PETROLOGY OF UNIQUE IMPACT MELT ROCK, RAMSDORF (L CHONDRITE)

A. Yamaguchi, E.R.D. Scott, and K. Keil; Hawaii Institute of Geophysics and Planetology, SOEST, University of Hawaii at Manoa, Honolulu HI 96822, USA.

We have studied a unique impact melt rock, the Ramsdorf L chondrite. We have discovered that Ramsdorf contains not only clast-poor impact melt [1] but also a chondritic portion (>60 g) with prominent chondritic texture. Detailed mineralogical studies suggest that most (~90 vol%) of the chondritic portion was melted by shock. Ramsdorf was produced by melting of a type 3-4 chondrite and crystallization in situ. The associated shock pressure could have been ~75-90 GPa, with a post-shock temperature of ~1400-1600 °C. The shock stage of this rock may be the highest among ordinary chondrites and other rocks, namely shock stage S6+ [2].

INTRODUCTION. The L-chondrite impact melt rock, Ramsdorf has been studied in detail by Begemann and Wlotzka [1]. In our study, we discovered that Ramsdorf contains not only clast-poor impact melt matrix [1] but also portion with prominent chondritic and intermediate texture. We studied Ramsdorf petrologically, focusing on the chondritic region, with the aim of elucidating the shock and thermal histories and its origin, with reference to recent results of the shock studies [2].

RESULTS. A sample of Ramsdorf, ASU #703.2 (61.2 g) shows prominent chondritic texture. We made 2 PTSs (UH 50 and 51) from this sample. For comparison, we also studied other 2 PTSs; PTS USNM 5749-1, showing the impact melt texture described by Begemann and Wlotzka [1], and PTS USNM 1801-1, showing intermediate texture. The PTSs were examined by optical microscope, SEM and EPMA. Parts of the chondritic portion were also used for bulk chemical [3] and oxygen isotopic analysis [4]. Macroscopically, the chondritic portion appears to be composed of well-delineated chondrules (~0.5-1.5 mm in diameter) and dark matrix. Irregularly shaped metal-troilites are scattered evenly throughout. Several types of chondrules (or chondrule ghosts) were recognized; porphyritic olivine and pyroxene, barred and radiating pyroxene and olivine, and glassy types.

At high magnifications (>100x), the boundaries between chondrules and matrix are not clear and often absent. Furthermore, the textures in the groundmass of porphyritic olivine and pyroxene chondrules are virtually identical to those of the interchondrule matrix. Outlines of the original chondrules are defined solely by the distribution of olivine relics. Similarly, some of the barred pyroxene chondrules have well-defined outlines, but a few of them are poorly defined. There are also glassy chondrule-shaped regions which lack relic olivines and are texturally identical to the interchondrule matrix.

The matrix of the chondritic portion, which is textually identical to the matrix of the impact melt portion, shows typical melt texture comprising equant, euhedral olivine (10-30 μm in size); subhedral pyroxenes (~80 μm in size) that poikilitically enclose olivines; and interstitial glass. This melt texture is essentially the same as the texture observed in parts of other impact melt rocks, such as Chico [5] and Y-790964 [6]. The chondritic portion contains ~12 vol% of fine-grained olivine and ~13 vol% of pyroxene laths (see below). If both materials were melted (see discussion), the volume of the impact melt in the chondritic portion is ~90 vol%.

There are abundant narrow impact melt veins (<100 μm in thickness) that cut both the melt and the clasts, indicating a second shock event after crystallization of the impact melt.

The large irregular relic olivines (~100-800 μm in size) are surrounded by fine-grained granular (recrystallized) olivines (20-30 μm in diameter) and/or the melt matrix. The relic olivines often show mosaicism and sometimes contain polygonal smaller olivines and trace of melt. The fine granular olivines in some aggregates show similar crystallographic orientation. Olivine compositions vary from Fa21.3-24.4. Large olive relict crystals are enriched in CaO (0.21-0.29 wt%), compared with other ordinary chondrites. The tiny euhedral and granular olivines (<20 μm in diameter) in the impact melt matrix show generally lower CaO concentrations (0.07-0.30 wt%). Such enrichment of CaO in the relic olivines is not found in the Chico impact melt [5]. The pyroxenes show lath to irregular shapes with closely spaced mechanical twins (<2 μm spacing). Microphenocrysts (~80 μm in size) in the melt matrix show extensive Ca-zoning from core to rim (Wo24,Fs15.5-Wo24,Fs15.5). Pyroxene laths in the barred pyroxene chondrules are slightly zoned (Wo24,Fs15.5-Wo24,Fs15.5) as in the Ca-poor part of the microphenocryst. The interstitial materials are feldspathic glass as in the impact melt portion [1]. Metal-troilite in all portions shows melt texture [1,7].

