^{39}Ar-^{40}Ar DATING OF THREE ENSTATITE CHONDRITES AND THE SHALLOWATER AUBRITE;

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Radiometric determinations of the chronological histories of the enstatite chondrites and their igneous-derived analogs, the aubrites, are much fewer than chronologies of the ordinary chondrites and the basaltic achondrites. Formation ages of 4.5-4.6 Ga have been reported for many individual meteorites, whereas other meteorites show younger ages due to shock heating and other metamorphic processes that have operated on their parent bodies. ^{39}Ar-^{40}Ar ages are particularly sensitive to resetting by thermal events, and ^{39}Ar-^{40}Ar ages younger than 4.4 Ga are common among shocked chondrites and brecciated achondrites.

Enstatite Chondrite Ages: A whole rock Rb-Sr isochron of 4.52 ± .03 Ga (lambda = 1.42e-11) was determined for several enstatite chondrites (1). Individual mineral isochrons, however, showed varying degrees of disturbance; isochron ages (in Ga) were Abee (EH4) = 4.51, Indarch (EH4) = 4.39 ± .04, Saint Mark's (EH5) = 4.34 ± .05, and Saint Sauveur (EH5) = 4.46 ± .05. The younger ages were interpreted as being caused by shock metamorphism up to 200 Ma after their formation (1). U-Th-Pb data for three clasts from Abee (a breccia) are consistent with an age of 4.58 Ga, and two of these clasts suggest ^{39}Ar-^{40}Ar ages of 4.4-4.5 Ga (2). ^{39}Ar-^{40}Ar "ages" of three chondrules from Qinzhen (EH3) varied between 0.8 and 4 Ga, and "ages" for laser extractions of the sulfide mineral djerfisherite, which contains much of the K in Qinzhen (3), varied between 1.7 and 4.4 Ga (4). The Rb-Sr model age for a djerfisherite grain was 4.73 ± .09 Ga (5). These authors speculated that elevated initial $^{87}Sr/^{86}Sr$ ratios in Qingzhen, Indarch, and Abee may have been caused by metamorphism. Eleven enstatite chondrites yielded $^{129}Xe/^{127}I$ isochrons, with an apparent 4 Ma difference between EL and EH (6), consistent with the conclusion (7) that EL and EH chondrites originated from different parent bodies.

New Results: ^{39}Ar-^{40}Ar age determinations for the enstatite chondrites Pillistfer (EL6), Khairpur (EL6), and Saint Marks (EH5) are shown in Fig. 1 as a function of cumulative release of ^{39}Ar (produced by neutron irradiation of ^{39}K) during stepwise gas extraction. For St. Marks, Ar released above 35% cumulative ^{39}Ar release gives an average $^{39}Ar/^{40}Ar$ age of 4.36 Ga; the maximum observed age of 4.42 Ga may have been elevated by small amounts of ^{39}Ar recoil and redistribution during the irradiation. The average age of 4.36 Ga is essentially identical to St. Marks' Rb-Sr isochron age of 4.34 ± .05 Ga (for which two measurements fell off the isochron). This agreement indicates that St. Marks did experience a significant thermal event approximately 0.15 Ga after its formation. St. Marks also shows additional, later loss of ^{40}Ar from less retentive phases. Pillistfer and Khairpur show complex release curves (discussed below) with lower apparent ages for more retentive phases compared to less retentive phases. The average age is 4.47 Ga for Pillister and 4.53 for Khairpur. Both $^{39}Ar/^{40}Ar$ ages are within uncertainties of the 4.52 ± .03 Ga whole-rock, Rb-Sr isochron age determined by (1) for EH chondrites. Neither meteorite shows substantial loss of Ar at low extraction temperatures, suggesting no later thermal events of any consequence. These are the first reported ages of this type for EL (as opposed to EH) chondrites.

