**OXYGEN ISOTOPE DISTRIBUTION IN ANORTHITE-SPINEL-RICH INCLUSIONS FROM THE NINGQIANG CARBONACEOUS CHONDRITE.** Yunbin Guan[1], Yanting Lin[2] and Laurie A. Leshin[1,3], [1]Department of Geological Sciences, Arizona State University, Box 871404, Tempe, AZ 85287-1404 USA (yunbin.guan@asu.edu); [3]Institute of Geology and Geophysics, Chinese Academy of Sciences, P.O. Box 9825, Beijing 100029, China (linyt@mail.igcas.ac.cn); [3]Center for Meteorite Studies, Arizona State University, Box 871404, Tempe, AZ 85287-1404 USA (laurie.leshin@asu.edu).

**Introduction:** Ningqiang is an anomalous carbonaceous chondrite, with petrologic and chemical affinities to CK and CV chondrites. Bulk and *in situ* oxygen isotope analyses have been reported for its chondrule, matrix, and type A calcium-aluminum-rich inclusions (CAIs) [1-4]. In this study, we investigate the oxygen isotope compositions of another type of CAIs -- anorthite-spinel-rich inclusion (ASI) [5], in Ningqiang.

**Samples and Analytical Techniques:** We analyzed three CAIs from two polished thin sections of Ningqiang (NQJ1-1 and NQJ2-1). Two of the CAIs (NQJ1-1#1 and NQJ2-1#1) are irregular-shaped large (a few mm in size) ASIs previously described in [5]. They consist of a spinel-rich core, a spinel-anorthite-Ca-pyroxene mantle, and a melilite-spinel crust. Sodalite coexists with nepheline in the mantles in the ASIs, and both replace anorthite. The other CAI (NQJ1-1#2) is a small (~60 μm in diameter) melilite-spinel inclusion with a diopside rim.

*In-situ* oxygen isotope analyses of individual components in Ningqiang CAIs were carried out using the Cameca IMS 6f ion microprobe at ASU, and techniques described in [6]. Uncertainties on individual analyses, taking into account the variation on repeated analyses of the standard, are ~1-2‰ (2σ). Matrix effects are minor under our analysis conditions and no correction for such effects has been made.

**Results:** The oxygen isotope compositions of individual minerals in the three Ningqiang CAIs are plotted in Fig. 1. All the data plot along the CCAM line with spinel showing "typical" $^{16}$O-enriched $\delta^{18}$O and $\delta^{17}$O values at –40 to –50‰. Spinels in the mantle and core of the ASIs exhibit no obvious difference in their oxygen isotope compositions. The less $^{16}$O-enriched δ–values (-37‰ and -40‰) of two spinels, one in the crust of NQJ1-1#1 and the other in the center of NQJ1-1#2, result from slight beam overlap onto $^{16}$O-poor melilite (see following results) during analysis. Two diopside grains, one in the crust of NQJ1-1#1 and the other in the rim of NQJ1-1#2, contain intermediate $^{16}$O-excesses, plotting along the CCAM line at δ-values of about –30‰.

Two anorthite spots from the NQJ1-1#1 mantle have δ-values of ~ –15‰ and –12‰. Similar oxygen isotope compositions were observed in two melilite grains separately located in the crust of NQJ1-1#1 and the center of NQJ1-1#2.

Sodalite in the mantle of NQJ1-1#1, which contains $^{36}$S excesses from *in situ* decay of the short-lived radionuclide $^{36}$Cl [7], is slightly less $^{16}$O-enriched than melilite and anorthite.