DISCUSSION. Apparently, this rock suffered from at least two shock events; the first produced most of the major impact melt and the second event formed minor interconnected glassy veins. The presence of the recrystallization texture of the olivine and the large volume of the impact melt are the prime criteria for shock stage >S6 [2]. We infer from the interconnected veins and the ubiquitous mosaicism in relict olivines that the second shock event was shock stage of S3-S4.
The origin of the pyroxene laths in the barred and radial pyroxene chondrules is problematic because they could be either the precursor chondrule relics from chondrite or more recently formed crystals from the melting event. If this rock was shocked > 45 GPa (S6), pyroxene may show mosaicism [2] which was not observed. Thus, the pyroxene laths probably crystallized from pyroxenitic melt during the major shock event. In this case, the rapid cooling at the first event or the second shock event (S3-S4) produced the mechanical twins in the pyroxene crystals. The similarity in the zoning trend of the pyroxene crystals and the core portion of the microphenocrysts also suggests that the pyroxene crystals formed as a result of shock melting. The granular olivines around the irregular relics may have crystallized from the melt. Thus, post-shock temperature could be between the melting temperature of olivine (~1600-1800 °C) and pyroxene (~1400-1550 °C). The relict olivine has significantly higher CaO content (~0.3 wt%) which is higher than those found in type 3.0 chondrites [8]. This may be due to superheating above the liquidus temperature of the rock. Solidification was extremely rapid to prevent the mixing of the heterogeneous melt and segregation of metal-troilite, resulting in the preservation of the original chondritic texture. Cooling rates during crystallization of metal are ~1 x 10^3 °C/sec based on the zoning of metal [9] and 0.1 °C/sec (1400-1600 °C) based on the spacing of the arms on metallic dendrites [8]. The silicate mineralogy also suggests rapid cooling from peak temperatures to solidification temperatures. We suggest that both chondritic and impact melt portions of Ramsdorf were briefly heated to ~1400-1600 °C, causing ~90 vol% melting. Textural diversity probably reflects different degrees of stirring during melting. The chondritic texture survived because of minimum stirring. We propose that the shock stage of Ramsdorf could be the highest among the ordinary chondrites: namely S6+.

The bulk chemical composition of the chondritic part of Ramsdorf is entirely consistent with L chondrite classification except for the low FeS (3.9 vs. 5.8±0.8 wt%) and high metallic Fe (9.1 vs. 6.9±1.3 wt%) [3]. This may result from vaporization of S. Fayalite content in olivine (Fa21,3.24.4) is low compared to those of other L chondrites [10] perhaps as the result of shock melting. The unusual oxygen isotopic composition of Ramsdorf, which is near the range of H3 chondrites [4], cannot be simply explained. The well delineated chondrite texture indicates that the petrologic type of the precursor material was type 3–4. The absence of elongated chondrules suggests that it had low porosity, suggesting type 4.

Bogard et al. [11] reported an 39Ar-40Ar age for Ramsdorf of ~0.4 Ga. Since the second shock event (S3-S4) could not have totally outgassed the Ar, this age probably represents the first impact melting event (S6+), which may be the same event that caused extensive impact melting at 0.5 Ga on the L chondrite parent body [11]. Ramsdorf could be derived from the central part of crater (>several km in diameter) where shock pressures were highest [2]. However, since most heavily shocked materials reach the highest speed, it is difficult to explain the lack of stirring.

Figure 1. Photomicrograph of chondritic portion of Ramsdorf. Detailed mineralogical studies suggest that this portion was almost completely melted by shock. Width of field is 6.6 mm. Plane light.