MULTIPLE SHOCK EVENTS AND DIAMOND FORMATION ON MARS. A. El Goresy[1], Gillet[2], Ph., Miyahara[3], M., Ohtani[3], Ozawa[3], S., Lin[4], Y., Feng[4], L. and Escerig[2]. S., [1]Bayerisches Geoinstitut, Universität Bayreuth, 95447 Bayreuth, Germany, E-Mail: Ahmed.Elgoresy@uni-bayreuth.de , [2]EPFL, CH-1015,Lausanne, Switzerland, [3]Tohoku University, Sendai 980-8578, Japan, [4]Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China.

Introduction: It was only recently unambiguously demonstrated that shergottites were subjected to pervasive shock deformations considerably erasing their original igneous textural integrities and resetting original igneous crystallization ages [1]. These results cast considerable doubt on claims of hypothetical high peak-shock pressures and question short radiometric ages as alleged "*igneous crystallization ages*" of less than 474 Ma [2-10]. Here, we report our findings in Tissint, NWA 6162 and NWA 856 adding meaningful implications to the nature and sequence of the dynamic events in the young history of Mars and to evaluating archaic igneous ages of shergottites [11]. We decipher in Tissint three dynamic events with specific shock-induced high-pressure inventories including: jadeite, majorite-pyrope$_{ss}$ + magnesiowüstite, ringwoodite in olivine and dissociation of olivine to $MgSiO_3$ perovskite + magnesiowüstite, none of which were ever recognized before [2-10]. We also report the first finding of shock-induced diamond in Mars.

Results: The following shock events were deciphered in Tissint according to their spatial, texture and mineral inventories: (1) Presumably the relatively oldest dynamic event induced in Tissint total melting of feldspar and its quenching to maskelynite glass ($An_{62-66}Ab_{35-37}Or_{1-0}$) at high-pressure followed by glass relaxation at Mars ambient pressure [1]. We encounter in the Tissint shergottite for the first time clear evidence for quenching of liquidus acicular jadeite crystals in bands aligning pyroxene (CPX) in the maskelynite enclaves. Nature of jadeite was unequivocally verified through the characteristic Raman Bands: 383 cm^{-1}, 703 cm^{-1} and 1015 cm^{-1}, respectively in addition to a band at 502 cm^{-1} characteristic of maskelynite glass. Several maskelynite enclaves also depict feathery jadeite inclusions occupying major part of their interiors. Measured chemical composition of jadeite is identical to that of maskelynite thus strongly suggesting the presence of other unidentified silicate glass. (2) The subsequent event is documented by an array of countless thin shock-melt veins (< 2 µm wide) fanning the whole Tissint matrix. They contain idiomorphic majorite-pyrope$_{ss}$ + magnesiowüstite quench crystals; the former along with amoeboid carbon clots in the interior of the veins and the latter aligning contacts to the partially molten CPX (Fig. 1). Veins depicting this assemblage also cross cut jadeite-bearing bands but terminate at the contact to underlying maskelynite glass. This arrangement is strongly suggestive that these veins formed in a subsequent event after solidification of both maskelynite and jadeite. (3) The third event is represented by veins filled with tightly crowded, fragmented, crushed and mobilized anhedral majorite-pyrope$_{ss}$ + magnesiowüstite grains (Fig. 2). The veins also enclose anhedral carbon fragments variable in size (Fig. 2). Incoherent olivine to polycrystalline ringwoodite inversion is encountered in grains entrained in melt pools or adjacent to them. Identity of ringwoodite was confirmed through characteristic Raman bands at 803 cm^{-1} and 826 cm^{-1}, respectively. Some olivine grains depict two sets of ringwoodite lamellae. Their nature was also confirmed by laser microRaman. In addition, few olivine crystals show ample evidence of dissociation to $MgSiO_3$ perovskite + magnesiowüstite similar to the recently reported finding in a shergottite by [12].

NWA 6162 and NWA 856: These shergottites enclose a unique type of broad shock-melt veins with a novel assemblage containing *rosette-like objects surrounded by comb-structured net-like pattern* (Fig. 3). Each of the polygonal comb-like entities contains a small (<2µm) inclusion of carbon. Such bizarre carbon-bearing objects were never observed before in any Martian meteorite [1-10, 12]. Preliminary laser micro-Raman investigations showed that some of the carbon inclusions in NWA 6162 depict the T_{2G} band of diamond at 1327 cm^{-1} that shifted 5 wave numbers below the characteristic Raman mode at 1331 cm^{-1} and further shifted to 1324 cm^{-1} upon increase of the laser power thus confirming the probable nano-sized diamond nature as previously demonstrated by [13]. This is the first report of shock-induced diamond in a Martian sample. We encountered in NWA 856 orderly arranged carbon particles also in comb-like objects in rows in a shock-melt pool. Nature of the carbon particles in Tissint, NWA 6162 and NWA 856 are under investigation and are subject of further detailed Raman study and isotopic scrutiny by NanoSIMS 50L. Detailed results will be presented at the conference by [14].

