condensation of refractory condensates ($F_{La}$ = 0.002) had occurred [6]. A similar pattern has been found in Allende inclusion EK 1-4-1 [7].

The oxygen isotopic compositions of two anorthite-rich chondrules in Ningqiang, reported in [8], indicate that these objects are similar to refractory inclusions and the most $^{16}O$-rich porphyritic chondrules in Allende.

In summary, the anorthite-rich chondrules have petrologic and geochemical properties of both chondrules and refractory inclusions. The similarities among these objects suggests they may have formed in related events. References: [1] Steele I. M. (1986) *GCA* **50,** 1379. [2] Kring D. A. and Wood J. A. (1987) *Meteoritics* **22,** 432. [3] Bischoff A. and Keil K. (1984) *GCA* **48,** 693. [4] Sheng Y. J. *et al.* (1988) *LPS* **19,** 1075. [5] Lui Y.-G. *et al.* (1988) *LPS* **19,** 686. [6] Boynton W. V. (1975) *GCA* **39,** 569. [7] Nagasawa H. *et al.* (1982) *GCA* **46,** 1669. [8] Clayton R. N. *et al.* (1988) this volume.

**Why Do Allende Chondrules Lie on a Different Oxygen-Isotope Mixing Line Than Allende CAIs?—A Model.** David A. Kring and John A. Wood. Department of Earth and Planetary Sciences, Harvard University, and the Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138 USA.

The oxygen isotopic compositions of Allende refractory inclusions and matrix define a line that has been interpreted to represent mixing between endmember reservoirs consisting of $^{16}O$-enriched dust and $^{16}O$-depleted gas. The oxygen isotopic compositions of Allende chondrules do not fall along the CAI mixing line (Figure 1); they seem to require different endmember reservoirs. Clayton *et al.* (1) propose the existence of a second $^{16}O$-depleted gas reservoir, which mixed with solids having isotopic compositions on the CAI mixing line.

However, there is another way to understand the offset of the chondrule line from the CAI line, which this paper explores. The chondrules could have formed from precursor material that had been isotopically mass fractionated from an earlier generation of presolar material that had compositions on the CAI mixing line. Isotopic mass fractionation would have been particularly effective during vaporization and recondensation of the presolar dust. The oxygen from the dust would have mixed with the local gas, producing gas with an intermediate isotopic composition on the CAI mixing line. When the system cooled, dust would have recondensed that was isotopically mass fractionated from the gas. We have modelled this process by considering the vaporization and recondensation of forsterite in a system of cosmic composition at $10^{-5}$atm. Forsterite condenses from 1294 to 1169 K, at which point

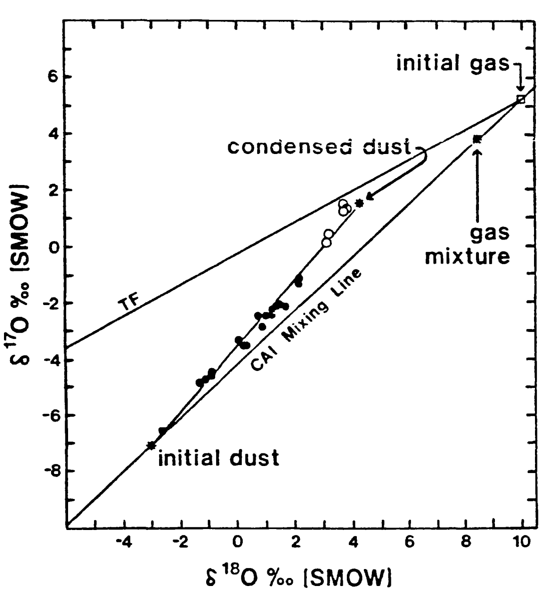


FIG. 1. TF = terrestrial fractionation line, ● = porphyritic chondrules, ○ = barred olivine and radial pyroxene chondrules.

99.9% of the Mg has been removed from the gas. The amount of isotopic mass fractionation has been assessed on the basis of fractionation factors determined by Onuma *et al.* (2) as a function of temperature and composition. Figure 1 shows the oxygen isotopic composition of the newly condensed, mass fractionated dust. The chondrule line may have been formed by simple mixing of recondensed dust in various proportions with unvaporized dust; or recondensation may have occurred directly onto relic dust, which formed composite grains with bulk oxygen isotopic compositions distributed along the chondrule mixing line. The chondrules themselves were formed by remelting of this precursor dust.

