MICROMAGNETIC MODELLING AND MULTIPOLE EXPANSIONS FROM MICROMAGNETIC TOMOGRAPHY

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Micromagnetic Tomography [1] is a technique that combines **X-ray micro computed tomography** (micro-CT) and **scanning magnetometry data** to obtain magnetic information of individual grains embedded in a rock sample [1,2]. Recovering magnetic signals of individual grains in rock samples and synthetic samples provides a new pathway to study the rock-magnetic properties of remanent magnetizations that are crucial to paleomagnetic studies. **The magnetic moments of individual particles can be uniquely determined [3] as dipole and higher order multipole moments [4].** Here we show that such complex magnetic information of individual grains can be used to constrain their internal magnetic configuration.

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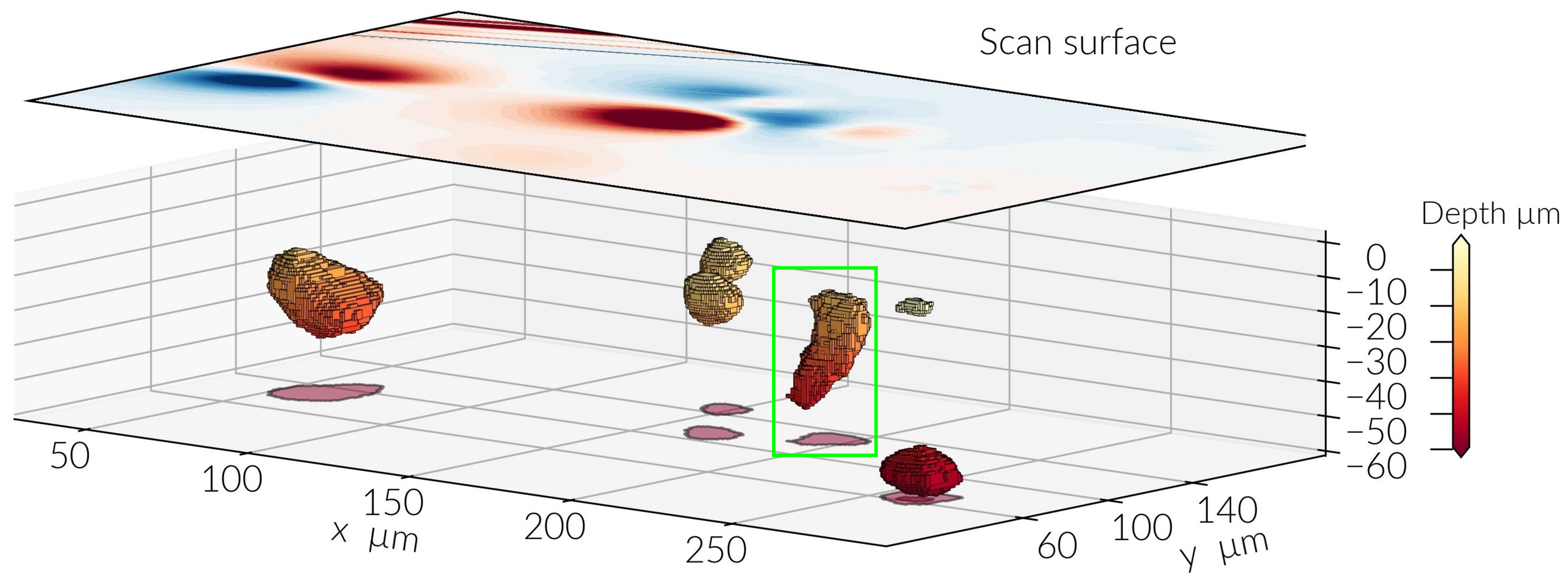

In **FIG 1** a scan surface records the out of plane magnetic field signal from the individual grains. In this case we show the results of scanning SQUID magnetometry applied to a synthetic sample with magnetite grains, which is reported in [2]. Below this surface the profiles of the magnetic grains are depicted as aggregations of cuboids. These profiles are modelled from micro-CT measurements, which also provide the location of the particles.

