UNITED STATES
DEPARTMENT OF THE INTERIOR
BRANCH OF ASTROGEOLOGY
GEOLOGICAL SURVEY
Box 1906
Flagstaff, Arizona

November 30, 1963

MEMORANDUM

TO: V. R. Wilmarth

FROM: E. M. Shoemaker

SUBJECT: Monthly Report for Director and Secretary

1. Highlights and noteworthy results:

Lunar Investigations

As the result of additional mapping in the equatorial belt of the Moon, the stratigraphic nomenclature used in previous maps has undergone extensive review by the entire staff engaged in lunar geological mapping. The most significant change is the reduction of the previously designated Procellarian System, to a rock stratigraphic unit, the Procellarian formation. Some Archimedian craters, previously categorized as pre-Procellarian, may be of the same age as the Procellarian formation.

A more detailed classification of small craters and rilles in the maps currently being compiled will enhance the use of crater distribution as criterion of age.

Henry Moore has shown that the lunar surface may be nearly completely covered with impact craters ten meters across and smaller. The distribution of impact craters on the lunar surface may be estimated by combining data derived from hypervelocity impact cratering experiments with data on the distribution of interplanetary dust, micrometeroids, and larger meteoritic bodies, which are continually bombarding the lunar surface. An estimate for a billion year old lunar surface composed of sand or rock indicates that at least eighteen percent of the area of the lunar surface would be occupied by craters with diameters between one and ten meters. Eighteen percent of the total surface would be occupied by craters with diameters between ten centimeters and one meter. In general, the smaller craters would be found on and between the larger craters.

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Experimentation by J. F. McCauley for the purpose of developing a visual observing system for the 60" McMath Telescope at Kitt Peak National Observatory, 50 miles southwest of Tucson, Arizona, has shown that this large telescope is unusually well suited for visual work on the Moon. Viewing devices constructed by the Geological Survey have enabled the Branch of Astrogeology personnel to carry out observing with reasonable consistency in the range of resolution necessary for effective lunar geological mapping. As this telescope was primarily designed for daytime solar work, it has been possible to schedule the instrument extensively for lunar research.

Crater Investigations

D. J. Milton has found the structure of the largest of the meteorite craters at Henbury, Australia, is more complex than in any other meteorite crater that has been mapped geologically, with the possible exception of the Reis Kessel in Germany.

The deformation during impact produced asymmetric folds overturned outward and overthrust nappes. In several places these nappes override the pre-crater ground surface.

On his return from Australia, Milton spent several days examining a craterform depression at the Pretoria Salt Pan, South Africa. He found the small scale structures in the walls of the crater indicate an outward displacement from a rather shallow focus of energy. These structural features are consistent with an impact origin for the crater.

3. New Projects Started

Terrain Analysis for Landing Areas in the Lunar Equatorial Belt:
The study under the direction of John F. McCauley will include photometric slope measurements of part of the lunar equatorial belt (10° N to 10° S lat and 60° W. to 15° E long) using a method devised by D. E. Wilhelms. The purpose is to obtain slope frequency distributions over the area studied. The areas of lowest slope frequency distribution will in turn be studied visually at the limit of telescopic resolution at a number of large telescopes by various Branch of Astrogeology personnel. This phase of the study will further delineate those areas that have the highest probability of containing safe spacecraft landing sites.

4. Outside Publications Reported During the Month

Chao, E. C. T., 1963, The petrographic and chemical characteristics of tektites in O'Keefe, J. A., Ed., Tektites: University of Chicago Press. p. 51-94.

Shoemaker, E. M., Gault, D. E., Moore, H. J., and Lugn, R. V., 1963, Hypervelocity impact of steel into Coconino Sandstone: Am. Jour. Sci., v. 261, p. 668-682

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5. Personnel

Wanda M. Wilkinson transferred from Branch of Personnel, Denver, Colorado, to the Astrogeology Branch in Flagstaff, Arizona, as Administrative Assistant.

C. H. Marshall has resigned; his investigation of the Mare Humorum region of the Moon is being continued by Spencer Titley, WAE, at the University of Arizona.

Lewis Calk has started work with Michael Carr on a study of extraterrestrial dust extracted from filter papers flown on high altitude aircraft.

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6. Conferences and Scientific Meetings Attended at Home or Abroad

Michael B. Duke conferred with E. P. Henderson, U. S. National Museum, Washington, D. C. in regard to obtaining meteorite samples for microprobe analysis.

A conference on lunar stratigraphy and structure held in Flagstaff, Arizona, November 1, 2, and 3, resulted in a revision of the existing nomenclature for the lunar maps that are now in final stages of preparation. The meeting was attended by Michael H. Carr, Richard E. Eggleton, Donald P. Elston, Robert J. Hackman, Harold Masursky, John F. McCauley, Daniel J. Milton, Henry J. Moore, Elliot C. Morris, Eugene M. Shoemaker, and Spencer R. Titley.

Michael H. Carr attended a Conference on Cosmic Dust sponsored by the New York Academy of Sciences, New York, November 21 and 22.

