THE METAMORPHIC, SHOCK AND BRECCIATION HISTORY OF EUCRITE ASSOCIATION METEORITES. J. David Batchelor and Derek W.G. Sears, Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701.

Introduction. The eucrite-association meteorites show petrologic and radiometric evidence for a complex metamorphic, brecciation and shock history. Exsolution lamellae and compositional gradients in the pyroxenes suggest varying degrees of metamorphism for the eucrites [1-3] (and sorting into the 'equilibrated' and 'unequilibrated' classes [4]), and mesosiderites have been sorted into types 1-4; type 4 even experienced partial melting [5,6]. The mesosiderite breccias have also been sorted into compositional classes A (feldspar >24%), B (feldspar <21%) and C (feldspar 0-5%) [7,8]. Similarly, the howardite breccias may be classified according to the relative amounts of eucrite and diogenite material [9]. Radiometric evidence for a complex thermal history includes: the Sm/Nd and Pb/Pb ages of the cumulate eucrites are significantly lower than other eucrites (4.41-4.46Ga [10-12] c.f. 4.53-4.54Ga [13]); the Estherville mesosiderite has a Rb-Sr whole-rock age of 4.24Ga compared with a mesostasis-free age of 4.53Ga [14,15]); Ar/Ar ages for eucrites and mesosiderites cluster around 3.5-3.7Ga [16] - LEW85302 is unusual, its low-temperature Ar yields an age of ≤1Ga [16]. It is unclear whether the low cumulate ages reflect different source magmas or slower cooling. Estimates for burial depths required for the latter explanation range from <100km [12] to about 10km [17], but depend on assumed closure temperatures and thermal conductivities; the current diameters of three basaltic asteroids show that depths ≥3.5km were possible [18]. There is also petrologic evidence that LEW85303 (paired with LEW85302) has been shocked [19], and this is presumably also the explanation for the low whole-rock age of Estherville [14,15]. The utility of induced thermoluminescence (TL) studies in understanding chondrite thermal history [20], including brecciation [21], has led us to apply the technique to the meteorites of the eucrite-association [22]. We have now completed a study of the TL properties of homogenised 150-500mg samples of 32 HEDs, 7 splits of the Bholghati howardite and 15 mesosiderites.

Results. EDX spectroscopy and TL of mineral separates (plagioclase, pyroxene, chromite, ilmenite) showed that feldspar was the only significant source of TL. The TL curves for most of these samples showed two peaks (115±5°C and 195±9°C), the low-temperature peak dominating except for LEW85303 and some diogenites (Fig. 1). Heating a cumulate, unequilibrated and equilibrated eucrite at 400, 600 and 700°C for 96 hours did not affect the TL curves, but heating at 800, 900 and 1000°C caused the 115°C peak to move to 160-200°C. In contrast, the TL curves for LEW85303 were not affected by these heat treatments.

All eucrite-association meteorites have low TL sensitivities relative to ordinary chondrites. Among the eucrites, two cumulates have the highest TL sensitivities, followed by the equilibrated eucrites, the remaining cumulate (Moore County), the unequilibrated eucrites, and finally the unusual Ibitira and LEW85305, which are extrusive lavas [23-25]. Howardites generally have TL sensitivities intermediate to equilibrated and unequilibrated eucrites. The howardite with the lowest TL sensitivity (LEW85313) is unusual for its high abundance of diogenitic material [26], while the howardite sample with the highest value, comparable to those of the equilibrated eucrites, is a eucritic clast from Bholghati. Bholghati matrix samples have TL sensitivities comparable to the lowest howardite values. The mesosiderites show an especially wide range of TL sensitivities, with values decreasing along the A-B-C series. There is also possible evidence for a relationship between TL sensitivity and metamorphism within chemical class A, with mesosiderites of type 3 having the highest TL sensitivity and type 1 the lowest. Mesosiderites of type 4 have low TL sensitivities. Four of the 5 mesosiderites with the lowest TL sensitivities are from the Antarctic, and weathering may have significantly lowered their values.

Discussion. The low TL sensitivity of eucrite-association meteorites, relative to ordinary chondrites, is due to the calcic nature of the feldspar [27], or, in the case of the diogenites and RKPA79015 (an unusual 2C mesosiderite with diogenitic silicates [28,29,8]), to the virtual absence of feldspar. Regolith working and brecciation also caused a decrease in TL sensitivity due to the shock and fusion of individual grains and clasts and the addition of low-TL sensitivity material, as in the gas-rich ordinary chondrites [21]. The low TL sensitivities of type 4 mesosiderites reflect the melting of feldspar. Some variations in TL sensitivity of howardites and mesosiderites are clearly due to the mixing of eucritic and diogenitic materials.

