Aeromagnetic anomalies, magnetic petrology, and rock magnetism of hemo-ilmenite- and magnetite-rich cumulate rocks from the Sokndal Region, South Rogaland, Norway

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ABSTRACT

Aeromagnetic maps of the Egersund Mid-Proterozoic igneous province show a spectacular range of positive and negative magnetic anomalies with a contrast up to 15 600 nT. The positive magnetic anomalies are over magnetite norites and overlying mangerites and quartz mangerites of the Bjerkreim-Sokndal layered intrusion. These rocks are dominated by multi-domain (MD) magnetite. The negative magnetic anomalies are over ilmenite-rich norites of the Bjerkreim-Sokndal layered intrusion, the Tellnes ilmenite norite ore deposit, and massif anorthosites. These rocks are dominated by hemo-ilmenite and/or by silicates containing fine-grained oxide exsolution lamellae. Electron microprobe analyses of coexisting Fe-Ti oxides in the layered intrusion confirm earlier observations that oxides in early magmatic rocks are dominated by hemo-ilmenite with minor end-member magnetite, followed by more reduced oxides dominated by titanomagnetite with minor near-end-member ilmenite. What is not fully understood is the property of ilmenite with hematite exsolution lamellae, or, even more striking, hematite with ilmenite lamellae, to produce strong remanent magnetization of high coercivity and with a Néel temperature equal to or above the Curie temperature of magnetite. This property makes the rhombohedral oxides an important candidate to explain some high-amplitude deep-crustal anomalies on earth, or strong remanent magnetization on other planets. A remarkable feature in the Egersund province is that primitive magmas produced rocks rich in hemo-ilmenite causing negative magnetic anomalies related to magnetic remanence, and more evolved magmas produced rocks rich in magnetite related to positive induced magnetic anomalies, all in the course of crystallization-differentiation.

INTRODUCTION

Aeromagnetic surveys have become an indispensable tool in the exploration for mineral resources, as well as an important adjunct to regional geologic mapping programs, and will play an important role in planetary exploration. The interpretation of aeromagnetic surveys is closely linked to the physics of rock magnetism (Reynolds et al. 1990). Too commonly magnetite has been assumed to be the predominant magnetic mineral in the Earth’s crust (Mayhew et al. 1991). The conventional interpretation of the magnetic signature of crustal rocks has been to attribute magnetic anomalies solely to magnetite and to attribute magnetic low regions to “non-magnetic crust.” Fundamental to this assumption was that induced magnetization would dominate over remanent magnetization, unless the magnetite is in the single-domain (SD) state. It was also assumed only 0.5% of multi-domain (MD) magnetite would dominate the crustal response with a large induced component. Nevertheless, examples were encountered where magnetic susceptibility was lower than would be expected for coarse-grained magnetite, and where the rock body could be shown to contain a remanent magnetization commonly acquired in an ancient magnetic field with an orientation different from the present Earth’s field. In this paper, we show that ilmenite with finely exsolved hematite can contribute to, and even dominate, the magnetic response of rock bodies even with coexisting multi-domain MD magnetite.

Our example is from the Mid-Proterozoic Egersund anorthosite-norite province within the Sveconorwegian province of the Baltic shield in south Norway (see review by Ashwal 1993). These igneous rocks, mostly dated around 930 Ma (Schärer et al. 1996), intrude rocks previously regionally metamorphosed to granulite facies around 980 Ma (Bingen and van Breemen 1998), and are surrounded by an impressive very-high-temperature contact aureole (Schumacher and Westphal 1999). The province is dominated by six bodies of “massif-type” anorthosite-leuconorite, and by the large (230 km²) Bjerkreim-Sokndal (BKS) norite-mangerite-quartz mangerite layered intrusion (Wilson et al. 1996). The BKS complex comprises a sequence of cumulates produced by repeated influxes of parental magma. It has a maximum thickness of ~7 km (Duchesne and Wilmart 1997). The anorthosites contain a variety of Fe-Ti oxide-rich mineral deposits, the most important being the Tellnes ilmenite norite, which contains 12% of the world’s resources of ilmenite (Force 1991; Korneliussen et al. 2000) and has yielded the youngest U-Pb igneous age in the