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Magnetic anisotropy of single crystals

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Magnetic fabrics in rocks are a direct consequence of mineral alignment, and thus often used as proxy for mineral fabrics. Specifically, magnetic fabrics arise from (1) crystallographic preferred orientation of grains possessing magnetocrystalline anisotropy, (2) shape preferred orientation of strongly magnetic non-spherical grains, and (3) heterogeneous distribution of strongly magnetic grains. The latter two are mainly associated with magnetite, whereas the former can occur in paramagnetic and diamagnetic as well as ferromagnetic (sensu lato) grains. Interest in magnetocrystalline anisotropy dates back to the 1850s. Initial studies performed torque magnetometry on spherical samples to describe the anisotropy of single crystals. Later studies, using high-field methods or low-field anisotropy of magnetic susceptibility (LF-AMS), investigated the magnetic anisotropy in single crystals for many rock-forming minerals. The minimum susceptibility of phyllosilicates was found to be normal to their basal plane, with biotite having a higher AMS degree than chlorite and muscovite. For mafic minerals, the reported orientations of principal susceptibility axes were inconsistent. This was attributed to the presence of ferromagnetic inclusions in some crystals, and methods have been developed to separate the dia/paramagnetic and ferromagnetic contribution to the AMS. The isolated dia/paramagnetic AMS is constrained by Neumann's principle, which states that any property of a crystal must include all the symmetry elements of the crystal lattice. Diamagnetic AMS is further related to the preferred shape of the electron cloud, and paramagnetic AMS depends on the distribution, concentration, and site geometry of Fe atoms, as well as the Fe^{2+}/Fe^{3+} ratio. In calcite, for example, the minimum susceptibility is parallel to the crystallographic c-axis for low Fe contents, but for high Fe contents, as well as in siderite, the maximum susceptibility is parallel to the c-axis. For olivine, the maximum susceptibility is parallel to c, but the minimum susceptibility can be parallel to the a-axis (3-5% FeO) or b-axis (6-10% FeO). In clinopyroxenes, the maximum susceptibility can be at a 45° angle to the c-axis (augite and diopside, mainly Fe^{2+}), or parallel to c (aegirine, mainly Fe^{3+}). The degree of anisotropy generally increases with Fe content for micas, amphiboles and pyroxenes, but is additionally affected by the Fe^{2+}/Fe^{3+} ratio, so that it is significantly lower in aegirine than other clinopyroxenes. Well-characterized single crystal properties help to better understand and interpret AMS in rocks. For example, knowing that the maximum susceptibility is parallel to the b-axis in amphiboles, while their c-axis defines macroscopic lineation, helps explain why maximum susceptibility and lineation are parallel in some, but oblique in other amphibolites. Information on magnetocrystalline anisotropy in single crystals thus facilitates linking AMS to mineral alignment and geodynamic processes, and allows for a more quantitative interpretation of magnetic fabrics.