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Development of scanning SQUID microscope system and its applications on geological samples: A case study on marine ferromanganese crust

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We present developments and applications of a high-resolution scanning superconducting quantum interference device (SQUID) microscope for imaging the magnetic field of geological samples at room temperature. The scanning SQUID microscope (SSM) uses a hollow-structured cryostat. A directly coupled low-temperature SQUID with a 200 μm × 200 μm pickup loop, which is mounted on a sapphire conical rod, is separated from room temperature and atmospheric pressure by a thin sapphire window. Precise and repeatable adjustment of the vacuum gap between the SQUID and the sapphire window is performed by rotating a micrometer spindle connected to the sapphire rod through the hollow portion of the cryostat. When the SQUID was operated in superconductive shield with the low-drift FLL, we obtained a field noise of 1.1 pT/√Hz at 1 Hz. While the typical environmental noise of the system operated within the two layered PC permalloy is about 50 pT. Environmental noise is reduced by subtracting a signal from a reference SQUID that is placed inside a cryostat. A geological thin section is placed on top of a non-magnetic sample holder with an XYZ stage that enables scanning of an area of 100 mm × 100 mm. The minimum achievable sensor-to-sample distance is measured as ~200 μm. The new instrument is a powerful tool that could be used in various geological applications.

A successful application of the SSM to a marine ferromanganese crust will be shown. Marine ferromanganese crusts are marine ore deposits rich in rare earth elements. They grow slowly and record long-term deep-sea environmental changes. We conducted magnetic field mapping with the SSM on a crust sample from northwestern Pacific and found beautiful stripes in the magnetic field images. It is known that the Earth's magnetic field experienced polarity changes in the past. Because the major polarity changes were studied well and the ages were determined with the other methods, we could make use of the boundaries of magnetic field changes to estimate an age of a deposition (a technique known as "magnetostratigraphy"). By correlating the obtained profiles with a standard geomagnetic polarity timescale, we obtained an average growth rate of several mm/Ma, which is consistent with that obtained by radiometric dating.

Keywords: Scanning SQUID microscope, magnetic field imaging, geological applications, marine ferromangense crust