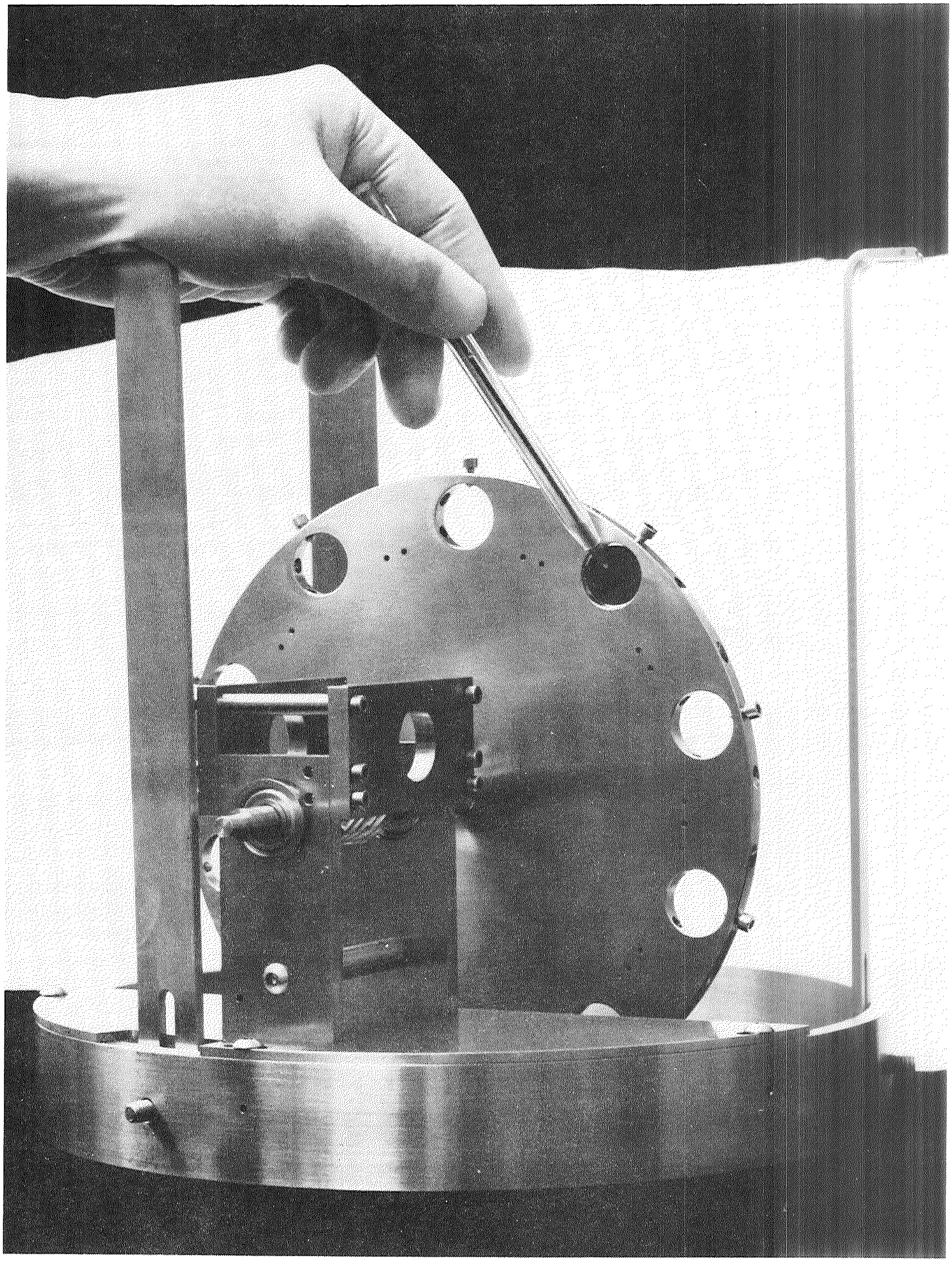


FIGURE 2. - Multispecimen Sample Holder and Drive Assembly for Diffusivity Measurements.

ANNUAL STAUS REPORT FISCAL YEAR 1971

Bureau of Mines NASA Program of Multidisciplinary Research

Task title: Use of explosives on the moon
Investigator: Richard W. Watson, Project Coordinator, Explosives Research
Location: Pittsburgh Mining and Safety Research Center
Pittsburgh, Pennsylvania
Date begun: July 1966 To be completed: June 1972

Personnel: Richard W. Watson, Research Physicist
John J. Mahoney, Laboratory Electrician
R. L. Brewer, Physical Science Technician
R. L. McNall, Physical Science Technician

PROGRESS REPORT

Objective

The objective of this program is to develop a body of fundamental information relevant to potential problems involved in the application of chemical explosives to mining and related activities on the moon and in other extraterrestrial environments.

Summary

Instrumentation for the large-scale vacuum test facility was designed and installed. Charge weights up to 100 grams of pentolite and Composition B have been fired and the results analysed.

Progress During the Year

A large-scale facility for use in investigating the detonation of explosives in a high vacuum was constructed and instrumented. It consists essentially of a 2.1-meter diameter, 11-meter-long steel tank which can be evacuated by a 780 cfm mechanical roughing pump capable of producing a vacuum of 5×10^{-3} torr, and by a 20-inch oil diffusion pump which has not yet been used but which is expected to produce better than the target vacuum of 10^{-4} torr (the criterion is a chamber radius that is less than the mean free path of the residual molecules). The interior of the chamber was sandblasted and coated with a low vapor-pressure epoxy resin-based paint to seal the pores in the metal. Instrumentation includes four strain gages to measure dynamic response of the walls to explosions within, and six fast-response (1 μsec rise time) piezoelectric pressure transducers to measure the internal blast wave pressure. Data from each channel are recorded by an oscilloscope; normally, only four channels are used.

