SHORT COMMUNICATIONS

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Thermally induced fractures in olivines of stony meteorites

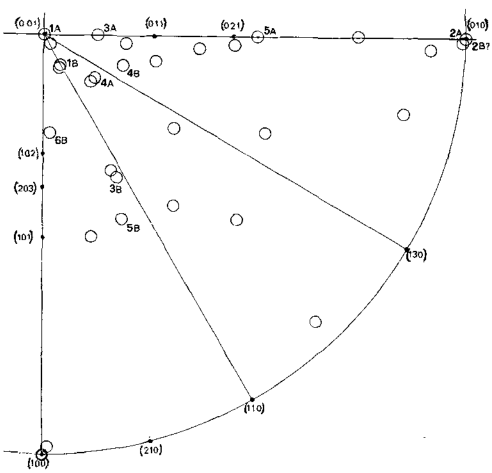
REGULAR fracture and cleavage in olivine crystals are considered as one of the metamorphic features indicating the presence of a shock event in the history of stony meteorites (see e.g. Carter *et al.*, 1968; Müller and Hornemann, 1969; Sclar, 1969; etc.). Recently, however, an alternative explanation was suggested, considering the effects of low-temperature thermal fatigue. Artificial induction of such features was experimentally obtained by thermal cycling. Samples of meteorites, displaying low to medium degrees of metamorphism, were exposed to thermal cycling between liquid nitrogen and room temperatures (from 83 K to 273 K); the treatment resulted in the generation of plastic and clastic deformations, including cleavage in olivine (Levi, 1973*a*).

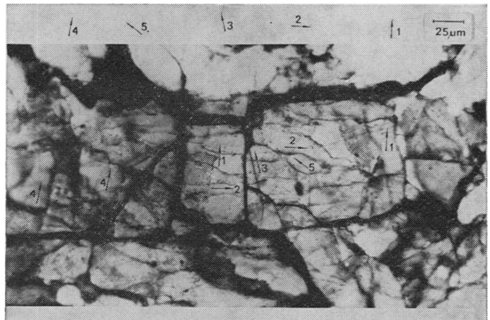
Our experiments have been later extended to over 3000 cycles, using the same technique (Levi, 1973*b* and 1973*c*), on samples of Mills, an H-chondrite recently described (Levi-Donati and Jarosewich, 1973 and 1974). A further considerable increase in the extension of damage was observed; both plastic and clastic deformations were present in a higher percent of individual crystals and each crystal appeared to be more severely damaged. This confirmed the action of 'thermal fatigue', i.e. of an accumulation of damage with increasing number of cycles, which may be explained as a consequence of hardening processes and propagation of microcracks.

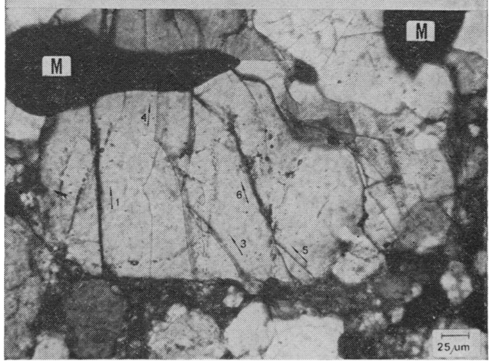
Cleavage in olivine was particularly evident and well-developed, so that we decided to extend our study determining the indices of planes of regular fracture and cleavage. The data were obtained by the use of the universal stage, on thin sections.[1]

The most common orientations of cleavage planes are pinacoidal, parallel to {010} and {001}; {100} are also frequent. Orientations corresponding to prismatic and bipyramidal fracture were observed, such as {130}, {012}, {021}, {0*kl*}, {0*k*$\bar{l}$}, and {*hkl*}. Frequently poles near, but not exactly corresponding to one of the known cleavage planes were found. Fractures parallel to several different orientations were often observed in the same crystal. Nearly all the olivine crystals present in a sample treated by 3200 cycles are affected by regular fractures, with identifiable orientations, but a considerable number of them, including smaller individuals, show evidence of cleavage, being marked by two or more parallel traces.