E. D. Jackson, A. H. Chidester, and M. F. Kane attended the Geological Society of American, November 17 through 20.

D. E. Wilhelms and J. F. McCauley conferred with Dr. Keith Pierce, Kitt Peak Observatory, in order to arrange for astronaut observing time at the McMath Solar telescope.

M. F. Kane conferred with Dr. Robert Kovach and F. E. Lehner of the California Institute of Technology, Seismological Observatory.

M. F. Kane conferred with John Harrel and Leonard Marsh of the California Institute of Technology, Jet Propulsion Laboratory.

Robert J. Hackman, representing the fields of geology and astronomy, was an advisor on prospective Science Fair Projects at the Kenmore Junior High School, Arlington, Virginia.

E. M. Shoemaker and Elliot C. Morris visited the Jet Propulsion Laboratory, Pasadena, California, to attend a meeting concerning space flight operations facilities for the Surveyor Project to be built at JPL.

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7. Talks or Papers Presented at Meetings

Harold Masursky	"Lunar Geologic Mapping" Geology Department San Jose State College
Carl H. Roach	Progress Report on the Branch of Astrogeology solid state investigations and outlined planned investigations to personnel of the Advanced Research Projects Agency, including Dr. R. L. Sproul, the new Director of ARPA.
John F. McCauley	"Mapping of the Moon" U. S. Forest Service Women's Club Flagstaff, Arizona
John F. McCauley	"The Stratigraphy of the Moon" Arizona Geological Society Tucson, Arizona

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8. Visitors

Visitor and Affiliation	Visited and Purpose
Dr. A. E. Ringwood National University of Australia	E. C. T. Chao Meteorite and high pressure mineral research.
Dr. Carleton Moore Arizona State University Tempe, Arizona	E. C. T. Chao and M. B. Duke Crater Studies, tektites, and meteorites.
Mr. Robert Fowler North American Aviation	Carl H. Roach to discuss feasibility of using solid state techniques as an on-site inspection for detecting clandestine underground explosions.
Mr. Charles Reeves U. S. Nuclear Corporation	Carl H. Roach to inspect the recent installation of a large Cobalt irradiator purchased from the U. S. Nuclear Corp, California.
Dr. Donald Lewis and Mr. Bill Orr Shell Development Company	Carl H. Roach over a two day period to discuss technical aspects of the Shell Development Company contract that provides for the design and construction of various types of solid state apparatus.
Lado Muhlstein, Nonsteady Phenomena Branch, Ames Research Center, Moffett Field, California	R. V. Lugn and H. J. Moore, to discuss possibility of use photogrammetric techniques in recovering experimental data from vibrating plates.
Dr. Harold Washburn, Jet Propulsion Laboratory, Pasadena, California	H. J. Moore to discuss lunar erosion by influx of micro-meteoroids and meteors.
Mr. Peter McCuen, Itek Corporation Vidya Division Palo Alto, California	Harold Masursky to discuss enhancement techniques in lunar photography.
1/Lt Vern G. Smalley, CRFL L. G. Hanscom Field, Massachusetts	Branch of Astrogeology facilities at Flagstaff.
Gordon A. Nesler Educational Service Branch NASA	R. J. Hackman to discuss lunar educational training projects.
Mehmet Yazar Muammeir Aksoy Ali Orhan Mehmet Ergoktas Istanbul, Turkey	R. J. Hackman to see methods and results of lunar photogeologic interpretation.

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General Information

USGS Observatory

Construction of the USGS Observatory building on Anderson Mesa, 15 miles southeast of Flagstaff is about 70 percent completed. It is expected to be completed by the first of January. Our 30-inch telescope which will undergo final inspection at Astromechanics, Inc., Austin, Texas, in mid-December, is to be installed in the Observatory prior to January 15.

Lunar Investigations

Compilation of the geology of the Timocharis quadrangle by Michael Carr has been completed on a stable base. The quadrangle lies almost wholly within the Imbrian basin, and the dominant geologic unit is the Procellarian formation. Numerous secondary craters related to Eratosthenes and Copernicus lie on the Mare surface in the southern half of the quadrangle; for that reason the crater size distribution in the southern area differs greatly from the distribution in the rest of the Imbrian basin. Copernican secondary craters are generally discrete and shallow with irregular outlines and small or non-existent rims. Secondary craters around Eratosthenes are more elongate than those around Copernicus and tend to grade into furrows radial to Eratosthenes.

The three largest craters that lie within the quadrangle, Timocharis, Euler, and Lambert, all have cratered central peaks. The morphology of the central peaks is, however, different in each case. The central peak in Timocharis is cone-shaped with a large circular crater occupying nearly the whole summit of the peak. An irregular depression occurs on the Lambert central peak and the peak itself has a vague shingled appearance. Euler has several small craters on its ridge-like central peak.

