UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

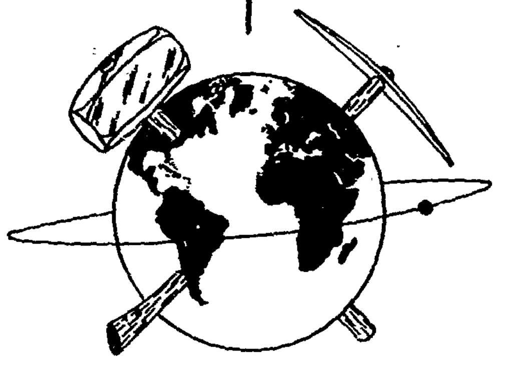
GPO PRICE $

CFSTI PRICE(S) $

Hard copy (HC)

Microfiche (MF)

ff 653 July 65



TWIN CITIES MINING RESEARCH CENTER

Walter E. Lewis, Research Director

N68-12902
(ACCESSION NUMBER)
(THRU) 1
42
(PAGES)
(CODE) 30
CR#91290
(NASA CR OR TMX OR AD NUMBER)
(CATEGORY)
FF No. 602(B)

NASA Contract R-09-040-001

MULTIDISCIPLINARY RESEARCH LEADING TO
UTILIZATION OF EXTRATERRESTRIAL RESOURCES

Quarterly Status Report
July 1, 1967 to October 1, 1967

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

QUARTERLY STATUS REPORT — July 1, 1967 to October 1, 1967

Contents

STATUS REPORT FIRST QUARTER FISCAL YEAR 1968

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

October 1, 1967

Task title:	Core group activity
Investigator:	Thomas C. Atchison, Senior Research Scientist
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	April 1965 To be completed: Continuing

Personnel: Thomas C. Atchison, Supervisory Research Physicist
David E. Fogelson, Supervisory Geophysicist
Clifford W. Schultz, Metallurgist
James Paone, Supervisory Mining Engineer
Other Bureau personnel, as assigned

PROGRESS REPORT

Objective

To provide the basic scientific and engineering knowledge needed for subsequent development of an extraterrestrial mineral resource extraction, processing, and utilization technology for supporting and enhancing the economy of manned lunar and planetary missions.

Progress During the First Quarter

The core group prepared and submitted two proposals for consideration by NASA. One proposal, requested by NASA's Office of Space Sciences and Applications, was a revision of an earlier proposal for measuring the engineering properties of lunar surface rocks brought back by the Apollo astronauts. The original proposal was turned down because of the small amount of material that will be returned and the large number of scientific measurements that NASA desires to have made. The revised proposal, in addition to emphasizing the importance of engineering properties, outlines the measurements that can be made on a small amount of material and points out that the material tested will still be usable for many of the planned scientific measurements. NASA's Office of Advanced Research and Technology is giving strong support to the proposal.

The purpose of the other proposal was to provide for a continuation of the Bureau's NASA program into its fourth and fifth years. It describes the background, present status and future plans for the program. The funding level will probably remain at $300,000 per year, although the proposal indicates areas where additional funding would be desirable.

The NASA core group, with the cooperation of the thermal fragmentation group, prepared an analysis of currently available information on the electrical properties of rock for NASA headquarters. NASA requested the analysis to help evaluate a proposal by the Smithsonian Astrophysical Observatory for a study of translunar radio communication using the lunar surface layer as the transmitting medium. The analysis indicated that data on dielectric constant and dissipation factor under ambient Earth environment, including the Center's measurements on simulated lunar rocks, are adequate, but that major additional study is needed to determine the effect of moisture content, temperature, and pressure on the electrical properties of rock.

The progress and future plans of the Bureau's extraterrestrial resource utilization program were reviewed on September 20 at Minneapolis by NASA's program manager, James Gangler. Mr. Gangler was accompanied by Bruce Hall of the Army Engineers Extraterrestrial Research Agency. After a preliminary discussion of the entire Bureau program with the core group and Center management personnel, the review team visited the Twin Cities Center laboratories for discussion of individual tasks with the project personnel.

Status of Manuscripts

Summary of Electrical Property Data on Rock, an informal report by T. C. Atchison, R. L. Marovelli, and R. E. Griffin, was submitted to NASA in July.

Engineering Property Measurements on Returned Lunar Samples, a revised proposal by T. C. Atchison, was submitted to NASA in September 1967.

Proposal for Continuing Bureau Extraterrestrial Resource Utilization Program, by the core group, was submitted to NASA in September 1967.

Task title: Selection and sample collection of simulated lunar materials
Investigator: David E. Fogelson, Project Leader
Location: Twin Cities Mining Research Center
Minneapolis, Minnesota
Date begun: September 1965 To be completed: Continuing

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

PROGRESS REPORT

Objective

Select and obtain samples of rocks and minerals covering the range of materials likely to be found on the Moon.

Progress During the First Quarter

Principal work during the quarter was continued review of current information on the composition of the Moon's surface and collecting about one-half ton of Duluth gabbro from northern Minnesota.

We were requested to supply rock materials to the Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, for graduate research on the adhesive qualities of lunar soil in ultrahigh vacuum. Several pounds of flow basalt, granodiorite, serpentinite, rhyolite, semiwelded tuff, and pumice are being crushed to less than 1/2-inch size and prepared for shipment.

Status of Manuscripts

None.

Task title: Physical properties of simulated lunar materials
Investigator: Thomas C. Atchison, Senior Research Scientist
Location: Twin Cities Mining Research Center
Minneapolis, Minnesota
Date begun: October 1965 To be completed: Continuing

Personnel: All projects are participating

PROGRESS REPORT

Objective

To incorporate simulated lunar materials into basic fragmentation research currently in progress. By this means to determine the composition, elastic, strength, surface, thermal, electrical, magnetic, and explosive shock properties of simulated lunar materials in Earth environment.

Progress During the First Quarter

Several of our simulated lunar rocks were included in further studies of anisotropy by the Rock Physics laboratory. Cores were drilled along principal symmetry axes in cubes of rhyolite, dacite, semiwelded tuff, and pumice. Location of the axes in the cubes was determined from a study of the pulse velocity and the fabric orientation in companion spheres. The axes were designated as low, medium, and high velocity axes and are mutually perpendicular. The cores will be pulsed, resonated, and loaded in the compression machine for comparison of property data along the symmetry axes with data from the cubes and spheres.

Completion of the electrical property studies of the simulated lunar rocks by the Thermal Fragmentation laboratory has been delayed. Final analysis of the data from the dielectric constant measurements between 20 and 100 megahertz was completed and the results were considered satisfactory. However, considerable spread was found in the dissipation factor data and a decision was made to repeat some of the measurements. The check measurements were undertaken by an experienced electronics engineer, who was available only intermittently during the quarter, and have not yet been completed.

Thermal conductivity and expansion measurements at room temperature were obtained on some of the simulated lunar rocks, as part of the study of the effect of elevated and reduced temperatures on these properties, described later under the thermal fragmentation tasks.

The small-scale explosive cratering data obtained at the dunite, vesicular basalt #2, vesicular basalt #3, and semiwelded tuff field sites were analyzed by the Explosive Fragmentation group. In general, the results showed the dunite to be typical of similar hard rocks in its breaking characteristics. The tuff broke very readily, while the two vesicular basalts were very difficult to break. In most rocks, small charge cratering results (in this case two-gram charges were used) can be extrapolated to charge sizes of interest in blasting operations by the use of cube-root scaling. However, the vesicular nature of the two basalts may affect the crater scaling relations for very small charges. Larger charge crater tests will be needed to provide more information on the craterability of these types of rock.

Status of Manuscripts

Dielectric Constants and Dissipation Factors Between 20 and 100 Megahertz for 13 Simulated Lunar Rocks, by Russell E. Griffin, is being prepared as a possible journal article.

Impact Pulse Propagation in Rock, by Thomas E. Ricketts and Werner Goldsmith, is being prepared for submission to the Journal of Geophysical Research.

Small-Scale Cratering in Simulated Lunar Materials, an informal report by Dennis V. D'Andrea and Richard L. Fischer, was submitted to the core group in September.

Task title:	(1) Chemical reactivity and cold welding of freshly formed surfaces (2) Surface properties of rock in lunar environment
Investigator:	Clifford W. Schultz, Project Leader
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	January 1966 To be completed: March 1969
Personnel:	Clifford W. Schultz, Metallurgist William H. Engelmann, Research Chemist Wallace W. Roepke, Principal Vacuum Specialist Kenneth G. Pung, Physical Science Technician Ernest Bukofzer, Physical Science Technician

PROGRESS REPORT

Objective

Measure the equilibrium constants for the adsorption of gases on the surfaces of silicate minerals. Relate this quantity to the fractional coverage necessary to inhibit cold welding and to determine the rate at which various other processes inhibit or prohibit cold welding of vacuum-formed surfaces. Develop data on the fundamental frictional characteristics of mineral surfaces as related to their environments. Correlate the measurements of friction, surface energy, and hardness. Further establish the relationship among these various surface properties and between surface and bulk physical properties.

Progress During the First Quarter

The infrared gas cell was used this quarter to measure water vapor content in the argon carrier gas. The argon was saturated with water vapor and condensed to a dew point of 0°C. The output of the spectrophotometer was too small to permit its calibration at lower water vapor contents.

