EARLY DYNAMIC MANTLE MOVEMENTS IN YOUNG, SEMI-CRYSTALLIZED VESTA

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Introduction: Petrologic and geochemical studies of diogenites offer various, partly contradictory, crystallization scenarios [1], [2], [3], [4], [5], [6], [7], [8] on the HED parent body. With their ultramafic composition, diogenites could either represent mantle residue as a result of partial melting and the extraction of more evolved magma or constitute the product of fractional crystallization from molten magma, the latter occurring in magma chambers, multiple magma ponds or a larger scale magma ocean, or they were formed in combinations of these scenarios in multi-step processes. Structural analysis can complement petrologic and geochemical findings by revealing any syn- or post-crystallization deformation undergone by the diogenites, thus offering constraints on dynamic processes occurring and conditions prevailing during cooling of the parent body. Our structural studies of olivine-rich diogenites indicate that the solidification of the HED parent body was not a static progression, but involved large-scale dynamic mantle movements, not unlike those experienced by the early Earth.

Analyses: Comprehensive structural analyses were performed on three olivine-rich diogenites of varying olivine content: NWA 5784 (92% ol.), NWA 5480 (57% ol.) and MIL 07001 (13% ol.). We focused on the olivine crystals in each case, since olivine deforms more readily than orthopyroxene [9], [10], [11], the other abundant mafic mineral in these diogenites. Electron backscatter diffraction (EBSD) was applied to discover any lattice-preferred orientation (LPO) of the olivine crystals as indicator for the respective deformation mechanism. The EBSD analysis includes systematic manual data acquisition across the complete surface of the sample, as well as automatic mapping of selected areas, to measure and record the orientation of the crystallographic axes of each olivine crystal relative to the sample surface. Statistical EBSD data generate orientation, phase and grain-size distribution maps, also rendering a closer look at the grain and phase boundaries. Stereographic plots of the orientations reveal any LPOs, allowing the dominant slip systems activated for the deformation to be identified. Transmission electron spectroscopy (TEM) was applied (in the case of NWA 5480) to visualize more closely the dislocations in the olivine crystal lattice responsible for the discovered deformation. Micro-computer-tomography (Micro-CT) was applied for 3D-visualisation of any internal structures and phase distributions, based upon density measurements. Optical microscopy (OM) was applied to visualize any textural fabrics and grain boundary conditions. The structural analyses were complemented by geochemical analyses using microprobe (EPMA) measurements. In addition, numerical modeling [12] of the asteroidal solidification progression was performed based upon estimated Vestan parameters [12].

Results and discussion: Neither of the three diogenites show any indication of shock-related deformation. However, the results confirm all three diogenites underwent post-crystallization, solid-state plastic deformation under high temperature, anhydrous conditions. For at least two of the three samples, NWA 5480 and NWA 5784, this plastic deformation is clearly distinct from the axial compression [10] or shape-preferred orientation typically occurring in magma chambers or thick lava flows, ruling this deformation mechanism out. NWA 5480 and NWA 5784 were deformed under activation of the slip systems {0kl}[100] and specifically (010)[100], respectively. Furthermore, a direct comparison of the LPOs for NWA 5480 and NWA 5784 confirms a link between these two samples, revealing a progression of increasing deformation temperature [13], or strain [10], also coinciding with increasing olivine content. NWA 5480 displays three different fabrics and hosts at least three populations of olivine crystals with different deformation histories, inferring polystage post-crystallization dynamics.

Numerical models reveal a plausible scenario of a dynamically cooling asteroid with downwellings of dense, cool material with high strength at the base of the solidified lid sinking into warmer softer material, dynamically inducing counter-upwellings of displaced lower-lying mantle. This model accommodates the temperature, strain and hydration constraints as well as the progression correlation inferred by the LPO results of NWA 5480 and 5784. The two slip systems activated for the deformation of these two samples, known as pencil-glide [13] and mantle LPO [14], respectively, are found to be the two most common active slip systems for olivine deformation in the terrestrial mantle [10], [14]. This striking resemblance between the olivine LPOs found in olivine-rich diogenites with those found in olivine mantle rocks from Earth strengthens Vesta's classification as a protoplanet and reaffirms our numerical model of large-scale downwellings in a dynamic mantle as a plausible scenario for the thermal evolution of the young and solidifying Vesta.

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