VII. Meteorites and formation of the planets

7.1 Meteorites

They are (by definition) chunks of extraterrestrial material which impact on earth. Meteorites are important because they‘re samples of the early solar system that have avoided most (or all) of the planetary accretion process and are thus unmodified.

7.1.1 Different types of meteorites

I. Irons

II. Stony-Irons

$$\text{III. Stones} - \begin{cases} \text{a) Achondrites} \\ \\ \text{b) Chondroties} - \begin{cases} \text{carbonaceous chondrites} \\ \text{ordinary chondrites} \end{cases} \end{cases}$$

I. Irons - mostly Fe-Ni metallic alloy

II. Stony-irons - about half Fe-Ni and half silicate similar to terrestrial minerals.

III. Stones - primarily silicate

a) achondrites - like terrestrial igneous rocks (ultramafic and gabbroic)

b) chondrites are distinguished by texture - a matrix with chondrules - ‘hard bits’ 1-2 mm across, embedded.

7.1.2 Carbonaceous chondrites

Carbonaceous chondrites have a matrix mostly of low-temperature *sheet* silicate minerals and up to 5% complex organic compounds.

Also:

i) chondrules consisting primarily of olivine and orthopyroxene, with some FeS and Fe-Ni metal,

ii) Ca-Al-Mg-Ti rich inclusions.

Both of these are high-temperature condensates (as discussed next) - they somehow formed very differently from the matrix.

Why all this uproar?

CARBONACEOUS CHONDRITES are very ‘primitive’ - they are considered to be close in composition to the original solar nebula. Argument - they are chemically very similar to solar abundances except for the most volatile (H, He, O, C, N).