The thermal conductivity bridge was chosen, therefore, as the gas composition detector. Tungsten-rhenium resistance elements of recent design are being used in place of pure tungsten elements used in an earlier trial of the thermal conductivity bridge. The former have a 2:1 sensitivity advantage with superior oxidation or burnout resistance.

The thermocouple bridge has been calibrated at water vapor contents corresponding to dew points of 0° and -78°C. Both measurements were made in comparison to argon dried with magnesium perchlorate. Additional calibration points will be obtained at dew points of 16°C, -35°C, and -50°C.

The completion of the calibration then allows inserting the ball mill, charged with dry quartzite, into the measurement loop at the bridge. The reference loop senses the incoming argon which carries a fixed partial pressure of water vapor. Action of the mill creates new surface which has a strong affinity for water vapor but not argon. The measurement loop of the bridge experiences a lowered water vapor level (with respect to the reference loop), proportional to the adsorption capacity of the quartzite in the mill. The differences in gas composition give recorder deflections in proportion to the change. The calibration curve is then used to give quantitative measurements of the adsorption.

The outgassing studies on the simulated lunar rocks have been completed and a paper has been prepared for presentation at the national meeting of the American Vacuum Society at Kansas City, Mo., in October. This investigation has been fruitful in defining the problems which will be encountered in physical property testing in ultrahigh vacuum. Some of the more pertinent data are presented in table 1.

TABLE 1. - Outgassing of simulated lunar rocks in ultrahigh vacuum

Sample	Ultimate pressure (10^{-10} torr)	Outgassing rate at ultimate (10^{-12} torr liter/sec)
Empty chamber	1.5	
Dacite	2.0	nil
Pumice	2.5	2.0
Tuff	4.5	8.0
Serpentinite	7.0	8.0
Basalt	25	100
Granodiorite	3[illegible]	250

It can be seen that a high correlation exists between the rate of outgassing and the ultimate pressure that is attainable. It is interesting to note that the basalt which has a relatively low specific surface and very small pores presents a greater problem than does the tuff which has a high specific surface and a very "open" structure. The best case encountered was the dacite which has a low specific surface and very large pores.

The next work to be undertaken is the measurement of friction in an ultrahigh vacuum. In preparation for this work, an experimental device has been built and preliminary calibration has been made. The loading mechanism has been modified from that presented in the annual progress report. To further facilitate the friction studies, a manifold has been added to the system to allow the calibration of the mass spectrometer.

In addition to the experimental data which have been obtained, the work to date has resulted in two inventions which have been submitted to the Interior Department Solicitor's office. Patent applications will be made upon receipt of a favorable report from the Solicitor. The inventions are: (1) an oil vapor sieve trap for rotary mechanical pumps, and (2) an anion suppressor grid for mass spectrometers. The latter is a device which prevents cross coupling of th mass spectrometer and the nude ion gauge.

These inventions will be the subjects of notes to the editor for journal publication.

Status of Manuscripts

Mass Spectrometer Studies of Outgassing from Simulated Lunar Materials in UHV, by W. W. Roepke and C. W. Schultz, has been prepared for presentation at the American Vacuum Society Symposium in October 1967.

Vacuum Technology Course, an internal report by W. W. Roepke, is in preparation.

Oil Vapor Sieve Trap for Rotary Mechanical Pumps, by W. W. Roepke and K. G. Pung, is being prepared as a Note to the Editor in Review of Scientific Instruments.

Task title: (1) Fracture and other failure mechanisms in a lunar environment
(2) Strength and elastic properties of rock in a lunar environment

Investigator: Robert J. Willard, Acting Project Leader

Location: Twin Cities Mining Research Center
Minneapolis, Minnesota

Date begun: June 1966 To be completed: June 1969

Personnel: Robert J. Willard, Geologist
Egons R. Podnieks, Mechanical Research Engineer
Thomas R. Bur, Geophysicist
Richard E. Thill, Geophysicist
Peter G. Chamberlain, Geophysicist
Kenneth E. Hjelmstad, Geophysicist
Richard M. Brumley, Electronics Technician

PROGRESS REPORT

Objective

Extend current experimental studies of rock failure by such mechanisms as dislocation, twinning, and crack formation to include lunar environment. Extend current measurements of static and dynamic elastic moduli and compressive and tensile strengths of rock to include lunar environment.

Progress During the First Quarter

The final phase of the environmental test program, involving uniaxial compression tests on materials at -250°F with several different moisture contents, was carried out this quarter. Two simulated lunar materials, flood basalt and Devils Lake dacite, were among the rock types tested.

Tests were also conducted to relate preconditioning of samples in humid environment at various temperatures to the actual moisture content by weight.

A fracture morphology study was conducted on thin sections cut from dacite disks previously point loaded to failure during the environmental test program. The purpose of the study was to correlate the effects of humidity and temperature on crack propagation mechanisms.

Designs have been completed and construction started on bellows and platen assemblies to be used as interfacing between the compression test machine and the ultrahigh vacuum system. Minor modifications and improvements have been made on the vacuum system to insure that it will be operational as soon as the major interfacing assemblies are completed.

Test runs were conducted to obtain preliminary pump down curves for several simulated lunar materials in the ultrahigh vacuum system.

Mr. John McWilliams, the original investigator for these tasks, has transferred to a staff position at the Bureau's headquarters office in Washington, D. C. Dr. Willard has supervised the work during this quarter.

Status of Manuscripts

None in progress.

Task title:	(1) Rock vaporization, melting, and thermal fracturing methods in vacuum (2) Thermophysical, strength, and elastic properties of rock at elevated and reduced temperatures in vacuum
Investigator:	Robert L. Marovelli, Project Leader
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	October 1966 To be completed: September 1968
Personnel:	Robert L. Marovelli, Supervisory Mining Engineer Russell E. Griffin, Electronic Research Engineer Kuppusamy Thirumalai, Mining Engineer Carl F. Wingquist, Physicist David P. Lindroth, Physicist Sam G. Demou, Physicist Daryl J. Jersak, Engineering Technician Walter G. Krawza, Engineering Technician

PROGRESS REPORT

Objective

Investigate the feasibility of extending current thermal fragmentation studies to lunar vacuum environment. Currently the thermophysical, strength, and elastic properties of rock at temperatures up to the melting point are being measured. Extend this work to the low temperature range of lunar environment. Investigate the feasibility of extending these property measurements to lunar vacuum environment.

Progress During the First Quarter

Major effort during the quarter related to the above tasks consisted of: (1) further development of a probe for thermal conductivity work and laboratory tests of probes in granodiorite from the lunar suite, and (2) measurement of the thermal expansion coefficients of the lunar rock suite over the lunar temperature range. These activities relate most directly to task 2, but are needed inputs for studies under task 1. In addition, progress on certain phases of regular Bureau thermal fragmentation studies has a direct bearing on the two tasks.

Thermal conductivity measurements

A number of thermal conductivity probes were fabricated during the quarter and the design features tested in measurements on laboratory specimens. Progress was made on the problem of the contact resistance between the probe and the wall of the hole into which the probe is inserted.

Measurements were made on a 6.25-inch diameter core of granodiorite from the lunar suite. A 3-inch diameter core was then drilled out of the original, measurements taken, and the procedure repeated for a 2-inch cylinder. The same thermal conductivity values were obtained for all three sizes and we concluded that, for granodiorite, we could work with a 2-inch diameter by 3-inch long core. This represents an important step since there is a limited space available in the Center vacuum chambers and previous thermal conductivity tests required 6.25-inch cylinders.

At the end of the quarter, one of our physicists took over the thermal conductivity work begun by the University of Minnesota graduate student employed during the summer, and he will pursue both probe development and laboratory measurements on additional lunar rocks.

Thermal expansion

Elevated temperature thermal expansion measurements were made on three of the lunar type rocks over the temperature range 75°F to 2000°F. The dilatometer was then modified for measurements from liquid nitrogen temperature up to room temperature and a second series of measurements started.

Related Bureau work

Studies of spalling and inelastic deformation of quartzite, granite, and basalt were carried out with the help of the new thermal shock furnace, providing experience that will be applied later in task 1. Work on the effect of low temperatures on rock strength at the University of Wisconsin was continued, with the initiation in July of a Bureau-funded research grant to develop information on effective fracture energy over the -300°F to +300°F temperature range.

Status of Manuscripts

Flexural Strength of Rock from -320°F to 1600°F, by R. L. Marovelli and A. Hendrickson, is under preparation as a journal article and a Bureau Report of Investigations.

Task title: (1) Cuttings removal in drilling in lunar environment
(2) Cooling and lubricating bits in drilling in lunar environment

Investigator: James Paone, Project Leader

Location: Twin Cities Mining Research Center
Minneapolis, Minnesota

Date begun: January 1967 To be completed: December 1969

Personnel: James Paone, Supervisory Mining Engineer
Robert L. Schmidt, Mining Engineer
Harold F. Unger, Mining Engineer
Carl F. Anderson, Electronic Engineer
David A. Larson, Engineering Technician

PROGRESS REPORT

Objective

Investigate various means of removing drill cuttings with and without flushing media in lunar environment. Investigate problems of heat removal and bit lubrication associated with drilling in lunar environment.

