Norwegian anorthosites and their industrial uses, with emphasis on the massifs of the Inner Sogn-Voss area in western Norway

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Anorthositic rocks are common in several geological provinces in Norway. Many occur at scattered localities in different parts of the country, but the two largest anorthosite complexes in western Europe are situated in western Norway. These two Precambrian massifs, the Inner Sogn-Voss province (~ 1700 Ma), and the Rogaland province (~ 930 Ma) have been investigated for use as a raw material for various industrial applications. Anorthosite with a high anorthite content (An >70) is easily soluble in mineral acids, and the bytownite plagioclase of the Sogn anorthosite makes it well suited for industrial processes based on acid leaching. The high aluminium content, ca. 31% Al_2O_3, has made these occurrences interesting for various industrial applications, especially as an alternative raw material for the Norwegian aluminium industry. With this goal in mind, geological investigations and processing studies have been carried out at various times during the past century. At present, a refined process utilising both the silicon and the calcium contents of the anorthosite has renewed industrial interest in these acid soluble anorthosites.

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Introduction

Anorthositic rocks are common in several geological provinces in Norway and occur at many localities in different parts of the country (Fig. 1). Most of the bodies are of relatively small size, but a few are of appreciably larger dimensions. Among these are the Bergen Arc anorthosites (Kolderup & Kolderup 1940), and most prominently, the 500 km^2 Rogaland province and the 700 km^2 Inner Sogn-Voss province. These are the two largest anorthosite occurrences in western Europe and are of considerable interest for industrial applications.

Anorthosite is an almost monomineralic, feldspathic rock with a great variety of industrial applications (Table 1). Anorthosite massifs are known to host important ore deposits such as ilmenite and are, in many cases, excellent sources for high-quality rock aggregate and also for dimension-stone. The exploitation of anorthosite for industrial mineral products is growing, and the potential for future production of aluminium and other important constituents from anorthosites is considered to be quite considerable.

It is primarily the high aluminium content of the Sogn anorthosite which makes it attractive for a variety of industrial end uses. The aluminium content can be utilised in various processes. Most importantly, anorthosite can be leached with mineral acids in order to facilitate the liberation of aluminium. Simultaneously, the calcium component is liberated, and is thus available for other potential applications. Laboratory investigations (Graff 1981) have shown that plagioclase (albite $NaAlSi_3O_8$ - anorthite $CaAl_2Si_2O_8$) has a solubility which is highly dependent upon the An content of plagioclase (Fig. 2). Anorthosite with $An_{<50}$ is almost non-soluble

