COOLING RATES AND THE ^{53}Mn-^{53}Cr ISOTOPIC SYSTEM OF YAMATO 86753, AN EQUILIBRATED ORDINARY CHONDRITE. T. Tomiyama[1] and K. Misawa[1,2], [1]Dept. of Polar Sci., School of Phys., and Math., Grad. Univ. for Advanced Studies, Tokyo, 173-8515 Japan (tomiyama@nipr.ac.jp), [2]Antarctic Meteorite Research Center, National Institute of Polar Research, Tokyo, 173-8515 Japan.

Introduction: The degrees of metamorphism of individual ordinary chondrites (OCs) reflect thermal histories on their parent bodies. The thermal structure of the OC parent body (i.e., the geological setting of each petrologic type of OC) is not well known, because metamorphic degree depends not only on metamorphic temperature but also on duration of metamorphism. Detailed study of thermal history is necessary for elucidating the thermal structure of the OC parent body. We performed two-pyroxene geothermometry, olivine-spinel (ol-sp) geothermometry and metallographic cooling rate estimates [1,2,3] on equilibrated L chondrites, to determine individual thermal histories. Isotopic analyses of the ^{53}Mn-^{53}Cr system in olivines have been done on Yamato (Y) 86753, a rapidly cooled L5 chondrite.

Samples and Experiments: Polished thin-section of equilibrated L chondrites were examined using an optical microscope, a scanning electron microscope (JEOL JSM-5900LV equipped with Oxford LINK ISIS EDS system) and an electron microprobe (JEOL JXA-8800M). Two-pyroxene geothermometry, ol-sp geothermometry and metallographic cooling rate estimates were applied to coexisting mineral pairs of interest.

For isotopic measurement, we prepared a polished potted-butt sample of Y86753 (L5) with San Carlos olivines whose ^{55}Mn/^{52}Cr ratio was obtained from neutron activation analysis. Olivines with very low chromium contents were identified in Y86753 using electron microprobe. Isotopic analyses were carried out for these olivines, using a secondary ion mass spectrometer (SHRIMP II). The primary O_2^- beam was accelerated to 10 kV with a current of 3-4 nA, focused into a spot of ~ 17 µm. The secondary ion counting was operated through slight energy filtering and collector slit of 180 µm width, resulting in a mass resolving power of M/ΔM ~ 3400. We determined instrumental mass fractionation of Cr isotopes and sensitivity factor of ^{55}Mn/^{52}Cr ratio by measuring San Carlos olivines. Analyses on San Carlos olivine (n = 27) yield ^{53}Cr/^{52}Cr ratio of 0.11170 ± 0.00008 (95% confidence). There was an instrumental mass fractionation of ~ 15 ‰ favoring lighter isotope. Sensitivity factor of 2.06 for measured ^{55}Mn/^{52}Cr ratio was calculated from neutron activation data.

Results: Two-pyroxene geothermometry [1] yields equilibration temperatures of 890-920 ^{o}C for high-Ca pyroxenes and 810-860 ^{o}C for low-Ca pyroxenes in L5-L6 chondrites. Pyroxenes in L4 chondrites were not chemically equilibrated. The ol-sp geothermometry [2] yields equilibration temperatures of 620 - 650 ^{o}C for most L4-L6 chondrites (Fig. 1). The ol-sp temperatures of Y86753 (~ 710 ^{o}C) are higher than those of other chondrites. Fe-Ni metals in this chondrite were cooled at > 100 ^{o}C/Myr, whereas most Fe-Ni metals of other L4-L6 chondrites were cooled at 0.1-100 ^{o}C/Myr (Fig. 2). Isotopic analyses show that Y86753 olivines have ^{55}Mn/^{52}Cr ratios of up to ~ 280 (Fig. 3). There is no systematic relationship between ^{53}Cr excess and ^{55}Mn/^{52}Cr ratio.

Discussion: The parent bodies of ordinary chondrites accreted within a very short time period in the early stages of the formation of the solar system. After accretion, parent bodies might have been internally heated by sources such as the decay of short-lived radionuclides (e.g., ^{26}Al [4]). If such was the case, parent bodies should initially have had onion-shell structures, in which metamorphism increased with burial depth [5]. Metamorphic temperatures and cooling rates of OCs should then correlate with petrologic types. Pyroxene geothermometry shows metamorphic temperatures of L4 chondrites were lower than those of L5-L6 chondrites. This is partly consistent with a relationship between petrologic types and metamorphic temperatures. However, there is no significant relationship between petrologic types and ol-sp temperatures and metallographic cooling rates. Because a majority of OCs show similar ol-sp temperatures and metallographic cooling rates, this could mainly be due to the fact that applied geothermometries and metallographic cooling rate estimates are somewhat insensitive to small differences in thermal histories.