Progress During the First Quarter

A series of drilling experiments was completed using small laboratory rotary and percussion drills. From these tests drillability standards were achieved that will facilitate the prediction of drill performance in a simulated lunar environment. Data obtained under this project contributed toward the design of an experiment involving the 30-meter, post-Apollo, lunar percussion drill.

Three prototype bits for the 3-meter rotary-percussive Apollo Lunar Surface Drill were received from the Martin Company. Comparative tests for bit life, energy per unit volume, and bit temperature were conducted in five different simulated lunar rocks. Data obtained from these tests were supplied to the manufacturer and NASA for inclusion in subsequent ALSD designs.

Status of Manuscripts

None in progress.

Task title: Effect of lunar environment on behavior of fine particles
Investigator: David E. Nicholson, Project Leader
Location: Spokane Mining Research Laboratory
Spokane, Washington
Date begun: April 1966 To be completed: March 1969

Personnel: David E. Nicholson, Mining Engineer
Howard C. Pettibone, Civil Engineer
Richard H. Sprute, Electrical Engineer
Dennis J. Kelsh, Physical Chemist
Fred W. Houghton, Engineering Technician
Richard P. Curtin, Engineering Aid

PROGRESS REPORT

Objective

Determine basic physical properties which may influence the handling and transportation of fine particles in a lunar environment as an extension of current studies of fine particle behavior in mine backfill applications. Intergranular static and dynamic coefficient of friction and energy loss will be measured. Flow rates and shear strength at various states of particle packing and at various sizes will be determined and correlated with friction and energy loss properties. This work will initially be performed under conditions of normal earth atmosphere, but will be extended to perform selected tests, either in dry inert gas and/or ultrahigh vacuum. The work will be correlated with the study of electrostatic properties of granular particles being conducted at College Park and the study of frictional properties of mineral surfaces being conducted at Minneapolis.

Progress During the First Quarter

Progress during the first quarter followed the planned schedule of work. The crushing, impact milling, and classification circuit to produce simulated lunar sample material for the fine particle study is nearly complete. A 10- by 30-foot Butler building to house the circuit was moved from the old straining frame site to the Auxiliary Laboratory (former missile site) and erected on an existing building apron. A 2-inch gyratory crusher, for primary crushing of rock samples to 1/8-inch size, has been installed. A small chain conveyor will move the 1/8-inch crusher discharge to a shaker screen. Material passing the 1/8-inch screen will pass directly to the impact mill which will further reduce the material to a fine granular powder. Discharge from the impact mill will be fed into the fine particle classifier for final classification. The compressed air, electric, and water utilities have been brought into the building and all the process equipment installed. Final power connections to the equipment, construction of two discharge chutes, and the installation of a ventilation fan and ventilation and discharge ducts for the classifier will complete the installation.

Background literature research on handling and flow of bulk granular solids is being carried out to ascertain suitable theory, methods, and tests for determining static and sliding coefficients of intergranular friction. Zero lateral strain triaxial tests, with repetitive loading cycles, will be performed to develop relationships between coefficients of friction and the coefficient of earth pressure at rest, and the energy loss due to intergranular friction as observed by stress hysteresis. It is hoped to develop these values for both dense and loose packing. Also, standard direct shear or triaxial shear tests will be performed to develop angle of internal friction of material, which will be related to the coefficient of friction of the material. After independent test determinations of the coefficient of friction from earth pressure at rest tests, and of angle of internal friction from standard shear tests, we hope to be able to differentiate between the frictional strength properties due to friction at the grain contacts and the strength properties due to structural interlocking of the grains. This analysis assumes that the so-called static coefficient of friction develops from both the structural packing of the granular particles and the friction at the grain contacts while the dynamic or sliding coefficient of friction develops solely from the coefficient of friction at the grain contact. This analysis will further require comparison of test results for loosely packed granular materials, developing substantial friction strength at grain contacts, and densely packed samples, which are expected to develop combined structural and friction contact strength. These results should be correlatable with theoretical values of static and sliding coefficients of friction.

The conversion of the zero lateral strain compression chamber, originally planned for the second quarter, was started during this quarter. The chamber will be used to determine stress ratios and stress hysteresis in granular materials as discussed previously. Three low pressure cells are being installed in the loading head of the chamber, and three high pressure cells replaced in the base with low pressure cells. The cells will perform in the 0-150 psi range suitable for expected load ranges in the fine particle studies. Three balanced strain gage bridges in the lateral wall of the chamber have been tested up to 1000 psi applied load and found to be in good working order. A linear pot with dc output has been designed for use on the 12,000-lb testing machine so that load readings can be read directly into an automatic data recording system during the test series.

Status of Manuscripts

None in progress.

Task title: Support for underground lunar shelter
Investigator: Robert C. Bates, Project Leader
Location: Spokane Mining Research Laboratory
Spokane, Washington
Date begun: April 1966 To be completed: March 1969

Personnel: Robert C. Bates, Mining Engineer
Lester J. Crow, Mining Engineer

PROGRESS REPORT

Objective

To advance the ground support technology needed to carry on extraterrestrial mining in support of space missions, as an extension of terrestrial ground support research. Research will be conducted on a ground support material which has good potential for utilization in both lunar and earthly applications. The material selected for this investigation is sulfur. Not only can sulfur provide an economical and effective solution to terrestrial construction and ground support problems, but it has a high probability of being indigenous to the lunar surface and could, thereby, serve in an equivalent capacity for lunar shelter construction. The immediate objectives are to: (1) compile all available data on the properties and potential uses of sulfur; (2) conduct laboratory studies to improve certain properties and to determine the feasibility of certain uses; (3) to formulate design concepts for support systems utilizing sulfur materials; and (4) to develop techniques for fabrication or installation of these support systems.

Progress During the First Quarter

The literature available on the properties and potential uses of sulfur in support technology has been surveyed. The arguments in favor of sulfur include: low cost relative to plastics, no special curing time requirements like plastics or concrete, good tensile strength, excellent adhesion properties, and good water resistance. Poor abrasion resistance seems to be the main undesirable feature of sulfur, but this can be minimized by providing a tough ware coat on the surface.

Based on knowledge gained from the literature study, sulfur aggregate has been selected for future work. Abrasion resistance is improved with the addition of an aggregate, and might be further improved by addition of materials to the sulfur mortar or by providing a ware coat. Laboratory studies will be made on specially graded flow basalt (simulated lunar rock), lightweight, and high strength aggregates. Variations in strength with aggregate size and size distribution will be investigated. The size range for the aggregates has not been established, but it could extend from the large pieces produced by a mining machine down to silt-size particles. It is hoped that this approach will lead to design information for on-the-spot fabrication utilizing some of the material removed from the excavation whether it be on the Moon or on the Earth.

Laboratory equipment and materials are being assembled for the testing phase.

Mr. Ernest L. Corp, the original investigator for the task, has transferred to the Bureau's Marine Minerals Technology Center at Tiburon, Calif. Mr. Bates has assumed supervision of the work, and Mr. Crow, who joined the staff of the Spokane Laboratory in August, has been assigned to the task.

Status of Manuscripts

None in progress.

Task title:	(1) Effect of vacuum on explosive properties (2) Effect of micrometeoroid bombardment on explosives (3) Explosive blast effects in lunar environment
Investigator:	Frank C. Gibson, Project Coordinator, Explosives Physics
Location:	Explosives Research Center Pittsburgh, Pennsylvania
Date begun:	July 1966 To be completed: June 1969
Personnel:	Frank C. Gibson, Supervisory Research Physicist Richard W. Watson, Research Physicist J. Edmund Hay, Research Physicist Charles R. Summers, Research Physicist William F. Donaldson, Research Physicist Elva M. Guastini, Explosives Equipment Operator

PROGRESS REPORT

Objective

To develop a body of knowledge relevant to the use of chemical high explosives under lunar environment. Immediate goals are to determine the hazards associated with the storage, handling, and use of explosives in an environment characterized by high vacuum, extreme temperature cycling, and a flux of small hypervelocity particles, and to establish techniques for minimizing these hazards.

Progress During the First Quarter

During the quarter, the sensitivities of granular RDX charges having densities of 1.075 g/cm^3 and pressed RDX charges of 1.72 g/cm^3 density were determined at ambient temperature, -197.5°C (bp of N_2) and 115.5°C, indicative of the lunar temperature range.

The pressed RDX charges consisted of 1-inch diameter by 1-inch long pellets stacked to form a 5-inch long explosive charge. The attenuators were 3-inch diameter Plexiglas cylinders machined to within one mil of the desired thickness required for a specific gap. The donor charges were tetryl (3/4-inch long by 3/4-inch diameter) having a nominal density of 1.57 g/cm^3. They were equipped with 3/4-inch long by 3/4-inch diameter hollow Plexiglas Primacord holders. The donor assemblies were cemented to the bottom attenuator faces as shown in figure 1. The pressed RDX acceptor charges were drilled to accommodate five twisted pairs of enamel insulated wires used as time-interval sensors and were spaced as shown in figure 1.

