SHOCK-INDUCED METAMORPHISM IN THE LUNAR METEORITE NORTHWEST AFRICA 4734.

Y. Wang[1] and W. Hsu[1,2], [1]Key Laboratory of Planetary Sciences, Purple Mountain Observatory, Nanjing 210008, China (y_wang@pmo.ac.cn), [2]Space Science Institute, Macau University of Science and Technology, Macau.

Introduction: In the early history of solar system, impacts were ubiquitous and had played significant roles in the formation and evolution of asteroidal and planetary bodies. The moon had been modified by numerous dynamic events since its formation. However, high-pressure polymorphs of minerals were rarely found in lunar materials. Recently, a series of high-pressure silica (coesite, stishovite, and seifertite) have been reported in lunar meteorites Asuka-881757 and Northwest Africa (NWA) 4734 [1-2]. To better understand shock-induced metamorphism on the Moon, we carried out a comprehensive study of a lunar meteorite, NWA 4734, with micro-Raman spectrometry, electron back-scattered diffraction (EBSD) and electron microprobe methods.

Results and Discussion: NWA 4734 is an unbrecciated mare basalt consisting mainly of 58 vol% pyroxene ($En_{5\text{-}57}$ $Wo_{10\text{-}42}$) and 31% plagioclase ($An_{79\text{-}93}Ab_{10\text{-}15}$). Shock-induced metamorphism is pervasive. Pyroxene displays irregular fractures. Plagioclase was partly converted to maskelynite. Raman spectra of maskelynite (Fig. 1a) exhibit broad emissions near the characteristic bands of crystalline anorthite, 505 and 565 cm^{-1}. The band at ~995 cm^{-1} was shifted from ~980 cm^{-1} due to higher density of maskelynite relative to anorthite. Shock melt veins were observed with width from <10 µm to 700 µm. The glassy veins contain 45 wt% SiO_2, 17% FeO, 16% Al_2O_3, 13% CaO, 4% MgO, and 3% TiO_2 on average, indicating that pyroxene and/or olivine, and ilmenite and/or ulvöspinel were also melted in veins besides plagioclase.

Sulfide in NWA 4734 is mostly troilite ($Fe_{0.99}S$). In shock-melt veins and pockets, troilite was transformed to mackinawite ($FeS_{0.88}$) due to sulfur evaporation. Round morphology of mackinawite suggests that it was once melted spherules suspending in silicate melt due to immiscibility. Raman spectrum of mackinawite has indicative bands at 219, 285 and 399 cm^{-1} (Fig. 1b-1). Pyrrhotite ($Fe_{0.89}S$) forms eutectic with ilmenite. However, its Raman spectrum (Fig. 1b-2) indicates a composite of mackinawite and pyrrhotite, with characteristic bands at 219, 283, 336 and 369 cm^{-1}. This pyrrhotite was likely formed from mackinawite by re-condensation of shock-evaporated sulfur and the eutectic might have been quenched before completion of structural transformation.

High-pressure polymorphs were identified by Raman spectra collected on a partially melted silica grain (~200 µm). The Raman band (Fig. 1c) at 523 cm^{-1} is characteristic of coesite; the bands at 232, 587, 753, and 965 cm^{-1} are indicative of stishovite; and the broad bands near ~500, 800, and 1000 cm^{-1} are due to shock-induced silica glass. Seifertite, the α-PbO_2 type silica, is sensitive to laser and electron beam [2]. Seifertite was identified in this study by its EBSD pattern which is well indexed with the *Pbcn* structure (Fig. 2).

Our observation implies that NWA 4734 had undergone intensive shock-induced metamorphism at different pressure and/or temperature levels. Migration of volatile elements may be induced by impact events on the Moon.

References: [1] Ohtani E. et al. 2011. *Proceedings of the National Academy of Sciences* 108: 463–466. [2] Miyahara M. et al. 2013. *Nature Communications* 4: 10.1038/ncomms2733.

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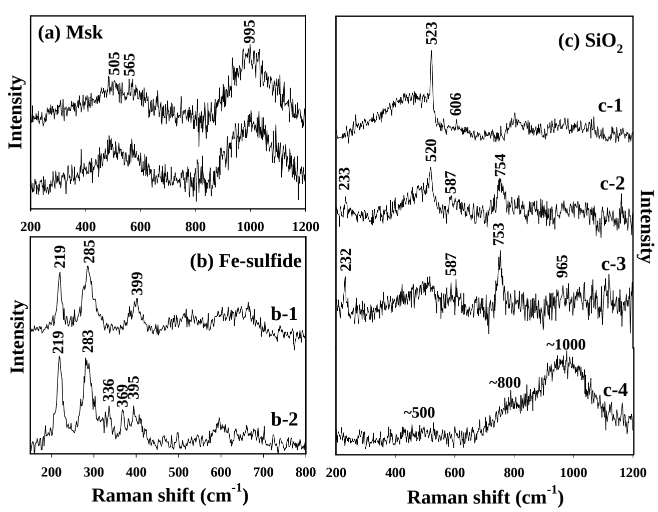

Fig.1 Raman spectra of (a) maskelynite, (b) Fe-sulfide, and (c) SiO_2 polymorphs in NWA 4734.

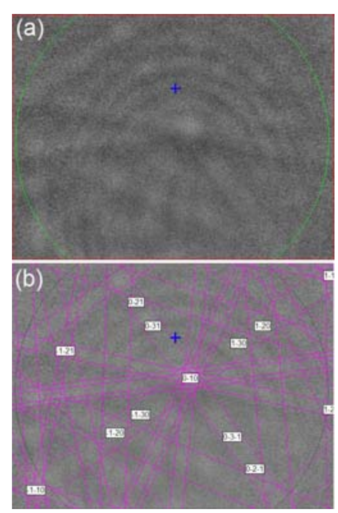

Fig.2 (a) EBSD pattern of a silica crystal, (b) the pattern indexed with the *Pbcn* seifertite structure.