Another effect may have helped establish the distribution of chondrule oxygen-isotope compositions. Vaporization of dust-enriched primordial systems would have produced gas mixtures that lie lower on the CAI line of Fig. 1 than the point shown; recondensation from these gases would yield dust that lies lower on the chondrule line than the point shown. References: (1) Clayton R. N. *et al.* (1983) In *Chondrules and Their Origins* (ed. E. A. King), p. 37. LPI, Houston. (2) Onuma N. *et al.* (1972) *GCA 36,* 169.

**Relationships Between Compact Type A and Spinel-Rich Inclusions Inferred from a Composite CAI.** S. M. Kuehner and L. Grossman.[1] Dept. of the Geophysical Sciences, The University of Chicago, Chicago, IL 60637 USA. [1]Also Enrico Fermi Institute, The University of Chicago, USA.

The Allende inclusion TS60F1 (10 mm × 5 mm) is a loosely packed aggregate of irregularly-shaped, rounded, spinel-, perovskite-rich nodules (SPR, ~90% of inclusion) upon which is attached a hemispherical melilite-rich region (1.7 mm dia.) resembling a compact type A inclusion (CTA). Individual nodules (180 $\mu$m to 1.8 mm) and the CTA margin adjacent to the Allende matrix are enclosed by concentric hedenbergite, Al-diopside and sodalite + anorthite rim layers. Spinel-rich inclusions have been proposed (1) to be the residual material produced after extensive partial melting/volatilization of interstellar material, with less extensively processed material forming types A and B CAIs. A study of TS60F1 was initiated to evaluate the genetic relationship between the SPR nodules and the associated CTA.

Unaltered SPR nodules are composed of ~30% subhedral perovskite (~5 $\mu$m dia.) set in a massive spinel matrix. EPMA of perovskite from any individual nodule reveals two distinct groups: $ZrO_2$-rich (0.3–0.6 wt.%) and $ZrO_2$-poor (<0.05–0.20 wt.%). Spinel grains in unaltered SPR nodules are FeO-poor (<2 wt.%) with minor $V_2O_3$ (0.14–0.20 wt.%) and $Cr_2O_3$ (0.08–0.17 wt.%). One unaltered SPR region contains an irregularly-shaped crystal of melilite (270 $\mu$m × 80 $\mu$m) that grades texturally from an inclusion-free center ($Ak_{34}$) into a region of melilite ($Ak_{2-7}$) + rounded spinel and minor perovskite at the grain edge. Adjacent to this crystal, the nodule is dominated by spinel + perovskite with minor melilite ($Ak_{4-10}$).

Excluding alteration minerals, the CTA is composed of >95% melilite, with minor amounts of spinel and perovskite. The melilite is homogeneous, $Ak_{15-17}$, but becomes slightly more gehlenitic towards the margins ($Ak_{8-11}$). Spinel grains are FeO-poor (<1.2 wt.%) but differ from spinel in the SPR nodules in being enriched in $V_2O_3$ (0.42–0.56 wt.%) and $Cr_2O_3$ (0.18–0.25 wt.%). Perovskite compositions fall in the $ZrO_2$-poor group of the SPR nodules. The outer margin of the CTA, internal to the rim layers, is composed of an ~75 $\mu$m wide spinel layer that contains numerous perovskite (<10 $\mu$m) and irregularly-shaped melilite inclusions ($Ak_5$). Spinel in the CTA margin is identical in composition to spinel in the SPR nodules. The perovskite compositions fall in the Zr-rich group as defined in the SPR nodules.

This study of TS60F1 shows that the range of spinel and perovskite compositions in the margin of the CTA is similar to that found in the unaltered regions of the SPR nodules, implying a similar process was involved in their formation. The origin of spinel + perovskite margins on melilite-rich CAIs may be the result of incomplete volatilization during a period of flash-heating (2). Such a process is consistent with the CTA melilite becoming slightly less Ak-rich near the spinel margin. Rare, incompletely digested melilite grains in the SPR nodules suggest that the nodules formed through more extensive volatilization of CTA material, which would also result in mixing of the two perovskite populations. The extreme abundance of perovskite in the nodules may indicate this process was accompanied by the introduction of Ti. Ref-

erences: (1) Cohen R.E. *et al.* (1983) *GCA* **41,** 1739. (2) Boynton W. V. and Wark D. A. (1985) *Meteoritics* **20,** 613.

