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Micromagnetic Tomography: Developments, Perspectives, and Outlook

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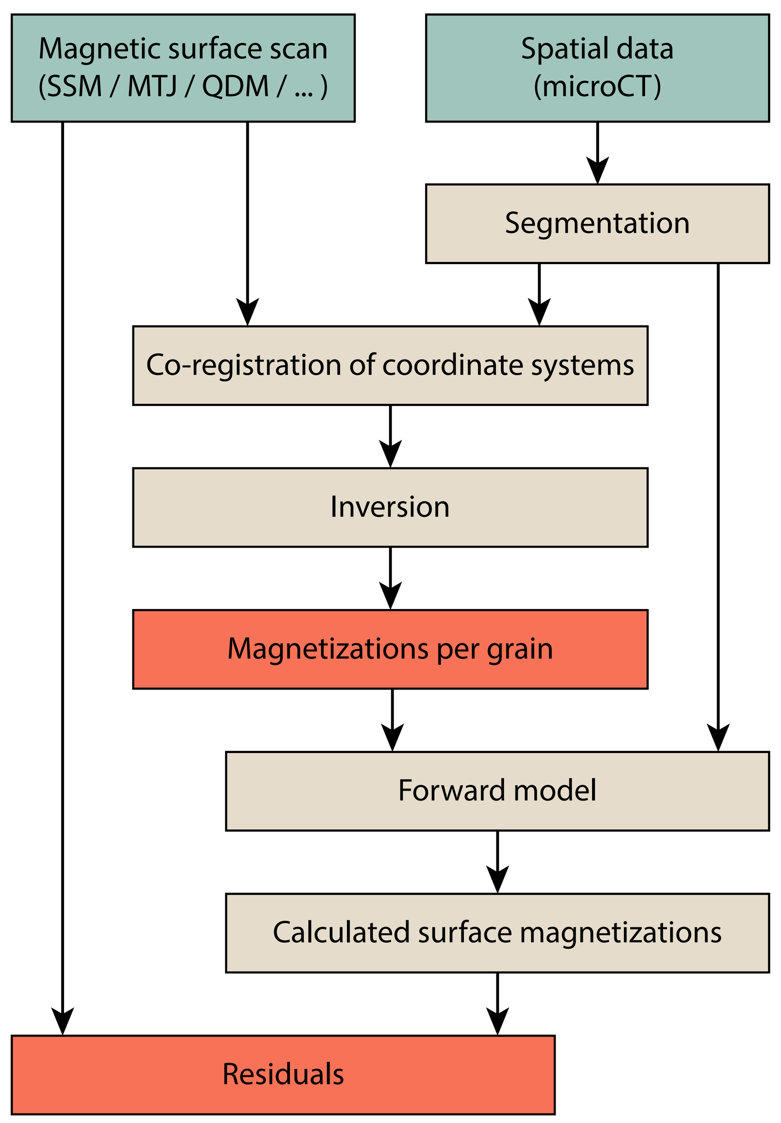
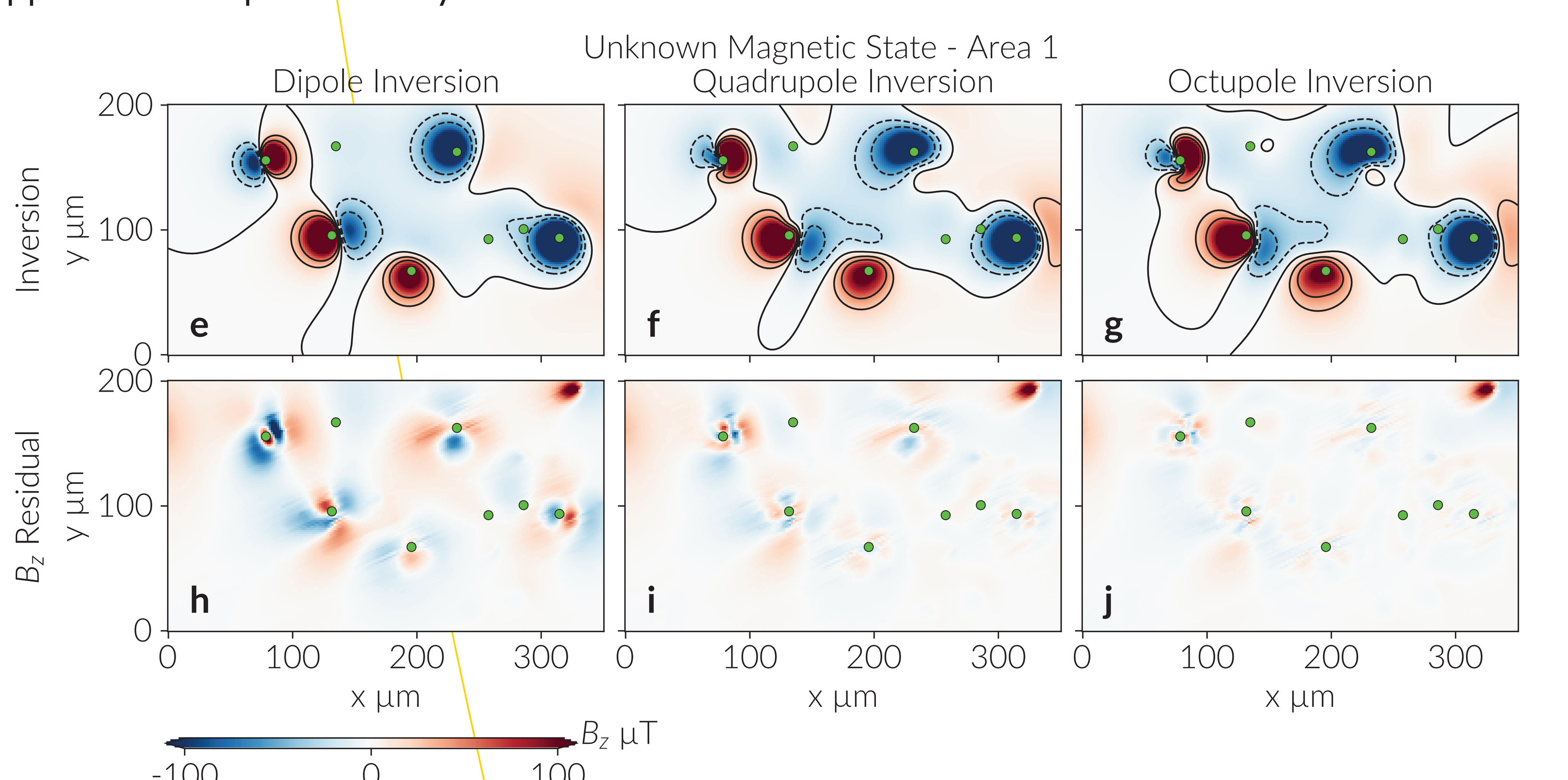
Introduction

