

EVIDENCE FOR SUPERPARAMAGNETISM IN THE ORGUEIL AND TIESCHITZ
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INTRODUCTION. Recently, we have reported (1) preliminary data indicating that a significant fraction of the iron in the Orgueil meteorite (USNM-234), a type I carbonaceous chondrite, is superparamagnetic. This implies a distribution of sub-domain particles of sufficiently small size ($\lesssim 300 \text{ \AA}$) that at higher temperatures atomic magnetic moments relax faster than the nuclear Larmor precession, and the 6-peak Zeeman splitting observed in the Mossbauer spectrum collapses to a two-peak paramagnetic spectrum. The signature for superparamagnetism, in contrast to the ordinary magnetic transition at the Curie or Néel point, is that this transition takes place over a wide range of temperatures as a result of an exponential dependence on a range of particle volumes (magnetic anisotropy energy). (2,3)

A superparamagnetic component requires an explanation of its origin, possibly as a result of aqueous activity after the formation of the parent body (3) or perhaps as a vapor phase condensate from the solar nebula (5). As proposed by Cameron (6), superparamagnetic particles might be cores of interstellar grains included at the time of accretion of the parent body.

We report here on additional data and analysis confirming the occurrence of superparamagnetism in the Orgueil meteorite, and on new data (7) suggesting the existence of superparamagnetism in the Tieschitz meteorite (provided by E. King), an unequilibrated ordinary chondrite. Although a similar study of the Allende meteorite, a type III carbonaceous chondrite, failed to reveal the presence of superparamagnetism, the results for Orgueil and Tieschitz suggest that superparamagnetism in meteorites may occur more widely than heretofore appreciated, and is a phenomenon worthy of systematic investigation.

RESULTS. In this study, as in Ref.(1), Mossbauer spectra were collected for a series of temperatures down to $\sim 20\text{K}$, obtained with an Air Products closed-cycle refrigerator. The Orgueil data are presented in Figure 1. They show a gradual decrease in the paramagnetic component of the spectrum near 0 mm/s below $\sim 70\text{K}$ accompanied by an increase in the magnetic component. The spectra of Fig. 1 were fit to a sum of 6-peak, 3:2:1:1:2:3 Zeeman spectra (magnetic component), a 2-peak, 1:1 Fe³⁺ component (the two strong central peaks at room temperature) and a weaker 2-peak, Fe²⁺ component. The fit shows that the sum of magnetic + Fe²⁺ areas is roughly constant at $\sim 86\%$ over the temperature range, indicating that as temperature decreases, a portion of the 3+ iron in the meteorite sample gradually converts from a paramagnetic state (random alignment) to a magnetic state (oriented). As stated earlier, this is the typical signature for superparamagnetism (3). From Figure 2, we estimate the superparamagnetic component to be 20-25% of the total iron content in the Orgueil meteorite.

In Figure 3, we present spectra from a similar study of the Tieschitz meteorite. In this case superparamagnetism becomes evident below $\sim 40\text{K}$ and shows up as a decrease in the Fe²⁺ paramagnetic peaks accompanied by a broad increase in the background curve. This is shown more clearly in Fig. 4, where difference spectra (relative to 100K) are plotted. Although the signature is different here, it is consistent with a superparamagnetic component in the Tieschitz meteorite.

A similar set of spectra (not shown) obtained down to 15K for a sample of the Allende meteorite failed to show any evidence of superparamagnetism.

CONCLUSIONS. By investigating the magnetic nature of three meteorites of the chondrite class with Mossbauer spectroscopy carried out over a range of

temperatures, we have demonstrated the presence of substantial amounts of superparamagnetic particles in two of these meteorites. These are fine-grained particles, the explanation of whose origin will help elucidate processes of formation in the early history of the solar system. To this end, additional work is underway in our laboratory employing lower temperatures, external magnetic fields, improved computer analysis, etc., on these and additional meteorite samples, in an effort to characterize the identity and nature of the superparamagnetic component(s) of meteorites of the chondrite class.

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Refs.: (1) Wdowiak & Agresti (1984) *Nature* 311, 140; (2) Kundig et al. (1969) *Phys. Rev.* 142, 327; (3) van der Kraan (1973) *Phys. Stat. Sol.* a18, 215; (4) Anders et al. (1973) *Science* 182, 781; (5) Haneda & Morrish (1979) *Nature* 282, 186; (6) Cameron in *Interstellar Dust and Related Topics* (1973) (eds. Greenberg & Van de Hulst), 545; (7) Qasem (1986) M.S. Thesis, Univ. of AL. at B'ham.

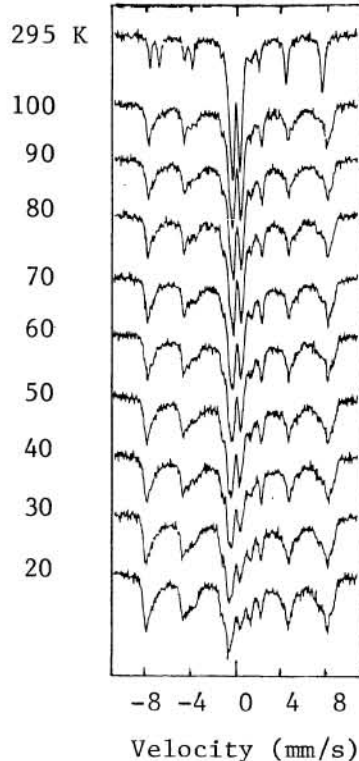


FIGURE 1.
Orgueil
spectra

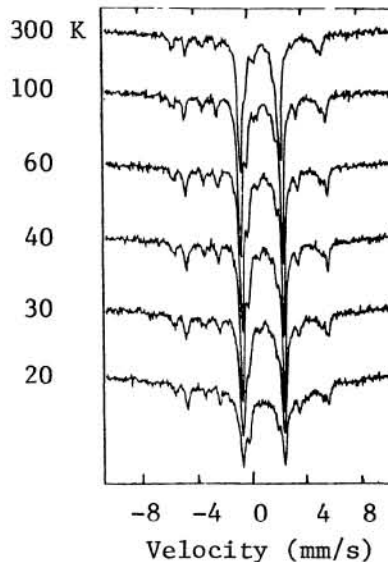


FIGURE 3.
Tieschitz
spectra

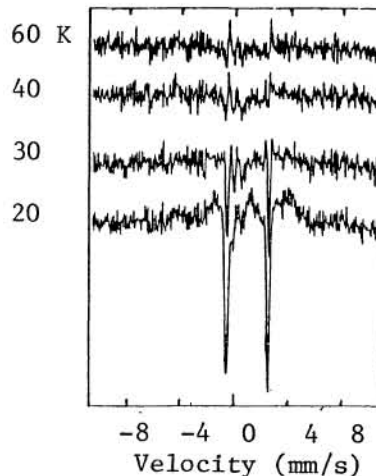


FIGURE 4.
Tieschitz
difference
spectra

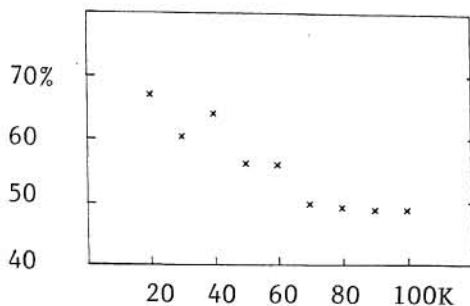


FIGURE 2.
Orgueil
magnetic
fraction