A copper-constantan thermocouple was used for temperature monitoring. The entire charge except the bottom surface which contacted the attenuator was then wrapped with thin asbestos paper for thermal insulation. The granular RDX charges were poured into 5-inch long, 1-inch od Plexiglas cylinders with 1/16-inch walls and having 0.050-inch thick Lucite

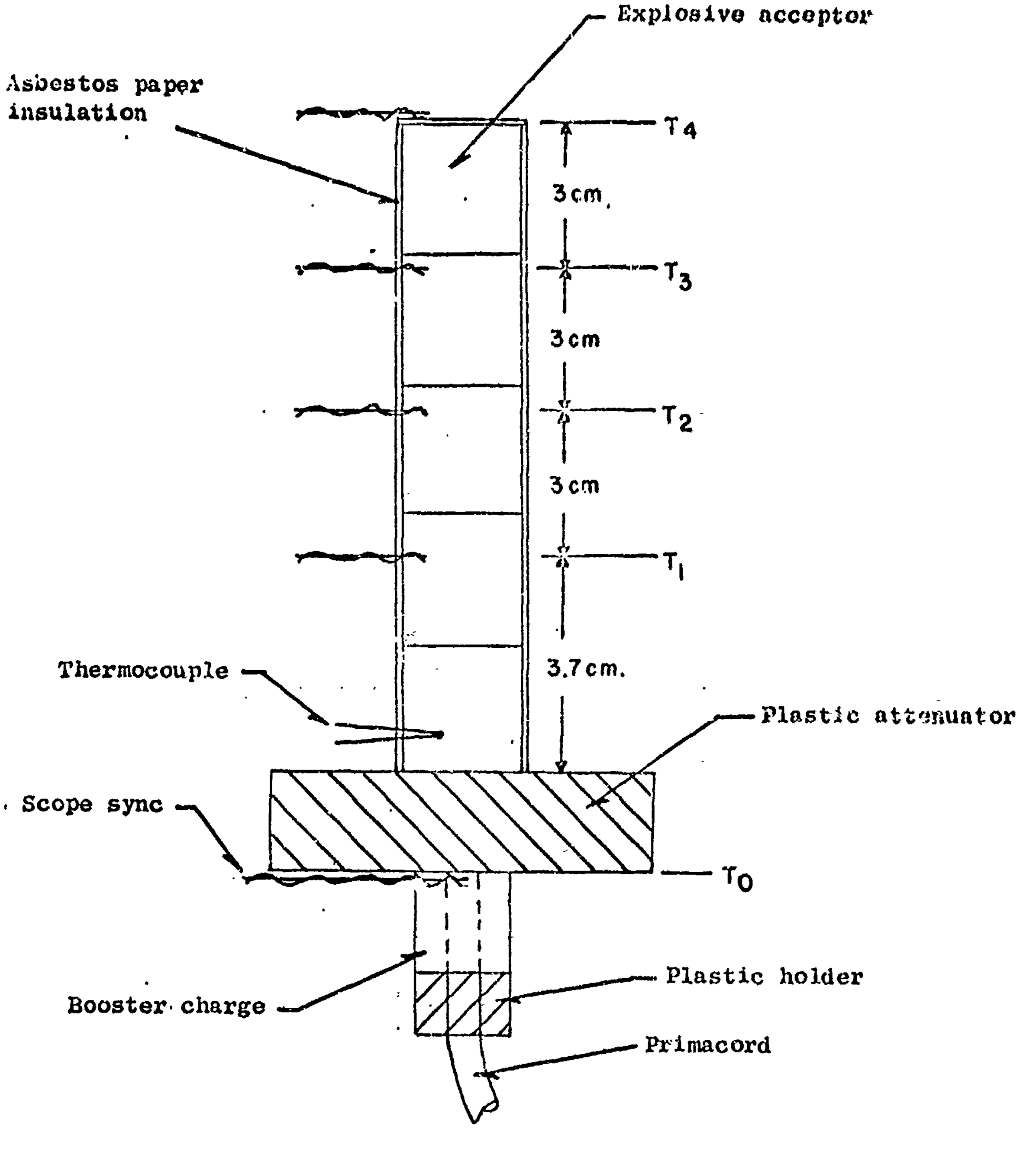


FIGURE 1. - Arrangement used for pressed charges.

bottoms. The time interval sensing wires and thermocouple were inserted through the Plexiglas walls and spaced identically to those in the pressed charges. The donor charge-attenuator assembly was identical to that used with the pressed charges as illustrated in figure 2. The Plexiglas cylinders were totally confined in a wrapping of thin asbestos paper.

The charges were transferred from the furnace or liquid nitrogen container to the donor-attenuator assemblies by a pulley mechanism operated from the control room. The device consisted of a metal arm coupled to a fixed pivotal shaft at one end. The charge was attached to the opposite or free end of the arm and could be rotated in a vertical plane through 180°. Initially, the charge was immersed in liquid nitrogen or inserted into the heating unit; and by movement through 180°, the charge was transferred to the attenuator which had been affixed to a properly located test stand. The mechanism is schematically shown in figure 3. The transfer operation required approximately five seconds after the charge attained the desired temperature; the temperature remained essentially constant to the time of firing.

Time intervals were measured between two sets of pick-up stations separated by 3.0 cm. The interval determinations were recorded between stations T_2 to T_3 and T_3 to T_4 using 10-megahertz counter chronographs. A similar station, T_0, was placed at the donor-attenuator interface to trigger the sweeps of two Tektronix oscilloscopes, models 533 and 545A. By employing 4-channel, Type M, plug-in units, these scopes recorded elapsed times between the entry of the initiating pulses and the arrival of the detonation waves at stations T_1, T_2, T_3, and T_4. The time bases were 10 µsec/div and 5 µsec/div for the 545A and 533, respectively. The oscillograph records gave induction times to detonation and more detailed description of the detonation propagation characteristics between stations than could be derived from the 10-megahertz counter chronographs alone.

On the basis of the foregoing and the use of the Bruceton up-and-down method, no statistical difference in sensitivity was observed for RDX at ambient temperature and 115.5°C, but a significant decrease was observed at -195.7°C. Both the granulated and pressed RDX charges exhibited this property. The gap values for a 50 percent probability of detonation are recorded in table 1 for both granulated and pressed charges at the temperature investigated. For the granulated RDX charges, the modified gap test difference of 0.067 inch between -195.7°C and ambient represents a significant decrease in sensitivity whereas the difference of 0.022 inch between 115.5°C and ambient temperature probably does not. Likewise, in the case of pressed RDX, the difference of 0.100 inch between ambient temperature and -195.7°C represents significant desensitization, but the 0.008-inch difference between 115.5°C and ambient temperature indicates no change has occurred.

Although instrumentation was employed to detect induction times to detonation, no differences were observed between -195.7°C and 115.5°C. Also, no varying trend in detonation velocities was evident over this temperature range as shown in table 1. The range of velocities measured at

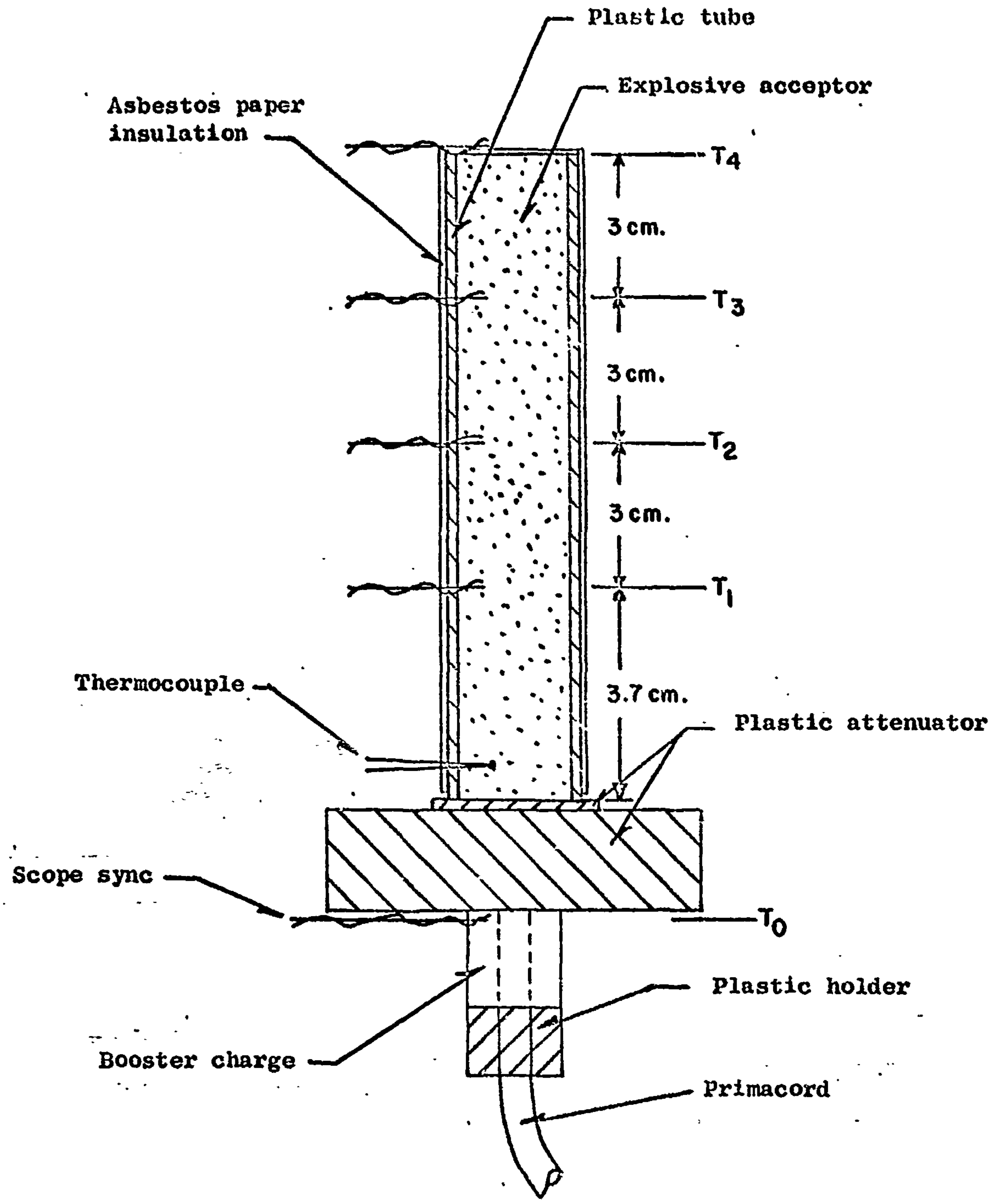


FIGURE 2. - Arrangement used for granular material.

