EXPERIMENTAL EVIDENCE FOR FORMATION OF NORTHWEST AFRICA 6962 CR-RELATED ACHONDRITE FROM A CR CHONDRITE PRECURSOR MELT. D. Abe[1,2], T. Mikouchi[1,2] and A. J. Irving[3], [1]Dept. of Earth and Planet. Sci., University of Tokyo, Hongo, Tokyo 113-0033, Japan (d_abe@um.u-tokyo.ac.jp), [2]University Museum, University of Tokyo, Hongo, Tokyo 113-0033, Japan, [3]Dept. of Earth and Space Sci., University of Washington, Seattle, WA 98195, USA.

Introduction: Most CR chondrites show evidence for aqueous alteration and have been classified into petrologic types 1-3 (mainly petrologic type 2) [e.g., 1]. However, some samples experiencing clear thermal evolution, such as NWA 12455, Tafassasset, and NWA 6962 have been reported whose O, Cr, and Ti isotopic compositions plot within the CR chondrite field [e.g., 2,3]. Therefore, it is of great interest to investigate these CR-related "carbonaceous achondrites" to better understand thermal evolution of the CR chondrite parent body. Among such samples NWA 6962 is especially interesting because it has been reported to show an olivine cumulate texture with melt inclusions [4], implying formation through extensive melting and olivine accumulation. In this study, we conducted partial melting experiments of a CR2 chondrite to evaluate whether olivine in NWA 6962 can be formed by crystallization of these partial melts to understand the petrogenetic link between CR chondrites and CR-related achondrite NWA 6962.

Samples and Methods: One polished thin section (PTS) of NWA 6962 was observed with optical microscope and FE-SEM (JEOL JSM-7000F @Univ. of Tokyo), and mineral compositions were analyzed by EPMA (JEOL JXA 8900F @Univ. of Tokyo).

We used NWA 7184 (CR2) for partial melting experiments. 80-100 mg of NWA 7184 powder was pressed into pellets and placed onto platinum wire loops. These pellets were heated at different temperatures (1200, 1275 ºC) with oxygen fugacities (fO_2) of log fO_2=IW-1 and IW+2 for 96-120 hours in a CO_2-H_2 gas mixing 1 atm furnace. At the end of the runs, the charges were quenched in air. Glass and mineral compositions of the charges were analyzed by EPMA, and equilibrium olivine compositions from these glasses were calculated by the MELTS software [5].

Results and Discussions: NWA 6962 shows a cumulate texture dominated by olivine exhibiting reverse chemical zoning ($Fa_{41.2\text{-}46.7}$, core: $Fa_{44.6\text{-}45.2}$, MnO=0.51-0.54 wt.%, CaO=0.30-0.49 wt.%). Accessory minerals are high-Ca pyroxene ($Fs_{11.1\text{-}25.2}Wo_{43.1\text{-}49.5}$), plagioclase ($An_{0\text{-}35.6}Or_{0\text{-}10.7}$), Fe-Ni metal, chromite and troilite. In this study, we also found olivine with melt inclusions (~50 µm) [6].

The charges heated at three different experimental conditions (1200 ºC/IW-1, 1200 ºC/IW+2, 1275 ºC /IW+2) contain olivine and glass with minor phases such as Fe-Ni metal and spinel (Fig. 1a). The charges heated at 1275 ºC/IW-1 contain low-Ca pyroxene, glass and Fe-Ni metal (Fig. 1b). All phases, except for minor phases, have relatively homogeneous compositions (Table 1).

