materials. Relative to solar composition, meteoritic materials have the following approximate C/Si ratios, Halley dust—.5, IDPs—0.15, CI—0.06, CM—0.03 and L—0.001.

To better understand carbon in IDPs—we have undertaken a study of carbon in chondritic IDPs and carbonaceous chondrites using both X-ray analysis with a thin window energy dispersive SiLi detector and energy loss analysis using a parallel EELS spectrometer. We are investigating bulk 10 μm particles and microtome thin sections less than 1000 A thick. The thin sections are critical for fine scale spatial analysis and for EELS work but they are also critical for bulk carbon measurement. Detected carbon X-rays from a chondritic composition particle are only generated in the outer 0.1 μm of the particle skin. True analysis of the bulk carbon content in a 10 μm particle can only reliably be made from a thin slice that transects the paticle interior. A major difficulty in this program is producing microtome slices that are not contaminated carbonaceous matter. We have partly solved this problem by embedding the samples in metal or a polymer that contains a molecular tag that provides a means of distinguishing indigenous carbon from the embedding medium.

Our bulk carbon abundances for chondritic IDPs are still preliminary but taken at face value they indicate that the mean C/Si atom ratio is 1.75. If this value is correct it implies that the IDP carbon abundance is intermediate between CI and that indicated for Halley dust from the PIA and PUMA mass spectrometers. Carbon distribution in many IDP's is heterogenous. Similar to the Halley results the IDPs contain submicron areas of pure carbonaceous matter (analogous to the CHONs at Halley) and submicron areas that contain carbon and silicates (analogous to the Halley "mixed"). They also contain single mineral grains with no carbon, analogous to the Halley silicate grains. Qualitatively, there is an apparent similarity between Halley and some of the IDP types.

An unusual insight into the carbon problem has come from the analysis of dust particles that were strongly heated during atmospheric entry and particles that were intentionally heated in the laboratory. These particles (the MMS or metal mound silicate) are composed of silicate spheres, FeNi metal mounds and irregular low Z material that was apparently immiscible in the spheres. These particles appear to have been very strongly heated but not sufficiently oxidized to destroy metal or carbon. The irregular low Z masses in these particles appear to be nearly pure elemental carbon. The survival of elemental carbon in particles that have experienced melting and partial evaporation of Si and Fe suggests that a significant fraction of the carbon in IDPs is in a nonvolatile form that is capable of surviving vacuum pyrolysis at high temperatures. In connection with the studies of carbon in Halley dust it is interesting to speculate that carbon in comet dust may be grouped into two distinct classes. One class is volatile and is lost from small interplanetary particles on time scales of minutes to years while the other is relatively refractory and partly survives extreme heating.

CM2 Carbonaceous Chondrite Matrices: AEM Studies of Matrix Phyllosilicates and Mass Balance Calculations Using a Linear Algebraic Method.

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The matrices of CM2 carbonaceous chondrites contain a mineral assemblage of phyllosilicates, oxides, sulphides, silicates and carbonates (1-5). This complex phase assemblage is widely believed to have formed by aqueous alteration (1, 5) of an anhydrous protolith (possibly CV3 matrix material) on the CM2 parent body. Using textural data (5) have suggested that the phyllosilicate phases, Fe-Mg serpentine and PCP (tochilinite intergrown with cronstedtite (6)) formed by sequential progressive aqueous alteration. This model predicts that the modal abundance of PCP decreases and Mg-serpentine increases as alteration proceeds. McSween (7) made an important step towards testing this model using a graphical method to obtain modal proportions of phases, but was limited by the compositional data available. To more rigorously constrain the proportions of phases in CM2 matrices and identify feasible alteration reactions, precise chemical data for the matrix phases in Murchison, Murray and Mighei, suitable for use in mass balance calculations, have been obtained by analytical electron microscopy.

