Box 8–4: Fennoscandian Shield – Rogaland Anorthosite Province

Tellnes Ilmenite Deposit: Lat. 58°20’ N, Long. 6°25’ E

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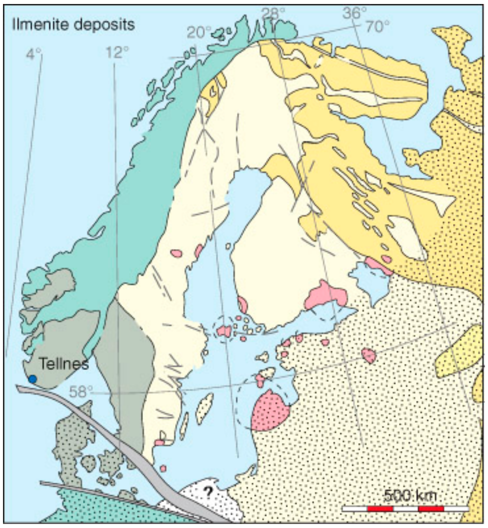

Fig. 1. Simplified geological map of the Fennoscandian Shield with the location of the Tellnes deposit indicated. Darker yellow is Archaean, pale yellow Palaeoproterozoic, grey Meso–Neoproterozoic, green Phanerozoic units, and pink Rapakivi intrusions (Mesoproterozoic). Stipple, units under younger cover.

Geology: The Tellnes ilmenite deposit (TID) was intruded into the centre of the Åna-Sira anorthosite massif, part of the late Proterozoic (930 to 920 Ma, Schärer et al., 1996) Rogaland Anorthosite Province, SW Norway (Figs. 1 and 2A). This was emplaced in the south-western part of the Sveconorwegian orogenic belt in granulite facies, ca. 40 million years after the last regional deformation of the Sveconorwegian Orogeny (Bingen and Stein, 2003). Fe–Ti showings and occurrences are widespread. The most important deposits were Storgangen and Blåfjell (Duchesne, 1999) but mining activities are now confined to the Tellnes deposit (Fig. 2B). This is an ilmenite-rich norite averaging slightly more than 18%TiO_2. It was discovered in 1954 by an aeromagnetic survey.

Producing mining deposit: Tellnes

Estimated annual production: 0.7 to 0.8 Mt ilmenite concentrate average 44.3%TiO_2. By-products Fe_3O_4 and Ni–Cu sulphide concentrates.

Estimated reserves: 57 Mt TiO_2.

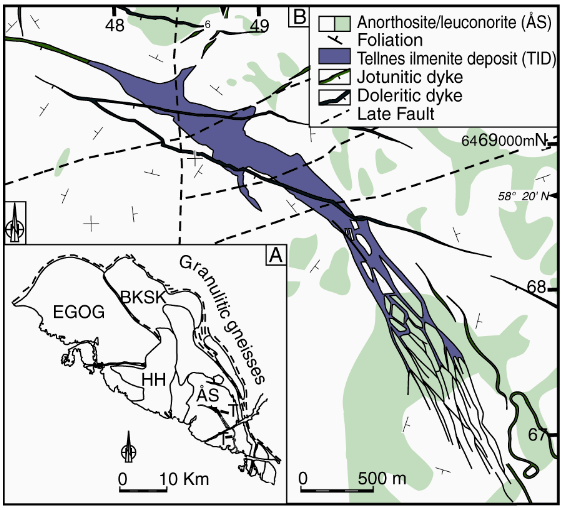

Fig. 2. (A) Geological map of the Rogaland Anorthosite Province. EGOG: Egersund–Ogna anorthosite; HH: Håland–Helleren anorthosite; ÅS: Åna–Sira anorthosite; BKSK: Bjerkreim–Sokndal layered intrusion; T: Tellnes "main dyke"; T': Tellnes ilmenite deposit. (B) Geological map of the Tellnes ilmenite deposit (Diot et al., 2003).