Aubrite Ages: A Rb-Sr isochron age of 4.57 ± .04 Ga (lambda = 1.42e-11) was reported for Norton County, but an evolved initial 87Sr/86Sr and the fact that feldspar did not lie on the isochron indicated metamorphism ca. 120 Ma after formation of the meteorite (8). An early investigation (9) reported apparent $^{39}Ar/^{40}Ar$ ages for Pena Blanca Springs between 5.2 and 4.2 Ga and for Bishopville between 4.6 and 3.0 Ga. Keil (7) recently summarized evidence for aubrites being derived from an enstatite-like parent body different from the parent bodies of EH and EL chondrites. Keil et al (10) also defined a very complex cooling history for Shallowater, the only known unbrecciated, igneous aubrite, and suggested that this history involved break-up and gravitational reassembly of a partially molten enstatite parent body. These authors concluded that Shallowater came from yet a fourth distinct enstatite parent body. *New Results:* Fig. 1 gives our $^{39}Ar/^{40}Ar$ results for Shallowater. Except for a small dip near the mid-point, the age-release curve is essentially flat and gives an average age for Shallowater of 4.53 Ga. This age is in agreement with the whole-rock Rb-Sr isochron age for EH chondrites (1), with ages determined for the Abee breccia, and with our $^{39}Ar/^{40}Ar$ ages for Pillister and possibly Khairpur. The Shallowater age appears older than the $^{39}Ar/^{40}Ar$ and Rb/Sr ages for Saint Marks, the Rb-Sr age for Indarch (1), and $^{39}Ar/^{40}Ar$ ages for Quinzhen (4), all EL chondrites. Shallowater may also be slightly older than the inferred metamorphic Rb-Sr age for Norton County (8). The old Ar age for Shallowater is consistent with its determined $^{129}Xe/^{127}I$ isochron (11). There is no evidence in the Shallowater Ar-age release of the metamorphic event experienced by the EH parent body. The complex cooling history of

Shallowater (10) must have occurred within a short time after its formation, a situation apparently unlike that for mesosiderites (12) and for several eucrites.

Details of Ar Release: In Quinzhen the iron-sulfide mineral djerfisherite contains much of the K and also significant amounts of Cl (3). Neutron irradiation produces "built-in" Ar tracers for K (^{39}Ar), Cl (^{38}Ar), and cosmogenic Ar from Ca (^{37}Ar). Fig. 2 shows the release of ^{39}Ar, ^{38}Ar, and the $^{36}Ar/^{38}Ar$ ratio as a function of cumulative release of ^{39}Ar for Khairpur. The $^{36}Ar/^{38}Ar$ ratio is produced by a mixture of trapped, primitive gas (36/38 =5.35), modest amounts of cosmic ray spallation gas (36/38 =0.6) and ^{38}Ar produced from Cl. ^{39}Ar (and ^{40}Ar) released from Khairpur suggests two phases that degas at different temperature, but only the higher temperature phase releases significant amounts of ^{38}Ar from Cl and shows intermediate values of the $^{36}Ar/^{38}Ar$ ratios (ca. 2). [The release of ^{37}Ar (not shown for clarity) suggests that cosmogenic Ar is also primarily released from the higher temperature phase.] Saint Marks does not show distinct phases in ^{39}Ar release, although both ^{38}Ar and ^{39}Ar increase with increasing temperature. If the high-temperature, Cl-containing phase in Khairpur (and to a lesser extent, Pillistfer) is djerfisherite, it is associated with the somewhat younger $^{39}Ar/^{40}Ar$ ages, which are similar to the $^{39}Ar/^{40}Ar$ and Rb-Sr age of St. Marks (Fig.1). We could speculate that the metamorphism which reset ages of some EH chondrites primarily affected the K-bearing sulfide phase, and that a similar metamorphism also affected the inferred sulfide phases in the EL chondrites Khairpur and Pillister. If so, the silicate phases of Khairpur and Pillister could suggest ages of ~4.55-4.6 Ga.

References: (1) Minister et al, EPSL *44*, p420, 1979; (2) Bogard et al, EPSL *62*, p132, 1983; (3) El Goresy et al, Meteoritics *18*, p293, 1983; (4) Mueller & Jessberger, LPSC XVI, p595, 1985; (5) Podosek et al, Meteoritics *25*, 1990; (6) Kennedy et al, GCA *52*, p101, 1988; (7) Keil, Meteoritics *24*, p195, 1989; (8) Minster & Allegre, EPSL *32*, p191, 1976; (9) Podosek, GCA *35*, p157, 1971; (10) Keil et al, GCA *53*, p3291, 1989; (11) Hohenberg EPSL *3*, p357, 1967; (12) Bogard et al, GCA *54*, p2549, 1990.