MAGNETIC FIELDS IN THE SOLID OBJECTS OF THE SOLAR SYSTEM: DID THEY BECOME MAGNETIZED IN A SOLAR DIPOLE FIELD? Strangway, D.W. and Sugiura, N., Dept of Geology, Univ of Toronto, Toronto M5S 1A1.

Many observations of magnetic properties and magnetic fields in the solar system solid objects have given us insight to the early history of the solar system. The study of meteorites can be divided into a study of the bulk sample of the meteorite and a study of the individual chondrules. We have examined the magnetic remanence preserved in chondrules and find that some are very magneticwhile others are only weakly magnetic. Samples of the Allende meteorite have been studied by measuring the magnetic direction in individual chondrules which are kept mutually oriented. The natural remanent magnetization (NRM) directions are the same in the individual chondrules and in the matrix. When demagnetization by alternating fields or thermal methods is used, the directions tend to scatter and we see that there are two components of NRM and the stable one tends to be randomly oriented. This suggests that the condrules were magnetized before they were assembled into the meteorite and hence they are recording pre-meteorite solar system fields. Paleointensity determinations on a few chondrules shows that they were magnetized by cooling in fields of several oersteds and as high as 16 oersteds. Thus large fields existed at least locally in the solar system before the meteorites were assembled (Lanoix et al, 1978; Sugiura and Strangway, in press).

A maximum temperature of about 300°C was achieved either during or after the assembly of the meteorite. Since the matrix and the chondrules have the same direction of magnetization it has also been possible to do paleointensity measurements on this softer, low temperature component by studying the whole meteorite. These determinations have suggested that fields of about 1 oersted were present when the meteorites assembled or they were subsequently heated to 200 or 300°C (Bannerjee and Hargraves, 1972; Butler, 1972). Thus we have evidence of early large solar system fields using the chondrules and the assembled meteorites as independent time separated probes.

Data on the NRM plotted against the saturation magnetization (J_s) for a wide variety of meteorites is shown in Fig. 1. The J_s value is roughly proportional to the metallic iron content, while the NRM is a measure of the remanence of the samples as first received and measured. A line with a slope of 45° corresponds roughly to a measure of the ancient field strength as discussed by Cisowski et al (1977). This is only a rough indicator however since it does not take into account secondary components and many other factors. In general it can be seen that many of the meteorites are highly magnetic, particularly the carbonaceous chondrites and the L and H chondrites. It should be noted that the individual chondrules generally carry more NRM than meteorites or lunar samples suggesting also that they formed in higher fields. In Fig. 2 we show the mean demagnetizing field (field required to reduce NRM to 1/e of the initial value (H_i)) versus the bulk coercive force for many of these same samples. Now the pattern changes somewhat and we see that the carbonaceous chondrites and the LL chondrites are the most magnetically stable and are therefore especially suited for studying solar system fields while the L-chondrites and the H-chondrites are the least stable.

It is likely, following this observation that the formation of the asteroids, planets and satellites also took place in the presence of magnetic fields. If these fields had a life time associated with them, which is comparable to the assembly time of the planetary objects, primitive portions of these objects may be expected to retain a signature of these early fields either from deposition or by cooling.