More than 50 crystals were surveyed and in the stereographic projection of fig. 1 the poles of the fractures measured in ten olivine crystals are indicated. The thin sections were cut from samples treated up to 3200 cycles. Two of these crystals appear







FIGS. 1 to 3: FIG. 1 (left). Stereographic projection: orientations of cleavage and regular fracture observed in ten olivine crystals from samples of an H-chondrite (Mills), artificially exposed to low-temperature thermal cycling. Fractures parallel to pinacoids repeat frequently, but they are plotted here only once. Numbered poles should be referred to crystal A (fig. 2) and B (fig. 3). FIG. 2 (top right). Crystal A: an olivine crystal from a sample of the Mills H-chondrite, exposed to 2075 cycles. The orientations of the structures whose directions are numbered are shown in fig. 1. FIG. 3 (bottom right). Crystal B: a second olivine crystal from a sample of the Mills H-chondrite, exposed to 3200 cycles. Damage is evident also in the neighbouring crystals; the metallic granules (M) may have contributed to the internal stresses and the localization of fatigue damage.

in figs. 2 (crystal A) and 3 (crystal B); some of the traces, for each observed cleavage direction, are numbered and correspond to the numbered poles in fig. 1.

We may conclude that the present study wholly confirms our previous results, giving an additional proof of the action of low-temperature thermal fatigue as a possible agent in the metamorphism of stony meteorites and lunar rocks.

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Heat treatment of some metamict allanites

LIMA-DE-FARIA (1958, 1964) studied X-ray powder patterns of heat-treated allanites, the object in that work being to identify, by X-ray diffraction, metamict minerals that showed no discernible powder lines before heating. We have studied the effect of heat-treatment in air and vacuum on three metamict allanites, using X-ray and Mössbauer methods. The allanites were supplied by the Department of Mineralogy, British Museum (Natural History). The specimens were originally from North Carolina, U.S.A. (BM 1957, 302), Ontario, Canada (BM 1924, 314), and Arendal, Norway (BM 42769), and were designated as A1, A2, and A3 respectively. Autoradiographic measurements, using previously analysed zircons (Vance and Mackey, 1974) as standards, gave the respective equivalent uranium contents as 0·5, 0·5, and 0·2 wt %.

X-ray diffraction data were obtained photographically, using filtered Cu radiation and a camera of 35 mm diameter. Although the samples contained iron, fluorescence was not a problem. The X-ray samples were single-crystal fragments, 1 to 2 mm in size. Data were obtained from the edges. Some powder patterns were also obtained. ^{57}Fe Mössbauer spectra of powders were measured using an arrangement of spectrometers described by Window *et al.* (1974). The samples were heated in platinum crucibles and the duration of the anneals was one hour.

No Laue spots or powder lines were observed on stationary-crystal X-ray photographs obtained from each sample; accordingly, the samples were severely damaged. The samples gave very broad Mössbauer spectra, which were similar to those obtained by Dollase (1971) on damaged samples. After A1 was annealed in air at 400 °C, a diffuse Laue pattern was obtained and the pattern sharpened after annealing in air at progressively higher temperatures up to 900 °C. After annealing at 700 °C in air, rather broad lines were observed on powder photographs; the *d* spacings were 2·92, 2·15, 1·90, and 1·64 Å, in agreement with the results of Lima-de-Faria (1958) for a Greenland allanite annealed at 700 °C in air. The Mössbauer spectrum sharpened considerably after annealing in air at 700 °C and agreed with with spectra of similarly heated allanites (Dollase, 1971); annealing in air increased the Fe^{3+}/Fe^{2+} ratio, as found by Dollase (1971) and Remy *et al.* (1970).

In contrast, no Laue spots were observed on stationary-crystal X-ray photographs obtained from A2 and A3 after annealing at 500 °C in air; however a faint, rather