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Constraining Micromagnetic Simulations by Introducing High-resolution Magnetic Surface Scans

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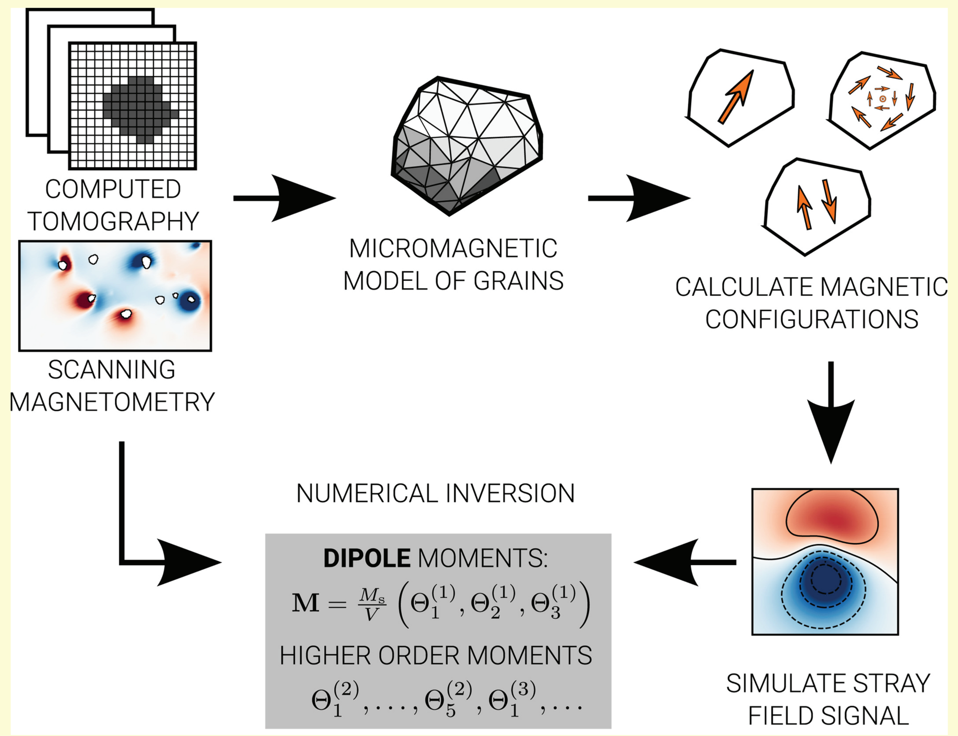
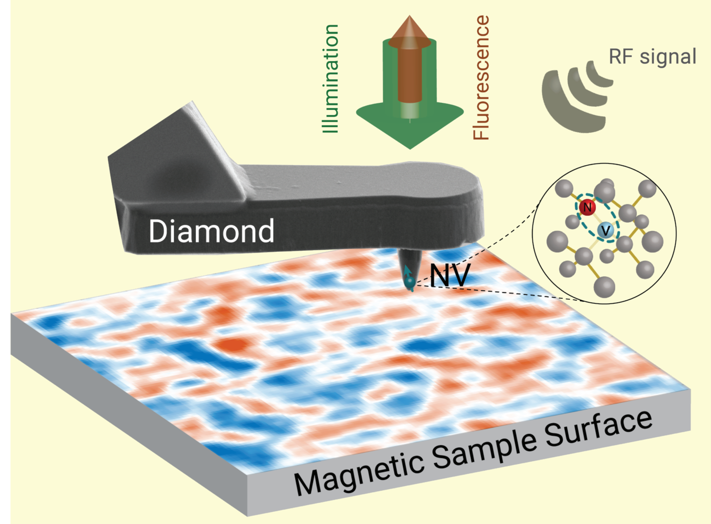
OBJECTIVE

We aim to determine the internal magnetic structure of natural magnetic minerals using micromagnetic simulations and high-resolution magnetic surface scans.

