"The contours of Watts' charts have been transformed into tables of rectangular co-ordinates. These co-ordinates are recorded on magnetic tape, and can be transferred to one exchangeable-disc cartridge thus allowing random access to every chart."

A report from W. L. Sjogren summarizes some results as follows:

"*Lunar Physical Shape:* Data from the laser altimeter aboard Apollo 15 and 16 have provided two complete profiles of lunar topography. Elevations are established at approximately every 30 km or one degree of longitude. One profile is at a 25° inclination and the other is at −10° inclination with a latitude displacement of 35° near the prime meridian. Mare Serenitatis, Crisium and Smythii are relatively flat with Mare Smythii the lowest basin. Lunar elevations on ACIC lunar charts do not agree in some areas (i.e. Ptolemaeus-Nubium, 2 km, and the Mare Tranquillittatis region near Theophilus, 2–3 km).

"Solution for the lunar radius of a best fitting sphere was 1737·4 km, having a center of mass offset of 2·5 km toward the earth, 1·2 km east and 1·0 km south. Of course the new reference system being initiated by Moutsoulas should use these new elevation points as strong ties for the global figure.

"*Lunar Gravitation Field:* Analysis of radio tracking data from Apollo 12-16 has revealed many new facts about the mascons and other surface features. Detailed gravity profiles obtained for Serenitatis, Nectaris and Crisium indicate that these mascons are relatively near surface features, disk shaped with tapering edges, all having a mass distribution of 800 kilograms per cm^2. The subsatellite from Apollo 15 has provided new data at low altitude (40–60 km) over the southern hemisphere (to 30°S latitude). Nectaris, Humorum and Orientale have been mapped in detail. Grimaldi has a positive anomaly – the smallest mascon. All large craters observed have negative anomalies. The Apollo 16 subsatellite will provide a profile at an 11 km altitude over Copernicus. The central highlands, the Apennines, and the Marius Hills are positive anomalies. The Altai scarp marks a definite positive ridge in the highlands. The Apennines appear to have had considerable isostatic compensation where as the Marius Hills have not.

"Surface gravity measurements using the accelerometers on the lunar module have correlated well with orbital results.

"Normal points formed on orbits of the Apollo 15 subsatellite data will provide indirect data for the farside gravity field. Some 4000 consecutive free fall orbits must be predicted with a gravity model. We should see improvements over the JPL 15-8 and the Langley 13-13 spherical harmonic models.

"Some 600 surface disks have been estimated to describe the front side local gravity field using primarily the old Lunar Orbiter data. This will be updated with the subsatellite data. Future efforts should be directed towards obtaining direct measurements of farside gravity. If the regions like Hertzsprung, Korolev, and the large hole at 180° longitude are large positive anomalies then Urey's theory of impacting planetesimals for the mascons is realistic and the lava mechanism needs re-evaluation. Relay satellites or a gradiometer in a low circular polar orbit would be ideal. Also combining Soviet data would be helpful if it could be made available."

INTER-UNION WORKING PARTY ON LUNAR LASER RANGING EXPERIMENTS

A joint COSPAR-IAU Working Party on Lunar Laser Ranging, under the Chairmanship of C. O. Alley, was appointed in 1970. In 1971, the International Union of Geodesy and Geophysics (I.U.G.G.) decided to get involved in this cooperation, as a special study group of I.A.G. (International Association of Geodesy).

The U.S.S.R. laser program is conducted in cooperation with France. A French laser retro-reflector was placed on the Moon in the Lunakhod roving vehicle of the mission "Luna 17". Laser echoes were collected from the U.S.S.R. station of Crimea and the French Observatory Pic-du-Midi, although the lunar dust raised by the motion of Lunakhod on the Moon reduced quickly the reflecting power of the mirrors.

The U.S. program was conducted by the U.S. National Group "Lunar Ranging Experiment Team (LURE)" under the Chairmanship of J. E. Faller. The following report is from P. L. Bender:

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"The LURE Team advises the NASA Office of Space Science concerning the work on lunar ranging which is being funded by that office. This work is currently being carried out by the following institutions: The McDonald Observatory, the University of Texas, the Jet Propulsion Laboratory, AFCRL, Wesleyan University, the University of Maryland, the Goddard Space Flight Center, the Institute for Geophysics and Planetary Physics at UCLA, Princeton University, and the National Bureau of Standards. Present activities can be divided into the following categories: (A) ranging activities at the McDonald Observatory; (B) design and construction of apparatus for a new lunar ranging station on Maui (Hawaii); and (C) analysis and interpretation of the range observations obtained at McDonald.

"The lunar ranging operations at the McDonald Observatory under Dr E. Silverberg gives an accuracy of the round-trip travel time for most of this period of 2 nanosec. A substantial number of differential measurements to all three Apollo reflectors during the same observing period have been obtained.

"Dr W. Kaula started some work in summer 1972 at UCLA on a numerical integration of the physical librations using an approximate lunar ephemeris and including third degree terms in the lunar gravitational field. A more complete numerical integration using an accurate lunar ephemeris is now being caried out at JPL by Dr M. Slade and Dr J. Williams. Works has also been developed at Ohio State University.

"The accuracy of our present lunar information, which Dr Mulholland discusses at COSPAR (1972) in Madrid, is not yet close to what we expect. However, the limitation is almost entirely in the theory rather than in the data. New physical libration calculations of increased accuracy are expected to be finisihed at JPL in 1972. We then should be able to very much improve our determinations of the libration parameters and of the differences in coordinates of the retro-reflectors by using differential measurements to the different retro-reflectors obtained within a few hours of each other. The limitation on determining the absolute retro-reflector coordinates to high accuracy will come from the problem of separating polar motion and earth rotation variations from lunar effects with better than one meter accuracy. With data from a single station this could be a slow process, but it will go much more quickly when two or more high-accuracy stations are in regular operation.

