SHOCK METAMORPHISM OF THE DHOFAR 378 BASALTIC SHERGOTTITE. T. Mikouchi[1] and G. McKay[2], [1]Dept. of Earth and Planet. Science, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, JAPAN, [2]Mail Code KR, NASA Johnson Space Center, Houston, TX 77058, USA, E-mail: mikouchi@eps.s.u-tokyo.ac.jp.

Introduction: Shock metamorphism is one of the most fundamental processes in the history of Martian meteorites, especially shergottites, which affect their mineralogy and chronology [e.g., 1]. The formation of "maskelynite" from plagioclase and shock melts is such major mineralogical effects. Dhofar 378 is one of the recently found desert shergottites that is mainly composed of plagioclase and pyroxene [e.g., 2-3]. This shergottite is important because of its highly shocked nature and unique plagioclase texture, and thus has a great potential for assessing a "shock" age of shergottites. We have been working on a combined study of mineralogy and chronology of the same rock chip of Dhofar 378. This abstract reports its mineralogical part. Chronological studies are reported somewhere in this abstract volume [4,5].

Petrography: Two thin sections were prepared from a rock chip of Dhofar 378. After the thin sections were made, the rest part was used for chronological study. The sections studied (5 x 3 mm, respectively) are mainly composed of plagioclase with smaller amounts of clinopyroxenes (Fig. 1). Plagioclase areas comprise about 50-60 % of the sections and the largest plagioclase area reaches 3 x 2 mm in size probably because it is a composite of several "grains" (Fig. 1). These "grains" are however composed of fibrous minute crystalline plagioclase needles usually ~100 µm long and <10 µm wide. These plagioclase grains often contain vesicles (~500 µm) with dirty halos around them. Although most parts of the grains show crystalline fibrous plagioclase, several grains contain glass areas that are isotropic under optical microscope. These glass areas are present as thin bands (~50 µm wide and ~500 µm long) in many cases near the center of plagioclase grains. Brown to black shock melt veins are observed. Plagioclase grains show a flow texture near these veins. Pyroxene grains show mosaic or undulatory extinction. Thin (~1 µm) exsolution lamellae are common, but they are usually deformed probably by shock. The FEG-SEM observation of pyroxene edges adjacent to plagioclase grains showed fairly sharp boundaries and no intergrowth of pyroxene was observed unlike the section previously studied [3].

Mineral Compositions: Most plagioclase "grains" do not show igneous chemical zoning in major elements, instead zoning patterns are complex (Fig. 2). The plagioclase composition ranges from $An_{58}Or_1$ to $An_{40}Or_7$. The glass areas in plagioclase grains are enriched in Na and K (Fig. 2). Some of them have a chemical composition identical to the plagioclase stoichiometry, but most of them are not. The ranges of K_2O and Na_2O are 0.5-6.5 wt% and 5-11 wt%, respectively. There is no clear correlation between Na and K abundances of the K-rich glass. The abundance of FeO and MgO in all feldspathic phases is less than 1 wt%, suggesting little contamination with surrounding minerals (pyroxene) during plagioclase crystallization.

Discussion: Petrography and mineral compositions of the Dhofar 378 sections studied are generally similar to the section that we previously studied [3]. The presence and chemical compositions of K-rich glass are almost identical to the previously studied section. However, the shock textures of the previously studied section are more extensive than those of sections studied this time. In fact, it appears that the sections studied here show intermediate shock metamorphism between [2] and [3]. Probably, shock effects were heterogeneous even in a small meteorite (total recovered mass: only 15 grams).

Heating experiment of Zagami "maskelynite":

As we already reported [3], the fibrous plagioclase needle is possibly a product of recrystallization from originally large plagioclase grains. The presence of both recrystallizing plagioclase rims and the inner K-rich feldspathic glass areas is similar to experimentally heated "maskelynite" in Zagami [6]. We performed these experiments only at 900 ^oC (for 1, 4, 8, 12, 24, 72 hours). In order to see textural and mineralogical changes of maskelynite at higher temperatures, we performed additional experiments at 1000 ^oC and 1100 ^oC. The sample heated at 1100 ^oC shows nearly complete plagioclase recrystallization (formation of fibrous plagioclase) even only for 1 hour. We could find thin partial melt areas between pyroxene and plagioclase, and pyroxene grains look somewhat rounded. The sample heated for 24 hours at 1100 ^oC shows drastic changes. The plagioclase grains are turned into clear brown glass and large vesicles formed. Only small areas show recrystallizing plagioclase. In this sample, we could not find any Ca phosphates probably because they were melted. We also found that K-rich feldspathic melt intrudes into cracks of pyroxenes. In contrast, the sample heated at 1000 ^oC shows no evidence of partial melting and rather similar to samples heated at 900 ^oC. However, the sample heated for 1 hour already shows nearly complete recrystallization of plagioclase. In this sample, thin K-rich glass bands are present in plagioclase grains. The sample heated for 24 hours does not significantly change from the sample heated for 1 hour.

Shock heating and cooling of Dhofar 378:

In our previous study [3], we discussed the origin of recrystallizing plagioclase in Dhofar 378 and concluded that a strong shock event (possibly during impact ejection from Mars) caused plagioclase shock melting and subsequent cooling from high temperature allowed partial recrystallization of plagioclase. We ruled out the possibility that maskelynite was already present by an early shock event and later it was somehow reheated on Mars causing recrystallization of maskelynite, and another shock event ejected it from Mars, because Dhofar 378 shows heterogeneous shock metamorphism in a cm scale [2,3].

