SULFUR-RICH SHOCK VEIN IN 2.4 GA BASALTIC MARTIAN METEORITE NORTHWEST AFRICA 8159: REMNANT OF MARTIAN SOIL COMPONENT?

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Introduction: Martian regolith/soil records important information on the surface environmental evolution of the planet Mars. Several Mars landers and rovers have analyzed such soils to find that sulfates are the most major constituent phases despite the different landing sites in present day Mars [e.g., 1]. There has been a discussion whether such Martian soil components were trapped or not in shock melts of some shergottite Martian meteorites such as EETA 79001 [e.g., 2-4]. The argument is based upon high abundance of sulfur in shock melts due to either incorporation of sulfate minerals in Martian soils or preferential melting of igneous Fe sulfides. However, there has been no solid conclusion yet and more definite evidence is required. To further explore this issue, we analyzed shock veins in NWA 8159 which is a 2.4 Ga augite-rich basaltic Martian meteorite and pairing with NWA 7635 has been discussed [e.g., 5-7] because such an old igneous rock may have a better opportunity to experience shock melting episode with a higher chance of soil incorporation over time.

Samples and Methods: We studied a polished thin section of NWA 8159 (*ca*. 4 x 3 mm). The thin section was first observed by an optical microscope and then by back-scattered electron (BSE) imaging using JEOL JXA-8530F FE-EPMA at Univ. of Tokyo. We obtained elemental X-ray maps of the shock vein areas and analyzed the shock vein composition with broad electron beam (beam diameter: 5 μm) by FE-EPMA using well-characterized standards.

Result and Discussion: The NWA 8159 thin section studied shows the presence of network of shock veins crosscutting the section. The width of the shock vein reaches up to 0.5 mm in width. The EPMA X-ray mapping analysis shows that the shock vein is relatively homogeneous on the scale of ~100 μm although some compositional variation is of course present (Fig. 1). The EPMA quantitative analysis gives that shock veins in NWA 8159 have SO_3 of 0.5 to 7 wt%, which is weakly correlated to other elements such as Si (SiO_2: 45-54 wt%), Ti (TiO_2: 0.2-0.7 wt%), Fe (FeO: 15-27 wt%), Mg (MgO: 1-4.5 wt%) and P (P_2O_5: 0.1-0.5 wt%), but the correlation to Al (Al_2O_3: 5-15 wt%), Ca (CaO: 6-10 wt%) and Na (Na_2O: 1-3 wt%) are unclear (Fig. 2). The correlation of S with some elements can be interpreted by incorporation of certain mineral phases such as olivine, pyroxene and plagioclase, originally present in NWA 8159. However, it is remarkable that the sulfur abundance is clearly much higher than that of the surrounding unmelted areas where sulfide minerals are nearly absent (Fig. 1). The absence of sulfides is extremely rare for shergottites, but this may be related to the distinct parental melt composition and old crystallization age of NWA 8159 as well as its high oxygen fugacity ($\log fO_2$ slightly above the QFM buffer) [5,6]. Such high sulfur abundance is then interpreted as incorporation of S-rich minerals during shock melting originally absent in NWA 8159. The candidate phases are either sulfide or sulfate minerals. Because we found a positive correlation between S and Fe (Fig. 2), the source could be either Fe sulfide (pyrrhotite) or Fe sulfate. Since pyrrhotite is nearly absent in the NWA 8159 primary mineralogy, the most plausible candidate is Fe sulfate. Although jarosite [$KFe^{3+}_3(SO_4)_2(OH)_6$] is abundantly known on the Martian surface [e.g., 8], this is not the likely source of sulfur in the NWA 8159 shock vein because K abundance is very low (K_2O is <0.3 wt%). Therefore, the possible source mineral would be a hydrous Fe sulfate such as ferricopiapite [$Fe^{3+}_{0.67}Fe^{3+}_4(SO_4)_6(OH)_2\cdot 20H_2O$] [e.g., 9].

High magnification BSE observation and X-ray mapping analysis reveal that shock veins in NWA 8159 show recrystallization of ~1 μm crystals as reported in [7] (Fig. 3). Droplets of Fe sulfide and vesicles are present as seen in QUE 94201 [10]. The recrystallization degree is rather prominent among shergottites and it may be related to its rather weak shock degree (15-23 GPa [5,7]) (e.g., presence of crystalline plagioclase) compared to typical shergottites.