"Frequent data of high accuracy at different hour angles from a number of stations in both hemispheres is needed in order to be able to regularly monitor fluctuations in the polar motion and earth rotation down to one day periods.

"The final decision on the location for the planned new lunar ranging station in the Hawaiian Islands was made in the fall 1972. The station will be located at 3000 meters elevation at the top of Mt Haleakala on the island Maui. It will be run by the Institute for Astronomy of the University of Hawaii.

"It is still hoped that spacecraft from the U.S.S.R. will carry additional packages, in accordance with the IAU Working Group statement adopted in Brighton. It is extremely unfortunate that no-one has reported returns from the Luna 17 package recently and that it thus possibly is no longer operating. Because of its location roughly 50 degrees from the center of the Moon, it would have permitted putting an unambiguous limit of a few centimeters on the possible lunar tidal distortion, as well as giving an additional reference point for lunar cartography."

Furthermore, J. D. Mulholland, from MacDonald Observatory reports:

"At the moment, further studies with the typical points are being pursued at the Joint Institute for Laboratory Astrophysics and the Jet Propulsion Laboratory, while the discussion of the full set of some 5000 individual observations proceeds at the University of Texas under the direction of J. D. Mulholland.

"Initial results from the laser observing program (Mulholland, Alley, Bender *et al.*, 1971) showed residuals on the order of a few hundred meters, much of which was due to insufficient knowledge of telescope and reflector locations rather than to ephemeris error.

"At the direction of COSPAR Working Group 1, a report was prepared on standards for distribution and documentation of lunar laser ranging data (Mulholland 1972a). Data from the Apollo Lunar Laser Ranging Experiment are being deposited in a form compatible with these standards in the U.S. National Space Science Data Center which also functions as a COSPAR World Data Center. The facts of each deposition have been submitted to the IAU Information Bureau on Astronomical Ephemerides as well as to other appropriate offices. These data are openly available from the Data Center."

WORKING GROUP GEOLOGY AND GEOPHYSICS OF THE MOON

Membership: G. Fielder (Chairman), E. Anders, R. B. Baldwin, W. E. Elston, B. Levin, J. O'Keefe, S. K. Runcorn, R. G. Strom.

The goal of the Working Group was formulated as follows:

"The principal aim of the Working Group is to assist with the geological and geophysical interpretation of the Moon, in close connection with astrophysical implications. The Working Group might also wish to make recommendations on the most efficient means of analysing the lunar surface and interior including returned samples."

Upon the invitation of NASA Headquarters, the Working Group was involved in the final selection of the Apollo 16 and 17 landing sites.

Recommendations by the experts of the W.G. were formulated as an introduction in the book *The Moon*, IAU Symposium no. 47, Newcastle-upon-Tyne, 22–26 March 1971, S. K. Runcorn and H. C. Urey Editors (D. Reidel Pub. Co. 1972).

The Working Group prepared, under the direction of G. Fielder, an important progress report about the scientific results acquired during the past three years on the geology and geophysics of the Moon. This basic document is following.

A review of the scientific results 1969–1972

1. *Anomalies in the Moon's elemental abundances*

Spectrometric measurements from the Apollo 15 and 16 command modules of the fluorescent X-rays produced by the interaction of solar X-rays with the Moon's surface have shown that maria have relatively low Al/Si ratios and the highlands have higher values of this ratio characteristic of plagioclase-rich materials (anorthosites) (Adler *et al.*, 1972). The highland material returned by Luna 20 and Apollo 16 consisted almost entirely of anorthositic rocks: this lent strong support to the hypothesis that the lunar highlands were, in general, of anorthositic composition.

The bulk composition of the Moon is apparently unique among sampled astronomical bodies; it is neither primitive (solar or chondritic) nor Earth-like. By comparison with solar abundances the elements are consistently depleted, relative to silicon, by amounts which depend chiefly on their volatility. No trace of water in free or combined form has been proved in lunar rocks. Carbon and nitrogen are present in abundances of only 1 to 10 ppm.

No indigenous or noble gases have been found. The depletion of other elements ranges from two to three orders of magnitude for highly volatile metals such as Pb, Bi, Tl, to from ten to three-fold for the somewhat less volatile alkali metals Na and K. The group of noble metals (Co, Ni, Au, Ir, Re, the platinum group, and other metals near the centre of the periodic table) are deficient though by no means volatile. It is generally believed that, on the Earth, these elements were reduced to the metallic form, dissolved in molten iron, and drawn down to form the core. The depletion patterns on Earth and Moon differ, however, gold being more strongly depleted on the Moon by two orders of magnitude. In general the noble metals of the lunar surface rocks have abundances of only 10^{-4} to 10^{-5} times their solar abundances, implying segregation of a metal phase. Apparently the Earth and Moon lost their noble metals in separate events, under different chemical conditions.

The depletions of volatile elements seem to reflect an initial deficiency (probably fractionation during accretion from the solar nebula) rather than a subsequent loss.

Refractory elements (Al, Ca, Sr, Ti, Zr, Th, rare earths) are so abundant in lunar surface rocks that at least their source region of these rocks (upper 200 to 300 km) must have been enriched 3 to 10 fold, originally, over solar abundances.

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