THE I-Xe SYSTEM IN LODRANITES SUGGESTS IMPACT-RELATED RAPID COOLING.

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Introduction: Lodranites are a class of primitive achondrites, in the same clan as acapulcoites – they may in fact represent a continuum [1, 2]. Lodranites are coarse-grained (540-700 µm) olivine- and pyroxene-rich rocks, depleted in troilite and plagioclase; acapulcoites are finer-grained (150-230 µm), with approximately chondritic abundances of olivine, pyroxene, plagioclase, metal and troilite [3, 4]. Rare, relict chondrules have been reported in several acapulcoites, confirming that their precursor material was chondritic [3, 5]. These differences suggest lodranites reached higher peak temperatures and so experienced higher degrees of partial melting than acapulcoites, with associated loss of some metal/sulfide. The larger grain size implies they cooled more slowly.

It is tempting to view acapulcoites and lodranites as chondritic meteorites in which the continuum of thermal processing represented by variations in petrologic type is extended to the point of melt generation and, in the case of lodranites, partial extraction. However, among chondrites concentrations of primordial noble gases decrease strongly with increasing petrologic type [6], while acapulcoites and lodranites have high concentrations of primordial gases, much higher than those of more evolved achondrites [7, 8]. I-Xe data suggest closure of ordinary chondrites to Xe loss was increasingly late with increasing thermal processing, but phosphates in Acapulco closed to xenon loss ~30 to 50 Ma earlier than phosphates in H6 chondrites [9].

Experimental: Samples from three lodranites have been studied: Graves Nunataks 95209 (GRA 95209), Lewis Cliff 88280 (LEW 88280) and Gibson. GRA 95209 shows a number of properties intermediate between acapulcoites and lodranites, and may be termed a transitional lodranite. It is noteworthy that the smaller average grain size observed for GRA 95209 may indicate faster cooling than typical of lodranites in general.

Samples were coarsely crushed and a magnetic separate produced using a hand magnet, prior to irradiation. Aliquots of Shallowater were also included in the irradiations to monitor the ^{127}I to ^{128}Xe conversion. After irradiation Xe isotope ratios were measured using the RELAX mass spectrometer [10, 11] for all the samples and the aliquots of Shallowater. In total 9 samples of GRA 95209, 5 samples of LEW 88280 and 2 samples of Gibson were analysed.

Results: The ages of those samples which yielded high temperature isochrons are summarised in Table 1.

Two metal and one silicate separate from GRA 95209 gave ages that are consistent with each other (and with the I-Xe age of Acapulco feldspar [9]), yielding a mean closure age of -4.19 ± 0.53 Ma relative to Shallowater. This leads to an absolute age of 4558.1 ± 0.7 Ma (adopting 4562.3 ± 0.4 Ma as the absolute age of Shallowater [12]).

An age of -10.4 ± 2.3 Ma relative to Shallowater has been determined for one whole-rock sample of LEW 88280. No isochron was observed in the metallic or silicate separates

No sample of Gibson produced a correlation from which an I-Xe age could be extracted. In fact, while some ^{129}Xe* was observed, model formation intervals were uniformly late, suggesting any chronological record from the I-Xe system in this meteorite has been overprinted by late addition of iodine.

Discussion: Identical I-Xe ages for Acapulco feldspar and our metal and silicate separates from GRA 95209 suggest a period of rapid cooling. Pellas et al. [13] proposed a cooling history for the acapulcoite parent body. They estimated that the parent body cooled from its peak temperature through ~720 K at a rate of 100 ± 40 K Ma^{-1}, followed by slow cooling below ~720K for consistency with fission track and Ar-Ar data. Incorporating a revised Pb-Pb CAI age [14] would lead to slightly slower average cooling rate of ~80 K Ma^{-1}. These estimates are orders of magnitude less than that implied by petrographic and metallographic observations (e.g. [3]), however there is no inconsistency since this cooling rate is an average from the time the material achieved peak temperature until the setting of the Pb-Pb system as phosphates cooled through ~720K.

Rapid cooling from high temperature such as that observed for the acapulcoites requires a change in the characteristics of conductive cooling to the surface – material must be deeply buried until a high temperature is achieved, then find itself in an environment nearer to the surface to allow rapid cooling. Such a transition might be a consequence of impact removal of overlying layers or of disruption of the parent asteroid, and could have occurred at any point after peak temperature had been achieved up to the time recorded by the closure of the phosphate Pb-Pb system. An average cooling rate based on the modified calculations of Pellas et al. [13] is thus consistent with a brief period of extremely rapid cooling as required by the petrographic and metallographic data.