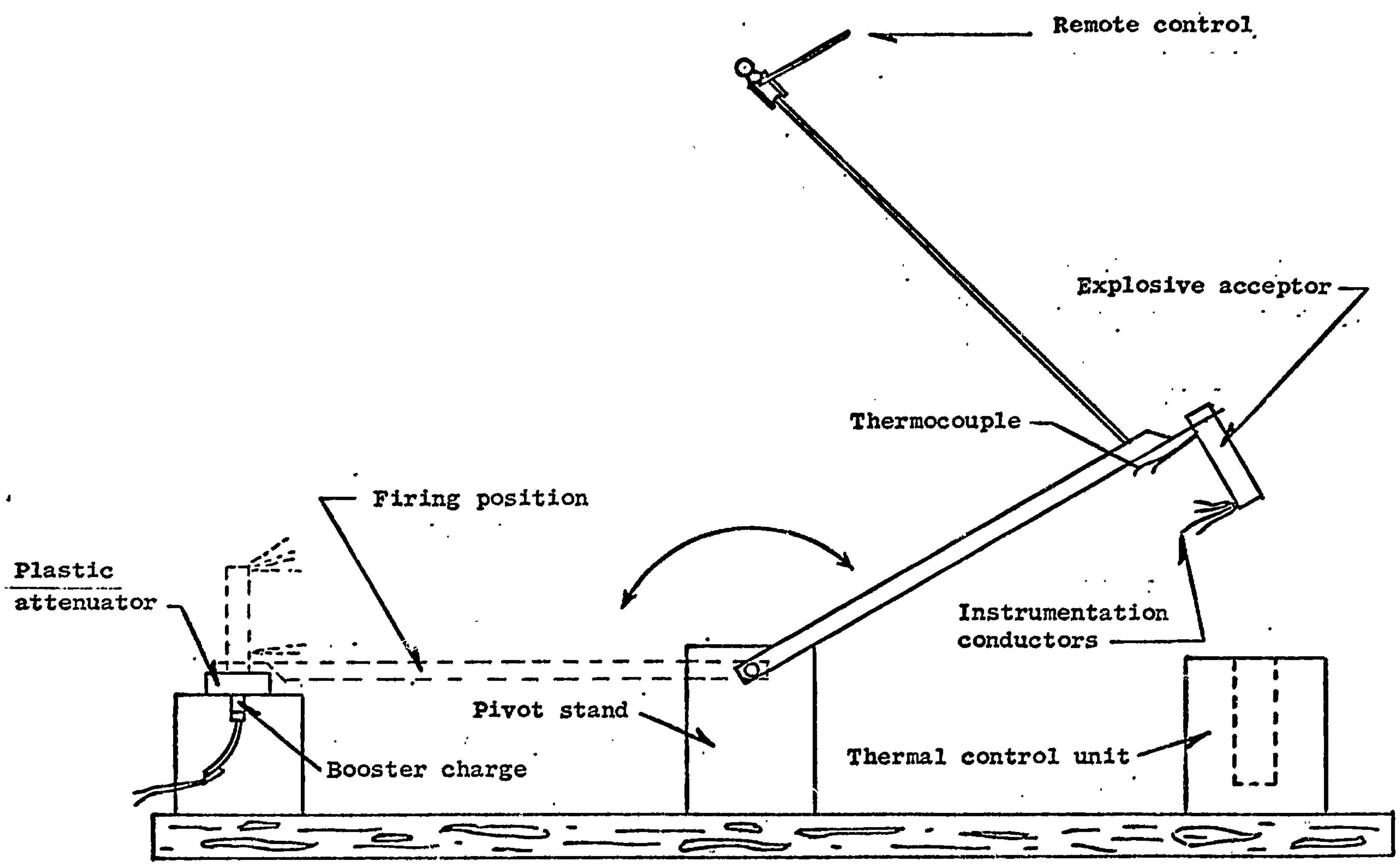


FIGURE 3. - Charge transfer apparatus.

TABLE 1. - Gap values for pressed and granulated RDX charges at the 50-50 point

Granulated RDX, Comp A-5
$\rho = 1.075\ g/cm^3$

Temperature (°C)	Gap (inches)	Detonation Velocity Range (m/s)
-195.7	0.855 ± 0.009	5775 to 6525
Ambient	0.922 ± 0.020	5450 to 6250
115.5	0.900 ± 0.003	5350 to 6250

Pressed RDX, Comp A-5
$\rho = 1.72\ g/cm^3$

Temperature (°C)	Gap (inches)	Detonation Velocity Range (m/s)
-195.7	0.628 ± 0.010	7900 to 8820
Ambient	0.728 ± 0.004	8325 to 8570
115.5	0.720 ± 0.020	7700 to 11,100

115.5°C in the case of pressed RDX is misleading due to one questionable value of 11,100 m/sec; otherwise, no abnormal velocities were observed at this temperature.

During the next quarter it is planned to start an investigation into the sensitivity of explosives to initiation by particle impact or electromagnetic radiation devices capable of simulating micrometeoroid fluxes in space. The DDC search of the unclassified literature failed to reveal any specific items pertaining to the sensitivity of explosives to small particle bombardment. However, many valuable references to fragment launchers and space environment articles were found accessible and have been requested.

Status of Manuscripts

None in progress.

Task title:	Volcanism and ore genesis as related to lunar mining
Investigator:	Rolland L. Blake, Project Coordinator
Location:	Twin Cities Metallurgy Research Center Minneapolis, Minnesota
Date begun:	June 1966 To be completed: May 1967
Personnel:	Rolland L. Blake, Geologist Others as assigned

PROGRESS REPORT

Objective

Study the genesis of ore deposits and the occurrence of minerals associated with volcanic activity here on Earth. Study the effects of the lunar environment and other environments on mineralization and ore genesis. Bring together the pertinent information found in the literature on these subjects and define those specific areas where additional work is needed.

Progress During the First Quarter

Work on this task ended in fiscal year 1967, except for the completion of a summary report and recommendations for further studies which is still in progress.

Task title:	(1) Reduction of silicates with carbon (2) Reduction of silicates in plasma torch
Investigator:	Sanaa E. Khalafalla, Project Coordinator
Location:	Twin Cities Metallurgy Research Center Minneapolis, Minnesota
Date begun:	June 1966 To be completed: May 1969
Personnel:	Sanaa E. Khalafalla, Supervisory Research Chemist Larry A. Haas, Research Chemist Howard W. Kilau, Chemist Thomas H. McCormick, Physical Science Aid

PROGRESS REPORT

Objective

Determine the optimum reaction rate criteria for extraction of oxygen from simulated lunar materials in a vacuum. The major emphasis of this research is to determine the kinetics and mechanism of the carbothermal reduction of siliceous materials in a high temperature vacuum furnace. This is one phase of a multidisciplinary effort to extract oxygen via carbon monoxide from possible lunar materials.

Progress During the First Quarter

The goal during the first quarter was to determine the interrelationship of the reduction rate with the number of silica reactant particles and their surface area. The results last quarter indicated that for a given silica size, the reduction rate increased almost directly with the number of graphite particles. This quarter the size of graphite was held constant and the particles of silica were varied. The low density graphite used had a mean diameter of 110 microns, a BET surface area of 2.1 square meters per gram and an estimated 2 million particles per gram. The particles per gram mentioned in this report were calculated by assuming tetragonal packing of nonporous spheres with a bed porosity of 30 percent.[1] This assumption was previously verified when a fair agreement was obtained between the calculated and measured number of graphite particles. The physical properties of the silica samples, which were obtained from Wausau, Wis., are shown in table 1. It was extremely difficult to obtain the true (BET) surface area of this silica because of its low porosity. The nonporosity of the silica was also ascertained when the density measured by the Beckman air pycnometer was the same as the true density. The Perkin Elmer sorptometer was modified by converting it from a dynamic to a static apparatus. Even with this modification, the surface area of only the very fine silica could be measured. The geometric surface area was also calculated for each silica sample, and with the finer samples was found to be approximately half as much as the BET surface area (table 1).

[1]Orr, Clyde, Jr. Particulate Technology. MacMillan Co., N. Y., 1966, p. 413.