The work of J. F. McCauley on the McMath solar telescope at Kitt Peak has shown that the instrument has a number of inherent advantages which make it particularly suitable for lunar mapping. These include

convenient viewing and efficient use of observing time. In this telescope, a 34-inch diameter image of the Moon is projected by the optical system upon a flat table. Any portion of this image can then be reflected into a viewing lens and observed from a comfortable position by the mapper. The field of view is changed easily by moving the viewer around on the image rather than having to move the image focusing and tracking mechanism. This is in distinct contrast to other telescopes where the observer is frequently in an uncomfortable position or is frequently adjusting his position to compensate for the tracking motion of the telescope. The McMath telescope has a theoretical resolution limit of approximately .07 seconds of arc which is roughly equivalent to 500 feet on the lunar surface. Its f60 primary mirror with a 300 foot focal length reduces the astigmatism and aberration normally present in large telescopic mirrors, and the telescope, under conditions of good seeing, may approach its theoretical resolution limit. The theoretical limit of the 24" reflector at Lowell Observatory is .17 seconds and the 36" Lick Observatory refractor is .12 seconds of arc. These were the two largest telescopes previously available to Geological Survey personnel. Because of the high resolution of the optical system and large image size, the telescope offers promise as a photographic tool. Research toward this end is continuing, and a temporary camera system is now being devised.

Lunar Color Phenomena

As a result of the sighting on October 29 and again on November 27 of "ruby red spots" in the Aristarchus area of the moon by selenographers at the Air Force Chart and Information Center, Lowell Observatory, Flagstaff, Arizona, a lunar spectrograph is being constructed by Kitt Peak National Observatory for the use of Geological Survey personnel observing on the McMath telescope. The instrument will be available for immediate use by observers in the event of future repetitions of this phenomenon.

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Crater Investigations

D. J. Milton is engaged in compilation of the results of recent field work at the Henbury meteorite craters, Australia. A topographic map of the main group of craters has been prepared at a scale of 30 feet to the inch with a five foot contour interval. These consist of an oval crater resulting from the impact of two objects and two circular craters separated from each other and from the oval crater by narrow walls. The geology is being assembled on this base map. The craters are excavated in a series of shale and sandstone beds dipping homoclinally at about 35°, which was capped by a varying thickness of soil and alluvium. Ten bedrock units are being distinguished on the map. None of these crop out through the alluvium outside the craters, so that the stratigraphy was necessarily developed from more or less disturbed blocks in the crater walls. Structural deformation is observable in almost all of the exposed walls, from the edge of the crater floor to the crest, in contrast to the Arizona crater, where small scale structures are largely restricted to the lip area. The overall pattern at the main craters at Henbury shows the bedrock units displaced outward from the centers of impact. The small scale structures show that this displacement was complex in detail. Impact was apparently accompanied by a momentary dilatation, with the consequence that blocks in the crater wall could move to some extent independently of their neighbors. In addition to overthrusting, at a few points underthrusting was observed. Elsewhere, blocks were punched outward with a relative displacement greater than in either the overlying or underlying blocks. It is tentatively concluded, pending construction of cross sections, that the overthrusting is a near surface phenomenon, while the underthrusting occurred at greater depth.

Michael Carr has determined the rate of attenuation of a shock wave in the Coconino sandstone, which must be known before the Hugoniot curve can be determined by the method now being used. Rods of Coconino sandstone 1 inch in diameter have been explosively loaded with rods of C-4 explosive 1 inch in diameter and 1 inch long. The shock speeds measured

ranged from 3.5 km/sec to 2.8 km/sec in the pressure range studied. The rate of attenuation was slower than with aluminum and followed the curve $d = 0.90 + .35t - .0001t^2$ where d is distance along the rod in centimeters and t is time. Thus the equation of the velocity attenuation curve is $u = 3.5 - .0002t$; where v = velocity.

C. H. Roach and G. R. Johnson have started a cooperative project with scientists of the Stanford Research Institute for the purpose of studying the mechanism of shock-induced thermoluminescence in various rock types. In an initial experiment, a block of Yule marble surrounded by momentum traps was explosively loaded with sheet explosive to determine the relation between reflected tensile waves and shock-induced thermoluminescence. Preliminary results of the experiment indicate the shock induced thermoluminescence mechanism is very complicated. A comparison of glow curves of several samples at equal distances from the point of origin of shock indicates that the amount of shock-induced thermoluminescence does not depend solely on peak pressure but varies in detail with the nature of the stress wave to which the samples are exposed. In a general way, the results of this experiment simulated the shock-induced thermoluminescence found in rocks exposed at terrestrial meteorite craters. More refined experiments are planned to attempt to obtain a better understanding of the shock-induced thermoluminescence mechanism.

An irradiator containing 6,000 curies of Co^{60} has been installed in the Solid State Laboratory in Denver. This irradiator will be used in a research program designed to study the influence of stress history on the total number of thermoluminescent type defects in various rock types. The irradiator will also be useful for studying the relations between color centers and geologic history of various menerals.

C. H. Roach and G. R. Johnson were technical participants in the Shoal Event, an underground nuclear explosion in granodiorite near Fallon, Nevada. The Shoal explosion was detonated on October 26 for the purpose of developing techniques for detecting clandestine underground nuclear explosions.