MAGNETISM AND THE EARLY HISTORY OF THE MOON, D. W. Strangway, NASA Manned Spacecraft Center, Houston, TX 77058, H. N. Sharpe, Lunar Science Institute and Dept. of Physics, Univ. of Toronto, Toronto, Ont. Canada, W. A. Gose, Lunar Science Institute, Houston, TX 77058, and G. W. Pearce, Lunar Science Institute and Dept. of Physics, Univ. of Toronto, Toronto, Ont., Canada

The discovery of remanent magnetization in the lunar samples has led to a variaty of speculations about the source of the magnetizing field. The required field seems to be in the range of a few thousand gammas. If this were due to a dipolar field, it would mean that the moon had a mean dipole moment of 10^{23}cgs units. This is more than 2 orders of magnitude greater than the upper limit of any dipole field which may be present today. All samples studied to date, fall in the age range from 3.2 to 3.9 b.y. and it is therefore a requirement that the magnetizing field was present during much of this time period.

Several workers have speculated that the presence of such a field supports the concept that the moon had a fluid, metallic core which behaved as a self-exciting dynamo at least during this period. This is still a strong possibility but it has been criticized on two major points - a) in order to separate out a metallic core early in the history of the moon a high initial temperature of 500 - 1000°C is required and b) there is a question of whether a slowly rotating, small core (maximum radius 300 - 400 km) could sustain a dynamo. As an alternate possibility Urey and Runcorn have proposed a model in which the moon became magnetized early in its history by an external field and that what we observe today is a remnant of this field.

We consider here an alternate hypothesis to the lunar dynamo, based on these ideas. Consider a moon such as shown in the figure. The inner portion is initially below 780°C, the Curie point of iron, and becomes magnetized by exposure to a field of say 20 gauss before 4.0 b.y. Alfven has pointed out that such a field may have been present early in the history of the moon as a result of a) early plasma instabilities in the solar wind or b) a close approach of the moon to the earth which might create turbulent motions in the earth's core thereby amplifying the earth's field. There is also an outer shell (say 200 km) a) which is initially hot and above the Curie temperature due to accretional energy or b) parts of which become hot early in the moon's history and, if already magnetized, are thermally demagnetized or c) if the exposure to this field took place after differentiation, the iron content of the crust must be sufficiently low that it does not contribute to the main dipole moment. If the inner portion has about 3% iron and if it behaves magnetically like igneous lunar samples such a field would lead to an isothermal remanent magnetization (IRM) of about $1\text{-}2\times10^{-3}$ emu/gm giving a dipole moment of $5\text{-}10\times10^{22}$cgs units and surface fields of 1000 to 2000 gammas.

The crust then cools below the Curie point and acquires a TRM in this residual field. This TRM must be less than 10^{-5} emu/gm in order to satisfy the present magnetic field observations. This implies that the crust has less than 1% metallic iron, consistent with sample observations. Mare basalts were formed, acquiring a TRM magnetization of about 10^{-5} emu/gm and

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explaining local surface anomalies up to a few gammas. Larger anomalies are also present (up to 300 gammas at Apollo 16) and these are probably due to breccia flows. One class of breccias have been found with magnetization up to 10^{-4} emu/gm and these may well be the source for the anomalies observed by satellites.

The last thing to happen in this hypothesis, is that the interior slowly heated up due to radioactive heating until much of the interior is above 780°C, thereby destroying the early IRM, but leaving the TRM of the surface and crustal rocks.

Either the concept of an early dynamo or this elaboration of the Urey-Runcorn-Alfven model, place different but stringent restrictions on models of thermal evolution of the moon.

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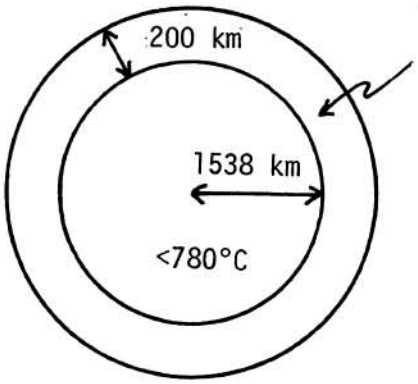
STAGE I
>4.0 b.y.

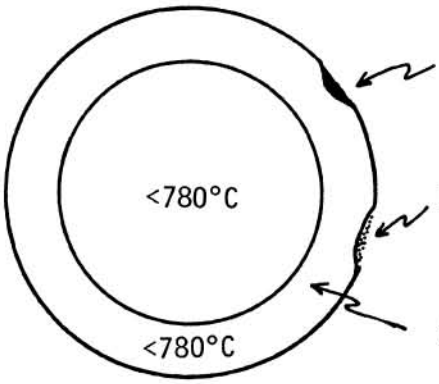


>780°C at some time before 4.0 b.y.

A 20 Oe external field produces an IRM of about 1 x 10^{-3} emu/g assuming a metallic iron content of 3 wt%. The resulting surface field is of the order of 1000γ.

Differentiation to form a crust either prevents a magnetization or thermally demagnetizes the IRM of the crust.

STAGE II
4.0 - 3.2 b.y.



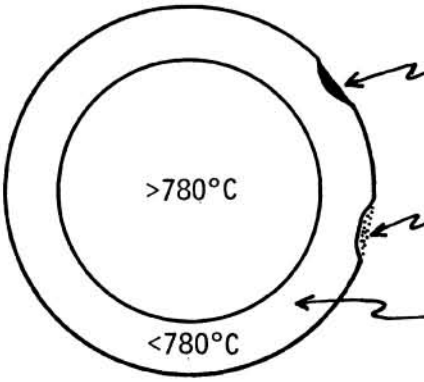
basalt

breccia flow

anorthositic material

acquire a TRM in 1000γ field

STAGE III
<3.2 b.y.



basalt contain ~0.1 wt% Fe, acquired a TRM of about 10^{-6} emu/g.

breccia flows contain 0.3 - 1.0 wt% Fe, acquire a TRM up to 10^{-4} emu/g.

anorthositic material contains <0.1 wt% Fe, acquires a TRM of about 10^{-7} emu/g.