Morphology: sickle-shaped outcrop (about 2,700 x 400 m) oriented WNW–ESE to NNW–SSE (Fig. 2B), trough-shaped in cross-section. Orebody prolonged to NW and SE by the older, not co-magmatic "main dyke" with composition ranging from jotunite to charnockite (Wilmart et al., 1989). The ore is a medium-grained (~0.5 to 2 mm) cumulate, equigranular and massive.

Age of mineralization: 920±3 Ma (U–Pb ages on zircon; Schärer et al., 1996).

Ore minerals: plagioclase, ilmenite, orthopyroxene and olivine; accessories magnetite, clinopyroxene, biotite, apatite, hornblende, Fe–Ni–Co–Cu sulphides and aluminous spinel.

Genetic model: The TID was previously described as homogeneous but recent investigations have revealed complex and systematic variations in the mineralogy, modal proportions and mineral compositions (Charlier et al., 2003; Kullerud, 2003; Robinson et al., 2003). Most important variations of modal proportions are the lower ilmenite and higher

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plagioclase and apatite contents at the margins of the orebody. The upper part contains increasing amounts of magnetite and sulphides while the lower part is nearly magnetite-free and poor in sulphides. Charlier et al. (2003) show that, in the deepest part of the orebody, plagioclase and ilmenite are the only liquidus minerals. In the upper part, olivine and orthopyroxene appear as cumulus phases, though orthopyroxene is present as an intercumulus mineral in the deepest part. Other minerals (clinopyroxene, biotite, apatite, magnetite and hornblende) are intercumulus, crystallized from the trapped liquid. Ilmenite has hematite exsolutions with variable MgO (~0.5 to 4.25%) and Cr (~80 to 2,000 ppm) contents. Cr in ilmenite decreases continuously to the higher parts of the orebody, together with an increasing content of magnetite. Systematic variations of plagioclase composition are observed from the margins to the central part of the deposit. More primitive compositions ($An_{49–45}$) are present in the central part while evolved ones (down to An_{39}) are observed at the margins. Variations of modal proportions and mineral compositions, resulting in variations in composition of bulk cumulates (TiO_2-poorer at the margins) are interpreted to result from variable amounts of trapped liquid. This liquid, which corresponds to the parental magma of the deposit, has the composition of a ferro-diorite (jotunite or hypersthene-bearing monzodiorite), a Fe-, Ti-, P-rich melt. The most challenging problem, in terms of emplacement of the TID, is to explain how ilmenite has concentrated to 40% of the whole-rock composition. Wilmart et al. (1989) proposed injection of a noritic crystal-mush where ilmenite enrichment is explained by dynamic sorting of denser ilmenite during movement of the mush, with progressive accumulation in the more central part of the conduit. The counterpart less dense plagioclase-rich cumulate of the crystal-mush would have been emplaced at the margins and in the SE apophyses of the orebody. Based on anisotropy of magnetic susceptibility and petrofabric evidence (Diot et al., 2003), the shape-preferred orientation of minerals is also interpreted to result from a similar mechanism. Robinson et al. (2003) proposed that the orebody was a magma chamber in which magma mixing occurred. In situ crystallization of the hybrid magma, with a composition in the stability field of ilmenite, would have resulted in its accumulation at the bottom of the chamber. However, the succession of two cumulus parageneses (plagioclase + ilmenite followed by plagioclase + ilmenite + orthopyroxene + olivine) and the important role of a liquid component of jotunitic composition indicate that the TID crystallized in situ in a sill-shaped magma chamber. Spatial variations of mineral composition result from fractional crystallization associated with a variable trapped liquid content, more abundant at the margins of the orebody. The present morphology of the deposit and the orientation of the ore would have been acquired during a gravity-induced solid-state deformation of the sill into a trough-shaped body. The reasons for such a high proportion of ilmenite continue to be debated.

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