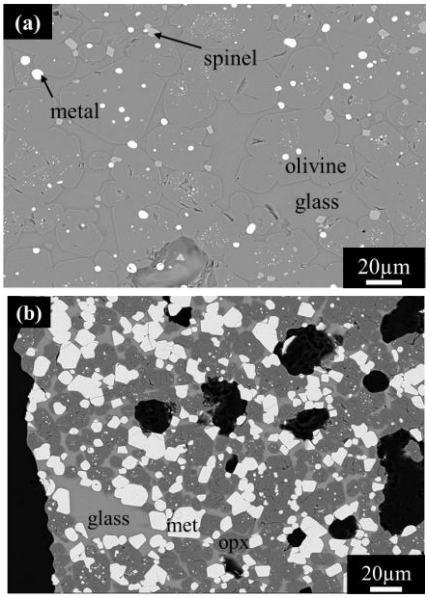

Fig. 1: Back-scattered electron images of experimental charges. (a) 1200 ºC, IW-1 (b) 1275 ºC, IW-1. Opx: low-Ca pyroxene. Met: Fe-Ni metal

Table1: Glass and coexisting olivine/pyroxene compositions in experimental charges

	1200 ℃		1275 ℃	
[wt.%]	IW-1	IW+2	IW-1	IW+2
SiO_2	47.9	42.9	51.6	46.5
Al_2O_3	11.5	11.9	5.9	9.2
TiO_2	0.48	0.56	0.25	0.39
FeO	20.5	25.2	16.1	26.6
MnO	0.22	0.22	0.23	0.30
MgO	7.3	5.8	13.6	6.6
CaO	8.7	10.7	9.6	8.0
Na_2O	1.2	0.60	0.41	0.57
K_2O	0.27	0.08	0.04	0.09
Cr_2O_3	0.33	0.08	0.05	0.18
NiO	0.05	0.16	0.29	0.09
P_2O_5	0.05	0.60	0.51	0.13
Total	98.4	98.7	98.5	98.6
Olivine	$Fa_{32.8}$	$Fa_{38.0}$		$Fa_{31.7}$
Pyroxene			$Fs_{7.9}Wo_{2.1}$	

We calculated Fa contents of olivine crystallizing from these partial melt glasses by MELTS and found that olivine compositions of NWA 6962 ($Fa_{44.6-45.2}$) crystallized at 1140-1150 ºC from partial melts of 1200 ºC/IW-1 and 1200 ºC/IW+2 runs. However, if we compared Ca and Mn contents in the calculated olivine composition, the partial melt of 1200 ºC/IW+2 could crystallize olivine with closer compositional match with NWA 6962 olivine (Table 2, Fig. 2).

In the same way, we also calculated Fa contents of olivine compositions crystallizing from CM and CV partial melts [7]. As a result, we found that olivine with the Fa content of that in NWA 6962 crystallized at 1130-1150 ºC from partial melts of CM and CV chondrites in the experimental conditions of 1200 ºC/IW+2 and 1275 ºC/IW+2 (Table 2). Especially, MnO in olivine produced from the CV melt (1200 ºC/IW+2) is close to that in NWA 6962 olivine. However, CaO in this olivine is much higher than that in NWA 6962 olivine, perhaps because of high abundance of CAIs in CV chondrites. MnO and CaO in other estimated olivine compositions are also different from those in NWA 6962 olivine.

