
We have carried out a mineralogical investigation of silicate inclusions in Campo del Cielo (1A iron) [e.g. 1,2] and sulfide inclusions in Mont Dieu (1IE iron) [3] to establish a better basis for understanding the segregation mechanism of partial melts. By chemically mapping a large area of cut surface of iron meteorites, we found plagioclase-augite-rich regions in a large slab of Caddo County (1AB) and proposed a model involving segregation of partial melts of chondritic materials [4]. The material can best be described as a magnesium anidesite in the terrestrial classification [5]. Some 1IE irons such as Colomera [6] and Weekeroo Station [7] contain alkali-rich, highly differentiated silicate inclusions. We have identified that the average bulk composition of many inclusions in Colomera is similar to the anidesitic material found in Caddo County [8]. To find more evidences of melt segregation, we have investigated Mont Dieu [3] and silicate inclusions in a new slice of a sample found in the strewn field of Campo del Cielo [1].

Samples and Experiments. Three polished slices, approximately 1.9×1.5, 1.8×1.4, and 1.5×1.0 cm across and 4 mm thick, which resemble areas found in Caddo County, were cut from a 3.7×2.5×0.4 cm slice of Campo del Cielo of the Inoue Meteorite Collections. A polished thin section (1.62×1.51 cm), CdC PTS was prepared forming the 1.9×1.5 cm cut. Two polished slices, 1.8×1.7 (MDA) and 2.0×1.7 cm (MDB) and 4 mm thick, were cut from a 7.3×4.9×0.4 cm slice of Mont Dieu. The slices were each embedded in plastic discs and one side was polished.

Inclusions in CdC PTS, MDA and MDB were studied along with polished slices with an optical microscope. Distribution of minerals were obtained using the “Area Analysis technique of the JEOL 8900 electron probe microanalyzer (EPMA) at the Ocean Res. Inst. (ORI) of the Univ. of Tokyo. Elemental distribution maps of Na, Al, Ca, Fe, K, P, Cr, Ni and S were obtained by the wave-length dispersive spectrometers (WDS) and of Ti and Si with the energy dispersive spectrometer. The maps of 650×550 pixels (1.32×1.10 cm area) were obtained for CdC PTS with 0.20 mm pixel size and 40 msec counting time. The same maps of the same elements of the entire sections for the MDA and MDB slices were obtained with the same conditions. A mineral distribution map of CdC PTS was constructed by combining the elemental maps. Mineral chemistry was obtained by EPMA, JEOL JXA-733 at ORI with WDS.

Results: There were three larger clasts in CdC PTS, but their boundaries are not distinct because rounded and subrounded mineral aggregates are distributed among them (Fig. 1). The clasts are polymineralic aggregates of chondritic silicates and other opaque minerals. Elemental distribution maps of Na and Al show that sodic plagioclase grains are abundant. Clast A (4.3×2.6 mm) is coarse grained (Fig. 1) and consists chiefly orthopyroxene (Opx, 61 vol.%), olivine (24%) and plagioclase (14%) and minor metal (0.2%). Opx reaches up to 0.8 mm in length and plagioclase up to 0.45 mm. The grain sizes of large plagioclase grains in metal and other clast are about 0.2 mm in diameter. Other clasts such as clast B (4.8×1.7 mm) are finer grained and modal abundance of minerals are: Opx 69%, olivine 9%, plagioclase 14%, metal 5%, schreibersite 2%. Augite, chromite and Ca-phosphates are rare in Clast A and B, but the largest clast C (8.6×3.0 mm) is more chondritic and contains one large grain of augite Ca48Mg40Fe5. Along the boundaries between clast B and blocky metal, elongated chromites, form a band extending 4.6 mm and the largest grain reaches up to 1.4×0.25 mm in size with Fe/(Fe+Mg)=0.46 and Cr/(Cr+Al+Ti)=0.92 atomic ratio. Orthopyroxene exhibits a small range in compositions (Ca1.3Mg92.6Fe6.2 to Ca1.5Mg91.6Fe6.9) and olivine Fa92.9 to Fa95.5 (ave. Fa94.1). Sodic plagioclase also exhibits a small range in compositions (Or3.8Ab82.1An4.1 to Or3.6Ab82.5An14.3 and ave. Or3.6Ab82.2An14.3). The mineral chemistry is comparable to those in silicate inclusions in IAB irons and winonaites.Inclusions in the Mont Dieu iron meteorites such as Colomera and Weekeroo Station showing numerous complex ameboid inclusions of silicates. According to Desrousseaux et al. [3] millimeter-sized FeS nodules are common. It is to be noted that in general, shapes of inclusions in MDA and MDB are very complex (Fig. 2) and similar to those of Colomera. Grain boundaries with metal contact reveal rounded to occasional spherical shapes and sometimes they form a curved chain like texture (Fig. 2). The elemental distribution maps of the 24 inclusions studied, indicate that the most common were dominated by FeS (troilite). Orthopyroxene occurs as a tiny crystal larger than 0.1 mm (Ca1.3Mg80.5Fe17.8 to Ca1.1Mg98.8Fe1.3), surrounded by FeS. Only a few inclusions contain a tiny chromite grain. One inclusion contains a very small silicate inclusion similar to those found in other 1IE irons such as Colomera. Twinned chromian diopside crystals 0.66×0.44 mm with one side skeletal rim are enclosed in glassy matrix of 0.94 mm in diameter and with high silica and alkali elements.