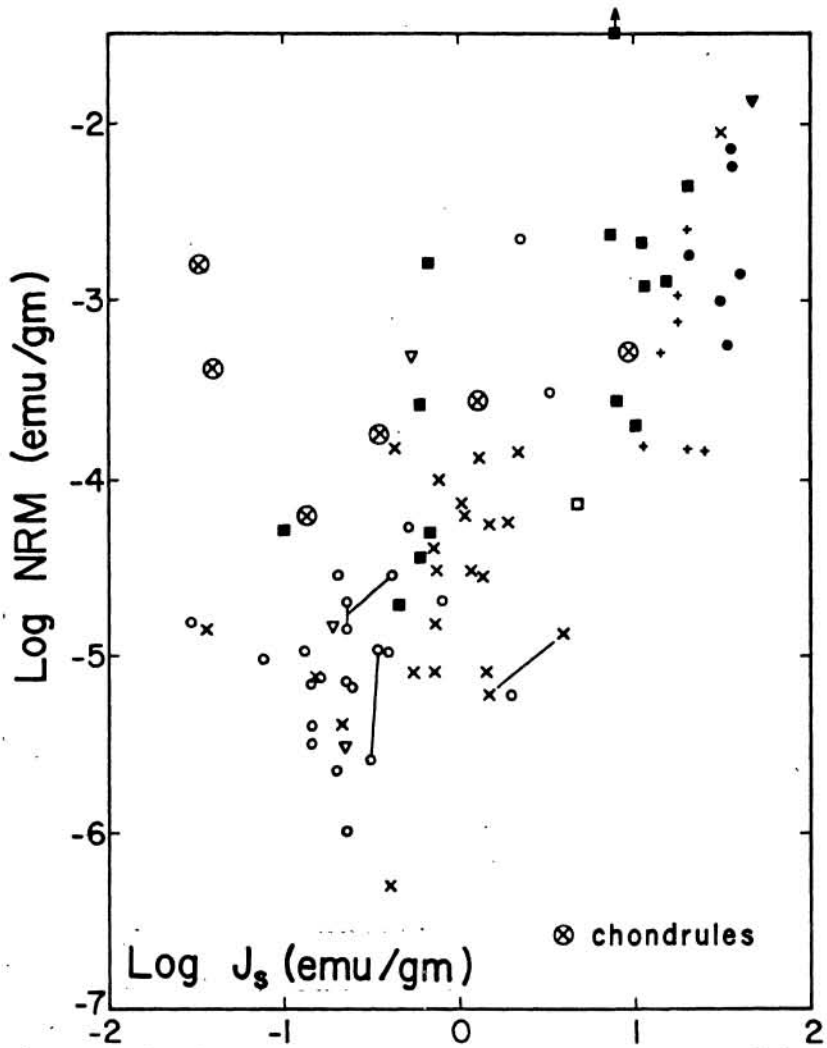

Fig. 1 Plot of the Natural Remanent Magnetization versus the Coercive Force for a large array of meteorites and lunar samples
+ L chondrites
H chondrites
o crystalline lunar rocks
x breccias lunar
carbonaceous chondrites
achondrites
enstatite chondrite
LL chondrites
x individual Allende chondrules

Mercury is known to have a significant dipole moment (Ness et al, 1975). Some models of Mercury's thermal history suggest that this is due to a currently operating dynamo while others suggest that this represents a frozen in field acquired during the terminal accretion stage when the crust was cooling in the presence of a solar system field. In this case, enough of the portion of the crustthat remained below the Curie point would have had to escape physical randomization by bombardment. Venus appears to have at the very most a weak magnetic field Russell, 1976). This could be associated with a fluid core or with a coherent memory effect preserved in the crust. The surface temperature is sufficiently high that only a very small volume of the surface material could be below the Curie point. Furthermore, if this is a global effect of the crust there can have been no plate tectonics operating to randomize the effect.

The earth's magnetic field is clearly of dynamo origin today and plate tectonics has operated for long enough to destroy any vestiges of a primordial crustal field that may once have been present. The moon shows only local magnetic anomalies but no overall dynamo or crustal field. There is much speculation on whether these anomalies represent a memory from an early dynamo or from an early magnetized object accreted and/or cooled in the presence of a field comparable to that found in the chondrules (Strangway and Sharpe, 1975; Runcorn, 1979). Recent studies suggest that the directions of the magnetization associated with the various sources are not random but are grouped in the general equatorial plane and with random inclinations in this plane (Hood et al, 1978). This grouping is difficult to explain on any hypothesis. An

