NEW INSIGHTS INTO THE MAGMATIC AND SHOCK HISTORY OF THE NAKHLITE METEORITES FROM ELECTRON BACKSCATTER DIFFRACTION. S. Griffin[1], L. Daly[1,4], M. R. Lee[1], S. Piazolo[2], P. W. Trimby[3], L.V. Forman[4], P. Chung[1], B. E. Cohen[1], R. Baumgartner[5], G.K. Benedix[4]. [1]School of Geographical and Earth Sciences, University of Glasgow, Glasgow G12 8QQ U.K. E-mail: s.griffin.3@research.gla.ac.uk, [2]School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK. [3]Oxford Instruments Nanoanalysis, High Wycombe, HP12 3SE, UK. [4]Space Science and Technology Centre, School of Earth and Planetary Sciences, Curtin University, GPO Box U1987, Perth, WA, 6845, Australia. [5]Australian Centre for Astrobiology, University of New South Wales, Sydney, NSW, Australia.

Introduction: Slip systems within crystals can provide important information about physical conditions related to deformation within a given environment that are controlled by the different stress, temperature, and water content within a given sample [1,2]. These slip systems can either be formed from magmatic or shock related microstructures [2], therefore great care must be taken when interpreting this type of data in the context of meteorites [2].

The nakhlites are a sub-group of 20 meteorites that provide unique and important information about the evolution of Mars, including Martian mantle composition, volcanic processes and alteration of the Martian crust by aqueous fluids [3]. Basaltic in mineralogy and chemistry, the nakhlites are comprised of varying proportions of clinopyroxene (augite), olivine phenocrysts in a fine grained feldspathic mesostasis [3]. Importantly, they generally exhibit lower degrees of impact shock metamorphism (5 – 12 GPa, ~5 – 40 K above ambient) than other groups of Martian meteorites including the much more abundant shergottites [3-5]. Thus the nakhlites can provide a clearer view of indigenous Martian processes as they lack the mineralogical and chemical changes that have invariably affected the more highly shocked specimens.

We have sought to obtain new insights into the mineralogy, petrogenesis and shock history of nine nakhlites by using electron backscatter diffraction (EBSD). This is a powerful crystallographic mapping technique that permits quantitative evaluation of petrofabrics, crystal orientation relationships, and internal misorientations [2,6,7].

Methods: A combination of premade and newly made sections were picked for EBSD analysis. Samples were selected in an attempt to capture the diversity within the nakhlites, taking into account recovery location, known age, and modal mineralogy. All samples were cut at random with no regard for any petrofabric. Samples were mechanically and chemically polished, as well as carbon coated (with the exception of Lafayette and Miller Range (MIL) 03346) prior to EBSD analysis using standard methods. EBSD data for Northwest Africa (NWA) 998 (UG-1 and T1), NWA 11013, Governador Valadares (BM 1975,M16), Yamato (Y)-000593, Y-000749 and Y-000802 were collected using a Zeiss Sigma variable pressure field emission gun scanning electron microscope (SEM; VP-FEGSEM) with a NordlysMax[2] EBSD detector and indexed using AZtec analysis software v3.3 from Oxford instruments at the ISAAC imaging facility, University of Glasgow; EBSD data for meteorites Nakhla, Governador Valadares, Lafayette, and MIL 03346 were collected using a Carl Zeiss IVO SEM at the geochemical Analysis Unit (GAU; Macquarie University) using a HKL NordlysNano high sensitivity EBSD detector; and EBSD data for NWA 817 was collected using a Hitachi SU70 FEGSEM equipped with a Symmetry CMOS detector and indexed using AZtec analysis software v3.4 at Oxford Instruments Nanoanalysis HQ in High Wycombe. The SEMs were run under high vacuum (except MIL 03346 and Lafayette which were run at low vacuum: ~ 49 Pa), 20 keV, 4-8 nA beam current and tilted at 70°. large area maps were collected using a 3.3 μm step size (2.5 μm North West Africa (NWA) 11013, and 0.4 μm for NWA 817)). The data were noise reduced using Oxford Instruments HKL Channel 5 software using a wildspike followed by a 6 point nearest neighbor zero solution reduction. Data for the crystal rotation axes were produced using the complete noise reduced data set which encompasses the mesostasis.

Results and implications: Our results from large area EBSD mapping reveal that the olivine crystals within the samples studied exhibit four types of slip systems (A/C, A, B, and A/B; Figure 1). This expands on the description in [7] where only A-type slip was reported. The nakhlites also exhibited a strong component of B and B/C type slip systems within their augite crystals, with the exception of the Yamato (Y) stones Y-000749 (A/C) and Y-000593 (A/C] with a strong component of C) indicating that different microstructures are present. The consistent slip system within the augite crystals contrasts with the varied slip systems present within the nakhlites' olivine. These new findings demonstrate the importance of large area mapping to give thin section scale relationships rather than using targeted area mapping that may not be representative.

