LARGE, RELICT, CHROMIAN SPINELS IN ALLENDE: A LINK TO MURCHISON? S. B. Simon[1], L. Grossman[1,2], D.S. Ebel[1], and C. Palenik[1], [1]Dept. of the Geophysical Sciences, 5734 S. Ellis Ave., [2]The Enrico Fermi Inst., 5640 S. Ellis Ave., Univ of Chicago, Chicago, IL 60637.

Introduction. A chip of the Allende CV3 chondrite containing an inclusion with a huge (1 mm), red, single crystal of Cr-bearing spinel was sent to us by Mr. S. Kambach of Lörrach, Germany. This discovery inspired a search of additional slabs of Allende for other red spinel occurrences. We now have a total of 17 thin sections, each of which contains one or more spinel-bearing objects. Coarse (> ~ 50 µm), Cr-bearing spinel grains are readily recovered from the dense fraction of the disaggregation products of the Murchison CM2 meteorite. They are rarely found *in situ*, however [1], making their origin difficult to determine. Preliminary analysis of the Allende spinels shows that some of them exhibit similarities to Murchison spinels with respect to size, zoning style, chemical composition, and even their silicate inclusions. Studying the grains *in situ* gives us an opportunity to interpret their petrogenesis. Also, detailed comparison with the Murchison spinel population allows us to assess whether these two otherwise quite different meteorites have this mineralogic component in common.

Observations. ALSP1 consists of a spectacular, 1.0 x 0.75 mm spinel crystal *fragment*, partially enclosed by forsterite grains (Fo_{95-99}) that are set in a fine-grained groundmass of nepheline and relatively Fe-rich (Fo_{59-85}) olivine. The forsterite grains are mostly 50-100 µm across and their cores exhibit strong, blue cathodoluminescence. They also have Fe-rich (Fo_{62-73}) veins and rims, which are typical of olivine in oxidized CV3 chondrites [2]. The spinel was deep red on the chip surface, and in thin section it is pale pink. Backscattered electron images show that it is chevron-zoned [1]. Its contents of Cr_2O_3 and V_2O_3 overlap those of chevron-zoned grains from Murchison; FeO and TiO_2 contents exhibit slightly wider ranges than the corresponding Murchison spinels. It has a broad, relatively Cr-poor (2.5-3.0 wt % Cr_2O_3) interior. Outward, Cr_2O_3 contents increase very gradually up to the outer ~200 µm, which consist of 4-6 alternating Cr-rich (up to ~ 8 wt % Cr_2O_3) and Cr-poor layers that are parallel to two intersecting crystal faces. The innermost Cr-rich/Cr-poor contact is straight and sharp, but others are irregular. As in the Murchison spinels, FeO contents in the ALSP1 spinel are not correlated with Cr_2O_3 contents. Unlike the Murchison spinels, which generally have uniform FeO contents [1], in ALSP1 FeO contents of the spinel increase continuously toward the crystal edge, ranging from 0.5 to ~15 wt %. The edge of the spinel crystal is embayed and most of the spinel/olivine contacts are serrated. The regions of the ALSP1 spinel that exhibit oscillatory zoning also contain rounded inclusions of aluminous diopside that are ~ 30 µm across and are associated with voids, like many of the diopside inclusions found in Murchison spinels [1].

It seems unlikely that, in ALSP1, the phases and their proportions together represent a liquid composition from which they crystallized. For ALSP1 to have crystallized from a liquid would require an Al-rich, Si-poor melt that not only crystallized spinel first, but did so in the form of a single, oscillatory-zoned grain. In addition, the observed trend of increasing Cr_2O_3 from core to rim is not consistent with fractional crystallization because Cr is strongly compatible in spinel [3], and forsterite would not crystallize from a liquid that yielded spinel with ~ 10-15 wt % FeO. This spinel is too Cr- and Fe-rich to have condensed from a solar gas [4]; a better explanation is condensation from a gas that was more oxidizing. Oxidizing conditions stabilize Cr in spinel, and the amount of Cr_2O_3 that can enter spinel increases with decreasing temperature. We have pursued this idea, using the method of [5]. In a vapor with $P^{tot} = 10^{-3}$ bar and a CI dust/gas enrichment factor of 100 relative to solar, log fo_2 = -11.9 at 1750K. Under these conditions, spinel would begin to condense at 1820K and be joined by forsterite at 1780K. The Cr# (Cr/(Cr+Al)) of the spinel would increase from ~0.01 at 1820K to ~0.1 at 1720K. The ALSP1 spinel falls within this range, except for its most Cr-rich layer. A period of slow cooling, followed by several fluctuations in temperature and/or fo_2 could account for the observed zoning pattern of Cr_2O_3 and the irregular contacts between layers in the ALSP1 spinel. Such a model was considered a possibility for the chevron-zoned grains from Murchison [1]. Despite the relatively oxidizing conditions, the calculated high-temperature spinel would have negligible FeO contents. In the above system, spinel with FeO contents like those of ALSP1 would condense at 1580-1200K but would have Cr#s of 0.6-0.8, much higher than is observed. Alternatively, diffusion of FeO into the spinel could have occurred later, after growth had stopped, but prior to addition of the forsterite grains. The latter are quite similar to each other and are probably related to each other, but not necessarily to the spinel. Formation of nepheline and Fe-rich olivine were the last events in the chemical evolution of ALSP1, reflecting reaction with a volatile-rich fluid.

