Rutile associated with eclogites in western Norway and scapolitised gabbros in southern Norway

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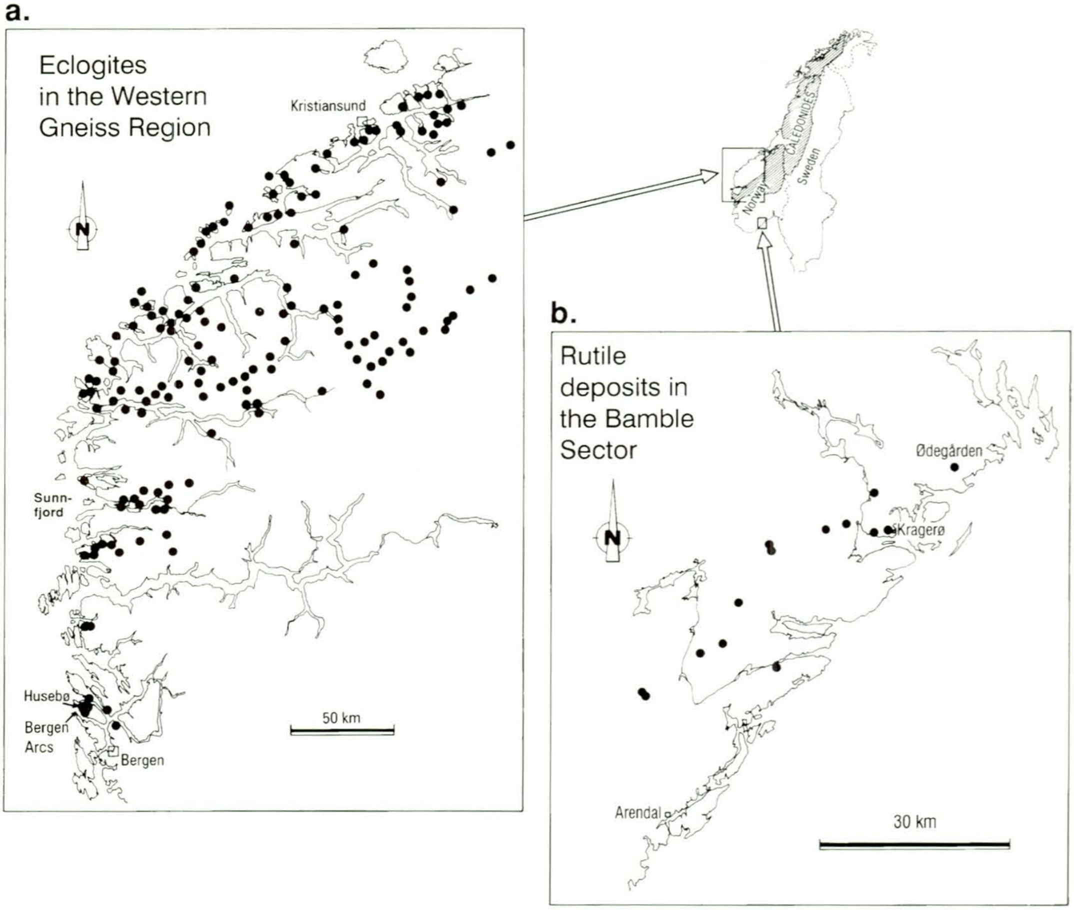
Ilmenite ($FeTiO_3$) and rutile (TiO_2) are Ti-bearing minerals of worldwide economic importance; ilmenite is more important in quantity while rutile is more valuable due to its higher titanium content. Their major use is as TiO_2 pigment in paints, paper and plastics. A variety of rutile-bearing rocks are known in Norway; the major types are Caledonian eclogites in West Norway and Proterozoic metasediments (cordierite gneisses) and metasomatised (scapolitised and albitised) basic rocks in the Bamble region of South Norway. Since the demand for rutile is expected to increase in the future, the investigation of rutile-bearing rocks in Norway has been given priority by NGU in recent years. A summary of NGU's rutile investigations has been presented by Korneliussen et al. (1992), while Dormann (1993) has given a detailed introduction into the

Fig. 1. Occurrences of (a) eclogites in the Western Gneiss Region and (b) miscellaneous metasomatic/hydrothermal rutile deposits in the Bamble Sector, South Norway. The eclogite location map is modified from Griffin & Mørk (1981) and Erambert (1991).



industrial use of titanium minerals, the market situation, and the profitability of Norwegian deposits. A review of titanium mineral deposits worldwide was presented by Force (1991). It is generally accepted that a hard-rock rutile deposit must be of a considerable tonnage, with in the order of 5 wt.% rutile, to be economic.