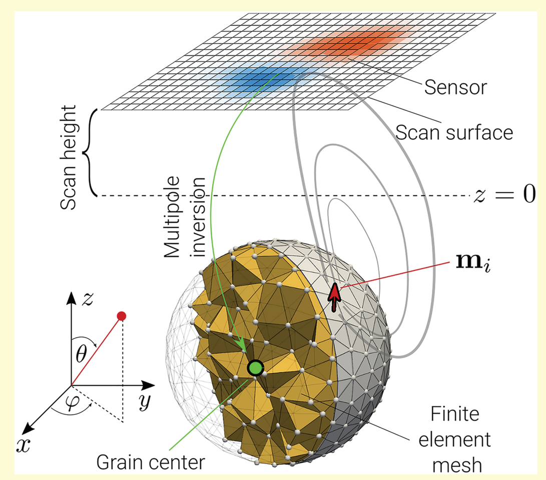
INTRODUCTION

Natural magnetic minerals capture the Earth's magnetic field during their formation, but not all serve as dependable recorders for paleomagnetic reconstructions. Advances in experimental and computational methods enable the study of magnetic behaviors of individual magnetic grains. In this study, we conduct high-resolution magnetic surface scans on natural magnetic samples and integrate these with micromagnetic simulations. Our aim is to bridge the gap between experimental observations and computational simulations.





Quantum scanning microscopy setup for high-resolution magnetic surface scans. Image from QZABRE

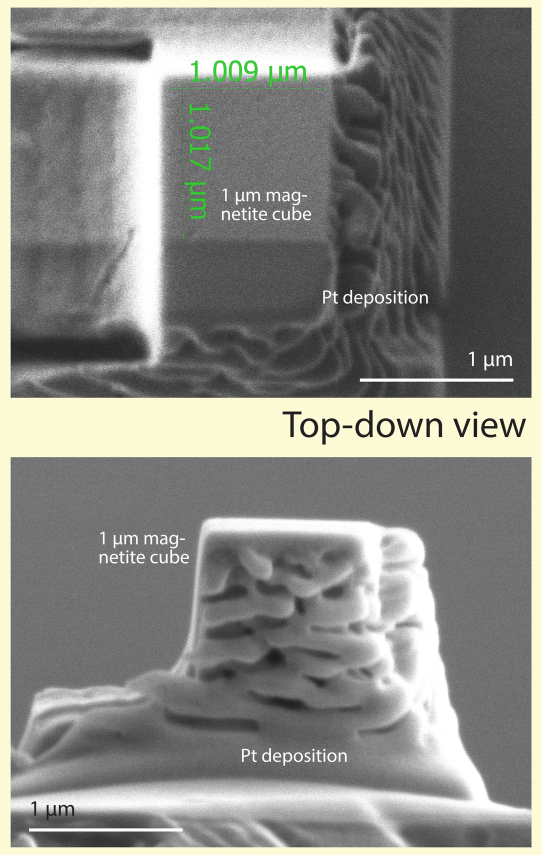


Overview of the micromagnetic modeling of an individual magnetic grain. Image from Cortés-Ortuño et al. (2022)