The second largest spinel grain we found is in ALSP11A, a 320 x 280 µm fragment dominated by a deep red, rectangular spinel grain that is 150 x 110 µm. Except for a thin, Fe-enriched rim, the grain is homogeneous in composition with 23.5 wt % FeO and 50 wt % Cr_2O_3. These are higher abundances than were found in any of the grains separated from Murchison by [1], but, typical of the homogeneous grains in Murchison, the one in ALSP11A contains no inclusions. Except along the broken edge of the fragment, the spinel is enclosed by subhedral olivine grains 5-90 µm across. Most of the olivine is Fo_{52-57}, but four of the larger grains have magnesian cores (Fo_{83-88}). There is much pore space between olivine grains in addition to cavities lined with euhedral olivine, giving the object a spongy texture. Enclosed in the Fe-rich olivine, near crystal edges, are fine (~5 µm) spinel grains that have higher FeO (~40 wt %) and lower Cr_2O_3 (~36 wt %) contents than does the coarse grain. We do not know if this object was ever molten. If it was, then the fragment is probably not representative of the original bulk composition, because that would give a liquid with ~15-20 wt % Cr_2O_3. Nevertheless, the relative size and high Cr content of the coarse spinel point to an unusually Cr-rich melt, unless the spinel is relict.

Spinel grains with patchy zoning [1] have been found in three Allende samples so far. ALSP14A is a 700 x 500 µm chondrule fragment dominated by a 400 x 400 µm embayed olivine grain in a matrix of fine-grained olivine, feldspathoids, and herringbone-textured clinopyroxene ± glass. No spinel is present in the mesostasis, but in the largest olivine embayments sit porous grains of patchy-zoned spinel 50-100 µm across, with 8-20 wt % Cr_2O_3 and 3-23 wt % FeO. The higher values for both oxides generally occur at the edges of the grains, and the lower values in their interiors. This composition range overlaps that of the patchy grains from Murchison [1]. The coarse olivine, deeply embayed and sitting in a Si-rich mesostasis, probably is relict. The zoning of the spinel, from Cr-poor to Cr-rich, and its patchy pattern are not consistent with crystallization from a liquid; these grains, or at least their Cr-poor cores, are probably relict too. Although it occurs in what seems to be a chondrule fragment, the appearance and composition of this spinel are quite like many of the patchy grains found in Murchison and are consistent with formation by sintering of aggregates of small grains, as concluded by [1] for those grains. Other occurrences of patchy spinel grains are in ALSP10 and ALSP8. Sample ALSP10 is a large (5.2 x 2.8 mm) lithic fragment. It consists of at least three chondrules plus additional individual olivine grains. One chondrule is a barred olivine chondrule (1.4 mm diameter) that is welded to the clast by an arcuate band of troilite + pentlandite that is ~100 µm wide and forms most of the chondrule/clast contact. In both this chondrule and in the host, patchy-zoned spinel occurs between olivine grains. This spinel is more Cr-rich (30-46 wt % Cr_2O_3) than any patchy-zoned spinel found in Murchison [1]. In several places, including the chondrule, spinel grew around olivine and conformed to its shape. Another occurrence of patchy spinel is in ALSP8, a barred olivine chondrule with patchy spinel present between olivine bars, but not enclosing any olivine grains. In this sample, the spinel has inclusions of anorthite.

Discussion. CM2 and CV3 chondrites have quite different CAI and chondrule populations [e.g. 6], but they also contain a minor component of near-end-member, blue-luminescing forsterite that is enriched in refractory oxides (Al_2O_3, CaO) relative to typical olivine. One interpretation of this observation is that these meteorites sampled the same, widespread population of condensate forsterite grains [7]. Could Murchison and Allende also have sampled a common population of spinels, grains which condensed in the nebula prior to chondrule formation? Many chondrites contain more oxidized iron than is consistent with condensation from a solar gas, possibly reflecting formation in a relatively oxidizing gas [2,5]. If so, conditions could have been sufficiently oxidizing that condensation of forsterite was preceded by condensation of aluminous, Cr-bearing spinel [5]. Condensation under relatively oxidizing conditions could account for the assemblage of Cr-bearing spinel enclosed in forsterite, and the relatively fayalitic veins and rims [2], seen in ALSP1.

It is difficult to find chromian spinels *in situ* in Murchison that are like those in the mineral separates from that meteorite, but we have found several such grains in Allende. It is interesting to note that these Allende grains appear to be relict, which is what we might expect if they were a widespread condensate in the early solar nebula, as has been suggested for certain forsterite grains. We suggest that, in the nebula, there was also a population of condensate spinels that was sampled by both Murchison and Allende.

References. [1] Simon S.B. *et al.* (1994) *GCA* **58**, 1313-1334. [2] Weinbruch S. *et al.* (1990) *Meteoritics* **25**, 115-125. [3] Irving A.J. (1978) *GCA* **42**, 743-770. [4] Yoneda S. and Grossman L. (1995) *GCA* **59,** 3413-3444. [5] Ebel D.S. and Grossman L. (1997) *Meteoritics & Planet. Sci.* **32**, A37. [6] Scott E. *et al.* (1996) *Chondrules and Prot. Disk*, 87-96. [7] Steele I.M. (1986) *GCA* **50**, 1379-1395.