Discussion: Higher abundance of sodic plagioclase in CdC than those of recrystallized chondrites suggests that Na-rich partial melts were segregated during the crystallization process. However, chromian diopside characteristic of the Caddo County anidesitic materials has not been found in CdC except for chondritic clast C. This observation may be explained by the following models: Higher concentration of Al took all available Ca or abundant P in the metallic iron took Ca to produce Ca-phosphates, which may be concentrated somewhere else. Another evidence of segregation of the materials is concentration of chromite at a boundaries between silicates and metal. Such chromite was previously found in acapulcoite EET84302 [9].

Presence of FeS inclusions in Mont Dieu is quite different from the other IIE irons [6-8]. Desrousseaux et al. [3] reported FeS nodules, but we recognized that the shapes are the same as those of the silicate inclusions in Colomera. Common minerals in the silicate inclusions of Colomera etc. are chromian diopside and sodic plagioclase (albite) with
fairly uniform compositions. They are often enclosed by or occur together with silicic glassy materials with near Na-feldspathic compositions. They are similar to andesitic materials rich in plagioclase and augite found in the Caddo County IAB iron meteorite. Up to the date, only tiny orthopyroxene crystals have been reported for Mont Dieu [3]. Our discovery of chromian diopside in an alkali-silica-rich material gives strong link between Mont Dieu and other IIEs.

A common theme in the formation models of the IIE irons is impact-generated melting and mixing [e.g. 7, 10]. Their models both involve collision between an FeNi-metal impactor and a silicate-rich target of H-chondrite affinity. It is difficult to explain near equilibrium growth of diopside and sodic plagioclase by such models. The presence of common alkali-rich materials in the IIE and IAB irons suggests common formation processes of partial melts. Our model deduced with reference to the IAB irons [9] assumes that segregation of Fe-Ni-S-P eutectic melt and Ca-, Al-, Na-rich partial melt took place side by side from the chondritic source materials. Finally, they experienced cooling of the entire system by the catastrophic mixing event of iron metal and silicates.

We note that the bulk Colomera has low S content. Our discovery of FeS inclusions with the same shapes as those of Colomera in the IIE irons, suggests that segregation of another partial melt, Fe-Ni-S eutectic melt took place in the same parent body. This fact solves the problem of low S concentration in other IIE irons. Preservation of the complex ameboid inclusions suggests fairly rapid mixing and cooling, but the final cooling of Colomera and Mont Dieu in the temperature region of 600°C and below was slow enough to develop Widmanstätten structure. In conclusions, our results are not in line with a model involving a large scale differentiation in a large body. Segregations of low temperature melts in a low gravity asteroid should be considered for future testings.

This study was supported in part by a grant to Chiba Inst. of Technology from the Japan Space Forum for the international Space Station. We are indebted to Prof. Wasserburg, Drs. G. Huss, W. Hsu, Profs. Y. Ikeda, M. Miyamoto for discussion and to Dr. T. Mikouchi for their help in microanalysis, and to Mr. S. Inoue for the samples.