However, we need another explanation for the distinctive results of Y86753. Higher ol-sp temperature and higher metallographic cooling rate indicate this chondrite experienced rapid cooling. Shock disturbance is unlikely because Y86753 is only a weakly shocked chondrite (S2). If there was any disturbance of parent body structure, cooling histories of OCs could have been different from those predicted by the onion-shell model. The parent bodies of L chondrites could have experienced disruptive collision during thermal metamorphism [6]. In this case, some source materials of OCs could have been excavated from the hot interior and cooled rapidly. Y86753 could be such a chondrite, which experienced this hot excavation.

The ^{53}Mn-^{53}Cr systemtics of meteoritic materials suggest that the formation of OC chondrules predated LEW 86010 formation by 10 Myr [7]. However, the ^{53}Mn-^{53}Cr system of Y86753 olivine does not retain ^{53}Cr excesses correlated with ^{55}Mn/^{52}Cr ratio. Thus thermal metamorphism prolonged after total decay of ^{53}Mn. The hot excavation of Y86753 should have occurred at the late stage of thermal metamorphism.

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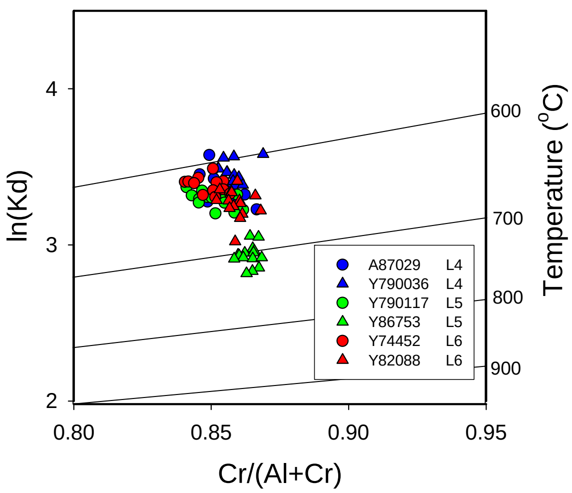

Fig. 1. Plots of Fe-Mg partition coefficients between coexisting ol-sp pairs against Cr/(Al+Cr) ratio of chromites, showing closure temperature of the ol-sp system [2].

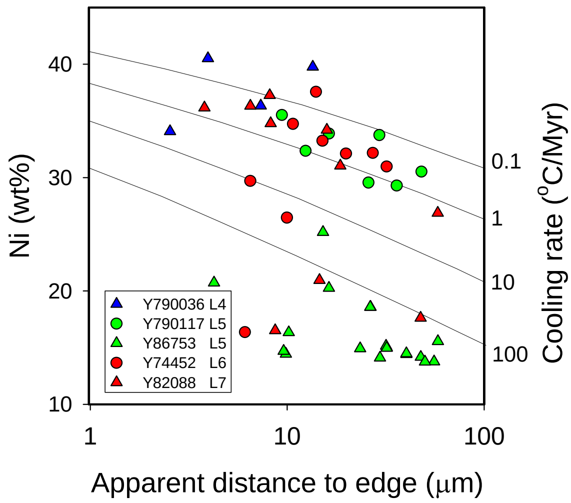

Fig. 2. Plots of Ni contents of taenites against the grain sizes, showing metallographic cooling rates [2]. Data for A87029 are not plotted because all analyses show too high Ni contents (> 44 wt%).

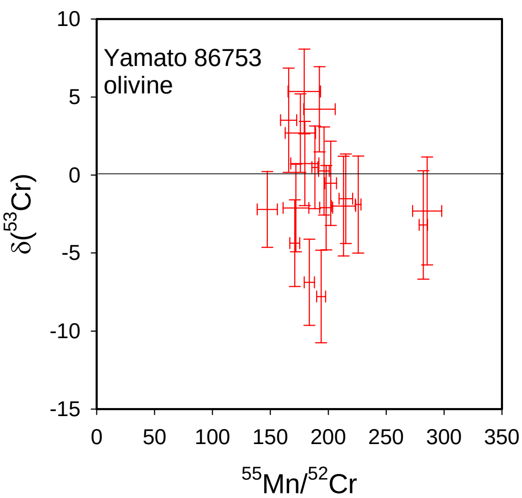

Fig. 3. ^{53}Mn-Cr ^{53}systematics of Y86753 olivines.
$\delta(^{53}Cr) \equiv ((^{53}Cr/^{52}Cr)_{unknown}/(^{53}Cr/^{52}Cr)_{standard} - 1) \times 1000$