The purpose of this contribution is to outline some general characteristics of rutile-bearing eclogites in West Norway and metasomatised gabbros in the Bamble province of South Norway, the latter exemplified by the Ødegården metasomatic rutile deposit. Both types require fairly Ti-rich protolith igneous rocks in which the primary magmatic oxide assemblage with ilmenite as the titanium-bearing phase has been replaced by a rutile-bearing assemblage.

Rutile in eclogites, western Norway

The Western Gneiss Region (WGR, Fig. 1a) is a heterogeneous gneiss complex with inclusions of a variety of metamorphosed basic igneous rocks. It is dominated by Proterozoic rocks of the Baltic Shield, but also contains Cambro-Silurian sequences (Bugge 1934, Hernes 1953, Robinson & Krill, in prep.) which were folded into, and metamorphosed together with, the Proterozoic basement during the Caledonian orogeny. These rocks experienced high-pressure eclogite metamorphism at c. 400 Ma during collision between Baltica and Laurentia (see Griffin 1987, Austrheim & Mørk 1988). Generally, basic mineral assemblages containing both ilmenite and feldspar were recrystallised during the eclogitisation process to omphacite- + garnet-rich parageneses, in places with additional water-bearing minerals such as clinizoisite, phengite and paragonite. It has been shown that eclogitisation takes place as aqueous fluids are introduced into the mafic assemblage under high-pressure conditions (Austrheim & Griffin 1985, Austrheim 1987, 1990, Jamtveit et al. 1990). As eclogitisation proceeded, ilmenite decomposed and iron was consumed in garnet-producing reactions; titanium remained to form rutile.

Fig. 2. SEM back-scattered electron image of rutile (grey) and ilmenite (white) intergrowth from the Husebø eclogite at Holsnøy, Bergen Arcs. Photo width 0,2 mm.

The actual rutile content in an eclogite is a function of both the whole-rock TiO_2 content as well as the metamorphic grade. Varying degrees of eclogitisation may leave large portions of the protolith rock uneclogitised (Mørk 1985 a,b), with only partial conversion of Ti-oxides to rutile. Rutile/ilmenite intergrowths of the type shown in Fig. 2 are common in eclogites all over western Norway, and may represent incomplete reactions. In addition, the rutile content of an eclogite may be reduced during retrogression: eclogite bodies are commonly retrograded along their margins and along shear-zones and cracks where rutile is altered to ilmenite. Titanium in silicates is negligible in most cases.

The rutile content in eclogites is generally in the range 1-2 wt.%; minor enrichments with 2-5 wt.% rutile within these low-grade rutile-bearing eclogites are fairly common. Eclogite bodies, or subareas within large eclogite bodies, with surface areas of more than 100,000 m^2 with 2-3 wt.% rutile, are found in the Sunnfjord district of the WGR (Korneliussen & Foslie 1985) and in the Bergen Arcs (Korneliussen et al. 1991).

Rutile associated with metasomatised gabbroic rocks in the Bamble region, southern Norway

The Proterozoic Bamble Sector of the Baltic Shield underwent a complex geological evolution (e.g. Starmer 1991, Dahlgren et al. 1993), including the Gothian (c. 1500-1750 Ma) and the Sveconorwegian (990-1250 Ma) orogenies, but was unaffected by the Caledonian orogeny. A characteristic and significant feature of the Sveconorwegian orogeny in Bamble was early, basic, magmatic activity followed by a period of hydrothermal activity that caused the metasomatic alteration of basic rocks.