The effective leak rate of the system appears to be less than 1 torr-liter per second; no attempt has yet been made to find and seal leaks as preliminary research can be done in the vacuums now attainable.

The explosive charges are generally spherical and are centrally initiated by a plastic-cased exploding bridgewire detonator selected for its insensitivity to extraneous electric currents as well as for its low content of metal that might pit the vacuum chamber. To date, up to 100-gram charges of pentolite and Composition B have been fired. The hoop strain in the walls was less than 5×10^{-5} (the lowest detectable value with the instrumentation used) which would correspond to a peak internal pressure at the walls of about 5 psi. This indicates that charges as large as 2.5 kg could be fired, which agrees well with preliminary design estimates. The residual pressure after a shot is about 2 torr; the partial pressure of water vapor should be less than 1 torr, which is far below the saturation vapor pressure of water at ambient temperature, so that products condensation will not be a problem.

In firings to date with dynamic pressure trandsucers located 90, 120, and 150 cm from the charge, reproducibility has been poor, at least in part due to synchronization problems and to stray signal pickup; these problems have been greatly improved but not completely eliminated. In general, results are consistent with a velocity of the leading edge of the products cloud of about 8-10 km/sec, in contrast to the value of 20 km/sec derived from luminosity observed at the walls of 17-cm diameter glass spheres. The side-on blast wave pressure at 150 cm is below the lowest detectable value of about 0.05 psi as expected; the stagnation pressure ranges from about 8 psi at 150 cm to about 30 psi at 90 cm. These values are consistent with product densities ranging from 0.5×10^{-6} g/cm^3 at 150 cm radius to 2×10^{-6} g/cm^3 at 90 cm radius. The densities of uniform spherical gas clouds of 100 g mass and corresponding radii should be 34×10^{-6} and 7.5×10^{-6} g/cm^3, respectively. A fairly consistent feature of the clearest pressure records is the existence of multiple pressure peaks which do not resemble instrumentation ringing. This may indicate species separation in the products cloud.

Status of Manuscripts

None scheduled.

ANNUAL STATUS REPORT FISCAL YEAR 1971

Bureau of Mines NASA Program of Multidisciplinary Research

Task title: Effect of lunar environment on behavior of fine particles
Investigator: David E. Nicholson, Project Leader
Location: Spokane Mining Research Center
Spokane, Washington
Date begun: April 1966 To be completed: June 1971

Personnel: David E. Nicholson, Mining Engineer
Donald R. Corson, Mining Engineer
Sam Pangerl, Engineering Technician
Robert Thompson, Engineering Technician
William G. Pariseau, Civil Engineer (Pittsburgh)
Kelly C. Strebig, Mining Engineer (Twin Cities)

PROGRESS REPORT

Objective

The objective is to determine the frictional and cohesive properties of simulated lunar rock powders which may influence the handling and transportation of fine particle materials in the lunar environment. An additional project task is to provide (from the impact mill and classification circuit at the Spokane Auxiliary Laboratory) classified fine particles of simulated lunar materials for other NASA sponsored research projects.

Summary

Planned work for the year was completed except for some additional shear tests, which are being run in the TCMRC vacuum system. In addition, the design and upgrading of a new one-dimensional compression chamber has begun. An improved chamber will allow determination of modulus and stress ratio constants for granular materials under lower pressures, characteristically present in gravity flow bins. Project research has developed physical property testing methods for granular bulk solids which allow analysis of initial stress conditions in bins evaluation and potential for gravity flow of the material.

For this analysis, an elastic-plastic finite element program has been adapted to the classical bin flow problem. Its application, hopefully, will develop a solution to the design geometry of gravity flow bins to optimize bin-wall slope, size of orifice, and height of bin. Further work on the new low-pressure K_o (earth pressure at rest chamber) should improve our physical property measurements, which are critical input for the finite element programs.

This is the final year of funding for the project, although minor support will be continued to develop optimal methods of gravity flow. The results of the research were presented at the International Powder Technology and Bulk Solids Conference in Harrogate, England, in May 1971.

Progress During the Year

The vacuum testing of simulated lunar soil material progressed during the year, to completion with instrumentation and construction of the torsional shear tester in the TCMRC vacuum system. We anticipate that these tests, now approximately 75 percent complete, will be finished about July 1. Preliminary examination of the data indicates that the tests give shear-strength values for the lunar soil in vacuum identical to those obtained under normal atmospheric conditions. It appears that the shear-strain rates have a considerable influence on the peak shear strength values. This observation conflicts with most soil mechanics science, in that the shear strength of cohesionless materials, such as the basalt powder used for our work is thought to be independent of the strain rates.

During the year, the project has developed a preliminary finite element program, permitting determination of initial stress conditions in typical gravity flow bins and hoppers. Knowledge of these conditions allows simulation of incremental filling of the bin and determination of the stress field. By incremental removal of the bottom nodal forces, the program (1) simulates the conditions of opening the bin orifice for draw-down and (2) provides for observations of the flow potential by observing the number of elements which are at plastic failure. This early work has been done with a model bin of fixed geometry. Future research will endeavor to develop an optimization program for bin design as funds permit.

Status of Manuscripts

Gravity Flow of Powder in a Lunar Environment by David E. Nicholson and William G. Pariseau in two parts. Part I - Testing of Simulated Lunar-Basalt Powder for Gravity Flow. Part II - Experimental Stresses and Velocity Fields in Gravity Flows of Granular Media Through Slots. This paper was presented at the International Powder Technology and Bulk Solids Conference, Harrogate, England, May 12-14, 1971. It will also be published as a Bureau of Mines Report of Investigations.