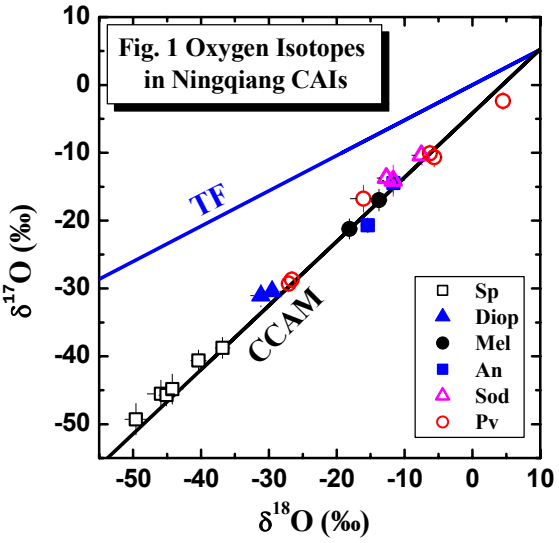
Intriguing oxygen isotopic data were observed for perovskite in the two Ningqiang ASIs. Perovskite grains in the two ASIs are normally about 10 μm or less in size. They can be found enclosed in spinel, melilite, and diopside (*e.g.* Fig. 2; Fig. 3). The oxygen isotope compositions of six perovskite grains show large variations and generally are not enriched in $^{16}$O. Two perovskite grains in the NQJ1-1#1 core (Fig. 2), obviously formed earlier than spinel and showing no sign of late reaction, have δ-values of about –27‰. SEM examination of ion microprobe craters indicated slight overlap onto the surrounding spinel for these two spots. Two perovskites in the NQJ2-1#1 mantle (Fig.3), probably endured a later alteration event during which anorthite and Ca-pyroxene replaced melilite to form the ASI mantle [5], give values of $\delta^{18}$O=-5‰ and $\delta^{17}$O=-10‰. Due to beam overlap, the δ-values ($\delta^{18}$O=-16‰ and $\delta^{17}$O=-17‰) of another perovskite grain of similar occurrence suffer from significant contribution from surrounding diopside, anorthite, and spinel grains. One grain from the crust of NQJ1-1#1, is the most $^{16}$O-depleted grain measured in this study, with $\delta^{18}$O=5‰ and $\delta^{17}$O=-2‰. Similarly $^{16}$O-depleted oxygen isotope compositions were previously reported for perovskite in type A CAIs from Leoville [8] and Ningqiang [4], and in a type B CAI from Allende [9].

**Discussion:** The oxygen isotope heterogeneity among spinel, diopside, melilite, anorthite, and sodalite in Ningqiang CAIS is generally similar to observations made in Allende CAIs [*e.g.* 10, 11], presumably produced by post-crystallization isotopic exchange between $^{16}$O-rich solids and $^{16}$O-poor nebular gas (or some other $^{16}$O-poor components). Ningqiang melilite, anorthite, and sodalite are somewhat less depleted in $^{16}$O than their counterparts in Allende CAIs [10, 11]. Anorthite in Ningqiang ASIs was formed by reaction of melilite with gaseous components [5], probably in a $^{16}$O-poor reservoir in the nebula. The intermediate $^{16}$O-exess of anorthite is consistent with its secondary ori-

gin. In addition, the reaction probably took place at least 1.5 My after formation of the original CAIs as indicated by the absence of $^{26}$Mg-excess in anorthite. Sodalite in the Ningqiang CAIs was produced by alteration of anorthite, which happened not much later than the formation of anorthite, otherwise the short-lived $^{36}$Cl should have decayed [7]. Sodalite shows only slightly less $^{16}$O-excess than anorthite, suggesting a similar oxygen reservoir for both minerals.