Our additional heating experiment of Zagami suggests that the texture of recrystallizing plagioclase and K-rich glass in Dhofar 378 is most similar to the heated Zagami at 1000 ^{o}C for 1-24 hours. Because no obvious partial melting is observed in the sections studied, the peak temperature during shock was lower than 1100 ^{o}C, probably ~1000 ^{o}C. This is consistent with the presence of Ca phosphates and the absence of feldspathic glass in pyroxene cracks in Dhofar 378. The cooling rate of Dhofar 378 after the shock event is difficult to estimate from our present results. If the peak shock temperature was 1000 ^{o}C, we know that 1 hour is enough to recrystallize most plagioclase grains, but this does not give quantitative cooling rate. We plan to perform cooling experiments of Zagami from 1000 ^{o}C and 1100 ^{o}C to constrain a post-shock cooling rate of Dhofar 378. However, another information about its cooling rate is reported in [7], which performed crystallization experiment of Los Angeles. As is already pointed out [2,3], Dhofar 378 is similar to Los Angeles in many respects except for different degrees of shock metamorphism. In our previous study [3], we interpreted that the absence of pyroxferroite breakdown products in Dhofar 378 was due to its shock melting and euhedral fayalite with pyroxene and the mesostasis in some areas of Dhofar 378 are products of recrystallization from shock melt of pyroxferroite breakdown products. Because the 2.5 ^{o}C/hour cooling experiment of the Los Angeles synthetic composition could produce similar fayalite textures, this cooling rate may be comparable to post-shock cooling history of Dhofar 378 [7]. If we take this cooling rate, it is 40 hours from 1000 ^{o}C to 900 ^{o}C. This duration is consistent with the recrystallization of plagioclase with only small amounts of K-rich glass left. However, 2.5 ^{o}C/hour cooling is very slow for shock environment, and we expect that Dhofar 378 cooled slightly faster than 2.5 ^{o}C/hour.

The strong shock event and “slow” post-shock cooling rate of Dhofar 378 is unique among shergottites. The Ar-Ar age obtained from the same rock chip used for this study gave ~143 Myr, which is interpreted as an earlier impact event rather than the ejection event from Mars [4]. The Sm-Nd result also shows a similar age of 157 Myr [5]. The strong shock metamorphism observed in Dhofar 378 may record this ~143 Myr event.

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References: [1] Bischoff A. and Stoffler D. (1992) *Eur. J. Mineral.*, *4*, 702-755. [2] Ikeda Y. et al. (2002) *Antarct. Meteorites XXVII*, 40-42. [3] Mikouchi T. and McKay G. (2003) *LPS XXXIV*, #1920. [4] Park J. and Bogard D. D. (2006) *Antarct. Meteorites XXX* (in this volume). [5] Nyquist L. E. et al. (2006) *Antarct. Meteorites XXX* (in this volume). [6] Mikouchi T. et al. (2002) *MAPS, 37,* A100. [7] Koizumi E. et al. (2005) *LPS XXXVI*, #2015.

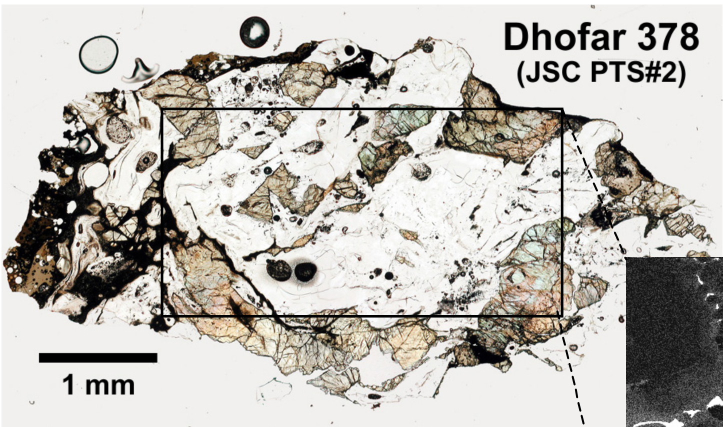

Fig. 1 (Left) Optical photomicrograph of one of the thin sections studied. This section contains a large area of plagioclase grains near the center. Shock melt is present at the left edge. Pyroxenes show sharp outer edges at the boundary to the plagioclase grains.

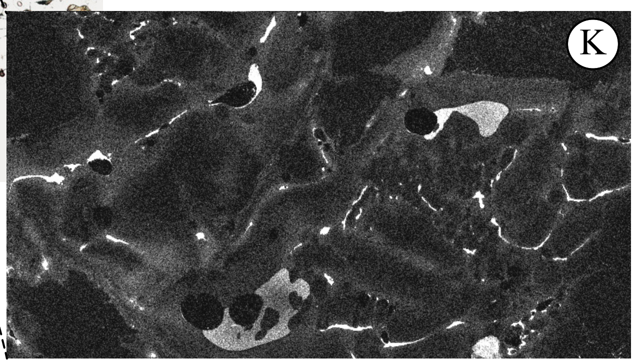

Fig. 2 (Right) K X-ray map of the area shown in Fig. 1. Note the presence of thin K-rich glass bands near the center of the plagioclase grains. These K-rich glasses contain 0.5-6 wt% K_2O. Plagioclase areas also show heterogeneous distribution of K.