Paleomagnetic and micromagnetic measurements of Middle Devonian pillow lavas from Germany

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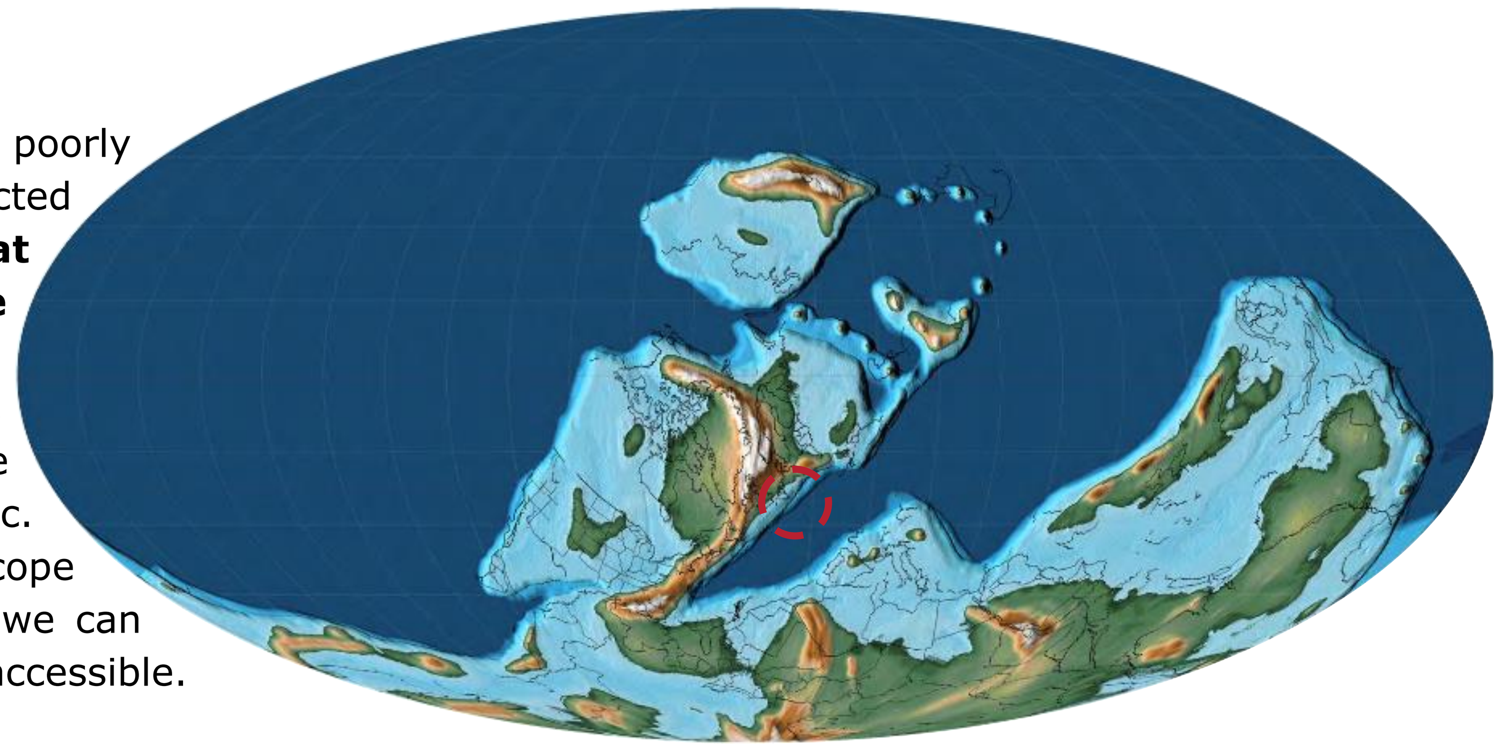
Introduction

The nature and behavior of the geomagnetic field in the Middle Devonian is poorly understood. Paleomagnetic directions and intensities often do not fit with expected paleogeography or dipolar field behavior. **We would like to understand what happened to the geomagnetic field during the Middle Devonian and why the configuration of the field was potentially unusual.**

We conducted paleomagnetic experiments on pillow basalts from Braunfels, Germany, indicated with a red, dashed circle on the paleographic map of the Middle Devonian[I]. The results of these bulk rock measurements are largely enigmatic. Therefore, we carried out surface magnetometry with a Quantum Diamond Microscope (QDM), to study the individual magnetic carriers in the rocks. With this method we can retrieve information on the behavior of the geomagnetic field that was previously inaccessible.