Perovskite is believed to be one of the high temperature primary phases formed early in CAI condensation or crystallization sequences [*e.g.,* 12, 13], and should consequently contain $^{16}$O-enrichments like most hibonite and spinel. All the *in situ* measurements available [4, 8, 9, and this study], however, indicate that CAI perovskite is relatively $^{16}$O-depleted. What could be the possible mechanisms that produced $^{16}$O-poor perovskite? If originally $^{16}$O-enriched, later partial melting might affect the perovskites in the type A CAI from Leoville [8] and the type B CAI from Allende [9], but little melting has been observed in the two ASIs [5] and the fluffy type A CAI [14] from Ningqiang. For later diffusion process to be the cause of $^{16}$O-depletion in CAI perovskite, it requires very fast oxygen diffusion rate in perovskite. There is no experimental data available; however, if the oxygen diffusion rate in perovskite is similar to that in spinel, which is extremely slow, diffusion could not be the cause for $^{16}$O-depletion in perovskite. In addition, the occurrence of $^{16}$O-poor perovskite enclosed in $^{16}$O-rich spinel is difficult to explain by diffusion processes. Another possibility is that perovskite are relict grains that formed with or without $^{16}$O excesses before their incorporation into the CAIs, which implies that they originated from a separate CAI formation episode as for spinel and pyroxene, and probably from a different oxygen isotopic reservoir as well. Obviously, further systematic investigation is needed to understand the implications of the observed $^{16}$O-depletion in CAI perovskite.

**References:** [1] Mayeda T. K. et al. (1988) *Meteoritics, 23,* 288. [2] Clayton R. N. and Mayeda T. K. (1999) *GCA, 63,* 2089-2104. [3] Choi B.–G. (2003) *GCA, 67,* 4655-4600. [4] Hiyagon et al. (2004) *MAPS, 39*, A46. [5] Lin Y. and Kimura M. (1998) *MAPS, 33,* 501-511. [6] Jones R. H. et al. (2004) *GCA, 68,* 3423-3438. [7] Lin Y. et al. (2005) *PNAS* (in press). [8] Caillet C. et al. (1997) *LPS XXVIII,* 199–200. [9] Kim G. L. et al. (2002) *J. Mineral. Petrol. Sci., 97,* 161-167. [10] McKeegan K. D. and Leshin L. A. (2001) *Rev. Mineral. Geochem., 43,* 279-318. [11] Yurimoto H. et al. (1994) *EPSL, 128*, 47-53. [12] Stolper E. (1982) *GCA, 46,* 2159-2180. [13] Beckett J. R. and Stopler E. (1994) *Meteoritics, 29,* 41-65. [14] Lin Y. and Kimura M. (2003) *GCA, 67,* 2251-2267.



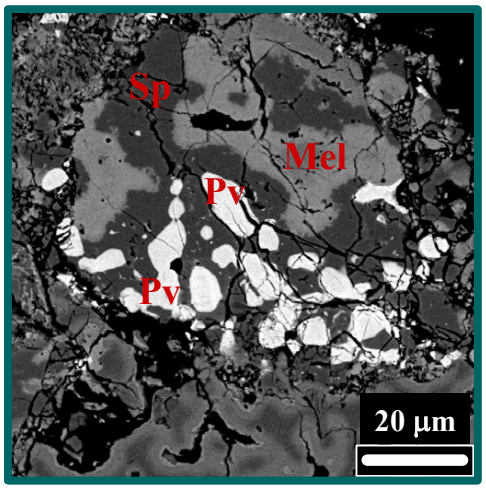




**Fig. 2 Perovskite in the core of NQJ1-1#1**

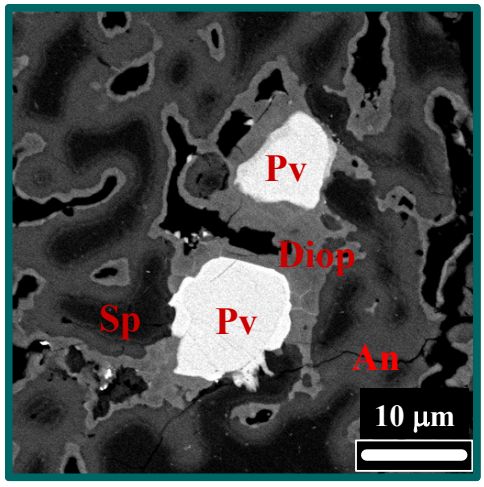



**Fig. 3 Perovskite in the mantle of NQJ2-1#1**