Micromagnetic Tomography (MMT) allows to reconstruct magnetic moments of individual grains embedded in a sample. Its workflow is in the flowchart to the right. MMT relies on combining a magnetic surface scan with a spatial characterization of the iron-oxide grains from a MicroCT scan. The spatial information on the magnetic sources helps to constrain the mathematical inversion and to overcome the traditional non-uniqueness of potential field inversion problems. The accuracy of the MMT results is assessed by assigning the grains obtained from the MicroCT scan their calculated magnetic moments and determining the surface magnetizations that they would produce. The difference between this map and the measured surface scan are the residuals that are not explained by the MMT inversion.



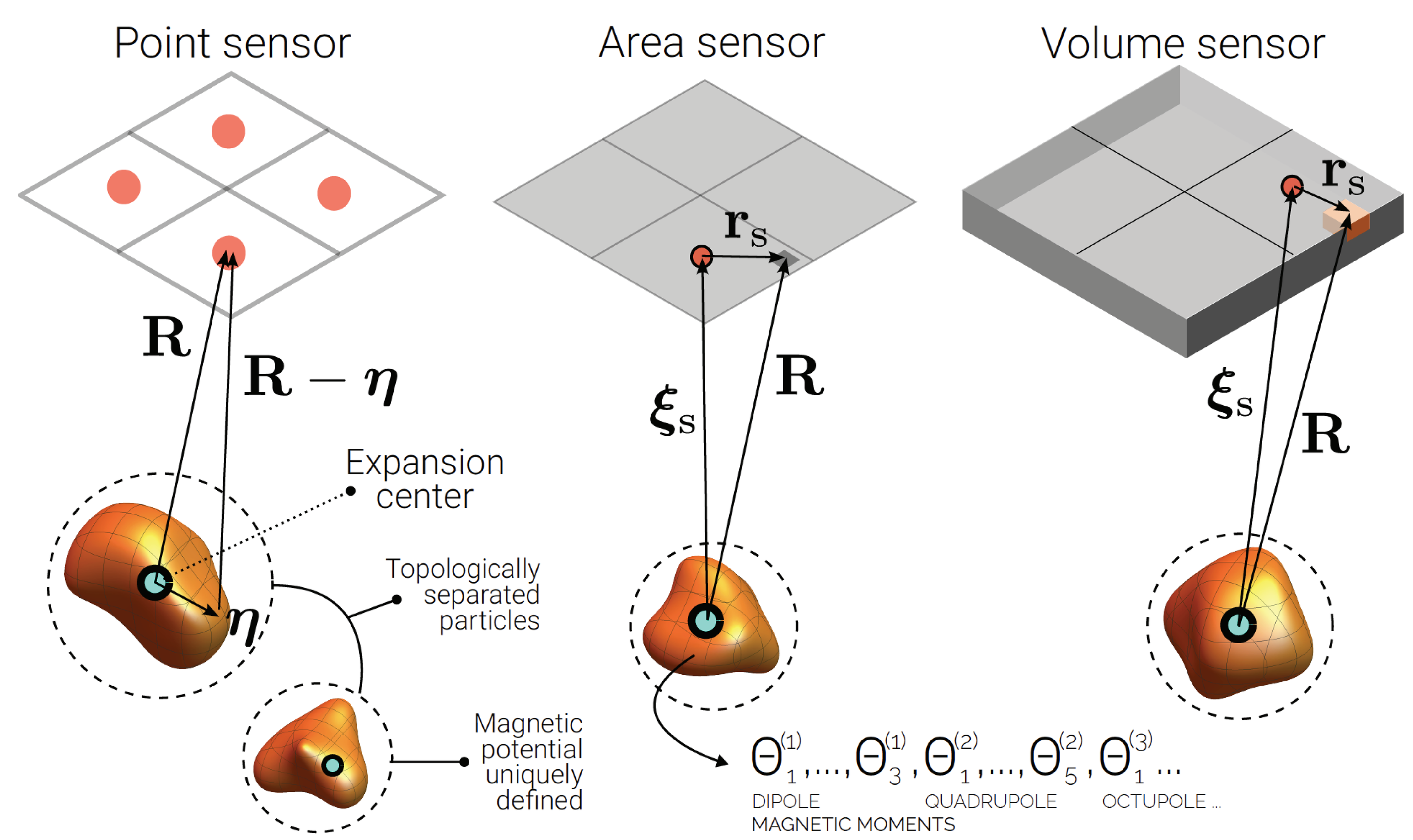
From fitting dipoles to spherical harmonics

Naturally occurring grains often have complex magnetic structures that can only be approximated as a dipole when the sensors are sufficiently far away from the grain. In most MMT studies, however, the sensor-sample distance is minimized. It is therefore necessary to describe the magnetic moments of the grains in spherical harmonics. As illustrated below, the residual of the inversion reduces when higher order spherical harmonics are used. Also, the higher order spherical harmonics accommodate e.g. measurement noise and co-registration errors. Fitting higher order spherical harmonics therefore also improves the dipole approximation produced by MMT.