The ranges of S abundances in the NWA 8159 shock veins are equivalent to those in Shergotty, Zagami, EETA 79001 and Tissint, and higher than those in QUE 94201 and Dhofar 378 (Fig. 2) [2,10]. Compared to the possible Martian soil compositions, the NWA 8159 shock veins are more Fe-enriched, suggesting an incorporation of more Fe-rich phases as discussed above, which is different from other shergottites. Since the incorporation of Martian soil components (assuming a Gusev and Meridiani composition [11]) is estimated to be 5-50% by the mass balance calculation for shergottite shock melts, shock veins of NWA 8159 may contain similar abundance of Martian regolith [2]. However, these estimates are highly model-dependent and more careful modelling is required.

Conclusion: Shock veins of NWA 8159 contain 0.5-7 wt% SO_3, which may be attributed to melting of some sulfate phase(s) in the Martian regolith such as hydrous Fe sulfates, since the elemental abundances of these shock veins are equivalent to the reported values in other shergottites [2]. The absence of Fe sulfide minerals in the NWA 8159 primary igneous mineralogy could be a strong support of the exogenic origin for the sulfur enrichment of shock veins, which is a different case from other shergottites.

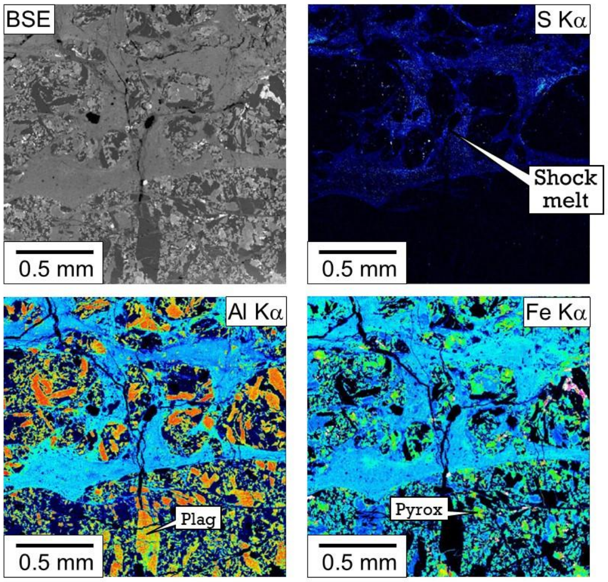

Fig. 1. BSE image and S, Al and Fe X-ray maps of shock veins and surrounding unmelted regions of NWA 8159. Note that S abundance is extremely low in the unmelted areas (lower portion of the S map).

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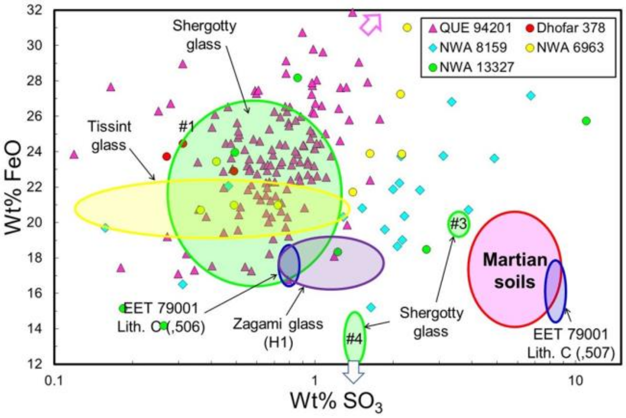

Fig. 2. FeO and SO_3 compositions of shock veins in NWA 8159. Compositions of Martian soils and shock melts of other shergottites are from [2,10].

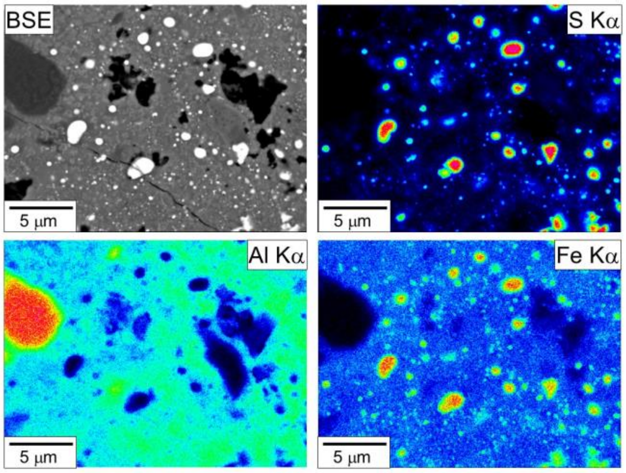

Fig. 3. High magnification BSE image and S, Al and Fe X-ray maps of the shock vein in NWA 8159. Note the presence of Fe sulfide droplet and irregular-shaped vesicles. Fe sulfide likely recrystallized from shock melt.