LETTERS TO THE EDITOR

ASTRONOMY

Possible New Evidence bearing on the Lunar Capture Hypothesis

INTEREST in the dynamical history of the Earth–Moon system was stimulated by the calculations of Gerstenkorn[1], who deduced that the Moon was originally an independent planet in a solar orbit close to that of the Earth and that it was captured into a highly elliptical retrograde terrestrial orbit of small perigee. The orbit was brought closer and its ellipticity was reduced by tidal interaction until a dramatically close encounter with the Earth flipped the Moon over into a prograde orbit, from which it has receded to its present position under the influence of tidal friction. Gerstenkorn's theory has been favourably reviewed by Alfvén[2,3] and very similar dynamical histories are deduced in several more recent calculations[4–6]. An exact estimate of the time since the very close approach of the Moon is not possible because tidal friction is dependent on several factors, including variable geometry of the oceans. Estimates vary between $2 \cdot 5 \times 10^9$ yr and $1 \cdot 4 \times 10^9$ yr (refs. 1 and 4).

During the close approach, dissipation of tidal energy within the solid part of the Earth would have been intense, greater than the dissipation by marine tides, and certainly sufficient to cause extensive partial melting in the mantle. Once the mantle had been fluidized by partial melting, however, tidal dissipation (and consequently the rate of change of the lunar orbit) would have been greatly reduced, allowing more time for heat to escape and precluding complete melting. Possibly partial melting would have been restricted to the upper mantle (which is nearer to melting than the lower mantle and also has a lower mechanical Q—that is, greater tidal dissipation[8]), but a dramatic disturbance, at least to the upper mantle, is an inevitable consequence of the lunar capture hypothesis. Absence of geological evidence for such a major disturbance has been regarded as a serious objection to the hypothesis and was one of the reasons which led MacDonald[7] to prefer a lunar origin by accretion in orbit. We draw attention here to recent lead isotope measurements, however, which we interpret as evidence for an upheaval of the kind required by the capture theory.

Published lead isotope measurements on young mantle-derived volcanics[9–14], together with some unpublished measurements, are represented in Fig. 1 as a plot of lead-206/lead-204 against lead-207/lead-204. There is a clear linear relationship with a gradient distinctly less than that of the single stage zero isochron, shown as a broken line, which would apply if the sources of the volcanics had been mutually isolated since the origin of the Earth $4 \cdot 5 \times 10^9$ yr ago[9]. We can therefore impose two boundary conditions on the mantle as a common source for these volcanics: (1) that the lead isotope ratios were uniform at a time geologically long after the origin of the Earth; and (2) that since that time the ratio of uranium to lead has been heterogeneous, so that radiogenic lead isotopes have been added at different rates in different environments.

An estimate of this time dates either the cessation of a long period of homogeneity or a brief event, such as lunar capture, which homogenized a previously heterogeneous mantle. We refer only to homogenization of lead isotope ratios, for which partial melting with some stirring would suffice.

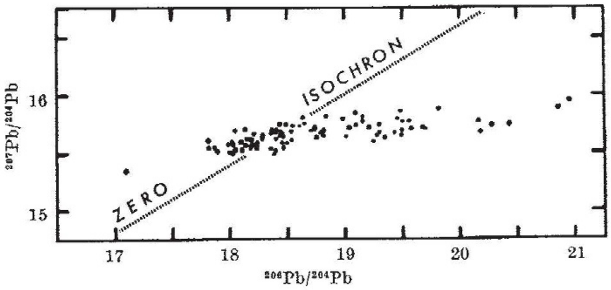

Fig. 1. Plot of lead-206/lead-204 against lead-207/lead-204 for lead isotope measurements on young volcanic material.

We previously estimated the time since mantle lead was isotopically homogeneous at $2 \cdot 8 \times 10^9$ yr (ref. 9). Other estimates from different data[11,12] range down to $0 \cdot 5 \times 10^9$ yr but the lower values were obtained from rocks with very limited isotopic ranges and are therefore of doubtful validity. Using all the data represented in Fig. 1 and allowing for open system processes, which we have considered previously[9], we obtain a preferred value of $2 \cdot 5 \times 10^9$ yr. This is uncertain by at least $0 \cdot 5 \times 10^9$ yr and many more data will be needed to establish or refute our conclusion with any certainty. If the average uranium/lead ratio in the source of the volcanics has remained unaltered during a prolonged multi-stage history[9], or if a simple two stage model is appropriate[10], the estimate of age will be reduced. This does not affect our two essential conclusions, however, and the coincidence of the lead isotope event and Gerstenkorn's original estimate of the time of the close approach of the Moon suggests that they were the same event. If this interpretation of the lead isotope data is accepted it not only removes an important objection to the capture theory of the lunar origin but makes the alternative theory of accretion in orbit much less attractive. Accretion at 40 Earth radii, as proposed by MacDonald[7], would not "switch" on an Earth tide sufficiently violent to account for the lead isotope event, for less than 20 cal/g of rotational energy would be dissipated in the Earth in the following 10^9 yr. Accretion at 5 Earth radii would initiate a tidal dissipation of nearly 80 cal/g in 10^6 yr, which would be sufficient, but the supposition that lunar material could remain in orbit at 5 Earth radii for 2×10^9 yr before accreting (or else suddenly appear in orbit) is difficult to accept. Thus on the present evidence the capture theory of the lunar origin is to be preferred.

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