Bulk magnetic behavior

Rock-magnetic measurements indicate the presence of near ideal magnetic recorders in the samples. Thermal susceptibility and thermomagnetic curves indicate major presence of magnetite and minor presence of maghemite. Isothermal remanent magnetization (IRM) acquisition demonstrates the capability of the magnetic recorders to capture a magnetic field.

Alternating field (AF) and thermal demagnetization experiments result in enigmatic directional data. Although a Kiaman overprint can sometimes be inferred, most data are scattered and do not cluster around an expected mean. Anisotropy of magnetic susceptibility (AMS) does not explain the directional data. Thermal Thellier experiments reveal an ultraweak paleointensity.

All rock-magnetic and paleomagnetic data are available upon request.

Micromagnetic results of demagnetization and remagnetization experiments

LED image

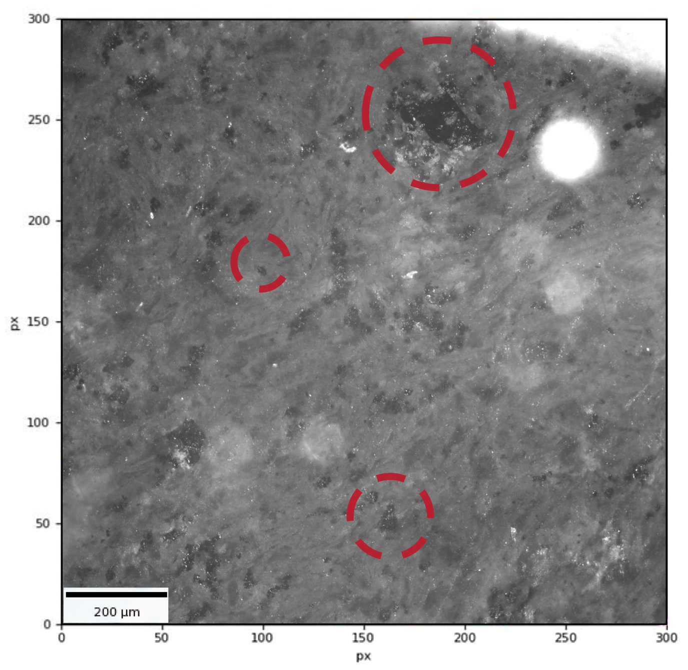


Figure a – Micrograph of a 30 µm thin section of sample PS5.2 showing the surface minerals. Magnetite grains are visible in black. The three red, dashed circles indicate three different magnetite grains and their magnetic signal in Figure b-f through various de-magnetization and remagnetization steps.