TABLE 1. - Carbothermic reduction data with Wausau silica[1]

Test No.	Mean silica particle diameter, microns	Number of particles per gram	Surface area, cm^2/g		Five-hour observed weight-loss, percent
			Geometric	BET	
1	1410	503	31.4	---	1.92
2	710	3,940	62.5	---	3.45
3	500	11,120	88.5	---	6.35
4	360	31,350	125	---	14.5
5	250	88,300	175	---	32.7
6	180	250,000	245	---	81.8
7	125	706,000	350	730	---
8	90	2,010,000	500	990	---

[1]The above tests were all performed at 1400°C in 10^{-2} torr vacuum for a period of 5 hours. The reductant was minus 100 plus 200 mesh low-density graphite. The charge consisted of 12 grams of silica and 2.4 grams of graphite.

The variation of the reduction rate, number of particles per gram and the geometric surface area with silica particle size is shown in figure 1, curves a, b, and c, respectively. It can be seen that curves a and b decrease nearly hyperbolically with increasing particle diameter and in a parallel manner but curve c which describes the surface area variation with particle subdivision decreases at a lesser rate. Since the number of particles should vary as the reciprocal cube of the diameter, a plot of the rate and number of particles was made against the cube of reciprocal particle diameter and is shown in figure 2, curves a and b, respectively. These plots are found to be linear, whereas the variation of geometric surface area on the same graph was not linear. On the other hand, when the reaction rate and geometric surface area were plotted against the reciprocal of particle diameter, the latter function exhibited a linear variation, as shown in curve b of figure 3, whereas the former function (and also the number of particles per gram) exhibit a cubic power variation, as shown in curve a of figure 3. Therefore, it appears that a better correlation of the reaction rate is obtained with the number of silica particles per gram than with their geometric surface area. In the last fiscal year it was similarly reported that the number of graphite particles were more important in determining the reaction rate than their surface area. These results add further credence to the contention that the carbothermic reduction process occurs by a solid/solid reaction and not by a preliminary gasification step followed by a gas/solid reaction. The number of particles of both reactants (silica and graphite) appear to play a predominant role in determining the reaction rate.

Study of the feasibility of reducing silicates with activated hydrogen in a plasma torch was completed during the last fiscal year. It was concluded that the process was not feasible although the phenomena involved in mineral dissociation in the high temperature plasma arc might

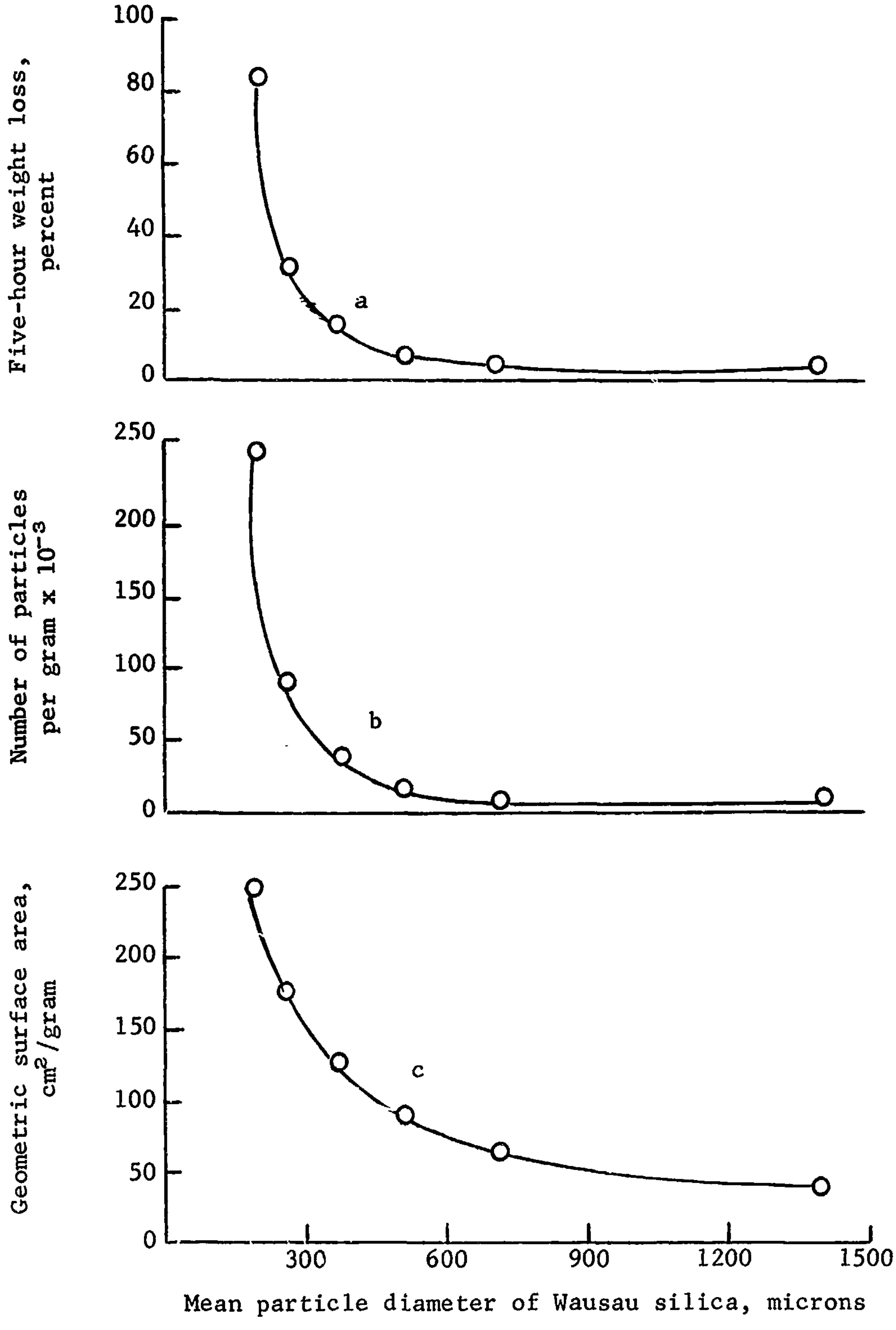


FIGURE 1. - Effect of Silica Particle Diameter on Reaction Rate, Number of Particles per Gram and Geometric Surface Area.

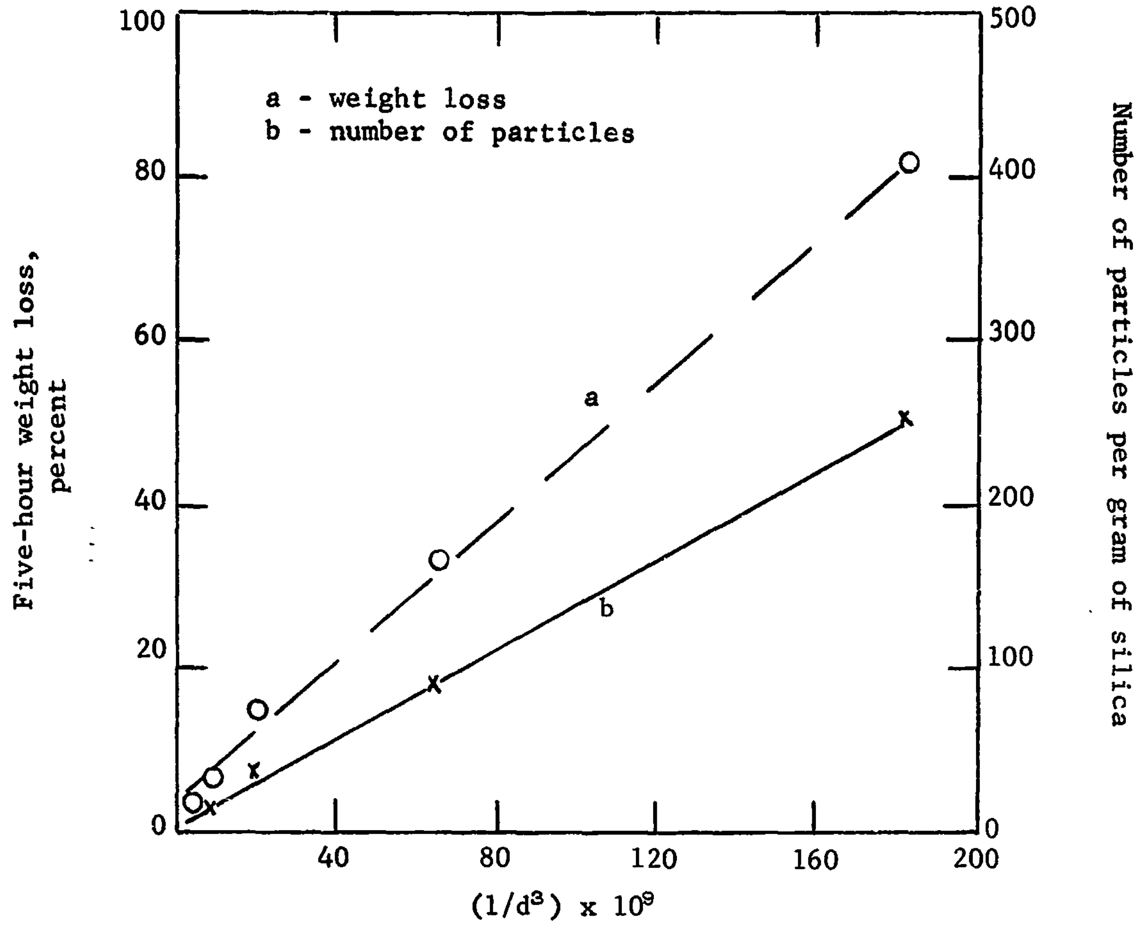


FIGURE 2. - Comparison of the Reaction Rate and the Number of Particles with the Reciprocal Cube of the Particle Diameter.

