Pseudo single domain magnetite as a stable natural remanent magnetization carrier in obsidian

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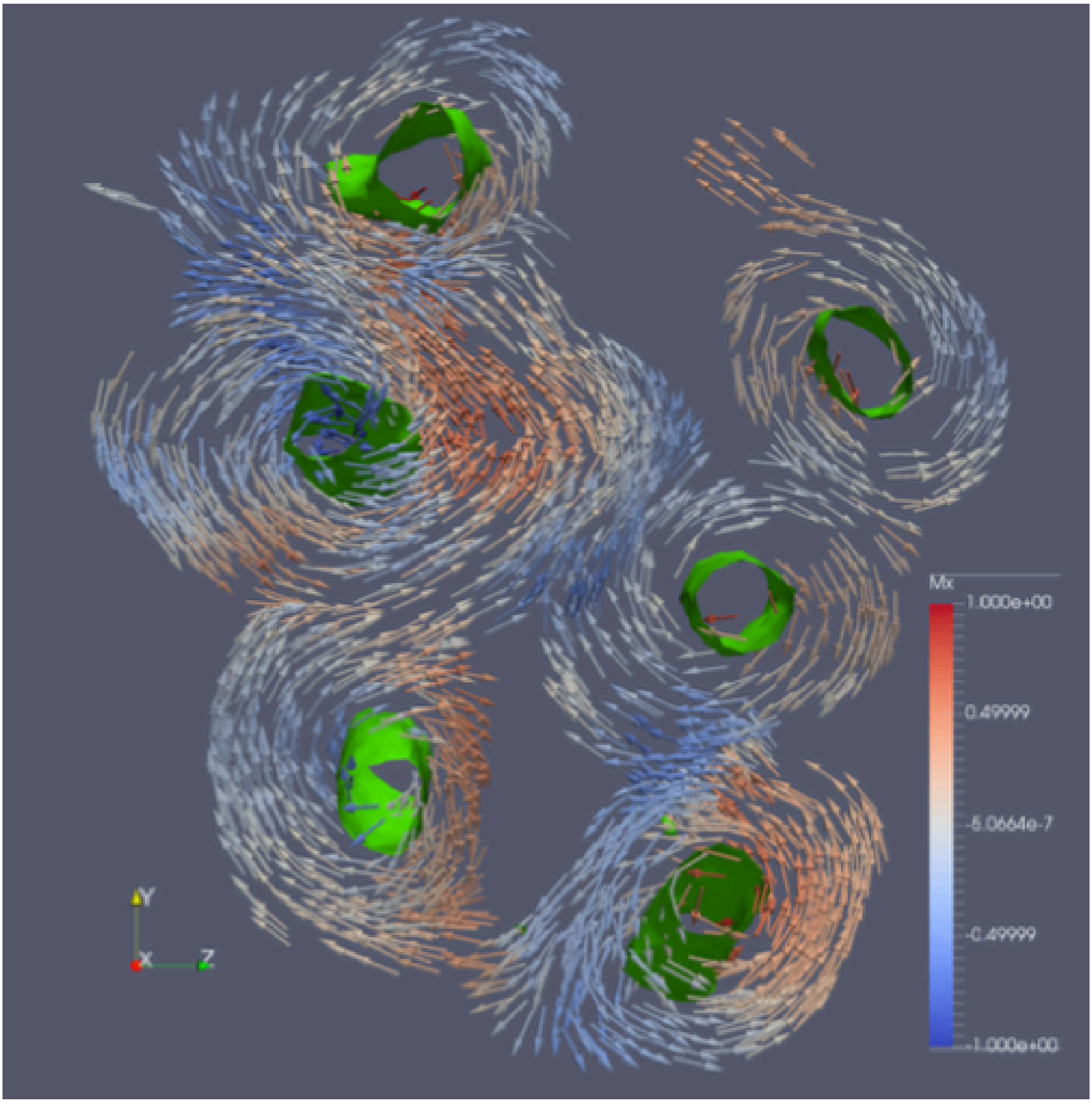
Most natural samples contain so-called "non-ideal" paleomagnetic recorders, which are magnetic particles larger than ideal, single domain recorders, but smaller than proper multi domain grains, which are poor paleomagnetic recorders. The grain size range for these recorders, which for magnetite comprises grains from ~100 nm to a few μm in size, is known as the pseudo single domain (PSD) domain state. Natural samples containing abundant PSD grains have been shown to reliably record thermomagnetic remanent magnetizations that are stable over billions of years. Here we investigate obsidian varieties from Glass Butte, Oregon, USA, which present the opportunity to study the simple case of PSD grains encapsulated in volcanic glass. To do this, we combine paleointensity experiments, rock magnetism, scanning electron microscopy (SEM) nanotomography, and finite-element micromagnetic modelling. Results from the Thellier-IZZI protocol indicate that PSD grains acquire a thermoremanent magnetization efficiently and have high blocking temperatures, similar to stable single domain grains. Using rock magnetism we identify PSD signatures via their diagnostic fingerprint in first-order reversal curve (FORC) diagrams. Tomographic reconstructions obtained by stacking SEM images acquired via sequential milling through sample volumes of a few tens of cubic μm reveal the presence of abundant grains that span the PSD grain size interval. These grains have a variety of shapes, from simple ellipsoidal particles, to more complex morphologies attained via the coalescence of neighbouring grains during crystallization, to intricate "rolling snowball" morphologies that formed during growth in a dynamic environment as the flowing lava cooled. Micromagnetic modelling of the simplest morphologies reveals that these grains are in single vortex states, with the remanence controlled by irregularities in grain morphology. Larger grains contain complex, multi-vortex structures and incipient domain walls, with remanence being controlled by the collection of PSD states from areas with pronounced shape anisotropy. Modelling the properties of these grains as a function of field and temperature allows a better understanding of PSD remanence acquisition in natural samples.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