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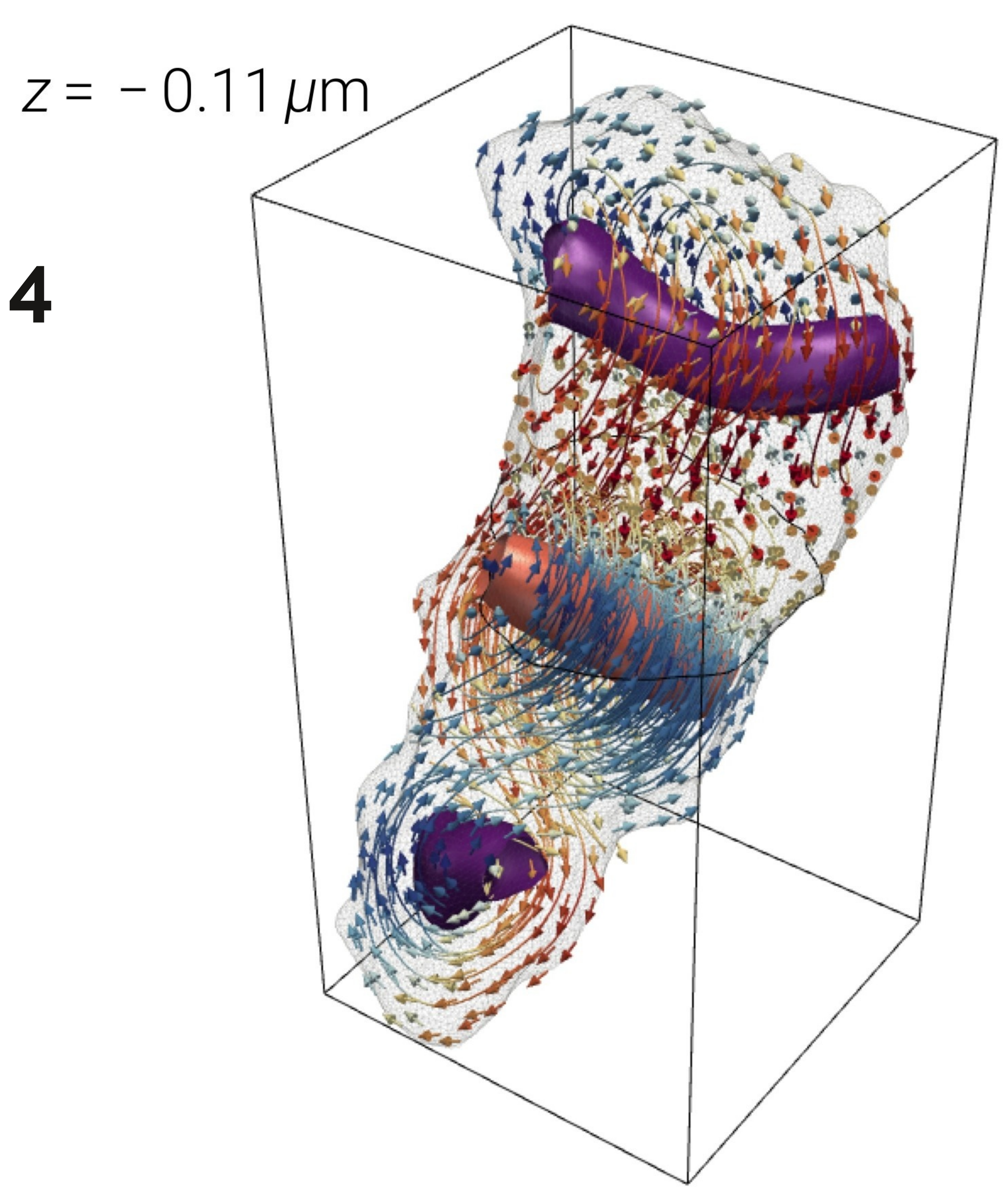