QDM image - NRM

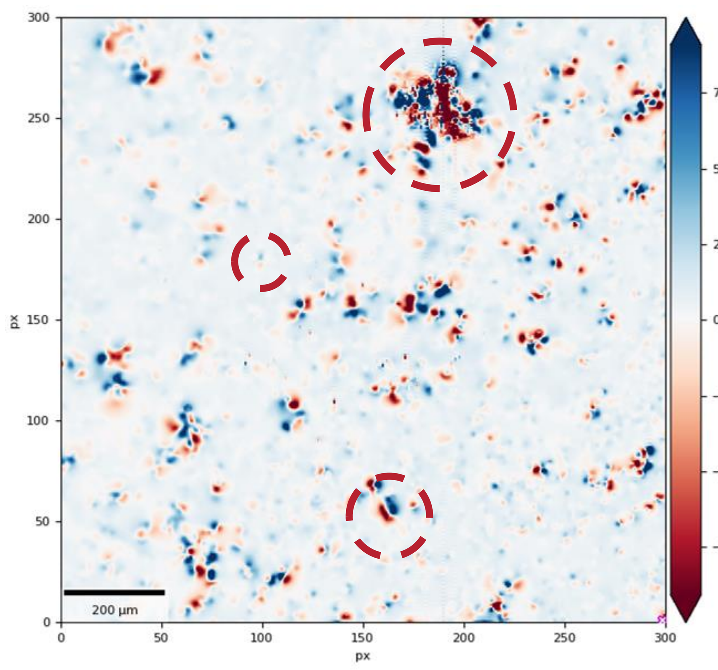


Figure b – Magnetic map of the Bz-component (see schematic below) of the natural remanent mag-netization state at the surface of sample PS5.2. The large magnetite grain, indicated by the large red circle, shows complex multidomain magnetic behavior. The two smaller grains show a more dipolar magnetic signal.

QDM image - 120°C

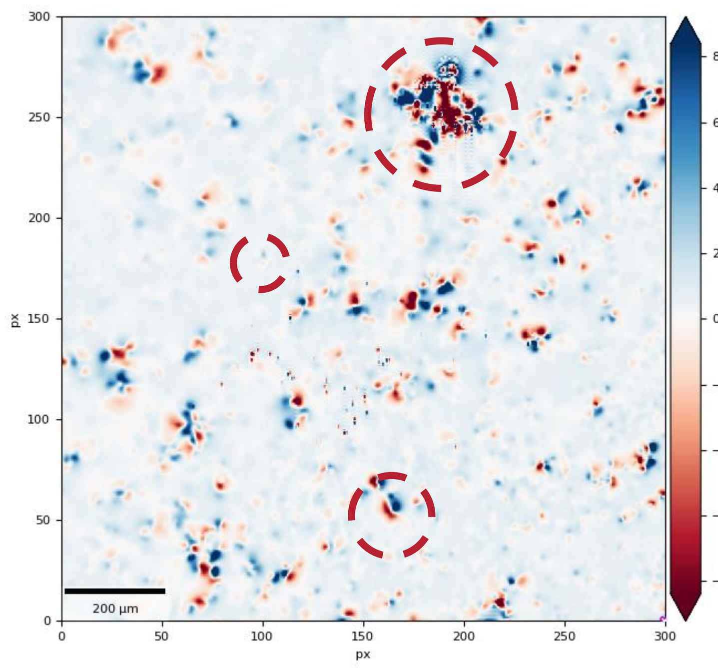


Figure c – Magnetic map of the Bz-component of the demagnetization state of sample PS5.2 after heating it to 120°C. This de-magnetization step is carried out to remove any secondary goethite interference. Since the main magnetic mineral in the sample is magnetite, this step does not notably alter the mag-netic state.