At Ødegården, metagabbros/amphibolites were metasomatically altered to a scapolite-hornblende rock called ødegårdite by Brøgger (1934). The classic ødegårdite locality is a 1.5 km long and 100 to 150 m wide, vertically dip-

Table 1. Average whole-rock major element chemistry (wt.%) of a metagabbro and its scapolitised equivalent (ødegårdite), Ødegårdens Verk. This metagabbro occurs as a 2,5 m thick gabbro relic from 86,5m to 89,0 m in Dh2 (see Korneliussen & Furuhaug 1993) and is surrounded by its ødegårdite equivalent. The chemical changes related to the metasomatic process are given in absolute and relative values. XRF-analyses.

	Metagabbro n=10	Ødegårdite n=8	Chemical change Absolute	Relative
SiO_2	46,07	48,72	2,65	6%
Al_2O_3	14,50	16,23	1,73	12%
Fe_2O_3	12,13	5,73	-6,40	-53%
TiO_2	2,94	3,21	0,27	9%
MgO	6,65	7,24	0,59	9%
CaO	8,51	8,26	-0,25	-3%
Na_2O	5,38	6,22	0,84	16%
K_2O	0,64	0,67	0,03	4%
MnO	0,08	0,03	-0,05	-60%
P_2O_5	0,39	0,48	0,09	23%
LOI	0,59	0,82	0,23	39%
SUM	97,88	97,61	-0,27	0%

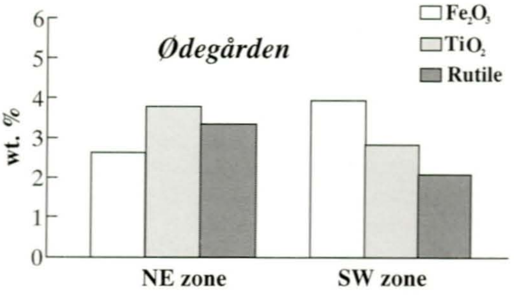


Fig. 3. Average Fe_2O_3, TiO_2 and rutile content in scapolitised metagabbro (ødegårdite) from the northeastern and southwestern parts of the ødegårdite ore-zone at Ødegården, Bamble.

ping, NE - SW trending zone surrounded by metagabbro/amphibolite. The northeastern part of this zone has also experienced albitisation postdating the scapolitisation process. The metasomatised rocks are cut by numerous, 1 dm to 1 m thick, apatite-bearing, phlogopite-enstatite veins that were mined for apatite from 1872 to 1945. The apatite in these veins was formed in equilibrium with high-temperature Cl-rich aqueous fluids (Lieftink et al. 1994). Hydrothermal dolomite rocks in the neighbouring Kragerø area, including a dolomite-albite-quartz dyke, have been dated by Dahlgren et al. (1993) at 1175 ± 37 Ma (Sm-Nd). Taking into account that dolomite veins have been reported to cut apatite-bearing phlogopite-enstatite veins at Ødegården (Bugge 1965), this age can be regarded as a minimum age for the hydrothermal events at Ødegården.

As shown by Brøgger (1934) the chemical composition of the Ødegården metagabbro /amphibolite was significantly changed by the metasomatic event; a major feature of the metagabbro is an inverse relationship between iron content and degree of metasomatic alteration. The whole-rock major element compositions of one of the metagabbro varieties found at Ødegården and its scapolitised, iron-depleted equivalent (ødegårdite) are presented in Table 1. During metasomatism, Cl-rich hydrothermal fluids leached iron from ilmenite while titanium, which is fairly immobile, was incorporated as rutile. Based on surface sampling, two drill-holes and chip-samples from the tailings of the old apatite mines (see Korneliussen & Furuhaug 1993), the rutile content in ødegårdite is found to vary generally from 1 to 4 wt.%, with the richest rutile zone (3-4 wt.%) in the northeastern part of the deposit. Fig 3. illustrates the average Fe_2O_3, TiO_2 and rutile relations from the northeastern and southwestern ore-zones.

Concluding statement: Rutile deposits, such as Ødegården, that have been reconnoitred from the geological as well as the economic points of view are marginal and probably uneconomic at present. However, it is believed that Norwegian rutile deposits in general represent a resource that might become of economic importance in the future. Its potential is dependent on continued investigations focusing on areas where large volumes of Ti-rich rocks have experienced rutile-forming metamorphic processes, i.e. the Bergen Arcs and the Sunnfjord region in West Norway and the Bamble Province in South Norway.

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