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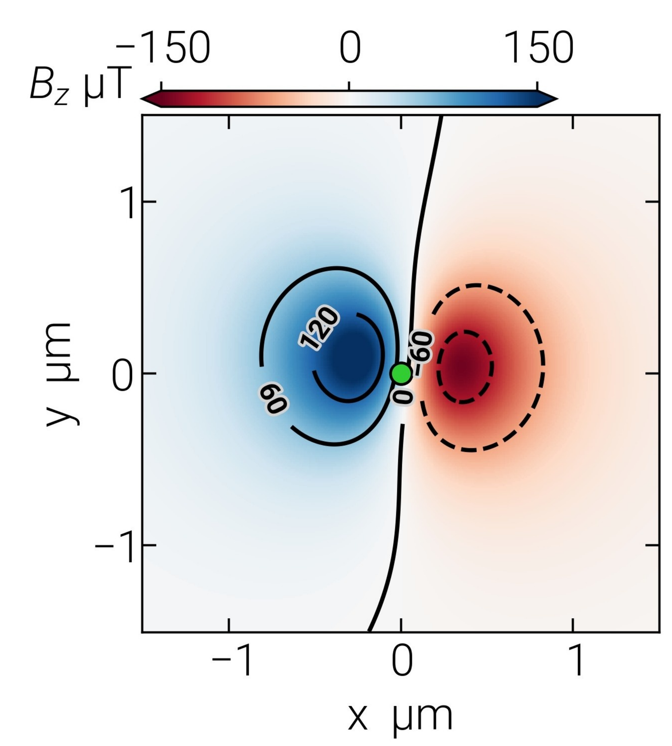

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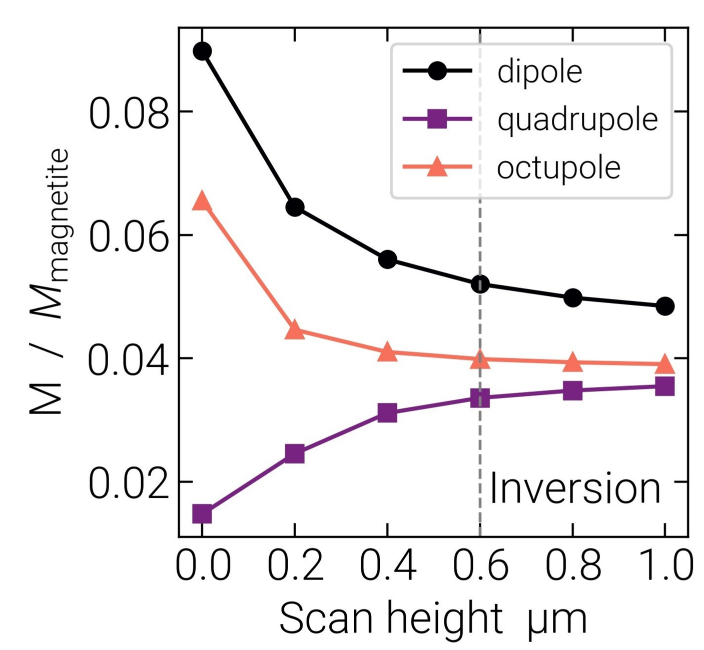