Discussion: Our investigations delineate several dynamic events recorded by the Tissint shergottite. Several lines of evidence allow to individually identify them and estimate the pertinent equilibrium peak-shock pressures: (1) The earliest event that induced pervasive melting of feldspar and crystallization of jadeite is indicative of peak-pressure < 19 GPa at T > 2000ºC followed by (2) An episode inducing an array of thin shock melt veins with idiomorphic liquidus majorite-pyrope$_{ss}$ + magnesiowüstite (Fig. 1). Inversion of olivine to ringwoodite can be assigned to the second event. Dissociation of olivine to $MgSiO_3$ perovskite + magnesiowüstite [12] probably took place during this event. Yet, these veins surprisingly didn't overprint the jadeite assemblage of the first event. Estimated equilibrium peak-shock pressure is 23-25 GPa at T > 2300ºC, (3) The presumably last event fragmented, crushed and mechanically mobilized majorite-pyrope$_{ss}$ + magnesiowüstite in several veins of the second event (Fig. 2).

All three shergottites display a diversity of carbon-bearing textures, species of probably different origins. Amoeboid carbon clot in Tissint didn't form at ultra high-pressure. It's scalloped shape and the presence of small majorite inclusions in it strongly suggests it's in situ formation by an unknown mechanism after decompression and perhaps not as a solid. Carbon fragments (Fig. 2) probably emerged from a late mild shock event that only fragmented and mechanically mobilized majorite$_{ss}$ and magnesiowüstite. Carbon and specifically diamond in comb-like intergrowth encountered in shock-melt pools in Tissint, NWA 6162 and NWA 856 probably recorded two unknown mechanisms: formation of the comb-like structure incorporating or? unmixing carbon; followed by entrainment in shock-melt pools at high-pressure thus inverting some of the carbon to diamond. We are currently addressing the origin of the various carbon types by detailed isotopic investigations with NanoSIMS 50L. Of special importance are isotopic compositions of C, N and H and trace element inventory of carbon in combs and particles [14].

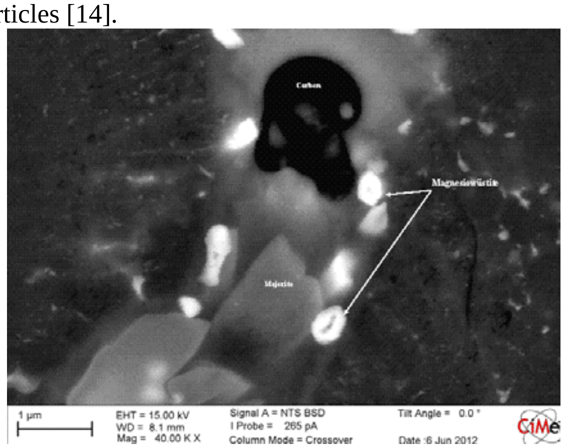

Figure 1: A BSE-SEM view at high magnification of a 2-3 µm wide shock melt vein in Tissint depicting liquidus idiomorphic majorite-pyrope$_{ss}$ + magnesiowüstite crystals and a clot of amoeboid-shaped carbon enclosing rounded majorite grains.

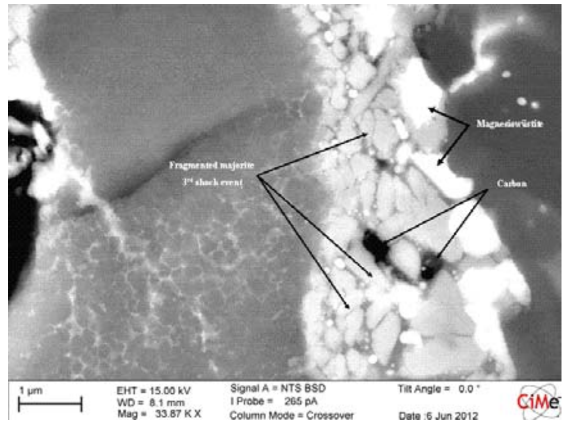

Figure 2: A view at high magnification of a shock vein in Tissint depicting tightly packed anhedral fragmented and mobilized majorite-pyrope$_{ss}$ + magnesiowüstite grains along with fragmented carbon grains of stark variable sizes in their interstices.

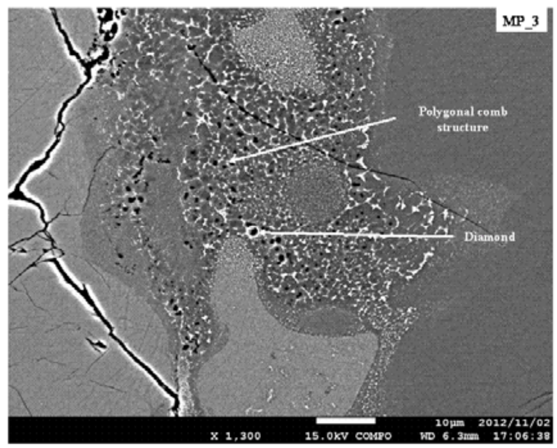

Figure 3: BSE-SEM view of an unusual comb-like texture in Tissint containing carbon inclusion inside each polygonal comb. Some of carbon particles are confirmed to be diamond.

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