EXPERIMENTAL RESULTS

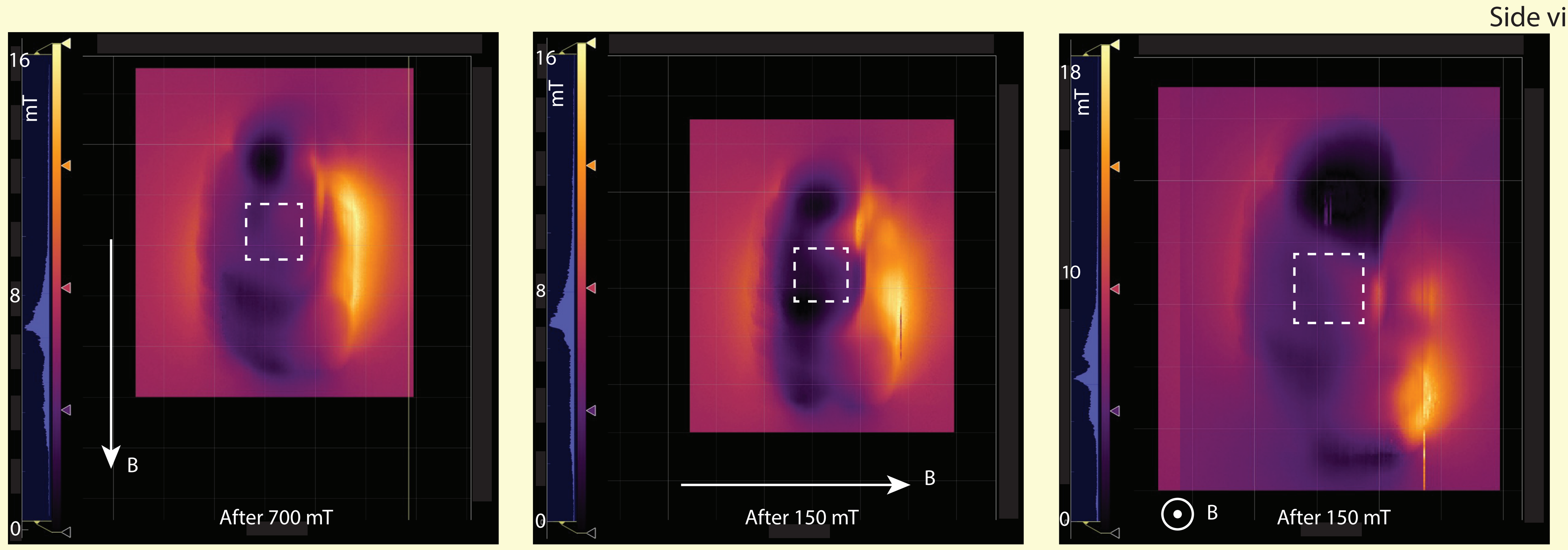
The study seeks to affirm the uniqueness of micromagnetic simulation outcomes by juxtaposing them against experimental data obtained through high-resolution magnetic surface scans. Utilizing quantum scanning microscopy (QSM) at a 30 nm resolution, magnetic surface scans were conducted on a 1 µm-cube magnetite grain. Initially, a pure magnetite grain of 1 µm was extracted using the focused ion beam technique. Subsequently, we magnetized this grain at ≈ 700 mT along one axis of the cube. Following this, the stray magnetic field was measured using QSM, positioned 300 nm above the sample surface. Additional scans were performed after subjecting the magnetite grain to 150 mT external field magnetization along the X and Z directions in subsequent trials.