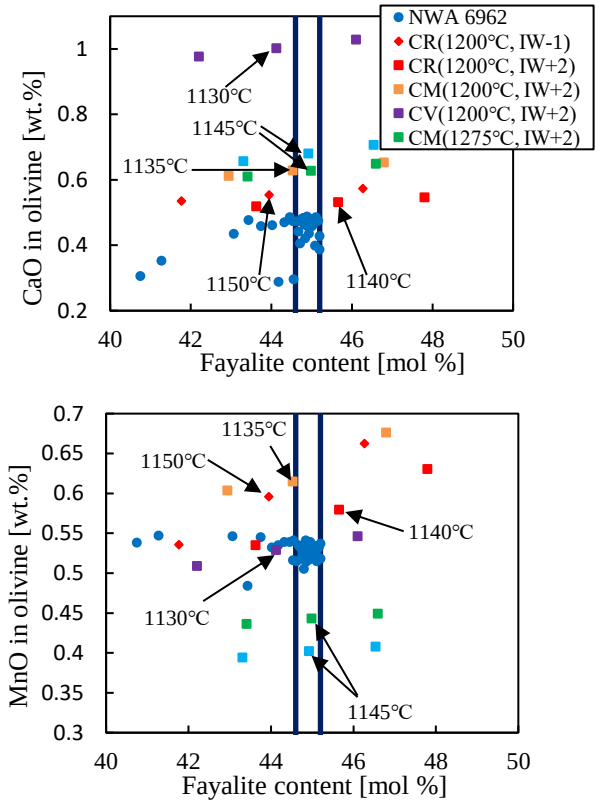

Fig. 2: Fa content vs CaO and MnO in olivine crystallizing from partial melts of CR, CM and CV chondrites. Dark blue lines exhibit a range of NWA 6962 olivine core. For each calculated olivine composition from the same experimental condition, Fa content is higher for the lower calculation temperature.

Table 2: Calculated olivine compositions crystallizing from experimental partial melts of CR, CM and CV chondrites.

Samples (experimental conditions)	T [ºC][#3]	Fa	[wt.%] MnO	CaO
CR[#1] (1200 ºC/IW-1)	1155	41.8	0.54	0.54
	1150	43.9	0.60	0.55
	1145	46.3	0.66	0.57
CR[#1] (1200 ºC/IW+2)	1145	43.6	0.54	0.52
	1140	45.7	0.58	0.53
	1135	47.8	0.63	0.55
CM[#2] (1200 ºC/IW+2)	1140	42.9	0.60	0.61
	1135	44.5	0.61	0.63
	1130	46.8	0.68	0.65
CV[#2] (1200 ºC/IW+2)	1135	42.2	0.51	0.98
	1130	44.1	0.53	1.00
	1125	46.1	0.55	1.03
CM[#2] (1275 ºC/IW+2)	1150	43.4	0.44	0.61
	1145	45.0	0.44	0.63
	1140	46.6	0.45	0.65
CV[#2] (1275 ºC/IW+2)	1150	43.3	0.39	0.66
	1145	44.9	0.40	0.68
	1140	46.5	0.41	0.71

#1: This study, #2: Jurewicz et al. [4], #3: Assumed equilibrated temperature when calculating by MELTS.

Conclusions: Our partial melting experiments of a CR chondrite and MELTS calculations using obtained glass compositions show that CR partial melt experimentally produced at 1200 ºC/IW+2 can subsequently crystallize NWA 6962 olivine at 1140-1145 ºC. However, the same calculations employing partial melts of CV and CM chondrites [7] do not well reproduce NWA 6962 olivine. Therefore, this study supports that NWA 6962 is a "CR-related achondrite" as O-Ti-Cr isotopic studies demonstrated [2], implying extensive thermal evolution in a CR parent body.

The formation history of NWA 6962 is considered as follows. (1) Partial melting of CR chondrite occurred at 1200 ºC at an oxidized condition ($\log fO_2$~IW+2) in the CR chondrite parent body. (2) The produced partial melt was cooled down to at ~1140-1145 ºC and accumulation of olivine crystals took place. (3) The intercumulus melt compositions became MgO-rich (e.g., reduction of magma or magma mixing) to produce olivine reverse zoning. (4) The final solidification was rapid because olivine cooling rate calculated using the observed Fe-Mg zoning of olivine is ~300 ºC/year (from 1100 to 800 ºC).

References: [1] Schrader D. L. et al. (2011) *GCA*, *75*, 308-325 [2] Sanborn M. E. et al. (2019) *GCA*, *245*, 577-596. [3] Irving A. J. et al. (2019) *82nd MetSoc*., #6399. [4] Dunlap D. R. et al. (2015) *LPS XLVI*, #2570. [5] http://melts.ofm-research.org/ [6] Meteoritical Bulletin (2015) *MAPS*, *50*, 1661. [7] Jurewicz A. J. G. et al. (1993) *GCA*, *57*, 2123-2139.