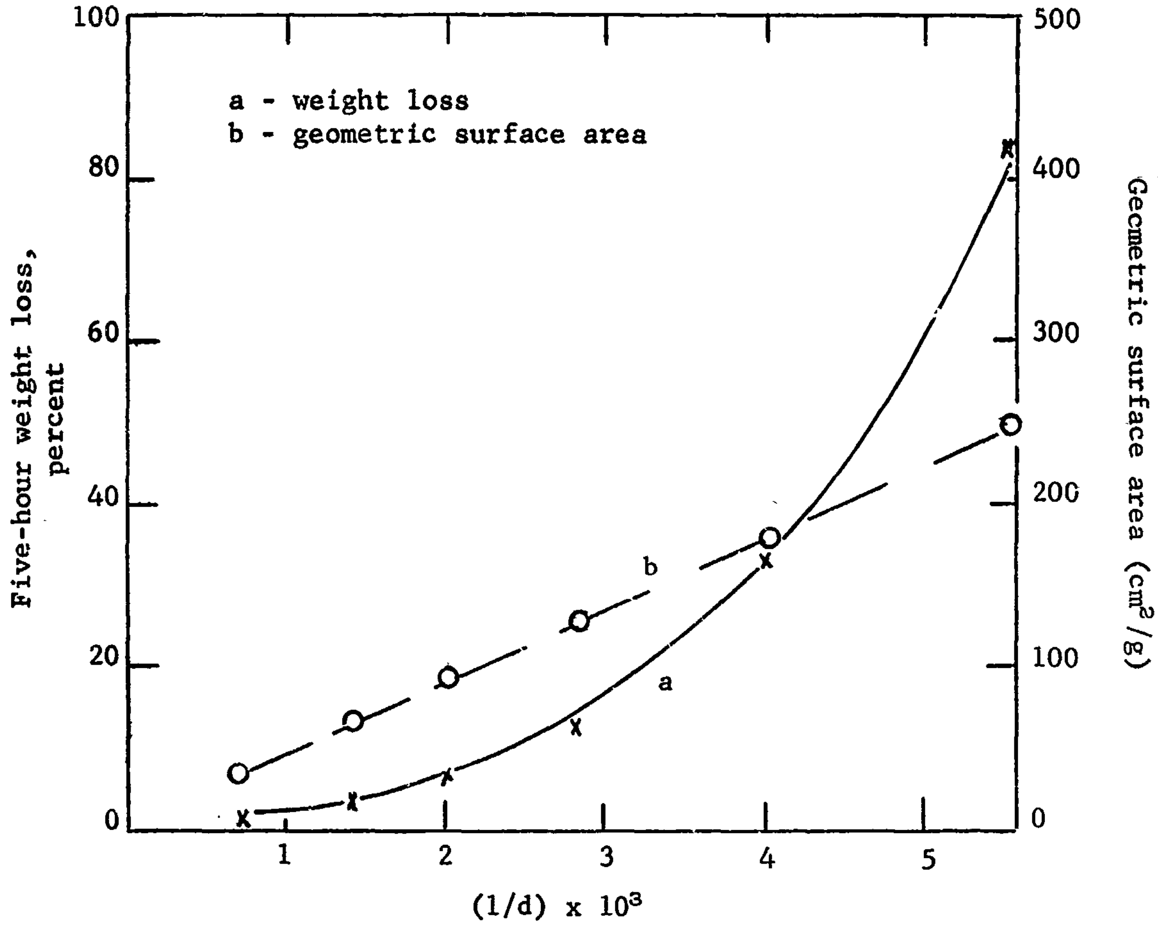


FIGURE 3. - Comparison of the Reaction Rate and the Geometric Surface Area with the Reciprocal of the Particle Diameter.

be worth further investigation. Experimental work would require purchase of additional equipment which does not appear warranted at present. A report on the results of the feasibility study will be prepared.

Status of Manuscripts

None in progress.

Task title: Magnetic and electrostatic properties of minerals in a vacuum
Investigator: Foster Fraas, Project Leader
Location: College Park Metallurgy Research Center
College Park, Maryland
Date begun: June 1966 To be completed: May 1969

Personnel: Ray A. Heindl, Supervisory Chemical Research Engineer
Foster Fraas, Metallurgist

PROGRESS REPORT

Objective

Study adsorption and contact electrification in a vacuum and determine their effect on the separability of nonconducting minerals.

Progress During the First Quarter

Objectives for the quarter were to initiate operation of the turbo-molecular pumping system and to test under vacuum the vibrating electrifier and bellows-sealed vibration feed-through.

The turbo-molecular pumping system and accessories to measure flow characteristics under high vacuum were completed. The accessories include the vibrating electrifier, a feed hopper, and a particle recirculating system. The particle recirculating system includes a bin which collects the falling particles and which may later be rotated to a position above the feed hopper where it automatically discharges the particles into the hopper. The vibrating electrifier is a horizontal plate type simulating the vibratory feeders used in ore beneficiation. The vibrating electrifier and particle recirculating system is illustrated in figure 1 with the stainless steel vacuum chamber elevated above the base plate.

A minus 20 plus 35 mesh mixture of quartz and microcline could be vibrated over the electrifier surface and recirculated with no indication of interfering adhesion of the particles. The vacuum during this operation was 3×10^{-6} torr. Although a vacuum of 5×10^{-7} torr was initially obtained with the pump, a stand-by period without a nitrogen backfill impaired the initial vacuum. Heaters for bake-out of chamber and pump are attached to the system, but a thorough baking-out has not been attempted because of faulty cooling of one of the turbo-molecular pump bearings.

Status of Manuscripts

None in progress.

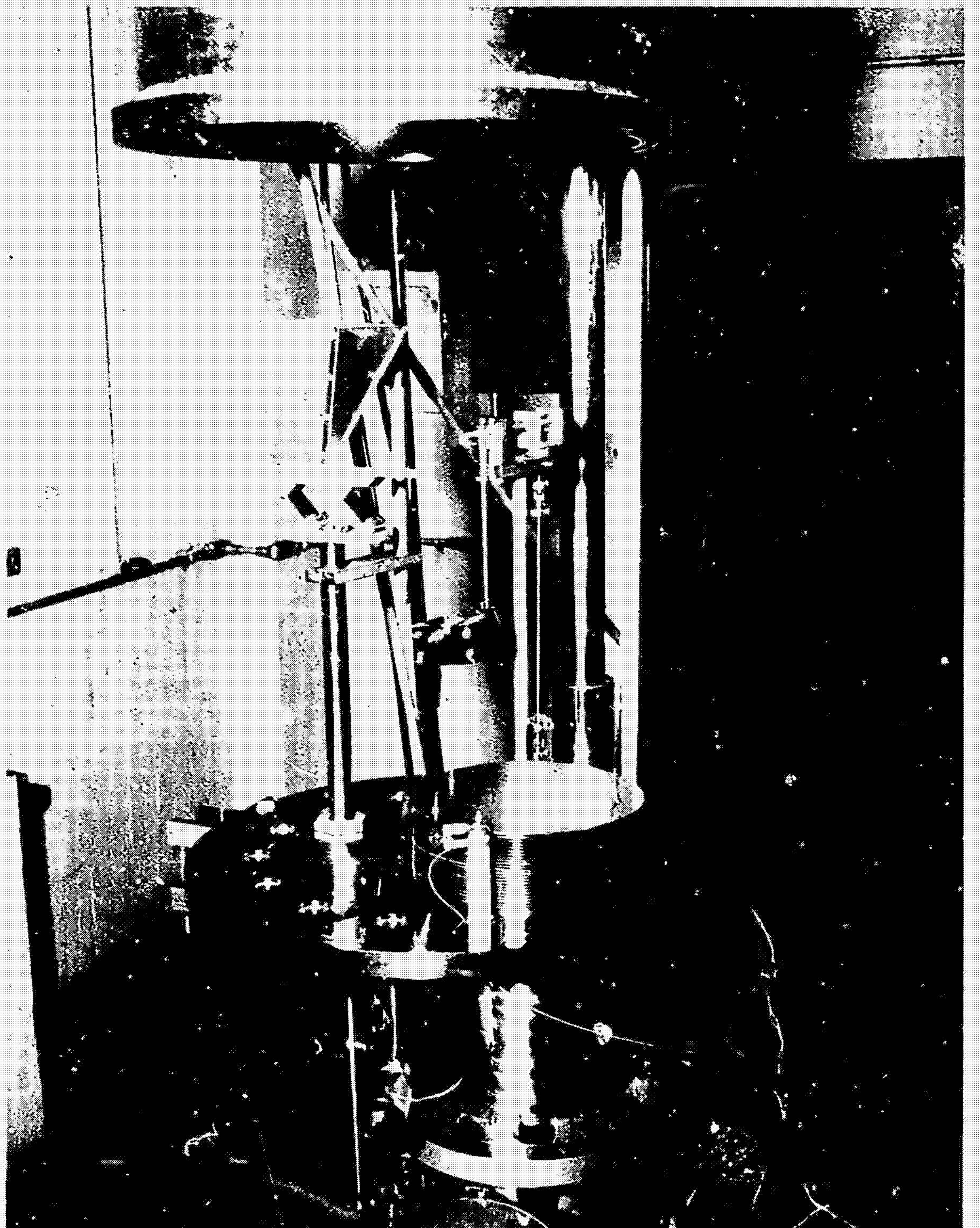


FIGURE 1. - Arrangement of Vibrating Electrifier and Particle Recirculating System in High Vacuum Chamber.