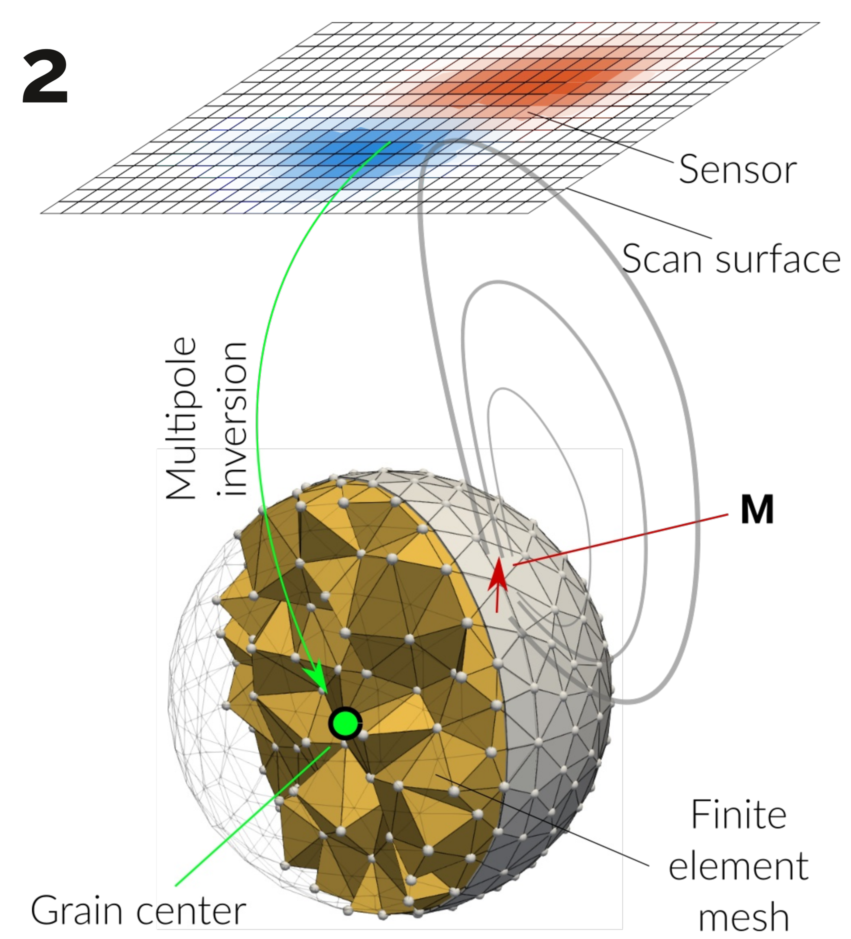
	Dip	Quad	Oct
Θ	85.4°	83.0°	80.3°
Φ	174.3°	172.9°	169.7°

Micromagnetic model of the grain from Area 2 of [1], which is marked in **FIG 1**. The grain has been down-scaled to 2% of the original grain size (due to computational limits) and is minimally contained in a box of dimensions 0.36 µm by 0.41 µm by 0.64 µm in the x, y and z directions, respectively. **FIG 4** shows the finite element model and one (energy minimum) magnetic configuration obtained with MERRILL. **FIG. 5** shows the stray field signal of this triple vortex state in a surface above the grain at z=0.4 µm. **FIG 6** shows the dipolar moments obtained from numerical inversions with different multipole moment order.

A limitation of the numerical inversion from the MMT technique is that it is not possible to obtain solutions for the exact magnetization structure within a grain [3]. On the other hand, the inverted dipolar and higher order magnetic moments per grain are unique and this information effectively constrains the magnetic state in the grain. This constraint is sufficient if all local energy minima of the grain system are known and only one of them corresponds to the observed multipole moments.

By analyzing the internal magnetic configuration of individual magnetic grains it is possible to statistically select ensembles of stable paleomagnetic recorders by classifying particles with similar properties.