The factor of 5 difference in TL sensitivities between equlibrated and unequilibrated eucrites, and probably the range shown by the class A mesosiderites, is best understood as being due to metamorphism.

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Devitrification rims around glass clasts have been observed petrologically [2], which suggests that metamorphism caused the production of feldspar from glasses. The data are therefore independent evidence for a metamorphic series in the eucrites and, probably, the mesosiderites. The TL peak temperature data show that the last sustained high temperature experienced by most eucrites, howardites and mesosiderites was ≤800°C. By comparison, three-pyroxene geothermometry yields metamorphic temperatues of 747-1080°C, depending on the calibration plot used. Oxygen isotope data for plagioclase and pyroxene separates [30] and recent calibration data [31] generally give 700-1000°C, while the data for the related LEW86010 give 820±80°C [32]. Exsolution features suggest equilibration temperatures of about 900°C [33]. Calculations based on the homogenization of pyroxenes at 1000°C and a regolith thermal model led [1] to suggest burial depths for equilibrated eucrites of 150m. Using the same model, our value of <800°C for the equilibration temperature yields >350m depths. (The value for unequilibrated eucrites (<50m) is unchanged.) The metamorphism recorded by the TL data could have resulted from large-scale bombardment at 3.6-3.7Ga and the generation of a deep regolith and regolith metamorphism [16], or metamorphism may have occurred much earlier and the 3.6-3.7Ga event recorded by the Ar/Ar data did not involve temperatures much above 800°C. Our calculated burial depths for equilibrated eucrites are then consistent with the slow cooling rates needed to understand the cumulate and non-cumulate Sm/Nd and Pb/Pb ages in terms of a common magma. Most recently, LEW85302/303 suffered intense shock-heating to ≥1000°C ≤1Ga ago [16,19].

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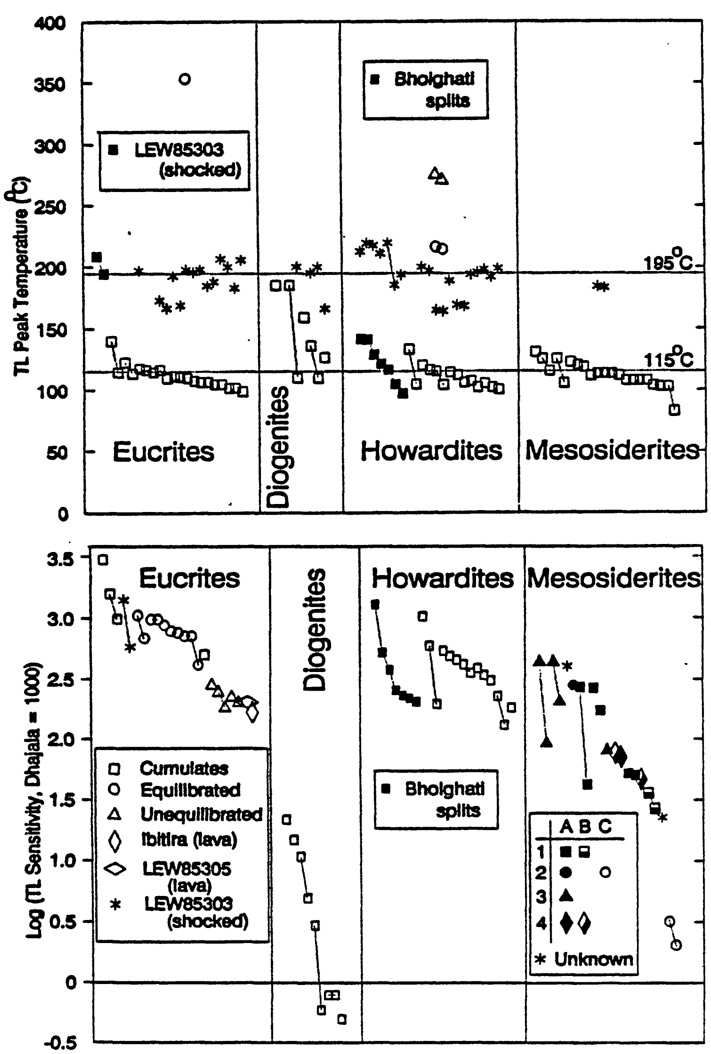

Fig. 1. (Upper) TL peak temperatures for eucrite-association meteorites. Up to four peaks may be present. In order of increasing peak temperature these are plotted as squares, asterisks, circles and triangles. Tie-lines connect splits.

Fig. 2. (Lower) TL sensitivities of eucrite-association meteorites normalized to the H3.8 ordinary chondrite Dhajala. The symbols for each class are explained in a key.