The data from analyses of 200 individual grains from Murchison and Murray show that 3 distinct compositional groups are present within the fine-grained matrix phyllosilicates. The most abundant phase is

cronstedtite (c = 7 Å and Si/Fe < 1) which is compositionally variable. This phase coexists with very fine-grained (<0.1 μm) Fe-serpentine (c = 7 Å and Si/Fe > 1) with Mg/(Mg + Fe) ratios between 0.37 and 0.55. The third phyllosilicate phase has high S consistent with PCP. The analyses show variable Si, Fe, S and Ni contents, but analyses with the lowest Si contents are identical to analyses of tochilinite from CM clasts in the Jodzie howardite and Murray (1).

These data have been applied to mass balance calculations for CM chondrite matrices using linear algebraic (9) and least squares methods. These mathematical procedures are rigorous methods of modal analysis which enable exact values for the molar proportions of the phases to be calculated simultaneously using several components and phases. The results for Murchison and Mighei, solved using the five most abundant phases, tochilinite, cronstedtite, Fe-Mg serpentine, pentlandite and olivine, are consistent with the observed modal abundances determined in this study. This procedure was then applied to CM chondrite matrices for which no data on the mineral compositions are available. Phase compositions were assumed to be the same as the average compositions of phases analysed in Murchison. The results of these calculations show that there is no clear relationship between the degree of alteration (as indicated by the matrix/chondrule ratio (7)) and the abundance of tochilinite in the matrix. The abundance of tochilinite appears to be a function of the bulk Fe/S ratio of the matrix which is not a function of the degree of alteration. Other factors, such as temperature and fluid composition, need to be considered in detail to understand fully the origin of the complex phase assemblages in CM2 matrices.

Correlated Isotope Fractionation and Formation of Purple FUN Inclusions.

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Allende coarse-grained inclusions characterized by a distinct purple color and high spinel contents ($\leq$50 vol.%) exhibit a higher frequency of FUN isotopic anomalies ($\approx$20%) than the general CAI population ($\leq$6%). We used the ion microprobe to measure Mg, Si, Cr and Fe isotopic compositions of three Purple Spinel-rich Inclusions (PSI = ψ) which are petrographically similar to Type B CAI to investigate: 1) variations in isotopic fractionation within inclusions, including secondary phases; 2) correlated isotopic fractionation; and 3) excess ^{26}Mg.

Isotope fractionation factors F_{Mg}, F_{Si}, F_{Cr} and F_{Fe} were obtained by measuring deviations in the isotopic ratios relative to the values in standards. B7F6 exhibited uniform F_{Mg} (17‰) for interior spinels and fassaite, but a gradient toward lower F_{Mg} for spinel near the edge. Fassaite exhibits variable F_{Si} (10-14‰), while hedenbergite exhibits F_{Si} = 0. Anorthite analyses yield a limit: ^{26}Al/^{27}Al $\leq$ 5 × 10^{-6}. B7H10 spinel and fassaite show uniform F_{Mg} = 36‰. Fassaite shows uniform F_{Si} = 16‰. Olivine mantling spinel grains exhibits $F_{Mg} \approx$ 11‰ and F_{Si} = 0. DH8 spinels exhibit a range in F_{Mg} of 9‰ (30-39‰), which is not correlated with FeO content. DH8 fassaite shows uniform F_{Mg} = 30‰, but variable F_{Si} (11-15‰). DH8 anorthite exhibits uniform F_{Si} = 15‰ and an upper limit: ^{26}Al/^{27}Al $\leq$ 1 × 10^{-7}. DH8 spinels exhibit variable F_{Cr} (7-15‰), but only small F_{Fe} < 3‰.

The data indicate large positive fractionation for Mg, Si and Cr, but no fractionation for Ca, Ti and Fe. The magnitudes of fractionation for Mg and Si for B7H10 and DH8 are the largest observed for any Allende CAI. Two inclusions (DH8 and B7F6) exhibit substantial variations in isotopic fractionation for Mg, Si and Cr. Since petrographic observations suggest crystallization from a melt, isotopic variability may be attributed to the addition of normal material. Isotopically normal Si in hedenbergite and olivine requires gas-solid reaction with normal Si during alteration. In B7H10, olivine with F_{Si} = 0 and F_{Mg} = 11‰ mantles spinel with F_{Mg} = 34‰, suggesting an alteration reaction: Sp → Ol + Fp;

requiring addition of all Si and 2/3 Mg in olivine from an isotopically normal gas phase.

