SELENOLOGY

Moon Revealed by Apollo 12

by our Astronomy Correspondent

It is now a little more than a year since the last Moon landing, and NASA marked the anniversary by gathering together some of those responsible for the instruments left behind on the Moon, and one of the astronauts who put the instruments there, Alan Bean. But with the possibility of further cancellations in the Apollo series being openly recognized, the event was not as cheerful as it might have been. Dr Frank Press of MIT, who was there to provide a summary of what has been achieved by the Apollo instrument package, said that it would be a pity if the exigencies of the moment were to deflect the United States from the further exploration of the Moon. The meeting also caught NASA employees looking over their shoulders at the Soviet successes with Luna 16 and 17. Alan Bean for one poured some cold water on the Soviet attempts to explore the Moon from the safety of a control room on the ground: "Apollo 11 brought back 50 pounds of rocks. We brought back 75 pounds. And the Russians on their last one brought back two-tenths of a pound. If the Russians were bringing back 50 and 75 pounds and we were bringing back two-tenths of a pound, think how you'd feel. I don't think we'd be so doggone excited as we (*sic* they?) are about their two-tenths of a pound".

All the experimenters had fascinating tales to tell, but it is the results from the seismometer which have captured the imagination. It is now clear, for example, that tidal strain is causing moonquakes when the Moon is at its nearest to the Earth, an effect which has been looked for on the Earth many times without success. If the only strain present was due to the tidal effect the slip would be first in one direction, and then the other, but oddly the indications are that the slip is always in the same direction. This is interpreted to mean that there is another source of strain within the Moon whose release is triggered once a month by tidal effects, and Dr Gary Latham (Lamont-Doherty Geological Laboratory) and his collaborators have recognized nine locations around the Apollo 12 station where the strain is being released. Each location gives a set of signals that are identical in every respect, and there are nine sets of these matching records, one of which appears to originate within the Fra Mauro crater close to a set of rilles and not far from the Apollo 14 landing site. Fortunately with moonquakes being no stronger than between magnitude 1 and 2 on the Richter scale, there seems to be no threat to the Apollo 14 crew.

What the source of the strain can be is unknown. The total energy release amounts to only 10^{-12} that of the annual energy release by terrestrial earthquakes, however, and this seems to rule out the possibility that the interior can be molten except in a few minor pockets. It could be, Latham speculated, that the Moon is expanding slowly as a result of radiogenic heating. Other possibilities being considered are that a residual effect from large impacts is being observed, or that local hot spots are responsible.

A second type of moonquake which does not fit the monthly pattern has been attributed to the impacts of meteorites, and the frequency and strength of these moonquakes should lead eventually to an estimate of

the amount of rock-sized fragments in space. As a preliminary indication Latham and his group say that kilogram-size meteorites strike the region up to 200 km from the seismometer on average once a month.

What do the experiments say about the interior constitution of the Moon? The key here comes from the seismometer records following the two artificial impacts. The famous reverberations are taken as indicating that the mare is made up of loosely consolidated rubble that becomes increasingly compacted with depth down to at least 20 km, the greatest penetration reached by the artificial signals. This of course rules out a lunar equivalent of the Mohorovičić discontinuity, but leaves several possibilities for the origin of the surface material—pulverization of the original rock by impacts; removal of the original rock by a large impact, followed by flooding of the crater with lava and subsequent pulverization; or even that the rubble represents material swept up from the solar system during the final stage of accretion of the Moon.

Information about depths greater than the 20 km penetration of the seismic signals comes from the magnetometer which indicated a magnetic field of 35 gamma, only 10^{-3} that of the terrestrial field at the equator but more than people expected assuming a cold Moon. This appears to be a paleomagnetic field which could have originated during a conjectured close approach into the Earth's magnetosphere, or by the dynamo process which in turn implies that the Moon at one time had a hot interior. More important for an understanding of what the interior of the Moon is like at present is the comparison of the field measured at the surface of the Moon with that recorded by the space probe Explorer 35 in orbit around the Moon. The comparison indicates that the solar magnetic field is generating eddy currents inside the Moon, detected by the surface magnetometer, and the decay of the currents gives values for the conductivity and temperature. According to Dr Charles P. Sonett (Ames Research Center) reporting for the magnetometer team the data fit a model in which the temperature is increasing into the Moon by 2 or 3 degrees per kilometre. Sonett suggested a core temperature of perhaps $1,000^{\circ}\text{C}$, and if this is not exceeded at the centre then none of the rock need be molten.

The other experiments left by Apollo 12—the solar wind spectrometer and the suprathermal ion detector—refer to the environment around the Moon, chiefly the solar wind, but measurements taken following the impact of the Apollo 13 Saturn 4B stage might have something to say about the constitution of the lunar surface layers. As well as plotting the time variation of the solar wind, particularly as the Moon swings through the Earth's magnetotail, the two instruments picked up what seemed to be swirling clouds of ions shortly after the rocket impact. Oddly enough, the impact was downwind of the instrument package. The suprathermal ion detector recorded the cloud twenty seconds after the impact as a burst of ions with energies up to 500 eV. The acceleration mechanism is something of a mystery. Within a minute or two of the impact the cloud was observed by the spectrometer. According to Dr John Freeman (Rice University) the origin of the ion clouds is less likely to be the remaining fuel in the rocket's tanks, than gases such as helium, argon and krypton held in the surface layers of the Moon.