**The Plutonium-244 Story.** P. K. Kuroda. Environmental Research Center, University of Nevada, Las Vegas, NV 89154 USA.

In 1868, Pierre Janssen went to India to study a total eclipse of the Sun. He observed a strange spectral line and forwarded the data to Sir Joseph Lockyer, who attributed it to a new element he called HELIUM. Since Lockyer's report many strange lines have been discovered in the light of heavenly objects and some have been attributed to new elements named CORONIUM, GEOCORONIUM, NEBULIUM and so on. All of these have turned out to be just old elements under unusual conditions. All, that is, but one. The one exception was HELIUM. Twenty seven years later, the existence of helium was discovered on earth by Sir William Ramsay.

In 1936, Francis Aston went to Japan to study a total eclipse of the Sun and gave a lecture at the University of Tokyo. Most scientists in Japan at that time are said to have failed to understand the connection between the Sun and Aston's mass spectrograph. Twenty seven years after Aston's expedition to Japan, the foundation of a new science called Xenology was being established in the United States by John Reynolds (1) at Berkeley. The discoveries of the Renazzo-type (2) and Pasamonte-type (3) fission xenon then followed in succession in 1964 and 1965. While the latter soon became accepted as the spontaneous fission product of plutonium-244 which existed in the early solar system, the origin of the former became the focus of heated controversies in the 1970s and the 1980s. Manuel *et al.* (4) were the first to recognize it as possible r- and p-products from a supernova. Srinivasan and Anders (5) then followed with their claim of the discovery of s-products from a supernova. These strange xenon components which are now identified variously as CCF, CCFX, X, R, HL and so on remind the speaker of the strange spectral lines discovered in the light of heavenly objects by various investigators in the 19th century. They are not pure substances. Instead, they are mixtures of plutonium-244 fission xenon and mass-fractionated primitive xenon (6). References: (1) Reynolds J. H. (1963). *J. Geophys. Res.* **68,** 2939–2956. (2) Reynolds J. H. and Turner G. (1964) *J. Geophys. Res.* **69,** 3263–3281. (3) Rowe M. W. and Kuroda P. K. (1965) *Geophys. Res.* **70,** 709–714. (4) Manuel O. K., Hennecke E. W. and Sabu D. D. (1972) *Nature* **240,** 99–101. (5) Srinivasan B. and Anders E. (1978) *Science* **201,** 51–56. (6) Kuroda P. K. (1971) *Nature* **230,** 40–42.

**Noble Metal Abundances in Early Archean Spherule Layers from South Africa.** Frank T. Kyte, Donald R. Lowe[2] and Gary R. Byerly.[2] [1]Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024 USA. [2]Louisiana State University, Baton Rouge, LA 70803 USA.

Layers of altered spherules in Early Archean (3.2 to 3.5 Ga) sedimentary deposits from the Fig Tree Group, Barberton Greenstone Belt, South Africa and the Warrawoona Group, Eastern Pilbara Block, Western Australia have been interpreted as the oldest known impact deposits on Earth (1). Three spherule layers have been identified in South Africa and one in Australia. These layers contain high concentrations of spherules, some of which have relict quench textures. Individual layers can be identifed in outcrops separated by distances of up to 50 km.

Recent analyses of these spherule beds (2) have shown that all four layers contain high concentrations of Ir relative to surrounding sediments. The excess Ir is particularly anomalous in the youngest two spherule beds from South Africa. Samples from bed S3, the uppermost Fig Tree layer have been observed to contain Ir concentrations as high as 162 ng/g and samples from Fig Tree bed S2 have yielded Ir concentrations as high as 76 ng/g. Iridium concentrations of 5 to 10 ng/g in the other two layers are an order of magnitude higher than in surrounding sediments, but not much greater than in hi-Mg komatiites (0.5 to 5 ng/g Ir) found elsewhere in the section.