An excellent correlation is observed between the magnitudes of fractionation for elements of similar volatility (Mg, Si, Cr), emphasizing the importance of kinetic processes involving distillation for the production of isotopically heavy Mg, Si and Cr. Assuming that Mg and Si are the only major elements lost by evaporation, a Rayleigh model can be used to estimate a precursor ψ composition. Substantial mass loss (72% for B7H10) is required to produce the measured F_{Mg} and F_{Si}. Calculated initial compositions are consistent with formation by evaporation of a precursor with a composition similar to that of ordinary chondrules. Variable fractionation for Mg, Si and Cr and the lack of Fe fractionation result from alteration involving addition of normal material. This model explains the chemical composition and extreme isotope fractionation in ψ starting with a simple precursor and well-understood processes; however, it does not explain the absence of FUN effects in many ψ, the association of UN effects with extreme fractionation or the relation of ψ to normal CAI. ψ differ from Type B CAI in their high spinel contents and absence of melilite. A second model postulates formation of ψ from a precursor similar to Type B CAI, containing melilite which has been completely altered to secondary phases.

Solubilities and Partitioning of Noble Gases in Mineral/Melt Systems: Results for NE, AR, KR, and XE in Anorthite, Diopside, Forsterite, and Coexisting Melt with Implications for Terrestrial Planet Atmospheric Evolution.

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Introduction: The atmospheres of the terrestrial planets provide accessible, homogeneous reservoirs, which we can sample for noble gases. These samples can be used to detect any primordial heterogeneity in the material which accreted to form the planets, as well as to investigate the atmospheres themselves, *provided that* we know the relation between the measured atmospheric abundances and the bulk planet inventories. This relation is determined by the interplay of the degassing mechanisms which are operational on each individual planet. In particular, magmatic transport is the only mechanism, catastrophic or non-catastrophic, that can be shown to be important on Earth, Mars, and Venus [1]; therefore it is the focus of our experiments.

Experiments: To provide the necessary information we have developed a technique for the determination of equilibrium partition coefficients through (a) synthesis experiments in which phase separation is not required, and (b) reversal experiments and diffusion rate studies in which the equilibrium solubilities of noble gases in minerals and melts are established. We report on synthesis experiments for anorthite-melt, diopside-melt, and forsterite-melt systems. Two experiments were performed in which mineral-melt equilibrium pairs were held at 1300 °C for 18 days in a one bar atmosphere composed of 5% Ne, 93% Ar, 1% Kr, and 1% Xe. The mix is commercial and has not yet been reanalyzed by us.

All mineral samples show a clear trend of increasing solubility with increasing atomic number, however the absolute solubilities are extremely variable. This variation is real, and indicates that prior sample history affects solubility. For example, two subsamples of anorthite WU-617 run separately agree with one another and with past Ar synthesis results within a factor of two, yet differ from sample anorthite HO-228 by a factor of 100. Among the anorthites, HO-228 has the highest concentrations of all the noble gases, but is internally self-consistent: previously this anorthite sample yielded a much higher Ar concentration than four others run simultaneously [1].

In contrast, the melt solubilities show a clear trend of decreasing solubility with increasing atomic number and very little variation over a large compositional range. The spread in solubilities affects greatly the *absolute values* of partition coefficients, but is not significant in terms of partition coefficient *patterns*. These patterns show a clear trend of increasing compatibility with increasing atomic number.

Conclusions: The noble gases will be fractionated by partial melting involving anorthite, diopside, and forsterite. Equilibrium batch and incremental melting calculations indicate the initial planetary noble gas inventories were (a) dissimilar, with Mars < Earth < Venus, and (b) not derived from a common chondritic source. In general, the abundance patterns should not be interpreted as bulk planet inventories without understanding planetary differentiation in detail. References: [1] Broadhurst C. L., Drake M. J., Bernatowicz T. J. and Hagee B. E. (1987) *Meteoritics* 22, 342.