QDM image - 12.5 mT

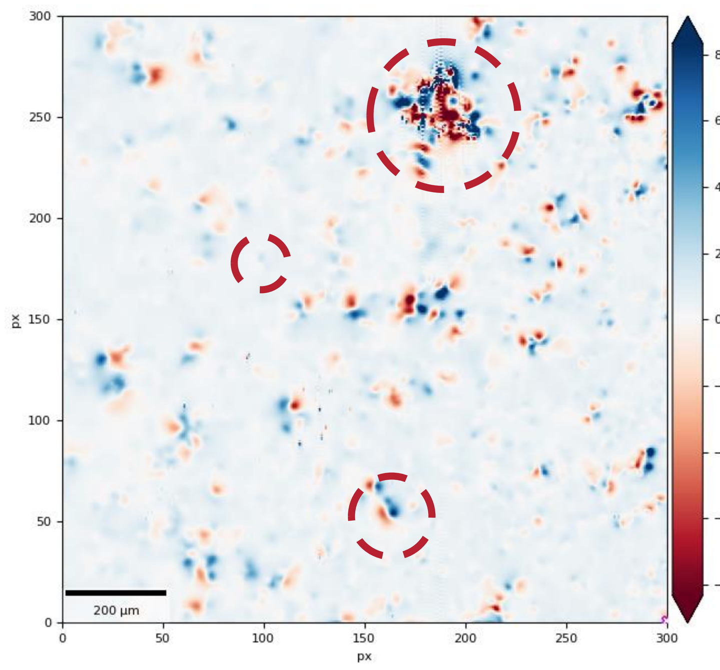


Figure d – Magnetic map of the Bz-component of the demagnetization state of sample PS5.2 after ap-plying an alternating field of 12.5 mT, this is approximately the median destructive field de-termined during bulk AF de-magnetization. The intensity of the two small grains changed, while the direction remained the same.

QDM image - 35 mT

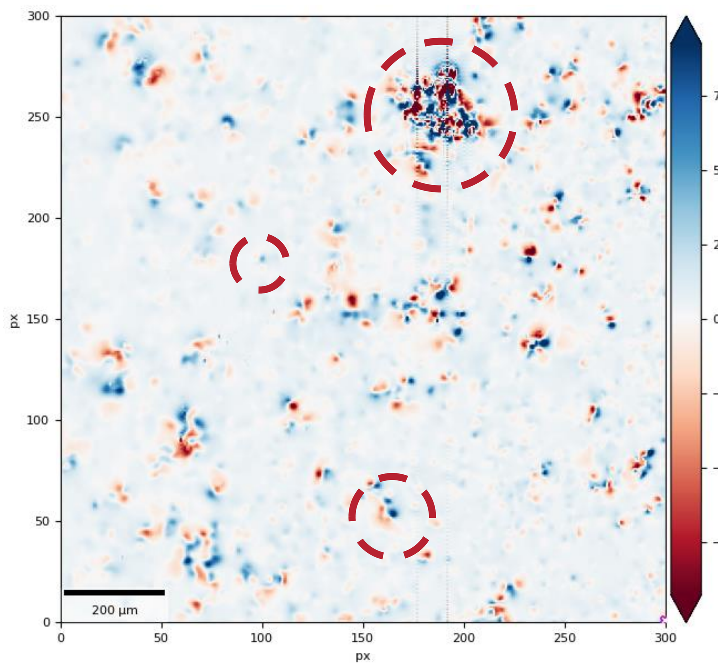


Figure e – Magnetic map of the Bz-component of the demagnetization state of sample PS5.2 after applying an alternating field of 35 mT, which is the destructive field where 75% of the NRM is lost. The random AF replaced the original magnetization of the large grain, which is visible in its smaller, more complex magnetic domains.