Task title: Biological production of sulfuric acid
Investigator: Joseph A. Sutton, Project Leader
Location: College Park Metallurgy Research Center
College Park, Maryland
Date begun: June 1966 To be completed: May 1967

Personnel: Ray A. Heindl, Supervisory Chemical Research Engineer
Joseph A. Sutton, Research Chemist
John D. Corrick, Research Chemist
Jerry M. Carosella, Microbiologist

PROGRESS REPORT

Objective

Establish the limiting environmental conditions for the survival of bacteria of the genus Thiobacillus. Determine the rate of sulfuric acid production within these limits. Conduct a literature survey and visit such laboratories as may be necessary to establish the state-of-the-art in the use of bacteria in any stage of a life support system in an extraterrestrial environment.

Progress During the First Quarter

Work on this task ended in fiscal year 1967 and results were reported in the annual status report. Preparation of a more detailed summary report and recommendations for further bacteriological studies is under consideration.

Task title:	Electrowinning of oxygen from silicate rocks	
Investigator:	Donald G. Kesterke, Project Leader	
Location:	Reno Metallurgy Research Center Reno, Nevada	
Date begun:	June 1966	To be completed: May 1969
Personnel:	Thomas A. Henrie, Supervisory Metallurgist Donald G. Kesterke, Metallurgist Freddy B. Holloway, Physical Science Technician John D. Lafontan, Physical Science Aid	

PROGRESS REPORT

Objective

To determine the feasibility of obtaining elemental oxygen from silicate minerals by electrolytic methods, for use by the Earth inhabitants of the Moon. Emphasis will be directed toward the determination of essential physical and electrochemical properties of silicate and silicate-base melts containing various amounts of halide salts. Complementary investigations will be made to find suitable nonreactive crucible and anode materials for use in silicate melts, or in melts containing halides.

Progress During the First Quarter

Objectives for the quarter were to determine the compatibility of platinum-group metals with molten silicates and silicate-plus-LiF systems, to investigate the possibility of saturating hot-pressed boron nitride with a molten silicate-plus-LiF mixture, and to begin a study of the effect of melt temperatures above 1,400°C on the electrical conductivity of fused silicates.

Experiments were conducted to determine the ability of platinum and iridium to withstand attack by fused silicates and LiF-bearing silicates. The tests were of a static nature in that a voltage was not applied to the specimens while they were suspended in the melts. Iridium was tested at about 1,500°C by immersion in a pyroxene-type mineral with and without added LiF, and in a serpentinite-plus-LiF mixture at 1,250° to 1,450°C. Complete dissolution occurred in less than 30 minutes in the pyroxene-bearing mixtures, and severe corrosion occurred after about 15 minutes in the serpentinite-bearing mixture. Platinum was similarly tested at 1,250° to 1,450°C in the serpentinite-plus-LiF system, and dissolution occurred within a few minutes. Since the effect of an applied voltage would be to cause dissolution at an even faster rate, these results indicate that platinum-group metals would be unsuitable for use as electrode materials.

Unsuccessful attempts were made to saturate hot-pressed boron nitride with an LiF-bearing silicate mixture for possible use as an electrode material. Boron nitride specimens were immersed in the melt for more than one hour at a temperature of 1,500° to 1,600°C, then they were removed and cooled. Microscopic examination of the specimens showed no penetration of the melt material.

Preliminary tests indicate that molten LiF-bearing silicates have significantly better electrical conductivity at temperatures greater than 1,400°C than was attained at a maximum of 1,300°C. A basalt-sinter mixture containing 10 weight-percent LiF was almost twice as conductive at 1,400°C, and four times as conductive at 1,550°C, than it was at 1,300°C. From extrapolation of the data attained, it is estimated that currents of more then 100 amperes at 30 to 40 volts can reasonably be expected at 1,500°C. Studies of this type will be extended to other silicate rocks and minerals to explore the possibility of designing an electrolytic cell in which thermal equilibrium is maintained by means of electrolysis current alone.

Status of Manuscripts

None in progress.

Task title:	Stability of hydrous silicates and oxides in lunar environment
Investigator:	Hal J. Kelly, Project Coordinator
Location:	Albany Metallurgy Research Center Albany, Oregon
Date begun:	April 1966 To be completed: March 1968
Personnel:	Hal J. Kelly, Supervisory Ceramic Research Engineer Raymond L. Carpenter, Research Physicist

PROGRESS REPORT

Objective

The long-range objective is the determination of the energy requirements for dissociating silicate and oxide minerals to recover oxygen and/or water. The immediate objective is to investigate the stability under high vacuum and elevated temperature of some silicate and oxide minerals employing differential thermal analysis (DTA) and thermogravimetric analysis (TGA).

Progress During the First Quarter

The objectives for the first quarter were to determine, from a review of the literature, what rock forming minerals are thermally active. To obtain samples of some of these minerals and make preliminary vacuum DTA runs on them to determine which ones are compatible with vacuum differential analyses. The improvement of the operation of the TGA equipment was also included in the first quarter's objectives.

A review of the literature revealed several groups of minerals which have thermally active members. Members of four groups - zeolites, epidotes, bauxites, and amphibole - have been selected for study. Several miscellaneous minerals have also been selected. The list of selected minerals is given in table 1.

Samples of some of these minerals have been obtained and preliminary vacuum DTA runs have been made on them to determine their compatibility with vacuum DTA. Gibbsite, diaspore, and goethite appear to have low temperature endothermic reactions. Furthermore, the samples of these minerals blew out of the crucible in all tests. Actinolite, hornblende, and epidote all appear to produce thermographs that can be used for the study of vacuum decomposition of minerals. Other members of the same groups should also be usable.

Actinolite was studied most intensively during the first quarter. DTA in air has shown that there were three endothermic peaks on the thermograph, at 685°, [illegible]30°, and 1,060°C. The first peak was of low magnitude, while the other two [illegible] moderate. The thermograph for vacuum DTA also showed three endothermic peaks, at 800°, 910°, and 1,070°C. The pressure temperature curve for the vacuum DTA run showed that outgassing

TABLE 1. - Minerals for DTA - TGA analysis

Zeolite Group

Analcite	$Na(AlSi_2)O_6.H_2O$
Heulandite	$Ca_2(Al_4Si_{14}O_{18}).12H_2O$
Stilbite	$(NaCa)(Al_2Si_8O_{36}).6H_2O$

Epidote Group

Epidote	$Ca(AlFe)_3(SiO_4)_3.OH$
Zoisite	$CaAl_3(SiO_4)_3.OH$

Bauxite Minerals - Alumina Hydrates

Gibbsite	$Al(OH)_3$
Beohmite	$AlO(OH)$
Diaspore	$AlO(OH)$

Amphibole Group

Tremolite	$Ca_2Mg_5(Si_4O_{11})_2(OH)_2$
Actinolite	$Ca(MgFe)_5(Si_4O_{11})_2(OH)_2$
Hornblende	$(Ca, Na, Mg, Fe, Al)_{7-8}[(Al, Si)_4O_{11}]_2(OH)_2$

Miscellaneous Minerals

Brucite	$Mg(OH)_2$
Apophyllite	$KFCa_4(Si_2O_5)_4.8H_2O$
Pyrophyllite	$Al_2(OH)_2Si_4O_{10}$
Goethite	$FeO(OH)$

started at 500°C, ended at 815°C, and started again at 980°C and ended at 1,100°C. TGA also was run in air. The first large weight loss started at 600°C and ended at 800°C. A second weight loss started at 1,000°C and ended at 1,100°C. There appears to be some correlation between the outgassing curve and the weight loss curve, but there does not appear to be any correlation between these curves and the DTA curves. X-ray diffraction data were obtained on material heated to 830°C and to 1,200°C in vacuum. These data show that heating to 830°C does not appear to alter the structure greatly, but heating to 1,200°C materially alters the mineral. After the material is heated to 1,200°C, the structure is altered to the pyroxene type. Work will be continued on this mineral.

Improvements were made in the TGA equipment. A smaller furnace was rebuilt so that it could be used with the TGA equipment and power supply. With the rebuilt furnace a constant heating rate of 9°C/min can be maintained up to 1,200°C in air. The control thermocouple was installed inside of the hangdown tube so that the temperature of the sample pan is about the same as that of the control couple. The large, 45mm, hangdown tube was replaced with one of 20mm id. This reduced the noise factor greatly. A blank run was made with just the sample pan. The balance was set up on the 100-mg range with the recorder range set at 4 mg, full scale. The noise level was ± 1 chart division of 0.04 mg, which is a marked improvement over the noise level obtained with the large diameter hangdown tube.

Status of Manuscripts

None in progress.