The slip systems identified using large area mapping are consistent across different thin sections of the same meteorite (NWA 998 and Governador Valadares) but vary between the different nakhlites, including the Yamato meteorites (Y-000593, Y-000749, and Y-000802), showing the nakhlites experienced contrasting styles of deformation. Thus our EBSD data provides further evidence for the Yamato meteorites to no longer be classified as paired stones. These contrasting slip systems in olivine have been shown to relate to contrasting temperature, water content, and pressure conditions as evidenced from experimental studies conducted under conditions relevant to the terrestrial mantle. These observed relationships should therefore be applicable to the martian lower crust/subaerial environment and useful in interrogating the slip systems present within the nakhlite subgroup.

The relationship between the differing slip systems in the olivine crystals and the dominant augite slip system provides textural evidence indicating that the nakhlites underwent different histories that may be related to either crystallisation or shock. Therefore we should be able to either establish what temperature/strain rate/water content etc. these rocks experienced during crystallisation or alternatively their relationship to the shock derived from impact. Thus, providing further information towards interpreting the formation history of the nakhlite lava flows on Mars.

Acknowledgements: We thank the Natural History Museum London, the Japanese Antarctic Meteorite Research Centre, Smithsonian Museum, NASA Meteorite Working Group, Macovich Collection, and The Museum of Western Australia for providing samples.. S.G. would also like to thank PSI and the Pierazzo award, as well as the UofG Early Career Mobility Scheme to L.D. for support in attending LPSC 2019.

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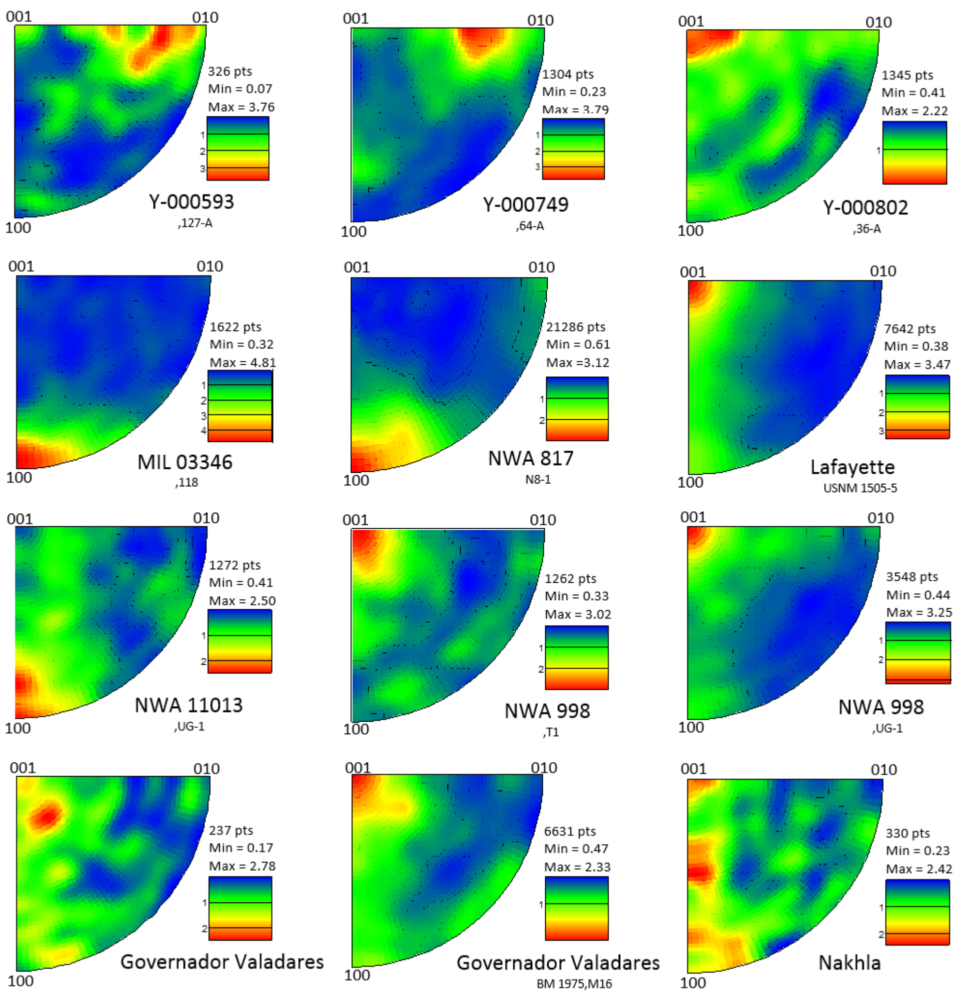

Figure 1: The nakhlite meteorites exhibit components of A/C-type (Y-000593, Y-000749), A-type (Y-000802, Lafayette, NWA 998, Governador Valadares), B-type (MIL 03346, NWA 817, NWA 11013), A/B-type (Nakhla) type slip present within their olivine crystals; CS crystal coordinate rotation axes, upper hemisphere equal area projection, half width 10°, Cluster size 0°, 2-10°.