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Tracing Ti-rich titanomagnetite oxidation with low-temperature magnetic measurements

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Ti-rich titanomagnetite is a primary magnetic mineral in submarine basalts, as well as in some terrestrial volcanic rocks. On geological timescale, it undergoes a slow oxidation forming titanomaghemites. This natural process may be modeled to some extent by a prolonged annealing at moderately elevated temperatures. We test this by treating at 355°C for 4, 40, 110, and 375 hours a sample of submarine basalt containing titanomagnetite of approximate TM46 composition with Curie temperature of 205°C. To characterize the oxidation products emerged during annealing, we have carried out magnetic measurements between at cryogenic temperatures between 1.8 K and 300 K and at high temperatures up to 700°C.

Temperature dependences of magnetic susceptibility measured in an argon atmosphere reveal that annealing for 4 hours already leads to the formation of new magnetic phases (Phases 1 and 2 thereafter) with Curie temperatures of 420°C and 590°C, respectively. At the same time, a phase close to the initial titanomagnetite still remains in a noticeable amount, although its Curie point also shifts towards higher temperatures. Upon further annealing, the initial titanomagnetite completely disappears, the Curie temperature of Phase 1 increases, reaching 500°C after 375 hours, and the Curie temperature of Phase 2 remains practically unchanged. Phase 1 appears unstable to heating to 700°C in argon atmosphere. In samples annealed for up to 110 hours, Phase 1 disappears on cooling, and a phase with the same Curie temperature as the initial titanomagnetite reemerges. In the sample annealed for 375 hours, traces of Phase 1 are still visible in the cooling branch of the susceptibility vs. temperature curve, and the Curie temperature of the reemerged initial-like phase is 250°C. The newly formed Phase 2 remains stable when heated to 700°C in argon.

Effect of prolonged annealings is clearly seen in low-temperature magnetic properties. In the fresh sample, about one quarter of magnetization acquired at 1.8 K is demagnetized by 5 K. This feature holds for the annealed samples as well. The titanomagnetite phase in the fresh sample manifests itself in a magnetic transition at 58 K. Below this temperature, the FC and ZFC curves sharply diverge, as previously observed for titanomagnetites of intermediate composition. For the annealed samples, the shape of ZFC and FC curves and the ratio between them remain generally

similar to those observed for the fresh sample, but there are also several differences. The magnetic transition temperature shifts to ~45 K, while the curves' shape above the transition changes from concave-up to concave-down. RT-SIRM cycle to 1.8 K in zero field for the fresh sample has a characteristic convex shape and is almost reversible. Magnetization at 1.8 K is about 20% higher than the initial value at 300 K, and magnetization loss after the cycle is only 2-3%. The shape of RT-SIRM cycles changes progressively with increasing annealing time, the degree of irreversibility increasing to ~30% for the sample annealed for 375 hours.

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