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Chronology of Early Events in the Eucrite Parent Body According to Hf-W Systematics

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Among meteorites, eucrites are volcanic rocks formed around 4.55 Ga ago. Their old age and the evidence for extinct short lived nuclide testify to the existence of an early magmatic activity in small planetary bodies. Parent bodies suffered another magmatic differentiation as well, related to the metal segregation and formation of iron meteorites. Isotopic studies by different chronometers on iron meteorites argue for an early differentiation. The question is to know if these two magmatic events are related to each other. The ^{182}Hf-^{182}W extinct radioactivity offers an unique opportunity to investigate this problem, since Hf-W fractionation is related to silicate/metal fractionation and the time scale of the ^{182}Hf radioactivity (9 Ma) is able to resolve the problem as already shown (Norman et al., 1983 ; Lee et al., 1995 ; Horan et al., 1998 ; Halliday et al., 1999). The Hf-W system involves two elements of strongly different geochemical properties : Hf is lithophile whereas W is moderately siderophile. The Hf-W chronometer has already permitted a quite important chronology of the early development of the solar system with a good time resolution. To complete the general scheme of the early solar system scenario, we have measured a set of 8 eucrites as well as some iron meteorites.

Eucrites define a straight line in the Hf-W isotopic diagram which is interpreted as an isochron with a slope of (8.11±0.28) 10^{-5} and initial $(^{182}W/^{184}W)_i$ = 0.86464±4 (-0.4 ε). The very high Hf/W ratios support the idea that these rocks derived from a reservoir from which iron was segregated. The ^{182}W excesses in eucrites are the result of an early ^{182}Hf decay. The slope of the isochron yields the ^{182}Hf/^{180}Hf ratio at the time of the last Hf/W fractionation in the source region of eucrites. Assuming a homogeneous initial ^{182}Hf/^{180}Hf ratio in the source region of eucrites, the isotopic variations reflect fractionation between Hf and W during the lifetime of ^{182}Hf. Using Hf-W internal isochrons for three H4 chondrites determined by Lee and Halliday (Lee et al., 2000), a time interval of 11.1±1.5 Ma is calculated between eucrites and the H4 chondrite Forest Vale.

Two events can fractionate Hf and W in the EPB : the iron segregation and the formation of basaltic melts. The iron segregation is the main process because of the high metal-silicate partition coefficient of tungsten. In the diagram of Hf-W isotopic evolution of the solar system, the Earth and the three H4 chondrites studied by Lee and Halliday (Lee et al., 2000) define a straight line in agreement with a chondritic evolution curve of the solar system. Eucrites plot on this line, the parent body had a chondritic composition concerning the Hf/W ratio. When a metal/silicate fractionation occurs on a body during the lifetime of ^{182}Hf, the tungsten isotopic composition in the metal is frozen whereas the resulting high Hf/W ratio in the silicates induces a sharp increase with time of ^{182}W/^{184}W in the silicate portion. If iron segregated in the EPB before formation of the basalts, the evolution curve of the residual mantle would have a sharp slope and the initial ratio of eucrites would not plot on the chondritic evolution curve as observed here. Consequently, we conclude that both differentiation events (iron segregation and formation of basaltic melts) are coeval or that the metal-silicates differentiation occurred only a very short time before partial melting of the mantle. The second hypothesis is reinforced by the high Hf/W ratios in the eucrites supporting the idea that these rocks derived from a reservoir which has already segregated its iron. Thus, both magmatic events probably occurred in a very short time interval of a few million years at a maximum which can not be resolved yet by the Hf-W system. Metal of most ordinary chondrites seem to have formed in the same time interval as iron meteorites and slightly later. According to the W-isotopic evolution curve, the iron of the EPB formed later. It is clear on this graph that eucrites do not correspond to the silicate portion of the same parent body that produced known iron meteorites. It is quite surprising to note that some differentiated meteorites like irons have formed before undifferentiated primitive material like H4 or H5 chondrites and much earlier than the time of eucrite parent body differentiation.

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