Such an interpretation accounts for the I-Xe data. A uniform average cooling rate would require the host phases of correlated iodine in our metal and silicate separates from GRA 95209 and Acapulco feldspar to have closed within the same ~200 K temperature range. Their agreement is more easily understood if cooling occurred more rapidly – this allows phases with different closure temperatures to record the same time, within error. Thus we propose that the I-Xe ages of Acapulco feldspar and our GRA 95209 metal and silicate separates record rapid cooling of the parent material that began after an impact removed material from, or fragmented, the parent body, leaving the source region closer to the new surface. In accordance with our data, this occurred at -4.19 ± 0.53 Ma relative to closure of Shallowater enstatite. Assuming the I-Xe closure intervals for metal and silicate separates from GRA 95209 and Acapulco feldspar correspond to rapid cooling, the later I-Xe age of Acapulco phosphate requires that it closed to xenon loss during the period of slower cooling through lower temperatures.

Fig. 1 shows a schematic representation of the cooling of the material sampled by Acapulco and GRA 95209 compared to the H6 chondrite Kernouve. The acapulcoite/lodranite parent body undergoes a period of rapid cooling constrained by our I-Xe data whereas the H chondrite parent body cools in a manner consistent with the models of Bennett et al. [15].

Fig. 1 illustrates how the intervals calculated in the I-Xe and Pb-Pb systems between phosphate closure in Acapulco and Kernouve can be consistent [9] even though absolute closure times differ. The line AB represents the minimum possible time difference between closure to I-Xe for Acapulco and Kernouve phosphates – 28.2 Ma [9]. AC represents the maximum possible time difference – 40.2 Ma. In Fig. 1 line ABC illustrates the highest temperature at which these age differences can be satisfied (847 K) and oldest ages at which closure of the Acapulco and Kernouve phosphates could have occurred (9.4 Ma and 40.2 Ma after the start of the solar system respectively). At temperatures below 720 K it is always possible to satisfy the condition of the differences in the relative ages – thus the agreement between I-Xe and Pb-Pb intervals is met even if the absolute ages are not comparable.

The I-Xe isochron age for the LEW 88280 chip may provide a hint that this sample cooled more slowly than GRA 95209. The release of correlated iodine occurs in a similar relationship to releases of fission Xe and ^{131}Xe by neutron irradiation from either barium or tellurium as is observed in the silicate sample of GRA 95209, suggesting that it relates to a similar phase and thus records cooling through a comparable temperature. The larger grain size of this sample may also reflect slower cooling of the end-member lodranites than acapulcoites and intermediate samples such as GRA 95209.

Sample Name	Description	Mass (mg)	Formation Interval (Ma)		Absolute Age (Ma)*	
GRA 95209, L4B	Metal	0.2	-4.17	0.73	4558.2	0.8
GRA 95209, L4D	Metal	0.04	-4.11	0.86	4558.3	1.0
GRA 95209, GRS2	Silicate	0.36	-4.6	1.7	4557.7	1.7
LEW 88280 Chip	Whole Rock	3.7	-10.4	2.3	4551.9	2.3

Table 1. Summary of I-Xe chronological data from samples that yielded isochrons.
*Using Shallowater age of 4562.3 ± 0.4 Ma [12]

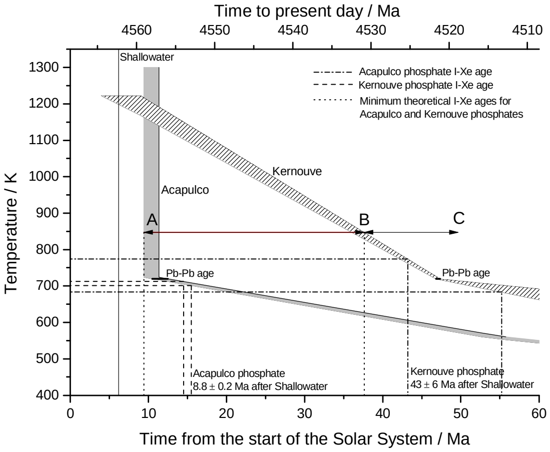

Fig. 1. Approximate cooling rates for Acapulco and Kernouve (H6). The Pb-Pb ages of the phosphates from the two meteorites are treated as fixed points in time at a fixed temperature of 720 K [16, 17]. The I-Xe ages [9] are related to the Pb-Pb time-scale using the absolute age of Shallowater [12]. The parent bodies are assumed to reach peak temperature 4 Ma after the Pb-Pb age of CAIs [13], and the cooling of the H chondrite parent body is then assumed to be consistent with the models of Bennett et al. [15].

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