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I-Xe STRUCTURE OF ILAFEGH 009 AND SHALLOWATER: EVIDENCE FOR EARLY FORMATION AND RAPID COOLING OF IMPACT-DERIVED ENSTATITE METEORITES:

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Introduction. Enstatite meteorites have proven to be ideal samples for past studies of the I-Xe system [1,2,8]. This work focuses on two enstatite meteorites that were formed by impact processes. Ilafegh 009 is a clast-free impact melt rock from the EL chondrite parent body [3]. The Shallowater aubrite likely formed when a fully molten planetesimal collided with a solid planetesimal, mixing fragments of the solid planetesimal into the enstatite mantle of the molten planetesimal. A complex three-stage cooling history resulted from this mixing and later break-up and reassembly of the parent body [4]. The present study indicates that the I-Xe structure of these two meteorites resulted from *in situ* decay of live ^{129}I and that both experienced xenon closure of the iodine host phase at approximately the same time. I-Xe cooling rates are consistent with the cooling rates derived from mineralogic and petrologic studies of these objects [3,4]. The similarities in ages suggest that the region of the nebula in which enstatite parent bodies formed must have experienced an intense early bombardment.

Results. We have extracted Xe from neutron-irradiated samples of Shallowater and Ilafegh 009 by stepwise heating (Fig. 1a,b). The released gas included trapped xenon of normal composition and minor amounts of fission xenon, but the major contributions to ^{129}Xe and ^{128}Xe were due to the decay of extinct ^{129}I ($t_{1/2}$ = 17 Ma) and ^{128}Xe produced by neutron capture on stable ^{127}I. The radiogenic ^{129}Xe ordinate in Figs. 1a,b is shifted 10% to prevent overlap of the release patterns. Release of both iodine-derived isotopes in concert demonstrates that essentially all of the iodine in the meteorite remains associated (in fixed proportion) with radiogenic ^{129}Xe.

Linear isochrons (Figs. 2a,b) also illustrate the intimate association between radiogenic ^{129}Xe and ^{127}I. These isochrons plot the higher temperature extractions, which represent 96% of the radiogenic ^{129}Xe in Shallowater and >98% for Ilafegh 009. The precision of the slopes of these isochrons (defined by 27 temperature steps for Ilafegh 009 and 17 for Shallowater) corresponds to an uncertainty of about 80,000 years for each with xenon closure occurring in Ilafegh 009 about 400,000 years earlier than in Shallowater (about 1.6 Ma earlier than Bjurbole).

We have obtained cooling rates (Table 1) from the approach to the isochron, assuming that differences in closure temperatures were proportional to differences in extraction temperatures. These cooling rates are qualitatively consistent with cooling rates derived from petrologic studies [3,4]. The impact melt rock Ilafegh 009 cooled at hundreds of °C/Ma at high temperatures, decreasing asymptotically to a few °C/Ma at lower temperatures. The more limited temperature range for Shallowater reflects its narrow release pattern (Fig. 1b). I-Xe cooling rates, which suggest rapid cooling at high temperature with a sharp decrease in the cooling rate at lower temperatures, are consistent with the three-stage cooling history derived from petrological studies [4]. I-Xe does not maintain a reliable record at very low temperatures (~600 °C), at which very fast cooling is indicated by the kamacite-taenite system.

Chronological Significance. Variations in the observed ratio of ^{129}I to stable ^{127}I in the host minerals can, in principle, be due to isotopic heterogeneity instead of radioactive decay. However, the release patterns (Figs. 1a,b), which demonstrate that the ^{129}Xe comes from *in situ* decay of live ^{129}I, and the regular variations of initial iodine with release temperature, interpreted here in terms of cooling rates, both favor chronometric interpretation. The observation that the I-Xe chronometer seldom seems to agree with other chronometers [5] does not invalidate the I-Xe chronometer. In fact, we might not expect similar results from other chronometers which are dominated by other host phases. Instead, we should focus on the meaning of the I-Xe chronometer, especially for the enstatite meteorites.

The interpretation of the I-Xe structure depends critically on the siting of iodine in the meteorite. In many cases iodine is predominately located in secondary phases such as sodalite and apatite [6,7], and the I-Xe system reflects the chronometry of *secondary* processes (explaining, to a large extent, the discordancy with other chronometers). In the enstatite meteorites, the host phase is probably the major mineral enstatite [5,8] and here the I-Xe structure reflects crystallization and closure of this mineral.

Implications. Although Ilafegh 009 and Shallowater formed in different ways and on different parent bodies, impact played a role in the formation of both meteorites. It is interesting that the iodine-bearing phases of both meteorites closed for xenon within 400,000 years of each other. Even if isotopic heterogeneity should play some role in establishing the initial isotopic ratio, ^{129}I *does* decay to ^{129}Xe and the inferred time differences can then only *overstate* the actual differences in xenon closure times. Further, I-Xe studies of Happy Canyon [2], another impact melt form the EL parent body [3], indicates formation at essentially the same time, midway between Shallowater and Ilafegh 009. Thus, the impact events which formed Shallowater, Ilafegh 009 and Happy Canyon must have occurred essentially simultaneously, suggesting an early epoch of bombardment that was intense and terminated abruptly in the region of the solar nebula in which the enstatite meteorites formed.

References. [1] Hohenberg (1967) *EPSL* **3**, 357-362. [2] Kennedy *et al.* (1988) *GCA* **52**, 101-111. [3] McCoy *et al.* (1992) *LPSC XXIII*, 869-870. [4] Keil *et al.* (1989) *GCA* **53**, 3291-3307. [5] Swindle and Podosek (1990) In *Meteoritics and the Early Solar System* (eds. Kerridge and Matthews), 1127-1146. [6] Nichols *et al.* (1992) *Meteoritics* **27**, 268. [7] Swindle *et al.* (1988) *GCA* **52**, 2215-2227. [8] Kennedy (1981) Ph.D. Thesis, Washington Univ., St. Louis.

Table 1. Inferred I-Xe Cooling Rates (°C/Ma)

Temperature (°C)	Ilafegh 9	Shallowater
800	7.5 ± 1.2	
1000	3.5 ± 0.3	
1200	4.7 ± 0.2	
1400	43.6 ± 2.3	5.5 ± 0.3
1600	908 ± 500	4.7 ± 0.1
1800	~infinite	1500 ± 1500