Akaganeite, not Lawrencite, Corrodes Antarctic Iron Meteorites.

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A suite of 12 iron meteorites from various environments and locations in Antarctica was studied, representing a range of chemical compositions, metallographic structures, and degrees of weathering. Polished sections of unaltered metal with adhering corrosion products were examined optically and by electron microprobe, and material was removed from these sections for X-ray diffraction examination. Meteorites selected included 5 from group IA, 2 IIA, 1 IIB, 2 IIIA, and 1 IVA; with a range of Ni values from 5.26% to 18.9%. The major corrosion products observed with general formula and range of Ni and Cl contents are: akaganeite, β-FeOOH, 0.5–19% Ni, 0.3–5.4% Cl; goethite, α-FeOOH, 1.0–8.0% Ni, 0–0.5% Cl; lepidocrocite, γ-FeOOH, 0.5–11% Ni, <0.2% Cl; maghemite, γ-Fe$_2$O$_3$, 0.4–7.0% Ni, <0.1% Cl. The corrosion products contain small amounts of foreign mineral grains (quartz, olivine, feldspar, calcite, *etc.*), and the individual oxides contain small amounts of introduced elements (Ca, K, Mg, Al, Si, Na), and occasionally S from the weathering of troilite.

The corrosion reaction is fundamentally electrochemical in nature. Iron goes into solution at the anode (Fe^0 → Fe^{3+} + 3e). Oxygen is reduced at the cathode (O$_2$ + 2H$_2$O + 4e → 4OH$^-$). The two reactions may be separated in space, requiring an electrically conducting medium to move electrons from anode to cathode, and an electrolyte to move anions from cathode to anode. Taking into consideration that akaganeite is formed at the reaction front, the total reaction may be expressed as

$$2Fe + 3/2O_2 + H_2O \rightarrow 2\beta\text{-FeOOH}.$$
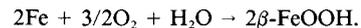
Corrosion products testify to a more complex process that employs the structural and ion exchange properties of akaganeite. Akaganeite accommodates both Ni^{2+} and Cl in its structure. It forms immediately behind corrosion fronts, with its highest Cl contents next to metal interfaces. A more realistic reaction producing akaganeite from kamacite is:

$$30Fe^0 + 2Ni^0 + 2H^+ + 2Cl^- + 47O + 21H_2O \rightarrow$$
$$2\ [Fe_{15}Ni][O_{12}(OH)_{20}]Cl(OH)_2.$$
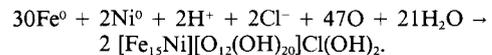
Cl$^-$ ion is apparently ubiquitously available in nature to supply electrical neutrality at the corrosion front, even under conditions of meteorite residence within and on Antarctic ice. Akaganeite transforms with time to the other oxides.

No justification for lawrencite, (Fe,Ni)Cl$_2$, has been found in this work. The rationale presented here accounts for the type of observations that have previously been made on similar materials and attributed to lawrencite, a name in the mineralogical literature that has never been adequately defined.

Twinned Diamonds in the Orgueil Carbonaceous Chondrite.

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Tiny diamonds were reported from insoluble residues from the Allende, Murray, Murchison, and Indarch carbonaceous chondrites by Lewis *et al.* (1), and there have been several confirming studies by other groups. We have found the first diamonds in residues from the Orgueil CI chondrite (prepared by Halbout et al. [2]). Such diamonds were not observed *in situ* in the HRTEM study of Orgueil by Tomeoka and Buseck [3], and so they are presumably extremely finely dispersed.

The Orgueil diamonds are from 10 to 60 Å in diameter. The crystal sizes follow close to a log normal distribution. We see no voids, inclusions, or defects that would accommodate trapped gases and so conclude that such gases, if present in the structural fashion implied by [1, 4, 5], must indeed occur as point interstitials.

Roughly 5 to 10% of the ~200 Orgueil diamond crystals we have observed are twinned and so are apparently unique among meteoritic