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METAMORPHISM OF EUCRITES AND EUCRITE-RELATED METEORITES AND IMPLICATIONS FOR PARENT BODY SOURCES.

D. W. G. Sears, S. J. K. Symes, and P. H. Benoit, Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville AR 72701, USA.

Introduction: Exsolution structures in pyroxene [1] and induced thermoluminescence (TL) data [2,3] suggest that eucrite and related meteorites have experienced significant levels of metamorphism on their parent bodies. In this respect, they are quite different from otherwise mineralogically and chemically similar lunar samples [4]. Eight petrologic types of eucrite have been defined on the basis of the heterogeneity and presence of exsolution structures in the pyroxenes and TL sensitivity. On the basis of pyroxene compositions and lamellae widths, metamorphic temperatures and cooling rates of, typically, 850°–900°C and 40°C/10^4 yr have been proposed [1,5,6]. Identifying the physical conditions under which metamorphism occurred, and the relative timing of metamorphism and brecciation, would provide insights into the parent body and eucrite history.

Evidence: Whole-rock-induced TL data are shown in Figs. 1 and 2. We have interpreted the peak temperature data with the help of heating experiments (Fig. 3) [2,3]. We find that heating the samples at temperatures above 800°C causes the TL peak temperature to increase from 120° to 220°C. We have performed these experiments with a wide variety of feldspar-bearing samples, and all plagioclase feldspars (including the most anorthitic) show this behavior. We have not identified the cause of this increase, but a similar change in peak temperatures occurs in terrestrial feldspars (Fig. 4) where it is associated with an increase in the Δ2θ parameter, suggesting that it is related to structural disordering [7]. However, the effect is indirect since the activation energy for the TL change is 10–20 kcal/mol [8] compared with ~70 kcal/mol for disordering [9]. Taken at the simplest empirical level of interpretation, the TL data suggest that most eucrites experienced metamorphism at temperatures below 800°C, broadly consistent with geothermometry based on mineral pairs. The TL data also provide a quantitative means of assigning the eucrites to petrologic types that are otherwise fairly qualitative.

An exceptional eucrite is LEW 85300 and its many pairings [10]. These meteorites have TL glow curves with a broad high-temperature peak very similar to that of normal eucrites heated >1000°C and lunar samples. We suggested that these meteorites had been severely shock heated, a conclusion that was borne out by petrographic observations [11].

Data for Clasts and Matrix Samples: All the clast and matrix separates from the LEW 85300 group have the same unusual

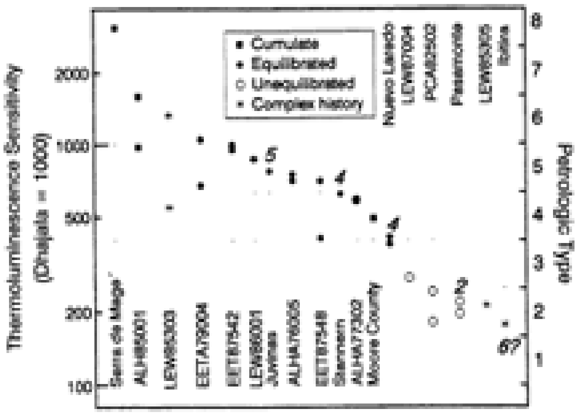

Fig. 1. Induced TL sensitivities for eucrites showing the petrologic types. We have suggested that the TL sensitivity increases with metamorphism as Fe diffuses out of the feldspar and into the pyroxenes.

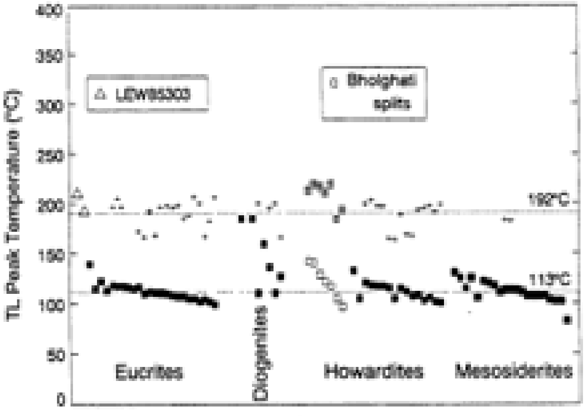

Fig. 2. Induced TL peak temperatures for eucrite, howardite, and mesosiderite meteorites. Minor peaks are indicated by a cross.

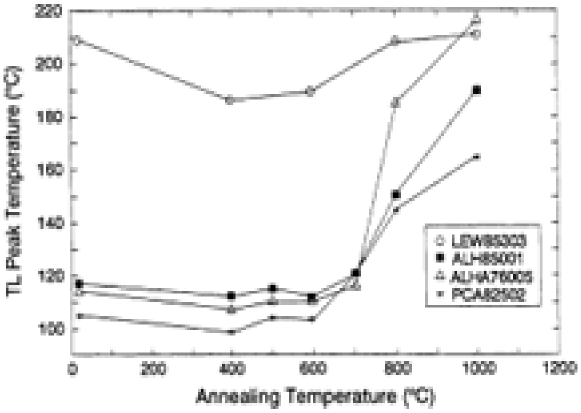

Fig. 3. Induced TL data for four eucrites as a function of heating temperature. The four eucrites were annealed for 96 hr.