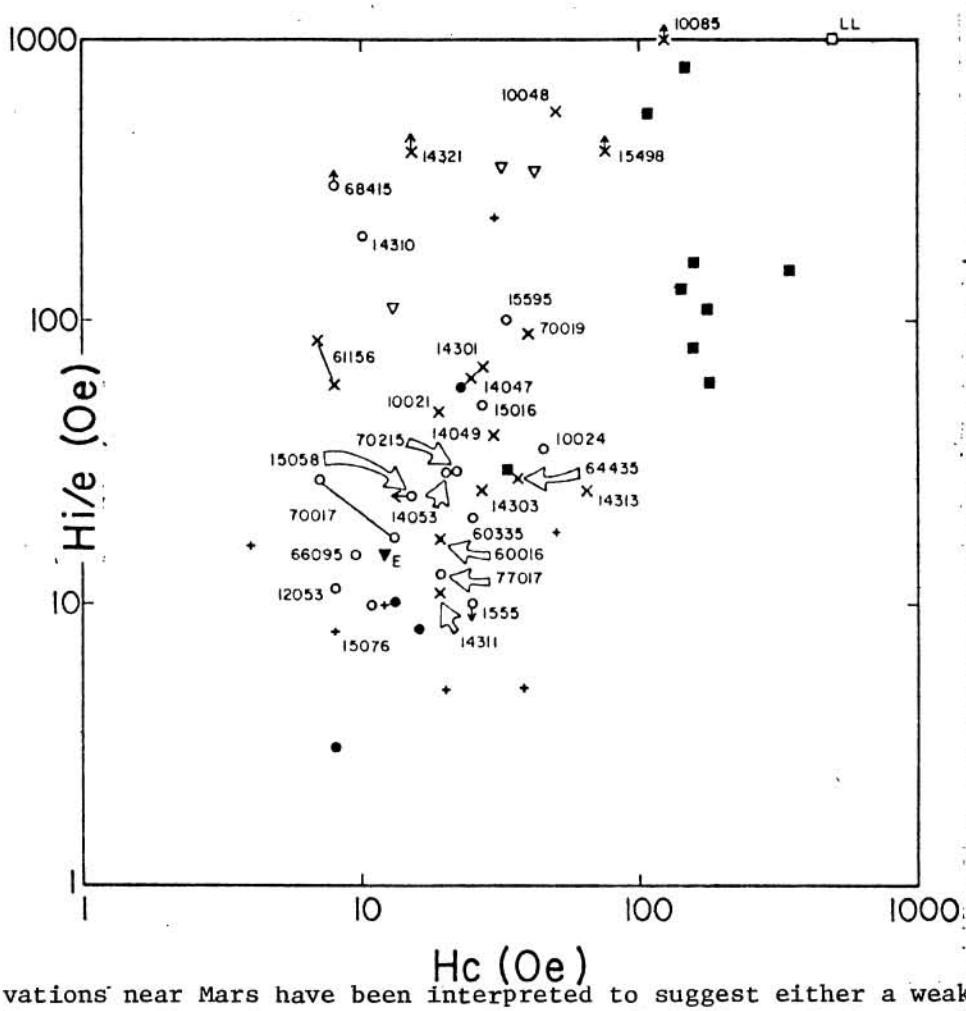

Fig. 2. Coercive Force (H_c) versus the mean demag field (Hi/e) for lunar samples and meteorites.

external field hypothesis would suggest that the dominant source field was normal to the rotation axis while the various blocks became cooled. Lunar sample properties are also shown in Fig.1 & 2 where it can be seen that the breccias and igneous rocks are weakly magnetic.

The magnetic observations near Mars have been interpreted to suggest either a weak field or no field at all. If there is a weak dipole field it could be carried by the unperturbed portions of the early cool crust. Since Mars has had large volcanoes formed in recent history, these would have cooled in field free conditions and might turn out to have acquired very little remanence(Dolginov et al,1973)

Finally we may speculate that many of the asteroids are likely to be primitive and many of them unheated since formation, so they may have been magnetized by early solar system fields. The satellites of Jupiter which are rocky will be of considerable interest since they are likely small enough to have no dynamos, past or present. Do they however preserve an early solar system memory?

There are important measurements of the magnetic fields ahead of us in connection with the exploration of the planets, satellites and asteroids. There are many measurements yet to be made on meteorites and on lunar samples, but the past decade has told that essentially all of the solid objects of the solar system have a magnetic story to tell. This field could have been a very strong solar dipole field giving Mercury, Venus and Mars a primordial crustal dipole. The lack of such a dipole on the moon could be a result of its rotation axis having changed from a very shallow inclination in the early solar system to its present high inclination (Hood et al, 1978). This would mean there was no average dipole value along the rotation axis while those planets with a high inclination would have a net dipole along the rotation axis resulting from cooling in a solar dipole field.