As a test of the hypothesized impact origin of these spherule beds, we have begun to analyze a suite of noble metals—Ir, Au, Pt, Os, and Pd in the most Ir-rich samples. In our first experiment, we have found that all of these elements are easily detectable in a sample from bed S3 and preliminary data for Ir, Au, Pt, and Os all show element/Ir ratios within a factor of two of those ratios in CI chondrites. Chemical yield data are not yet available for Pd, but we estimate that this element also has a roughly chondritic abundance relative to Ir.

These spherule beds and most of the other rock units in the Fig Tree Group have been heavily altered by metasomatic processes, primarily resulting in removal of most of the mobile elements and replacement of most minerals by quartz and phyllosilicates. However, relatively immobile elements (*e.g.,* Al, Ti, REE) appear to reflect the original concentrations of the precursor rocks. The high concentrations and roughly chondritic abundances of 4 or 5 noble metals are unlikely to be an artifact of alteration and probably reflect the composition of the source material. References: (1) Lowe D. R. and Byerly G. R. (1986) *Geology* **14,** 83–86. (2) Lowe D. R., Asaro F. and Byerly G. R. (1988) *Lun. Plan. Sci.* **19,** 695–696.

**Fractionation in Chondrites: Major Elements Revisited.** J. W. Larimer. Dept. of Geology and Center for Meteorite Studies, Arizona State University, Tempe, AZ 85287 USA.

The elements Fe, Mg, Si and O account for 80 to 90% by mass of chondritic material. All are fractionated among the various groups of chondrites and O displays isotopic fractionations which may be related to the elemental fractionations. Recent data have been combined with previous high quality data in an attempt to establish new constraints, and obtain some fresh insights, on the nature of these fractionations.

In CI chondrites (within solar value uncertainties) Fe (±20%), Mg (±40%) and Si (±20%), as well as most other elements, occur in solar proportions which is generally accepted as evidence that planetary material evolved from this composition. Additional evidence is obtained from mixing diagrams where the fractionation trends intersect at, or point to, CI composition. It is possible to quantify the fractionation: the amounts of Fe, Mg and Si and all the more refractory elements in the materials that accreted to form the chondrites varied by more than a factor of two. The fractionation of the lithophile elements apparently involved a component that compositionally resembled amoeboid olivine inclusions, which contain all the refractory elements in more or less solar proportions diluted by variable amounts of olivine. Relative to CI material, ordinary and enstatite chondrites accreted only a fraction of their Mg and Si. Since these elements are commonly used for normalization, the implication is that all elements are more severely depleted in the accreted material than previously considered. This means, for example, that E-chondrites should not be regarded as being as rich in volatiles as C-chondrites, instead they are better described as being depleted in Si. In addition metal/silicate fractionation is more extensive than thought; we are currently in the midst of reviewing and re-evaluating the data on siderophile elements.

When the information drawn from the fractionation patterns is combined with other observations some general conclusions can be drawn. Individual chondrules from unequilibrated chondrites vary markedly in their proportions of Fe, Mg, Si and O as well as in their proportions of O isotopes yet when blended together in the meteorite the average elemental and isotopic composition falls within the narrow ranges displayed by their more nearly equilibrated counterparts. Moreover, in carbonaceous chondrites where there are not only variations in composition between chondrules but also in the proportions of chondrules to matrix, the Mg/Si ratio remains remarkably constant. This indicates that the chondrules and matrix in each group of chondrites evolved from a parental material whose composition was already fixed by prior fractionation. Chrondrule formation must post-date the fractionation processes and cannot itself be a process that tends to remix the various batches of material from which each chondrite group evolved.

**New Systematics of Nuclear Reactions Induced by Proton or Neutron Bombardment in the Ga to Rh Target Mass Region.** Bernard Lavielle and Gabriel N. Simonoff. UA 451 CNRS, CENBG 33170 Gradignan, France.

Cosmic-ray-produced nuclides provide sensitive tools for studying exposure histories of terrestrial or extraterrestrial materials. A knowledge of the excitation functions for the nuclear reactions induced by protons and neutrons is essential for production rate calculations which take into account the shielding depth of the samples within a meteoroid and the meteoroid size. However, these excitation functions have been measured for only a few proton-induced reactions, and most of them