UNIQUE ACHONDRITES GRA 06128/06129: ANDESITIC PARTIAL MELT FROM A VOLATILE-RICH PARENT BODY. T. Arai[1], T. Tomiyama[1], K. Saiki[2], and H. Takeda[3]. [1]Antarctic Meteorite Research Center, National Institute of Polar Research, 1-9-10 Kaga, Itabashi, Tokyo 173-8515, Japan (tomoko@nipr.ac.jp), [2]Department of Earth and Space Science, 1-1 Machikaneyama, Toyonaka 560-0043, Japan, [3]Department of Earth and Planetary Science, Univ. of Tokyo, Hongo Tokyo 113-0033.

Introduction: Missing basaltic partial melts complementary to ultramafic primitive achondrites, ureilite, and igneous iron meteorites have been subjects of controversy. Though felsic materials were reported in silicate inclusions in IAB and IIE irons [1, 2], some acapulcoites [3, 4], polymict ureilites [5, 6] and LL7 chondrite [7], no hand specimen representing partial melts have been found in the world's meteorite collections. A newly recovered Antarctic meteorites, Graves Nunataks (GRA) 06128 / 06129 are ungrouped achondrites, weighing 447.6 g and 196.5 g respectively [8]. They display several unusual mineralogical features distinct from any known meteorites. The high abundance of Na-rich plagioclase implies an origin of low-temperature partial melts. The mineralogy and petrology were studied to understand the petrogenesis and planetary evolution in the solar system.

Sample and Method: A polished thin section of GRA 06128, 33 was provided by Antarctic Meteorite Working Group. Mineralogical analyses were performed with JEOL JXA8200 electron microprobe at National Institute of Polar Research.

Results: GRA 06128 (GRA) is a crystalline rock with heterogeneous texture and modal abundance (Table 1) within a thin section of 1.7 × 1.4 cm. It consists of two lithologies, which are heterogeneously interwined: (1) adcumulate texture with coarse-grained (1.2–5.3 mm across) plagioclase and some post-cumulus olivine with (Fig. 1a) and (2) granoblastic texture with moderate-sized (a few hundred μm to 1 mm across) subangular plagioclase and heterogeneously distributed fine-grained mafic-rich pocket (Fig. 1b). In lithology (1), fine-grained polygonal grains of plagioclase form veins and replace part of coarse-grained plagioclase. Some plagioclase grains display twin lamellae. In the mafic-rich pocket of lithology (2), subrounded olivine grains (0.3–1.0 mm across) are generally enclosed by smaller (mostly 60–150 μm across) polygonal grains of augite and/or orthopyroxene with 120^{o} triple junction. The texture of lithology 2 indicates extensive annealing.

Desptite the variable texture and modal abundance, mineral compositions are fairly equilibrated. Na-rich plagioclase ($An_{13-15}Or_2$) is overwhelmingly abundant. Fe-rich olivine (Fo_{39-42}) is closely associated with augite ($Wo_{42-45}En_{36-39}$, $mg\#_{64-68}$) and less amount of orthopyroxene (Wo_2En_{52-54}, $mg\#_{53-54}$). Fe/Mn ratios of pyroxenes are 30–48. Sub-micron scaled exsolution lamellae of low-Ca pyroxene are present in some augite grains. Chromite ($Ulvospinel_{39}Chromite_{50}$, $mg\#_{6.1-6.5}$) is associated with olivine. Composite grains of troilite and pentlandite (36.4–41.7 wt% Fe, 33.0–35.1 wt% S, 23.7–27.2 wt% Ni, 2.1–3.1 wt% Co) of submicron to 200 μm across are widely distributed as isolated grains, fillings in fractures, and metal veins within / across silicate grains. Ni-rich (66.8 wt% Ni, 0.89 wt% Co) taenite with troilite is also found as inclusion of coarse-grained plagioclase and olivine. Dusty cores with troilite / pentlandite inclusions are found in olivines, indicating part of olivine were melted and overgrown around the unmelted cores. Fine-grained polygonal plagioclase and pyroxene contain less metallic inclusion. Most of troilite grains are extensively weathered. Olivines are also partly weathered unlike other silicates. Numerous veins of hydrous ion oxides probably of terrestrial origin crosscut silicates. Olivines and plagioclases exhibit undulatory extinction due to shock effect.

Discussions:

The observed heterogeneous and variable texture and modal abundance imply a complex formation history at least with three phases. Firstly, coarse-grained plagioclase-rich cumulate formed from a melt. Olivine and minor augite, phosphate and ilmenite crystallized interstitial to the plagioclase. Secondly, the igneous rock was subject to an impact, generating local melting at grain boundaries and interstital mafic-rich portions. Also, a FeNi-FeS melt was injected into grain boundaries and fractures. The original igneous texture was disturbed by shock and may have been partly brecciated. Yet, the original texture was still locally preserved. Thirdly, a extensive post-shock annealing equilibrated the primary compositional variations within / among grains. During the annealing, grain boundaries and mafic-rich pockets effectively recrystallized with a small volume of melt, producing granoblastic texture. Polygonal pyroxenes surrounding olivines are likely a product of reaction between primary olivines and a SiO_2-rich melt produced by shock. Fractures filled with metal grains were healed, and troilite, Ni-rich taenite, and pentlandite crystallized from the injected FeNi-FeS melt. An equilibrium temperature of 700–800 ^{o}C obtained from pyroxene geothermometer [9] probably record the post-shock annealing. Accordingly, GRA may broadly preserve a composition of initial crystallization from a melt, despite its complex mineralogy and petrology.