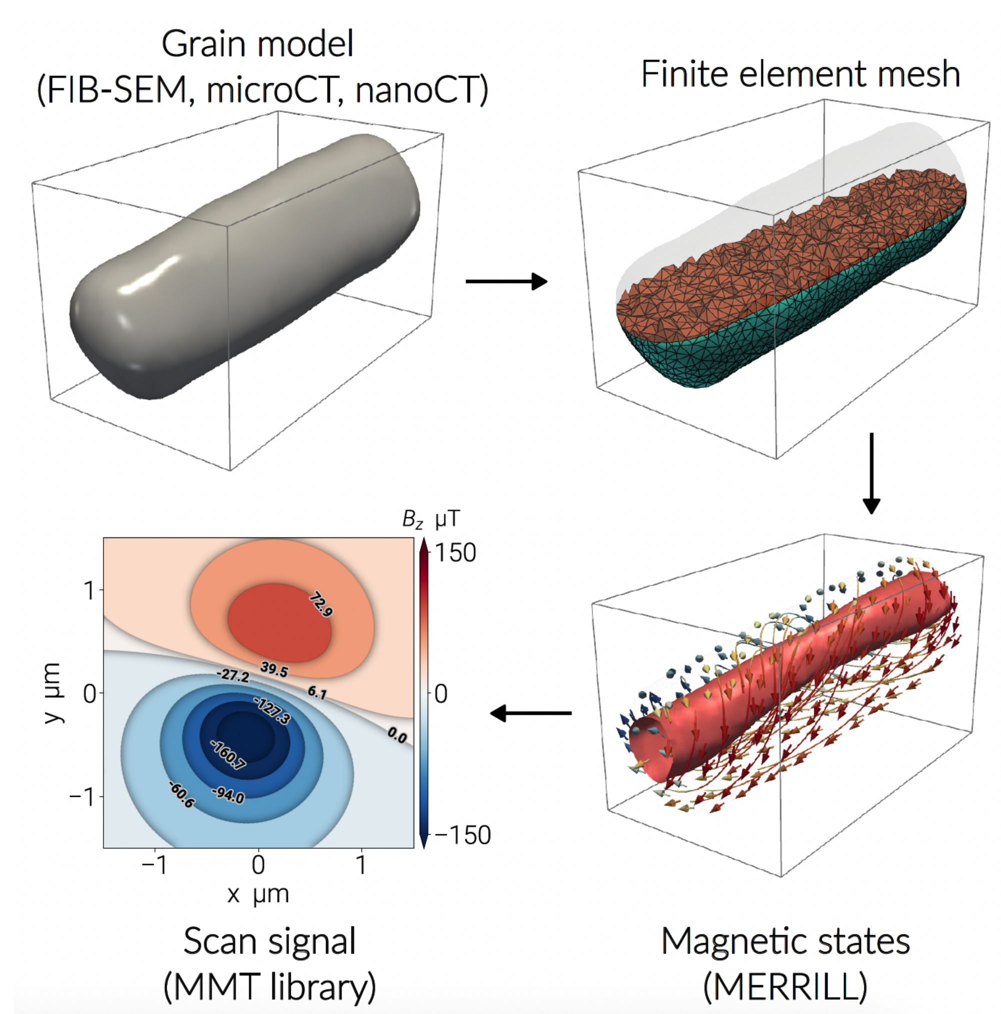
Characterizing the sensor

The magnetic surface scans for MMT studies are obtained using a Quantum Diamond Microscope (QDM). QDM is an optical technique that images (dips in) the fluorescence that arises from nitrogen-vacancy (NV) centers in a diamond chip. This layer of NV centers has a non-negligible thickness (1-2 µm) compared to the sensor-sample distance and the size of the magnetic centers. We therefore now model the sources for MMT inversions as volume integrals using the dimensions of the NV layer, as depicted below.



