SELENOLOGY

Lunar Conductivity

from our Geomagnetism Correspondent

IN principle, it is possible to determine the lunar electrical conductivity by measuring the electromagnetic response of the Moon to variations in the magnetic field of the solar wind. In the indirect method, the first step is to calculate the response of a theoretical conductivity distribution and compare it with the response obtained experimentally from magnetometer records. The conductivity structure is then adjusted until the observed and calculated responses agree as closely as possible. Using this technique with data from a magnetometer on the lunar surface and a second magnetometer on the lunar satellite Explorer 35, Sonett *et al.* (*Nature*, **230**, 359; 1971) first obtained an irregular conductivity-depth distribution, the chief features of which were a relatively low surface conductivity and a highly conducting zone at a depth of about 240 km. But Kuckes (*Nature*, **232**, 249; 1971), using the same data, came up with a quite different distribution comprising a uniformly conducting inner sphere and a non-conducting outer shell about 160 km thick. Yet both models agreed with the experimental data to within about one standard deviation.

As Hobbs (*Earth Planet. Sci. Lett.*, **17**, 380; 1973) now points out, if at least two quite different conductivity models can be consistent with the same data, it is reasonable to ask what any model derived from the data means. Accordingly, he has carried out an analysis of the lunar conductivity problem in the light of recent work by Backus and Gilbert (see, for example, *Phil. Trans. Roy. Soc.*, **A266**, 123; 1970) in which the general question of determining infinite-dimensional models from a finite quantity of data is examined. In the case of the Moon, the infinite-dimensional model is the lunar electrical conductivity at all radii, and the finite data are provided by the measured electromagnetic response at various frequencies and the associated estimates of error. Similar considerations would also apply to the Earth, of course; and because data on the response of the Earth to external magnetic field variations are far more abundant than those relating to the Moon, it is instructive at the outset to note the result of applying the Backus-Gilbert ideas to the problem of terrestrial conductivity. As Parker (*Geophys. J.*, **22**, 121; 1971) has shown, the fact is that in spite of the relatively abundant terrestrial data, the conductivity distribution in the Earth is still poorly defined. This emphasizes the importance of determining just what information the more fragmentary lunar

data can give before non-unique conductivity models come to be accepted uncritically as the basis of other investigations.

The specific aim of Hobbs in his first-order analysis was to determine the fineness of detail that can be resolved in the lunar conductivity profile using the available experimental response data. To set a limit on this fineness of detail, he assumed that the data are error free; in other words, if any errors are admitted, the uncertainty in the derived conductivity will be increased. The end product of the analysis is then a smoothed conductivity-depth distribution for each model originally found to be consistent with the data, the models examined being those of Sonett *et al.* and Kuckes.

When the smoothed conductivity profile from Sonett's irregular distribution is compared with that from Kuckes's two-layer distribution, both profiles are found to exhibit little variation in conductivity over the approximate depth range 170–700 km (no estimates are possible below 700 km because there is no field penetration for the frequencies considered) but a lower conductivity in the upper 170 km. In other words, the finest detail resolvable is that of a two-layer model in which the surface layer has a lower conductivity; and the irregularities in the Sonett distribution,

such as the high conductivity zone at 240 km, represent greater detail than the data can sustain. This is not to say that such irregularities do not exist, but only that they are not derivable from a first-order analysis of the available data. Moreover, nor are the smoothed profiles necessarily the most probable or best-fitting distributions; they are merely the smoothest distributions consistent with the data.

The conclusion is, therefore, that in spite of their obvious differences, the models of Kuckes and Sonett *et al.* really only give the same information about the distribution of the Moon's gross conductivity. In view of the fact that both models are based on the same data, this is hardly surprising. But what Hobbs does consider "a little surprising" is the persistence of models containing a thin, highly conducting layer near the Moon's surface. As he has shown, such models are consistent with the data but not derivable uniquely from them; they are the product of inadequate data rather than evidence for the idea of "frescons". Hobbs is thus, in effect, warning against taking the irregular distributions too seriously at this stage and strongly implies that, for example, the lunar temperature profile recently inferred by Duba *et al.* (*Earth Planet. Sci. Lett.*, **15**, 301; 1972) on the basis of the Sonett model is premature.

Sulphur Content of the Earth's Core

EVER since it was discovered that the density of the Earth's outer core is apparently 8–10% lower than the density of pure iron, there has been considerable discussion about the nature of the light component alloying with the iron. Perhaps the most popular contender is silicon, although another possibility—and one that has been receiving increasing attention in recent years—is sulphur. Because of the interest in sulphur, King and Ahrens have carried out a series of shock wave experiments on pyrrhotite to determine whether the equation of state is consistent with the seismic data and (in connexion with a forthcoming report by Usselman) whether the sulphur content inferred is in agreement with the Fe-FeS eutectic composition at core pressures. The results of these experiments are reported in *Nature Physical Science* (June 4) next Monday.

King and Ahrens have obtained shock pressure-density data over the pressure range 198–405 kbar using six pyrrhotite ($\text{Fe}_{0.9}\text{S}$) samples machined from a single crystal, and find that the slope of the resulting Hugoniot is significantly greater than that to be expected on the basis of the ultrasonic data. They conclude from this that the pyrrhotite in the pressure range 289–405 kbar is in a

shock-induced high pressure phase and that at the lowest pressure considered the pyrrhotite is of mixed phase, being only partially transformed to the high pressure phase. The estimated zero-pressure density of the new high pressure phase lies in the range 5.2–5.6 g cm⁻³, which compares with the 4.6 g cm⁻³ of the original material.

By extrapolating the data for the high pressure pyrrhotite phase to the pressure and likely temperature (about 3,500° C) in the outer core (which assumes, of course, that no further phase changes occur) and comparing the result with corresponding pure iron data, King and Ahrens estimate that the core density at the core-mantle interface (9.94 g cm⁻³) is achieved by the presence of 26–31% of the high pressure $\text{Fe}_{0.9}\text{S}$ phase or 10–12% (weight) of sulphur. Further extrapolation throughout the outer core introduces greater uncertainties but, taken at face value, implies a sulphur content of 10–15% to be consistent with the observed profile of pressure-density data.

These new estimates of the supposed sulphur content of the outer core agree well with the values of 10%, 15% and about 9–12% obtained by other workers using different methods.