Bulk composition estimated from modal recombination (Table 2) corresponds to andesite. Since chondrites contain ~10% of Na-rich plagioclase (An_{10}), the first ~10% of partial melt will largely consist of plagioclase. In fact, felsic materials rich in plagioclase have been found in acapulcoite, ureilite, silicate inclusion of iron meteorites. Silicate inclusions in Caddo County IAB iron contain a coarse-grained (> 3 mm across) andesitic material with Na-rich plagioclase (36%) in contact with FeNi metal and ultramafic residue within a few cm distance [1]. While it represents in-situ silicate partial melt, GRA seems to represent a segregated partial melt. Modal abundance of troilite which is lower than chondritic abundance (3.6–7.2 % for troilitite [10]) suggests that a FeNi-FeS euctectic melt was already segregated.

The GRA composition (bulk mg#=44) is unusually Fe-rich relative to the known felsic materials. A partial melting experiment of LL chondrite at high oxygen fugacity (IW+2, 1200 ^oC) yields a Na-rich ferroan andesitic liquid (56.9 wt% SiO_2, 9.3 wt% Al_2O_3, 1.58 wt% Na_2O, mg#=37) [11]. However, this composition can not be readily compared with the GRA composition because of the melting temperature (~1050 ^oC) much higher than low-degree partial melting. A partial melt at a peritectic point for a ordinary chondrite composition (mg#=0.8, $An_{10}Or_1$) calculated based on [12] consists of 70% normative plagioclase with mg#=54. The Fe-rich composition can be a consequence of a higher oxgen fugacity. Pentlandite is rare in meteorites. The presence of pentlandites and extremely Ni-rich metals would be attributed to lack of free iron and/or S-rich environment on its parent body, though terrestrial weathering is a possible option. The presence of pentlandite-troilite / Ni-rich taenite-troilite composite grains may indicate a S-rich and oxidized condition.

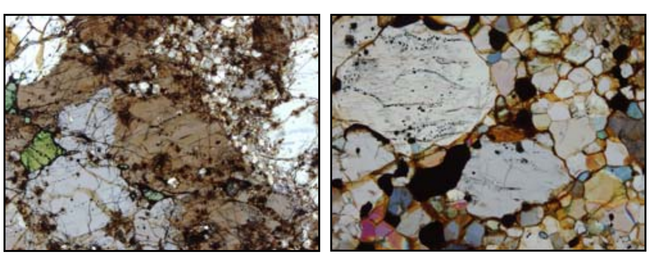

Fig. 1. Photomicrographs (crossed nicole) of
(a) lithology (1) (2.6 mm across) and
(b) lithology (2) (5.1 mm across).

Adding normative $NaAlSi_3O_8$ to the $CaAl_2Si_2O_8$-Mg_2SiO_4-SiO_2 system shifts the pyroxene-plagioclase and olivine-plagioclase cotectics toward plagioclase [13] and lowers the liquidus temperature by up to 100 ^oC [14]. Thus, cotectic melts with higher Ab/An ratios generate greater abundance of plagioclase and less pyroxene/olivine, which matches the modal and mineral composition of GRA. Addition of volatiles (possibly water) dramatically decreases viscosity of a felsic melt [15], which may lead to effective segregation of melt from solid.

GRA seems to represent a low-degree partial melt from a volatile-rich (probably wet) asteroid. It is distinct from previously known asteroidal basalts, such as eucrites and angrite with Ca-rich plagioclase. They represent a low-degree partial melt of a volatile-poor (probably dry) asteroid [16]. It seems unlikely that GRA corresponds to partial melts complementary to known primitive achondrites and iron meteorites due to the highly oxidized and volatile-rich nature. Carbonaceous chondrites seems a more suitable precursor than ordinary chondrites. Or GRA may be originated from unsampled, highly oxidized chondritic materials with terrestrial Fe/Mn ratios of pyroxene and oxygen isotopic ratios along the terrestrial fractionation line [8].

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Table 1. Modal abundances (vol%).

	Lithology (1)	Mafic-rich area of lithology (2)	Total PTS
Plagioclase	97.2	n.a.	89.4
Olivine	0.7	65.2	6.1
Augite	0.1	24.0	2.2
Orthopyroxene	< 0.1	5.3	0.5
Phosphate	0.1	4.6	0.4
Ilmenite	0.1	0.4	0.1
Chromite	< 0.1	0.7	< 0.1
Pentlandite, FeS	1.8	1.1	1.2

Table 2. Bulk composition calculated from modal recombination (vol%).

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cr_2O_3	P_2O_5	Total	Mg#
61.1	0.1	19.7	3.4	0.0	1.5	3.4	9.0	0.3	0.0	0.2	98.8	8.4