1 µm-cube magnetite grain



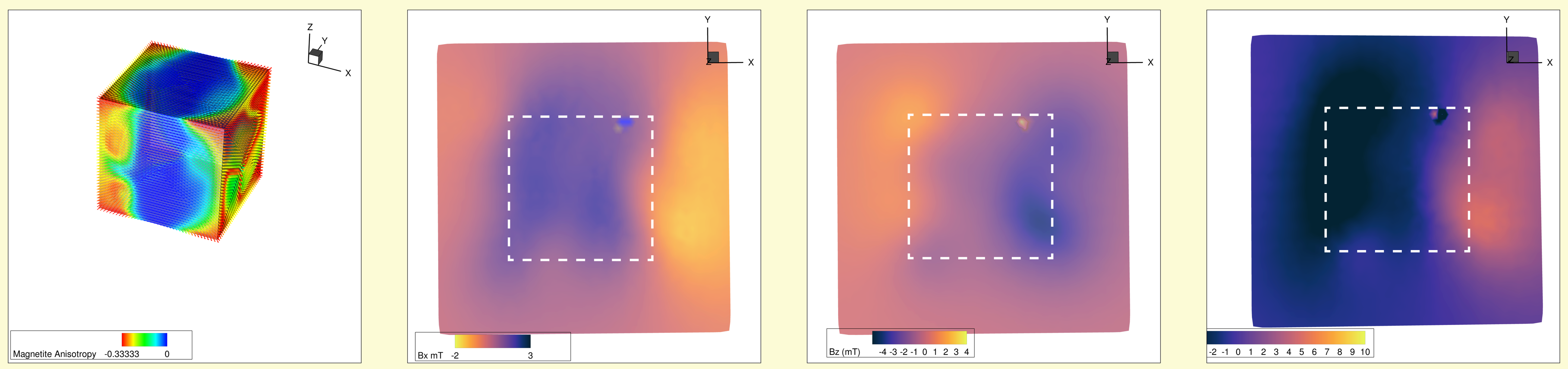
Top-down view

Side view



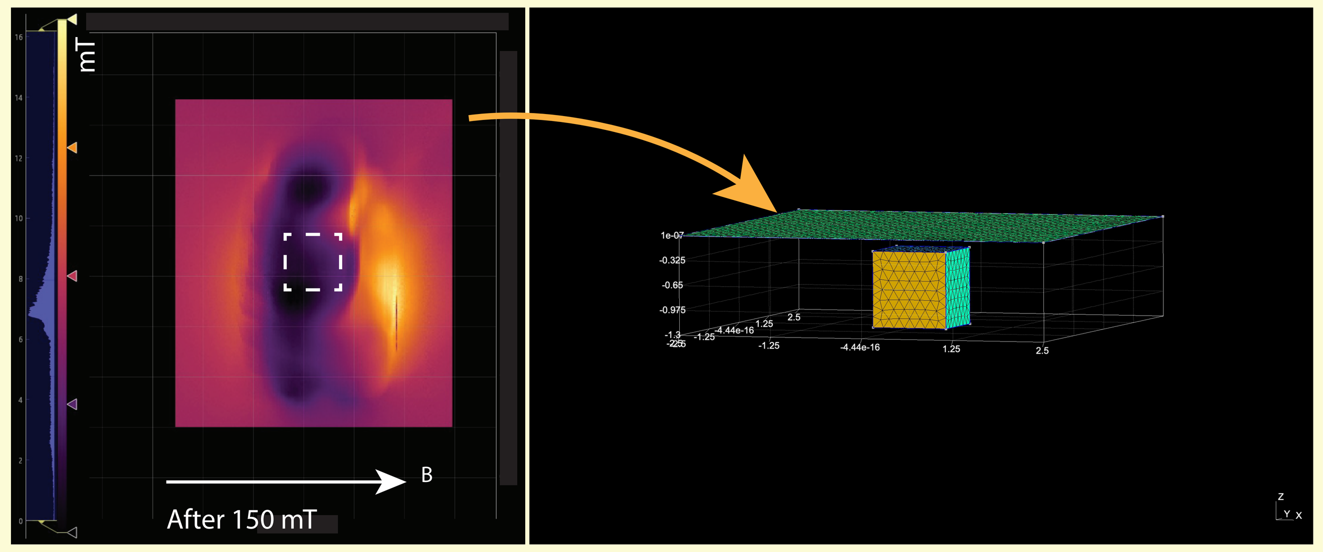
SIMULATION RESULTS

Micromagnetic simulations are performed utilizing MERRILL based on the magnetization histories of the magnetite grain. First, the meshed geometry and the material properties were put into MERRILL to determine the internal magnetization structure with a random initial state. The magnetization structure within the magnetite grain revealed multi-domain configurations. Magnetic stray fields above the sample surface were then calculated based on the magnetization of the grain to compare with experimental observations.



FUTURE STUDY

The next phase of the study will center on integrating high-resolution magnetic surface scan data into micromagnetic simulations to constrain the local energy minimization. This integration enables us to constrain the internal magnetic domain states of the magnetic grains using MERRILL.



SUMMARY

In this study, we conducted QSM measurements on natural magnetite grains, and obtained high-resolution magnetic surface scans of the stray field. Simultaneously, micromagnetic simulations using MERRILL were conducted aligning with the grain's magnetic histories. The resulting magnetization configuration within the magnetite grain revealed intricate patterns. Additionally, the stray field above the magnetite grain was also calculated from simulation. Comparing the simulated stray field with experimental observations, the QSM results facilitated the selection of the best-fit MERRILL simulations, thereby refining the most plausible magnetic configurations of the grain. In the upcoming phase, we aim to integrate the QSM results into MERRILL calculations to further determine the most probable magnetization states within the grain.

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