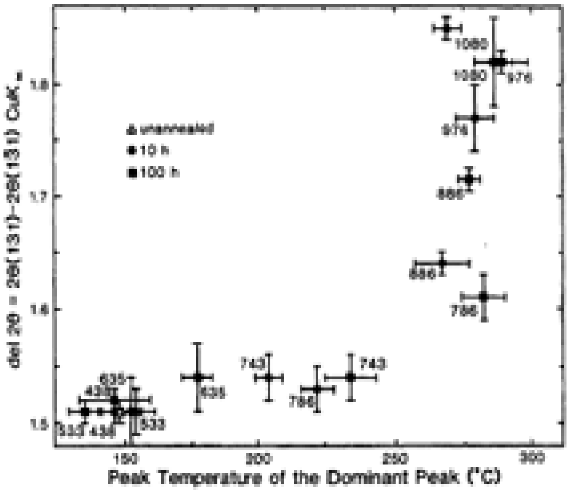

Fig. 4. Increases in peak temperature upon heating compared with the Δ2θ parameter, a measurement of the degree of structural disordering in a terrestrial oligoclase. The numbers alongside the data points refer to temperatures in °C. We suggest that the change in peak temperature is associated with disordering; however, the activation energy for the TL changes is considerably less than that required for disordering, so the effect must be indirect. Pasternak [22] suggested that the TL was reflecting defect production that preceded structural disordering.

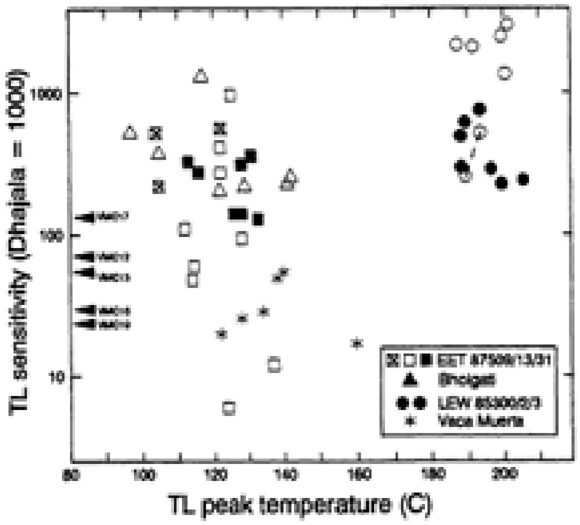

Fig. 5. TL sensitivity against TL peak temperature for the dominant peak (or the low-temperature peak when both peaks are of approximately equal intensity) in clasts (open symbols), matrix samples (filled symbols), and bulk samples (symbol with cross) of two howardites (EET 87509/13/31 and Bholgati), an atypical eucrite (LEW 85300/2/3), and a mesosiderite (Vaca Muerta). Peak-temperature data are not available for five Vaca Muerta clasts but their TL sensitivities are indicated by arrows.

glow curve shapes dominated by a high-temperature TL peak, while all the separates from the other three meteorites have normal low-temperature peaks consistent with a prolonged low-temperature episode (Fig. 5). Thus to a first approximation the clasts of a given meteorite have very similar thermal histories. The spread of TL sensitivity values for samples from the two howardites and the mesosiderite, and the differences in TL sensitivity between the howardites and the mesosiderites, largely reflect differences in mineralogy [12,13], but for the LEW 85300 shocked eucrite reflect the effects of shock and perhaps multiple impact events [10].

Implications: The bottom line of the induced TL work is that the eucrite association meteorites have suffered a prolonged period of low-temperature (<800°C) metamorphism. This has generated the strong low-temperature peak that is easily destroyed by even short-term heating above 800°C. In most cases, TL sensitivity variations reflect differences in mineralogy, but in a suite of mineralogically similar eucrites this too signals variations in metamorphic alteration and provides a quantitative estimate of petrologic type.

The main question is where and how the metamorphism occurred. A reasonable working idea is that these meteorites formed in a regolith on a large parent body. Recent theoretical treatments [15,16] and satellite observations of Gaspra, Ida, and Phobos [17,18] suggest that there are substantial regoliths on even small asteroids. We can reasonably assume that heat was deposited in that regolith by one or many impact events, while the bottom and top of the layer were maintained at a temperature of essentially zero. One can use the appropriate heat conduction equations [14] to investigate possible regolith temperature depth profiles as a function of time [3,6]. For a permeability of about 3×10^{-8} cm^2 s^{-1}, the most metamorphosed eucrites would have to be buried ~350 m in the regolith while the least metamorphosed eucrites would come from regoliths only ~50 m deep. The permeability chosen for these calculations might be rather high and smaller values would decrease regolith depths. However, the conclusion of significant burial seems hard to avoid.

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