BULK COMPOSITIONS OF CV AND CK CHONDRITES: SUPPORT FOR A CLOSE RELATIONSHIP. Junko Isa, Alan E. Rubin and John T. Wasson, Department of Earth and Space Sciences and Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA (jisa@ucla.edu).

Introduction. The CK group was first defined in 1995 by Kallemeyn et al. [1]; they noted the close compositional and textural relationship to the CV chondrites, but concluded that these are separate groups on the basis of refractory lithophile abundances and textural features such as the abundance of refractory inclusions and igneous rims around chondrules. More recently, Greenwood et al. [2] measured precise O-isotopic compositions in sets of CV and CK chondrites and found that many isotopic and petrographic properties of these meteorites are closely similar and suggested that they are parts of a single chondrite group differing only in the extent of thermal metamorphism.

Weathering effects in CK chondrites. The CK chondrites are extremely oxidized; this is attributed to aqueous alteration on the parent asteroid. Only two (Karoonda and Kobe) are falls, and Kobe is not generally available for study. As discussed in some detail by Huber et al. [3], weathering processes have produced serious fractionations in the CKs, and especially in samples from hot deserts. They noted that one common indicator of weathering is low Ni and Au contents.

Oxidation effects in CV chondrites. The CV chondrites fall into three redox types: the reduced Vigarano (CV_R) subgroup, and the oxidized Allende (CV_{OxA}) and Bali (CV_{OxB}) subgroups. An important question is whether there are significant compositional differences resulting from the different alteration histories of these types.

The old and new evidence. There is no doubt that CK and CV chondrites are closely related. CK O-isotopic compositions plot together with CV_R and CV_{OxA} chondrites on three-isotope diagrams. Their textures including chondrule sizes and abundances are similar as are most trace-element concentrations. The meteorites are all relatively oxidized (although it is well documented that the metal abundance varies from ~6 wt% in CV_Rs to <0.5% in the CV_{OxA} and CV_{OxB} chondrites). The CK chondrites are the most oxidized anhydrous group, but with a few poorly documented exceptions, they have been metamorphosed to types ≥4; it seems plausible that such oxidized materials could be produced by thermal alteration of either of the CV oxidized types. There are no documented examples of CV chondrites of petrographic type ≥4.

Kallemeyn et al. [1] analyzed 26 elements in CK chondrites by INAA and reported that Al/Mg ratios resolved the two groups; however, they observed complete overlap in Ca/Mg and Sc/Mg ratios. Their range in CK Al/Mg ratios was remarkably small, only 1.06. They also found that CK volatile abundances are, on average, 10-20% lower than those in CV chondrites; other than Zn and Se, these volatiles would be siderophile if metal were present. The lower CK values could partly reflect weathering which has selectively depleted siderophile and chalcophile elements in some samples.

Greenwood et al. [2] determined 16 elements in CK and CV chondrites by ICP-MS; their Al/Mg, Ca/Mg and Sc/Mg fields for CK and CV overlapped. All of their CK chondrites except Karoonda were collected from hot deserts.

M. Isa et al. [6] determined many elements in 19 Antarctic CK chondrites and about 4 CV chondrites using INAA and ICP-MS, the latter mainly to determine highly volatile elements. Mean Bi values in CK are ~3× lower than in CV and mean Tl values are ~30× lower. In contrast to OC, there is no relationship between CK abundances of these highly volatile elements and petrographic type. They thus concluded that these are nebular rather than metamorphic effects and that CKs and CVs had different nebular origins. However, the peak temperatures experienced by CK4-6 chondrites (based on the stability limit of pentlandite (≤610ºC) and the observation of nearly pure $FeAl_2O_4$ exsolution from magnetite) are <600ºC [4]. This is much lower than that of type 4-6 OC (600-950ºC) [5]. This and other arguments make volatile loss during thermal metamorphism unlikely.

We determined 27 elements for 7 CK chondrites (LAR 04318, EET 92002, MIL 090103, RBT 03522, BUC 10944, LAP 10030, Karoonda) and 7 CV chondrites (Allende, LAP 02206, MCY 05219, RBT 04143, GRA 06101, MIL 07002, MIL 090001). Most data are means of duplicate analyses of 300-mg samples. All chondrites are finds from Antarctica except CK4 Karoonda and CV3 Allende. We also included a sample of the CK3-an fall Ningqiang. We do not yet have data for Al and Mg.

In Fig. 1 we plot Zn/Cr and Sc/Cr against Sm/Cr. On both diagrams the CK and CV fields overlap. The CKs LAR 04318 and MIL 090103 have low Au and Ni values and are inferred to have experienced significant weathering; thus, the low Zn in the former and the high Sc in the latter should be neglected. We will analyze additional samples and refine the data but the current interpretation is that our CK and CV data do not support the conclusion of [1] that there are inherent compositional differences between CK and CV chondrites established in the solar nebula.

With the exception of MIL 07002 (possibly intermediate between CV_{OxA} and CV_{OxB}), our CV samples all appear to be CV_{OxA} chondrites; thus, our INAA data cannot be used to search for differences among the three CV subgroups.

