LIME(y) Silicates in Primitive Chondrites: Records of Nebular and Parent Body Processes. M. Komatsu1 T. J. Fagan2 and T. Mikouchi3, 1Waseda Institute for Advanced Study, Waseda University (komatsu@aoni.waseda.jp), 2Department of Earth Sciences, Waseda University, Department of Earth and Planetary Science, 3Graduate School of Science, University of Tokyo.

Introduction:
Low-iron, Mn-enriched (LIME, Mn/FeO ≥1) silicates are important components in the primitive solar system materials. They are interpreted as indicators of nebular condensation conditions [1-4]. They have been identified in IDPs [1], chondrules and matrices of primitive chondrites [2, 3], and in Wild 2 cometary grains [4].

LIME olivine has also been observed in some amoeboid olivine aggregates (AOAs) in primitive chondrites [5, 6]. Mineralogy and chemical compositions of AOAs are similar to those predicted by equilibrium thermodynamic condensation models [e.g., 7], suggesting that AOAs formed primarily by gas-solid condensation [8]. Some AOAs have olivines that are Mn-rich, although they do not have MnO/FeO ratio as high as LIME olivines as originally defined. In this study, we refer to all of these Mn-rich olivines as ‘LIMEy’. We recognize that the final MnO/FeO ratios of these olivines result from enrichments and depletions in Fe and Mn in the solar nebula and in parent body settings.

In this study, we examine the distribution of LIMEy silicates in AOAs and chondrules in the primitive meteorite Y-81020, and compare to those in variably metamorphosed type 3 carbonaceous chondrites. Our goal is to assess the roles of nebular and asteroidal thermal processing on formation and alteration of LIMEy silicates.

Results:
AOAs are irregularly shaped, fine-grained objects that constitute a few volume-percent of meteorites in most carbonaceous chondrite groups.

Y-81020 (CO3.0) is one of the most primitive carbonaceous chondrites. AOAs from Y-81020 show little evidence for secondary alteration. Most AOAs in Y-81020 are composed of nodules having anorthite ±spinel cores, Al-diopside-rich mantles and closely or loosely packed forsterite rims.

LIMEy olivines are commonly observed in AOAs in Y-81020. However, the Mn-contents and distributions of LIMEy olivine grains vary from AOA to AOA. Fig. 1 shows the Mn-Kα X-ray elemental maps of three Y-81020 AOAs with variable degrees and patterns of Mn-enrichment. Strong Mn-enrichment occurs from cores to rims of individual nodules in AOA#18. In contrast, no enrichment of Mn is observed in AOA#60. AOA#61 is intermediate between AOA#18 and #60 and shows increasing Mn-enrichment toward the AOA rim. All AOAs in Y-81020 show little or no secondary Fe-enrichment.

Some Y-81020 AOAs contain low-Ca pyroxene in addition to olivine. In these cases, Mn-contents in pyroxene and olivine appear to mimic each other (i.e., if olivine is LIMEy, coexisting pyroxene also is LIMEy).

In addition to AOAs, local Mn enrichments are also observed in chondrules and CAIs. Here we describe two Mn-rich objects in Y-81020.

Mn-rich chondrule

CHD#62 is ~30 μm sized spherical Mn-rich chondrule (Fig. 1a). This chondrule looks brighter in BSE image (Fig. 2a) than other chondrules because of its higher FeO content. CHD#62 is composed of low-Ca pyroxene which contains up to 2.5 wt.% of MnO. MnO content is relatively homogeneous, but it is slightly higher in the core than the rim of the chondrule (line analysis data; Fig. 2b) and shows a negative correlation between MnO and FeO (Fig. 2c). Because Y-81020 experienced only minor parent body alteration, the higher FeO content of CHD#62 may reflect a nebular origin.

Mn-rich CAI

CAI#64 is 100 × 70 μm in size with concentric texture. It has a core composed of fine-grained Na-rich grains (probably nepheline); they are rimmed by high-Ca pyroxene. The high-Ca pyroxene has high up to 3.6 wt.% MnO, which is even higher than OA olivine and low-Ca pyroxene.

Discussion:
Based on the condensation calculations [9, 10], Mn-rich silicates forms in the vapor of a solar composition. As temperature decreases, Mn in olivine increases more rapidly than Fe, which is condensing into Fe-rich metal at these low f(O2) conditions. The model increases in Mn/Fe with decreasing temperature, combined with our observed increases in Mn/Fe from core to rim suggest that some AOAs formed by core-to-rim condensation as temperature decreased [6].

Ebel et al [9] assumed that Mn partitions equally between olivine, low-Ca pyroxene and high-Ca-pyroxene in their condensation model. Our observations of similarities in Mn-enrichments of co-existing olivine and pyroxene in Y-81020 AOAs support this assumption.

Rubin [3] described some Mn-rich olivine and pyroxene in a chondrule in Allende. They are present only in the thick rim around the chondrule and contain ~4 wt.% of MnO, but also contain FeO up to ~9 wt.% Allende experienced a higher degree of alteration than Y-81020, and FeO content in silicates is higher than less altered CV chondrites. It is possible that the Mn-rich chondrule rim of [3] has a
mixed origin, with Mn-enrichment from a nebular process and high FeO due to parent body alteration.

Our recent study [11] shows that Mn-rich olivine is commonly observed in AOAs from weakly metamorphosed Kaba and Y-86009 (CVs), as well as in CR AOAs [5] and Wild 2 grains [4]. On the other hand, AOAs in metamorphosed type 3 carbonaceous chondrites lack LIME silicates. With increasing petrologic sub-types, FeO increases and MnO decreases in AOA olivine [11].

LIMEy olivine is common in AOAs from the primitive chondrites of this study. We suggest that LIME silicates were originally formed as primary phases in AOAs, and also were rarely present as chondrule or CAIs in wide range of carbonaceous chondrites, and then were lost during a parent body alteration. If so, MnO vs. FeO concentrations in AOA olivines can be sensitive indicators of both condensation and alteration conditions.

References:

Table 1: Representative compositions of LIMEy minerals in Y-01020

<table>
<thead>
<tr>
<th>Element</th>
<th>AOA10</th>
<th>AOA50</th>
<th>AOA61</th>
<th>CHD#62</th>
<th>CAP#64</th>
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<tr>
<td>Fe</td>
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<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
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<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
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</tr>
</tbody>
</table>

Fig.1. X-ray elemental maps of porous and compact AOAs in Y-81020. There is a clear enrichment in Mn content of olivines in porous AOA #18, whereas the two compact AOAs show minor (#61) and no (#60) Mn enrichment. Note the increase in Mn enrichment from core to rim of AOA#61.

Fig.2. BSE image of chondrule #62 (a). LINE analysis shows Fe enrichment in the rim of the chondrule (b), and negative correlation between FeO and MnO contents (c).

Fig.3. X-ray elemental maps of CAI #64 (a:Mg:Ca; Al, b: Mn, c:Na).and BSE image (d) of CAI #64.