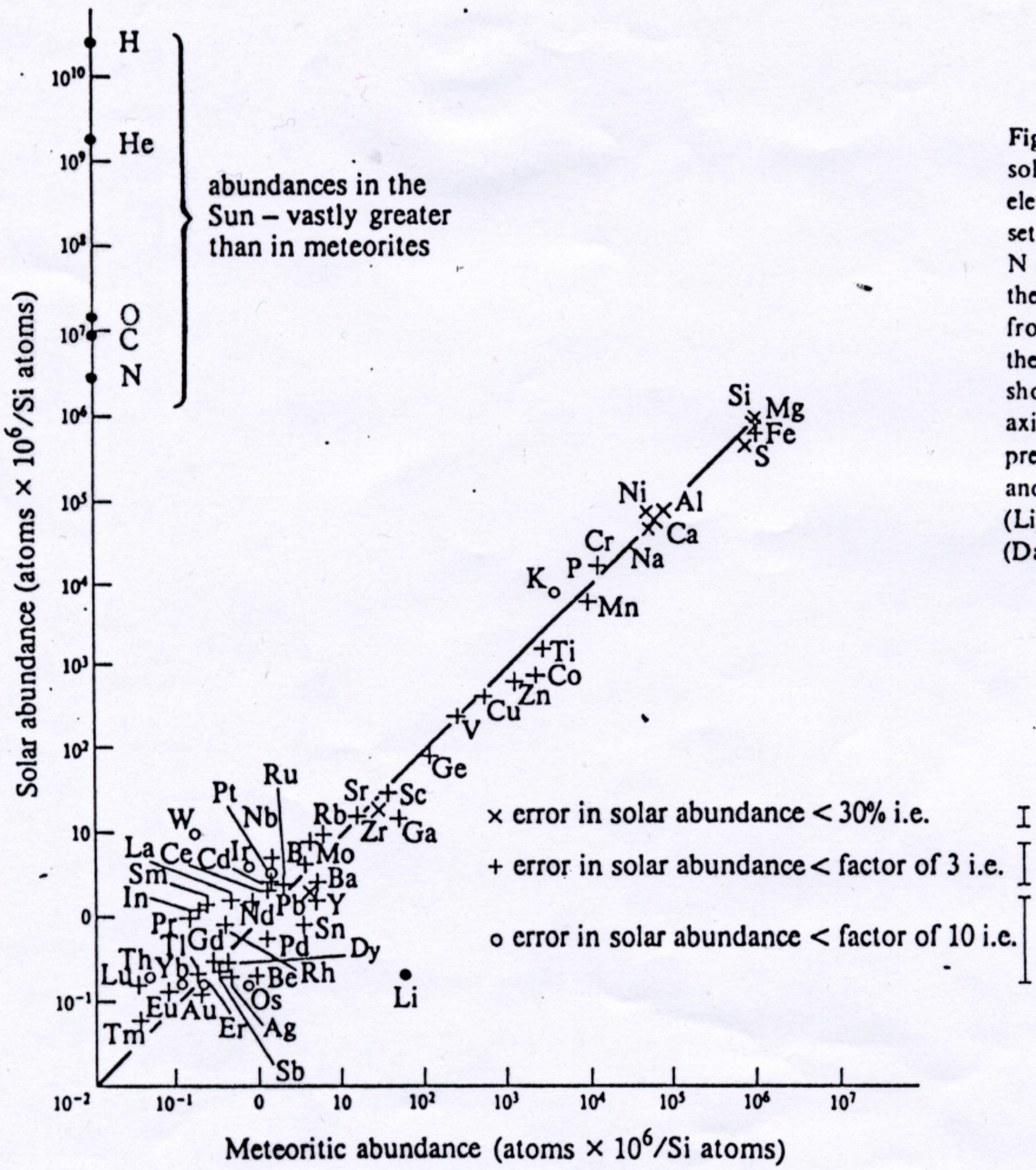

Figure 4.7 Comparison of solar and chondritic meteorite element abundances (silicon is set at 10^6). H, He, O, C and N are not compared because they have largely been lost from meteorites, owing to their great volatility, but are shown on the solar abundance axis to demonstrate their preponderance in the Sun. The anomalous position of lithium (Li) is discussed in Section 4.6. (Data from Trimble 1975.)

The behavior of these materials has been studied to simulate condensation in a solar nebula. Minerals are divided into high-temperature (refractory) and low temperature (volatiles)). The refractory minerals condense first as the nebula cools.

Table 5.1 Approximate condensation temperatures for grains forming in the cooling Solar Nebula at 10^{-4} bars (after Grossman and Larimer, 1974).

Mineral phase	*Composition*	*Condensation temperature* (K)	
Corundum	Al_2O_3	1680	more
Perovskite	$CaTiO_3$	1560	
Melilite	$Ca_2Al_2SiO_7$–$Ca_2MgSi_2O_7$	1470	Refractory
Diopside (pyroxene)	$CaMgSi_2O_6$	1410	
Spinel	$MgAl_2O_4$	1390	
Metallic iron	Fe(Ni)	1380	
Forsterite (olivine)	Mg_2SiO_4 ($-Fe_2SiO_4$)	1370	
Enstatite (pyroxene)	$Mg_2Si_2O_6$ ($-Fe_2Si_2O_6$)	1360	less
Anorthite (feldspar)	$CaAl_2Si_2O_8$	1230	
Alkali feldspars	$(Na,K)AlSi_3O_8$	1060	more
Troilite	FeS	650	
Magnetite	Fe_3O_4	410	
Hydrated silicates	various	300	Volatile
Water ice	H_2O	240	
Ammonia ice	$NH_3.H_2O$	130	
Methane ice	$CH_4.6H_2O$	90	
Nitrogen ice	$N_2.6H_2O$	90	less

The fact that the high and low temperature minerals coexist indicate that the carbonaceous chondrites have not been reheated and equilibrated - they are UNDIFFERENTIATED. They are very *old* - 4.6 BY!!

For these reasons the CHONDIRITIC SOLAR SYSTEM is often assumed - the solar system nebula composition was the same as carbonaceous chondrites.

In contrast, the achondrites, stony-irons and irons have been DIFFERENTIATED. They seem to have been part of small (few hundred km) planets that heated up and differentiated into i) silicate regions (analagous to earth's mantle) which gave rise to the achondrites. ii) metal regions (analagous to earth's core) which produced the irons.

These small planets later brok up into meteorites.