QDM image - 700 mT ↑

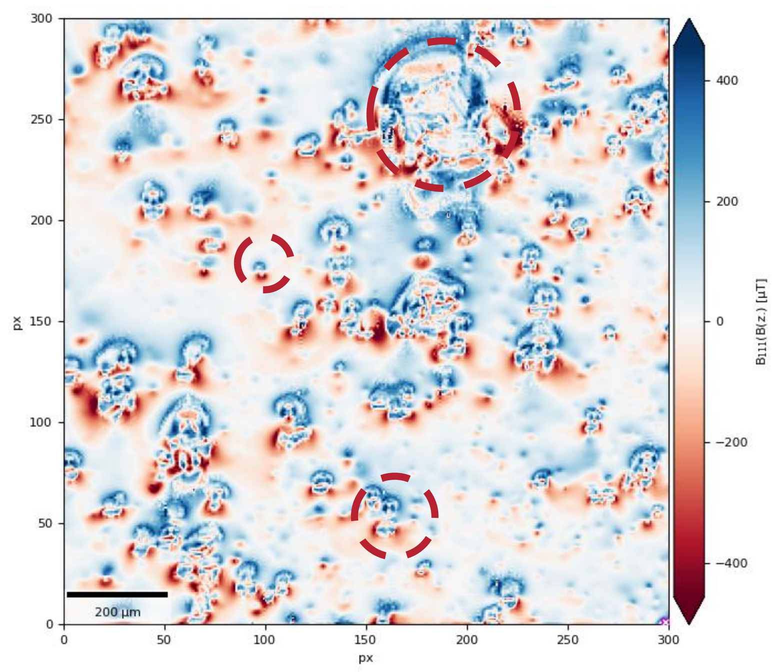
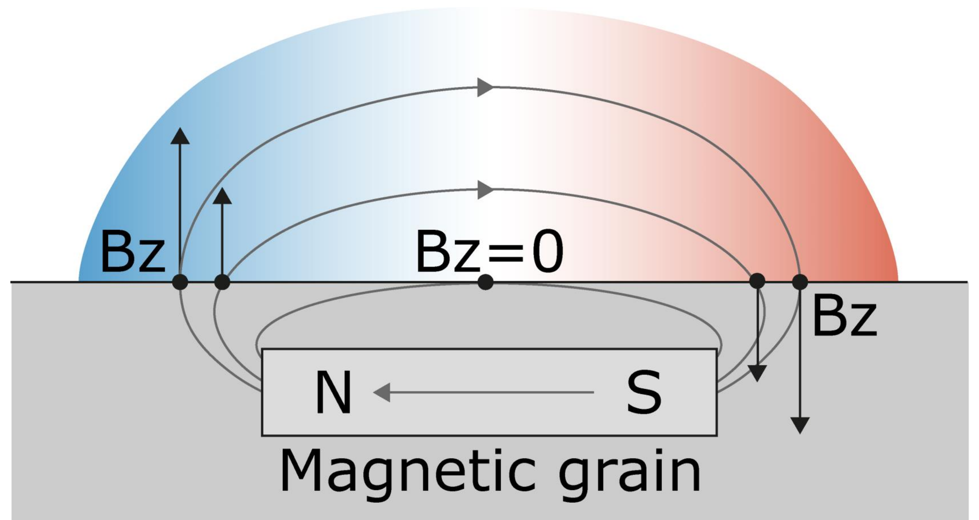


Figure f – Magnetic map of the Bz-component of the magnetic state of sample PS5.2 after an upwards directed IRM pulse of 700 mT. Note the scale difference of the color bar with Figure b-e. The small grains acquired a dipolar magnetization in the direction of the applied field. The large grain shows complex multidomain behavior.



Schematic illustration of the Bz-component used in QDM imaging.

Conclusions

- There are no rock-magnetic indications for 'bad' magnetic recorders in the samples. I.e. the typical enigmatic paleomagnetic results of bulk analyses are not caused by the composition or configuration of the rocks.
- If the uninterpretable paleomagnetic results are not caused by the rocks, they are a result of the configuration of the Middle Devonian geomagnetic field.
- Individual magnetic grains may contain information on the Middle Devonian magnetic field that cannot be derived by bulk magnetic analyses.

Outlook

- In the near future, nanoCT imaging will be carried out to obtain spatial and dimensional data of the magnetic recorders in the samples. This is needed to carry out Micromagnetic Tomography[II, III] to retrieve the magnetic moment per grain through inverse modelling.
- The results of Micromagnetic Tomography can be used to separate several generations of magnetic grains, based on e.g. mineralogy, size, shape, etc. The ultimate goal is to separate the 'good' and the 'bad' magnetic recorders and to retrieve the primary magnetization stored in the rocks.

References:
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[II] de Groot, L. V., Fabian, K., Béguin, A., Reith, P., Barnhoorn, A., & Hilgenkamp, H. (2018). Determining individual particle magnetizations in assemblages of micrograins. Geophysical Research Letters, 45(7), 2995-3000.
[III] de Groot, L. V., Fabian, K., Béguin, A., Kosters, M. E., Cortés-Ortuño, D., Fu, R. R., ... & Barnhoorn, A. (2021). Micromagnetic tomography for paleomagnetism and rock-magnetism. Journal of Geophysical Research: Solid Earth, 126(10).

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