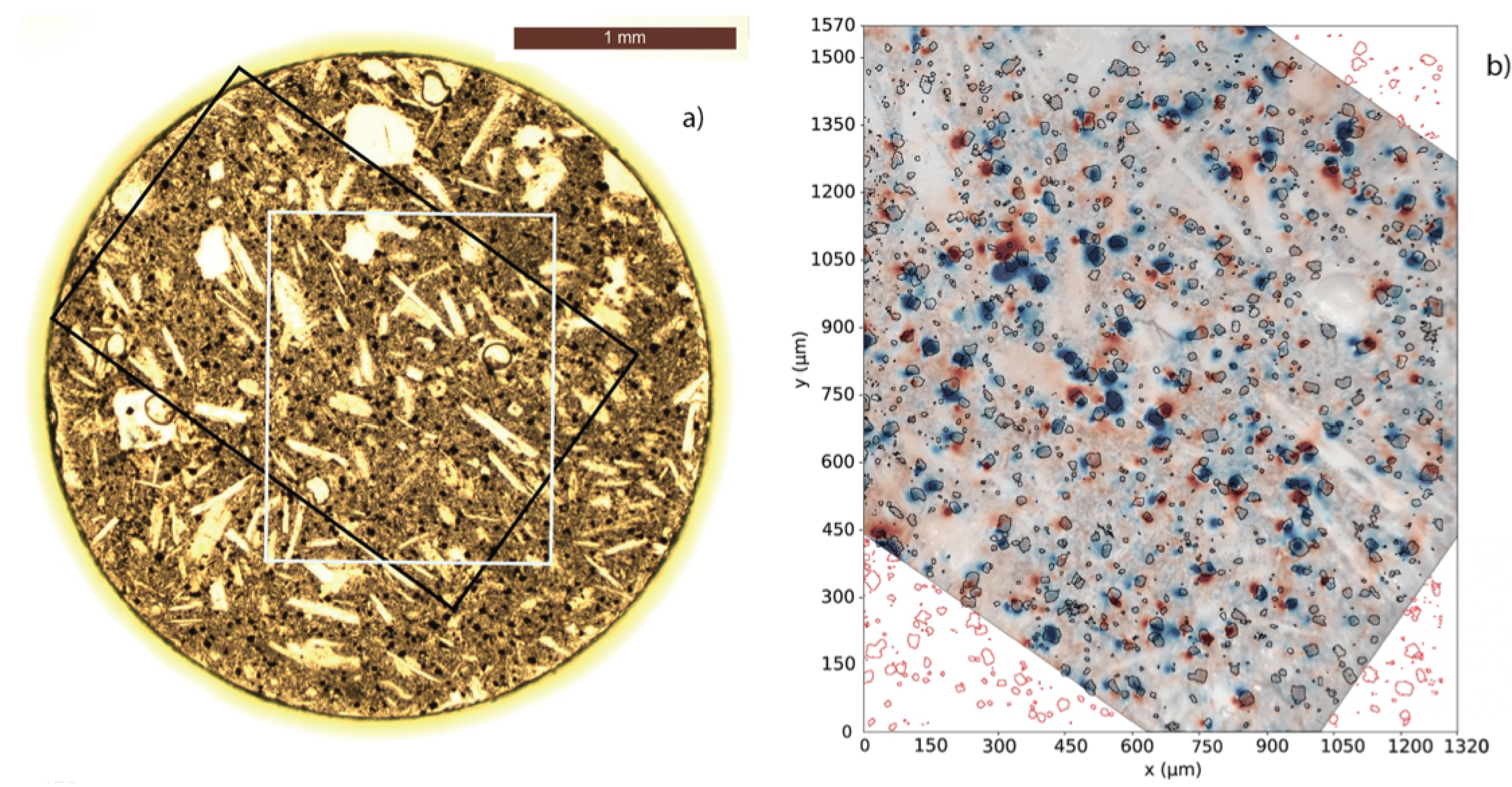
Unraveling magnetic domain states

MMT can also be used to assess internal magnetic domain states of individual grains. These domain states cannot be inverted for directly, but the stray field that is measured from a grain can be compared to the stray fields that are predicted by outcomes of micromagnetic models using e.g. MERRILL. This allows for selecting the micromagnetic model that best fits the measured stray field of an individual grain. See also the poster of *Ge Bian et al* in this session.



