

THE ORBITAL EVOLUTION OF ORDINARY CHONDRITES OVER THE LAST 50 MILLION YEARS

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Recent studies have suggested that the meteorite flux is subject to changes in its composition and possibly its intensity over various periods of time [1,2,3]. Many of these studies have concentrated on changes in the terrestrial flux using meteorite finds with large terrestrial ages (*i. e.*, Antarctic meteorites). In the present study we examine a collection of ordinary chondrite falls with terrestrial ages <30 years and for which cosmogenic nuclide data are available. We find that meteorites with long cosmic ray exposure ages apparently had smaller perihelia within the last 10⁵ years than those with smaller cosmic ray exposure ages. About half the spread in natural TL values of observed falls can be accounted for in terms of this secular evolution of their perihelia. Meteorite orbits apparently show an evolution of their perihelion to smaller values during the period represented by their cosmic ray exposure ages.

INTRODUCTION. Recent work has suggested that the ordinary chondrite meteorite flux is not constant with time, but displays variation in composition and possibly in intensity as well [1,2,3]. In a study of observed ordinary chondrite falls, Benoit *et al.* [4] observed that meteorites with cosmic ray exposure (CRE) ages <20 Ma showed a broad range of natural TL levels, including many with high TL levels. Meteorites with CRE ages >20 Ma, however, exhibited less variability in natural TL levels and none had high TL levels. They suggested that the restricted range of natural TL levels observed in meteorites with high CRE ages might reflect the extended orbital evolution of these meteorites; the low TL levels are interpreted as the result of recent orbits with perihelion < 1.0 AU. The dataset of Benoit *et al.* [4] included many observed falls with fairly large terrestrial ages, many of about 100 years. The initially rapid decay of TL under typical temperate climatic conditions means that significant scatter may be introduced in this dataset [4]. In order to examine the apparent orbital evolution of the ordinary chondrites in more detail, we have now measured the natural TL levels of a group of observed falls with very short terrestrial ages (<30 years). Our study included 17 equilibrated ordinary chondrites (11 H, three L, one LL and two L/LL chondrites).

RESULTS AND DISCUSSION. The new data also show a trend whereby natural TL levels decrease from 125 to 28 krad as CRE age increases from 0.9 to 51 Ma (Fig. 1). Our previous data show a similar trend [4], but is displaced to lower TL values as a result of terrestrial TL decay (Fig. 1). As noted by Benoit *et al.* [4], there is no basis for such a trend in the systematics of TL. Even under low temperature conditions, TL levels should reach equilibrium values in less than one million years. Other relevant factors, such as external radiation and dose-rate variation due to differences in shielding, are quantitatively unimportant for all but the largest and smallest meteoroid bodies [4]. The equilibrium value is therefore determined by temperature during irradiation in space, notably by the highest temperature experienced during a meteoroid's orbit which is at perihelion.

Making various assumptions about the albedo of meteoroid bodies, we can calculate an approximate perihelion for meteorites which represents an average perihelion for a period of time just prior to Earth impact. We find that, for our observed trend, perihelion decreases from about 1.0 AU (Zaoyang) to 0.90 AU (Xi Ujimqin) with increasing CRE age from 0.9 Ma to 51 Ma. This evolution of orbits among ordinary chondrites is summarized in Table 1. If we assume that the cosmic-ray exposure ages of meteorites largely reflect their irradiation while undergoing orbital evolution then one implication of these data is that the change in perihelia of meteoroid bodies is gradational and generally tends towards smaller perihelia. This, in turn, suggests that meteoroid bodies in Earth-approaching and Earth-crossing orbits do not generally exhibit chaotic orbital evolution over timespans of about 50 million years.

Two meteorites in the new database, Enshi and Laochengzhen, have very low natural TL levels (<1 krad) and do not plot along the TL vs. CRE age trend (Fig. 1). In all natural TL databases examined to date about 15% of meteorites also exhibit very low natural TL levels. It has been shown [4,5] that very small perihelion orbits (<0.85 AU) will drain TL levels to these low values. About 12% of observed falls had perihelia of <0.85 AU, as determined from their visual radiants [4]. Alternatively, TL levels could be drained to these low levels by shock-heating. Both Enshi and Laochengzhen have low TL sensitivities (0.62 and 0.16

relative to Dhajala, respectively) which may be indicative of destruction of feldspar during shock. In either case, the thermal event which drained the TL of these meteorites must have occurred within 10⁵ years before Earth impact so that natural TL levels did not rebuild to the higher "equilibrium" values. Enshi and Laochengzhen have also suffered ³He and ⁴He loss [6,7] which is indicative of thermal events. However, there are distinct differences between the response of TL and noble gases to thermal events. Natural TL is sensitive to fairly small thermal events but can recover from these events rapidly (about 10⁶ years or less). Noble gas loss, however, requires fairly large thermal events and its "record" is retained throughout the cosmic ray exposure history of the meteoroid body. Therefore, the low TL and ³He loss in Enshi and Laochengzhen indicate that the thermal event which affected both sets of data was (a) fairly intense and (b) occurred within the last 10⁵ years. There are no ³He data for two other meteorites with low TL levels in the present study (Peace River and Rochester).

Boxian seems to be an exception to the TL vs. CRE age trend in that it has a high TL level and a high CRE age (Fig. 1). This may indicate that LL chondrites do not follow the trend, although the dataset for meteorites with terrestrial ages >30 years does not support this suggestion [4]. Alternatively, it is possible that Boxian was "predosed" in a larger body. The noble gas data currently available [7] do not support a multi-stage irradiation history for Boxian, so perhaps this meteorite is a rare example of a meteoroid body with an unusual orbital history. Suizhou has a low natural TL but high equivalent dose [see 8], implying a sample heterogeneity problem.

CONCLUSIONS. We conclude that the natural TL levels of recently fallen meteorites correlate with their cosmic ray exposure ages, and this correlation is a result of orbital evolution in space. With increasing cosmic ray exposure age, meteoroid bodies tend to evolve to lower perihelia. The change in meteoroid perihelia as a function of time is not very large, generally between 1.0 to 0.90 AU over the last 50 million years but appears to apply to almost all ordinary chondrites.

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Table 1: The evolution relationship among perihelion, natural TL level and CRE ages of ordinary chondrites.

Perihelion (AU)	Natural TL krad @ 250 °C	CRE age (Ma)
1.1-1.0	>100	<10
1.0-0.96	100-60	10-20
0.96-0.93	60-40	20-30
0.93-0.90	40-30	30-50
<0.90	<30	>50

Fig. 1 (Right). Natural TL levels (at 250 °C) vs. cosmic ray exposure age for ordinary chondrites with terrestrial ages <30 years. The correlation between natural TL and cosmic ray exposure age (excluding the two chondrites with natural TL <1 krad) is shown by the dotted regression line which has a slope of 0.01 (r=-0.59, n=18). The chondrites are identified by the first three letters of their names.