Our data set included two anomalous chondrites. Our compositional data on Ningqiang (CK3-an) support earlier studies that showed it to have higher Zn than normal CK or CV. Our sample has low Sm (Fig. 1) and other REE even though Sc/Cr is in the normal range. We will analyze another replicate before attempting to interpret this value.

MIL 090001 is classified in the Meteoritical Bulletin as CV_R. Keller [7] identified MIL 090001 as a breccia and classified it as CV2 based on matrix phyllosilicates and the presence of magnetite framboids, plaquettes and spherulites. Our INAA data (means of duplicate analyses) call the CV classification into question. As shown in Fig. 1, relative to CV chondrites, Zn/Cr is 35% lower, Sc/Cr and Sm/Cr are 25% lower, Na is 70% lower, and K is ~35% lower. Our petrographic observations indicate that the meteorite is shock-stage S1 and has no noticeable petrofabric. It contains moderately abundant metal, although much of it has been terrestrially weathered; there is little coarse magnetite.

Conclusions. The conclusion of [1] that the CK and CV chondrite groups had distinct nebular and asteroidal origins seems doubtful. It currently rests on the original Al/Mg data of [1] and differences in volatiles such as Br [1], Bi [6] and Tl [6]. However, the total range of 1.06 in Al/Mg seems implausibly small; this implies a 1-σ error of ~2%. We would expect sampling and analytical errors to be appreciably larger (although these two elements were determined in the same INAA counts, eliminating one possible error source). The data for highly volatile elements in different metamorphic types of L chondrites are remarkably systematic (e.g., [8]), but the same regular progression has not been found in H and LL chondrites. If the volatiles were lost and the heat introduced during impact events [9], it would not be surprising if there were large variations in the products of these processes.

We conclude that the best working model is that the CV and CK chondrites are samples of the same nebular materials. And, as noted by [2], the similarity in cosmic-ray exposure-age distributions among members of these groups supports the view that they originated in the same asteroidal parent body.

References: [1] Kallemeyn G. et al. (1991) GCA 55, 881. [2] Greenwood R. et al. (2010) GCA 74, 1684. [3] Huber H. et al. (2006) GCA 70, 4019. [4] Righter K. and Neff K. (2007) Polar Sci. 1, 25. [5] Dodd R. (1981) *Meteorites – A Petrologic-Chemical Synthesis*, Cambridge, 368 pp. [6] Isa M. et al. (2011) LPS 42, 1876 pdf. [7] Keller L. (2011) LPS 42, 2409 pdf. [8] Tandon S. and Wasson J. (1968) GCA 32, 1087. [9] Wasson J. (2005) MaPS 40, A166.

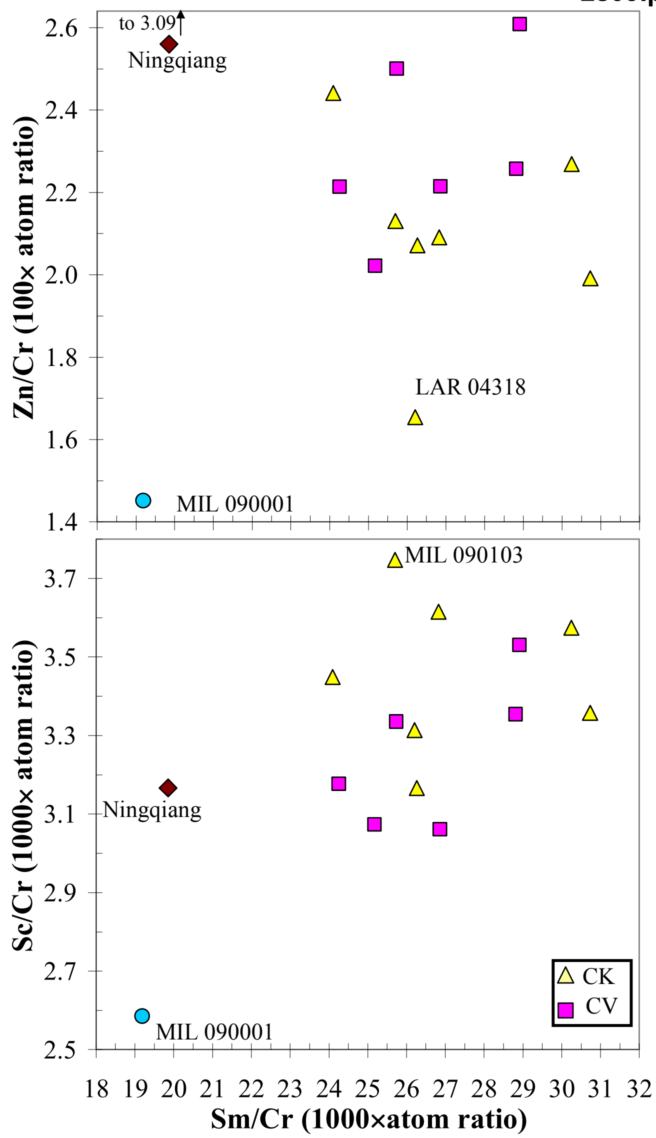

Fig. 1. Plot of Zn/Cr and Sc/Cr against Sm/Cr. The CK and CV fields overlap on both diagrams.