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Crustal Magnetism and Effects of Exsolution Lamellae on Magnetic Properties: Importance of Remanent Magnetic Anomalies

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Magnetic anomalies from crustal sources are measured over a wide range of scales and elevations, from near surface to satellites. Crustal anomalies reflect the magnetic minerals, which respond to the changing planetary magnetic field. Anomalies are influenced by the geometry of the geological bodies, and magnetic properties of the constitutive rocks. Commonly, magnetism of continental crust has been described in terms of bulk ferrimagnetism of crustal minerals, and much attributed to induced magnetization. Though remanent magnetization was crucial for dating the ocean floor, and is important in mineral exploration, its contribution to continental magnetic anomalies is commonly ignored. Over the last decade studying remanent anomalies in crustal rocks we discovered a new type of remanence, which we called 'lamellar magnetism'. This type of magnetization is due to interface layers of mixed Fe2+ / Fe3+ valence at contacts between exsolution lamellae and hosts of ilmenite and hematite.

The mixed-valence contact layers are placed by chemistry between hematite Fe3+ layers and ilmenite Ti 4+ layers, where they help reduce charge imbalance. Placement requires that the uncompensated spin of contact layers on opposite sides of lamellae be magnetically in phase. This produces a net ferrimagnetic moment per lamella of appx. 4uB per formula unit regardless of lamella thickness, thus net moment is greatest with the greatest density of magnetically in-phase fine lamellae. New studies demonstrate that the proportion of magnetically in-phase lamellae are in samples with strong preferred lattice orientation and is highly correlated with the angle of the statistical basal plane (0001) with respect to the magnetizing field at the time of exsolution, thus yielding strong net moments where a = 0 and the weakest moments where a= 90. Sample coercivity is much higher when ilmenite lamellae are in global linkage with an AF hematite host, than when hematite lamellae are in a paramagnetic ilmenite host lacking global linkage.

Lamellar magnetism is responsible most for the remanent continental magnetic anomalies presented here. It may also be an important contributor to deep-seated anomalies. To explore the effects of temperature and pressure on the solvus of the ilmenite-hematite solid solution, piston cylinder experiments were performed. Samples were held for 28 days at 10 kb and 580C. Samples were characterized by electron microprobe and transmission electron microscopy before and after the piston cylinder experiments. Magnetic properties of the natural and heated samples were compared. Microstructures due to the formation of exsolution lamellae appear to control the magnetic properties in both the natural and experimental samples. Because many of these rocks studied have high NRM values, some $>$ 50 A/m we have also postulated lamellar magnetism may be one of the sources of magnetism for Martian rocks.

Studying the nature of lamellar magnetism has provided other surprises. Some samples of titanohematite with very fine lamellae ($<$ 1nm thick) when cooled below the TN of ilmenite showed very large exchange bias, the largest ever observed in any material. This indicates a magnetic interface coupling between lamellar magnetism in the hematite host and the magnetically hard antiferromagnetic ilmenite. Such exchange bias has even been demonstrated using billion-year-old lamellar magnetism, cooled in zero field down to 5 K before the hysteresis experiment. This and other properties of lamellar magnetism may provide templates for modern magnetic storage technology.

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