2



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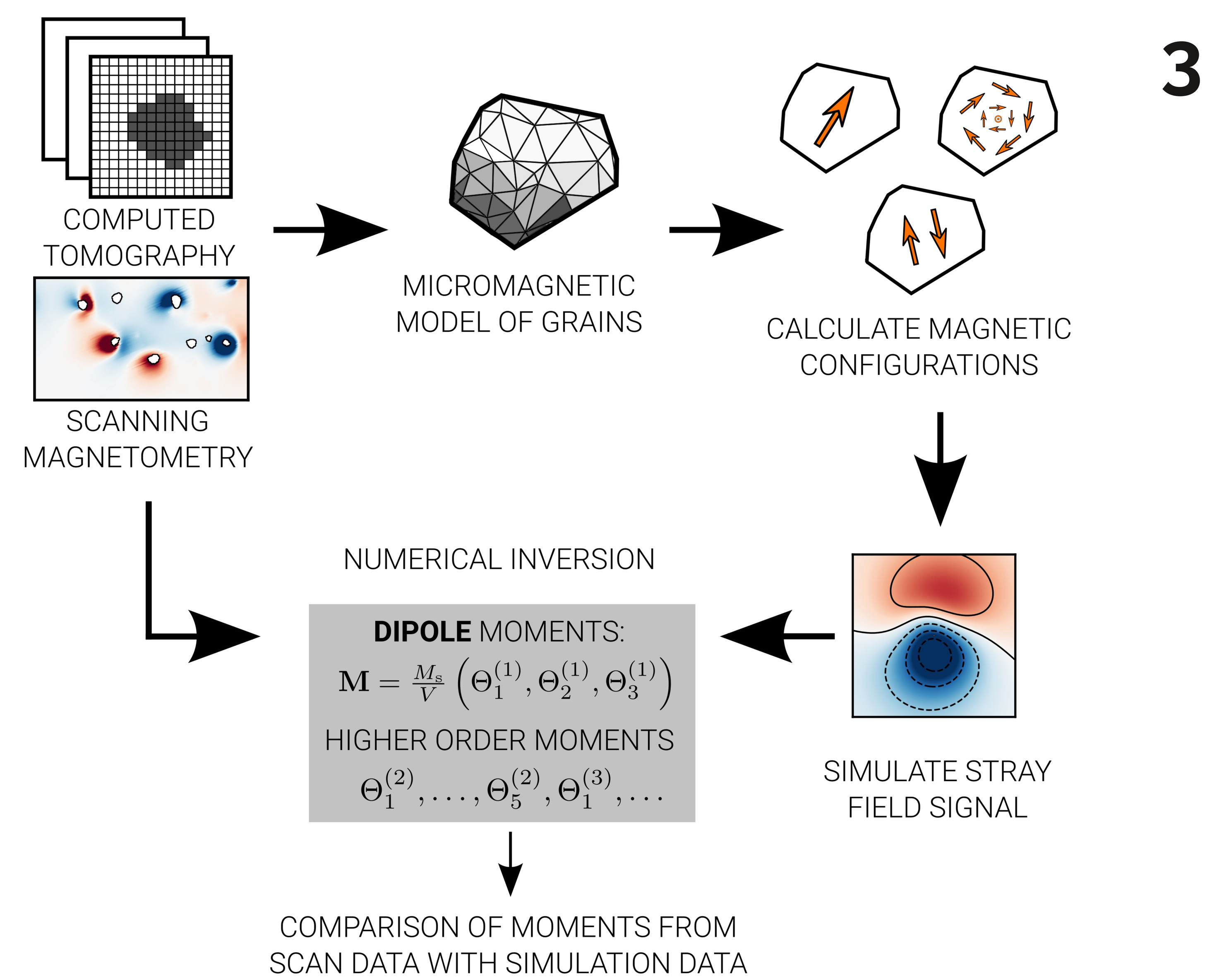

To analyze the magnetic configuration of grains at the nano- to micro-scale we use **micromagnetic modelling**, in which the magnetization structure of the grain is modelled as a continuous field that allows to compute the magnetic interactions within the particle, such as the **demagnetizing or stray field** of the grain, and its total magnetic energy.

Grains are modelled numerically by means of the **Micromagnetic Earth Related Robust Interpreted Language Laboratory (MERRILL)** finite element code [5].

FIG 2 and **FIG 3** show an overview of the micromagnetic modelling of a single grain:

1. The scan data is inverted to the geometric center of the grain to obtain its multipole moments.
2. The grain is modelled numerically using MERRILL and micro-CT data.
3. The energy of the micromagnetic system is minimized to obtain different magnetic configurations (local energy minima).
4. The stray field of the different configurations are computed in a surface above the sample and then numerically inverted into the grain center. Inverted multipole moments are associated to every magnetic configuration.
5. Magnetic moments from scanning magnetometry (1) are compared to the magnetic moments obtained from micromagnetic modelling (4) to infer the internal magnetic state of the grain.

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