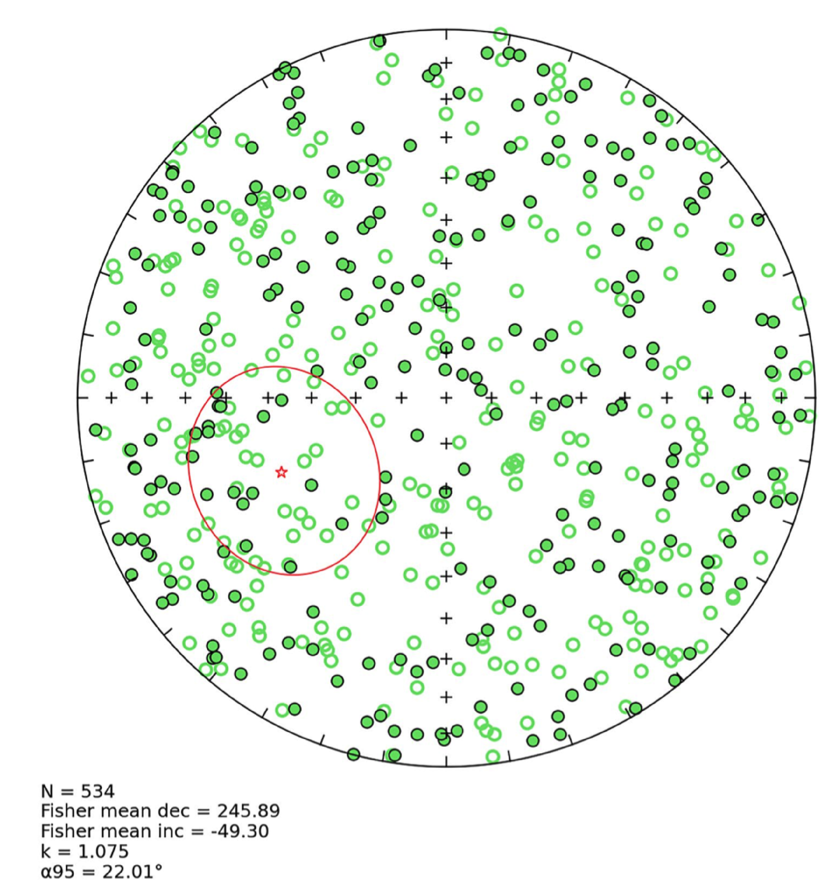
MMT results from natural samples

Using these developments in MMT we can now start to determine magnetic moments of individual grains in natural samples, e.g. a Hawaiian lava, below. For ~1600 grains that were in view of both the QDM and MicroCT analyses, we obtained magnetic moments. Determining which grains are reliable recorders of the magnetic field and which grains should be ignored is the current challenge in interpreting MMT results.



Interpreting MMT data

Techniques to obtain paleomagnetic data from bulk samples are well established. These techniques for bulk samples, however, cannot always be used for data obtained for (assemblages of) individual grains. Alternating field demagnetization experiments for example, lower the magnetic moment of bulk samples, but the moments of individual grains do not necessarily decrease. Obtaining a paleodirection from selected grains from a Hawaiian lava (on the right) is therefore not straightforward and illustrates the need for developing new paradigms.



Open Science, Open Software

The MMT inversions are programmed in Python and are fully open source. The manuscript describing the use of the codes is currently under revision for Computers & Geosciences. The codes are already available on Github and are citable using their Zenodo doi's. Scan this QR code for fast access to the MMT Github repository.

edu.nl/hb7hx

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