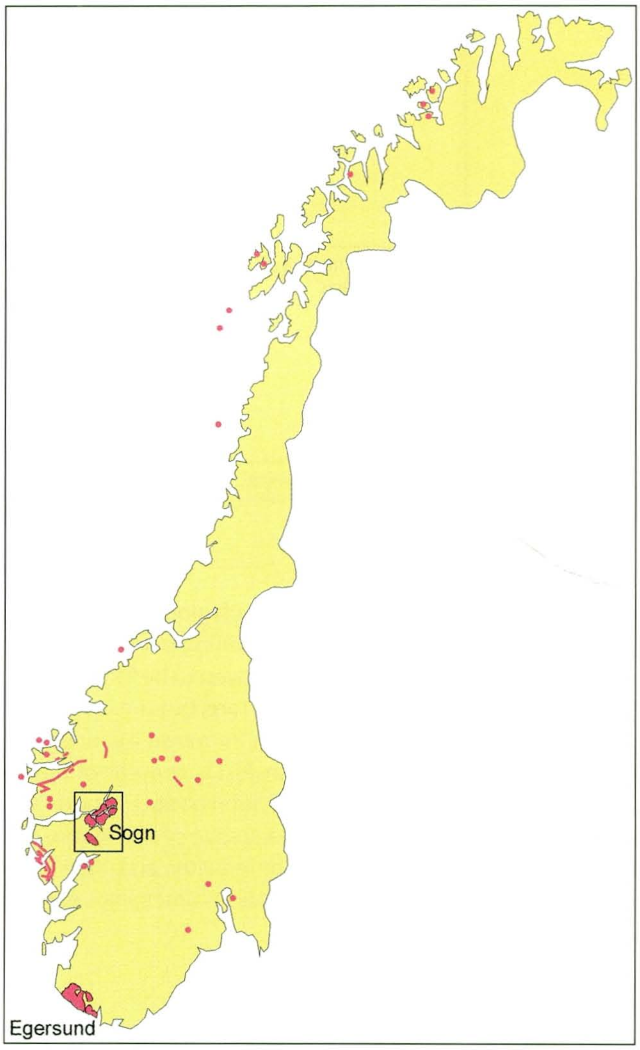

Fig. 1. Distribution of anorthosites (red) in Norway. Modified after Qvale (1982b). Boxed area – Fig. 3.

Processing	Products	Uses	Specifics
Physical.	Plagioclase grains with crystal structure intact	Aggregates	*Light coloured road surfaces, gardens,*
(dry or wet mineral		Building materials	*Concrete elements, dimension stone, industrial floors*
processing)		Abrasives	*Scouring powder, toothpaste,* sand blasting
		Fillers, extenders, coatings	Paint, plastics, rubber
Chemical	Aluminium chlorides	*Aluminium metal*	
	Aluminium oxide (alumina)	*Flocculent*	*Water and waste water treatment*
(acid or alkaline	Aluminium sulphate (alum)	Flocculent/sizing	Paper manufacture
leaching)	Calcium carbonate	Binder	Asphalt
	Calcium nitrate	Catalyst	Organic reactions
	Calcium silicate		Alumina speciality products
	Ammonium nitrate		Cellulose insulation
	Silica gels and sols		Cement components
	Sodium silicates		Cosmetics and pharmaceuticals
	Sodium carbonate		Food processing
			Nitrogen fertiliser
			Speciality metallurgical uses
			Synthetic wollastonite and zeolite
	Silica residue	Fillers and extenders	Polyester and epoxy resins, Polyurethane varnishes
		Coating	White enamel
		Absorbent	Kitty litter, radioactive pactides
		Silicon production	
			Cement additive
Melting	Fully or partial melting of plagioclase grains	Ceramics	*Floor and wall tiles,* electrical porcelain, bioceramics, ceramic glazes
		Glass fibre	
		Mineral Wool	*Rockwool*
		Welding fluxes	
		Al-production cells	*Cryolite bath insulation*
Direct reduction	*Al-S -alloys, Al- and Si- metal.*		

Table 1. Various industrial uses of anorthosite. Norwegian commercial and tested uses marked in italics.

in mineral acids, whereas labradorite plagioclase (An_{50-70}) is partly soluble. Only anorthosites containing plagioclase with more than 70% An (bytownite) are proven to be fully soluble. Such basic anorthosites are relatively rare, but the large massifs in the Sogn-Voss region contain immense quantities of easily soluble anorthosites with an Al_2O_3 content of about 31%. This makes these bytownite-anorthosites a potential alternative to imported bauxite as a source of aluminium ore for the large Norwegian aluminium industry, and they have been evaluated for this purpose at various times since early in the 20th century.

Main Norwegian anorthosite deposits

With regard to industrial uses it is adequate to group anorthosites into two categories; acid soluble and not acid soluble.

Large areas of the Voss-Sogn massifs (Figs. 3 and 6) are of outstanding quality concerning acid solubility, making them ideally suited for several industrial applications (see below).

Acid-soluble anorthosite might also be present in some of the much smaller occurrences in Norway, but none of the other major anorthosite deposits are composed of soluble plagioclase (Qvale 1982b). The ~75 km^2 Bergen Arc anorthosites, for example, are dominated by a plagioclase with $An_{<50}$ (Kolderup & Kolderup 1940).

The anorthosites of the 500 km^2 Rogaland province (Fig. 1) are dominated by andesine - plagioclase (An_{40-50}) (Duchesne et al. 1987) and are thus also insoluble in acids. This anorthosite complex is best known for its large norite-hosted ilmenite deposit at Tellnes. However, the anorthosite itself

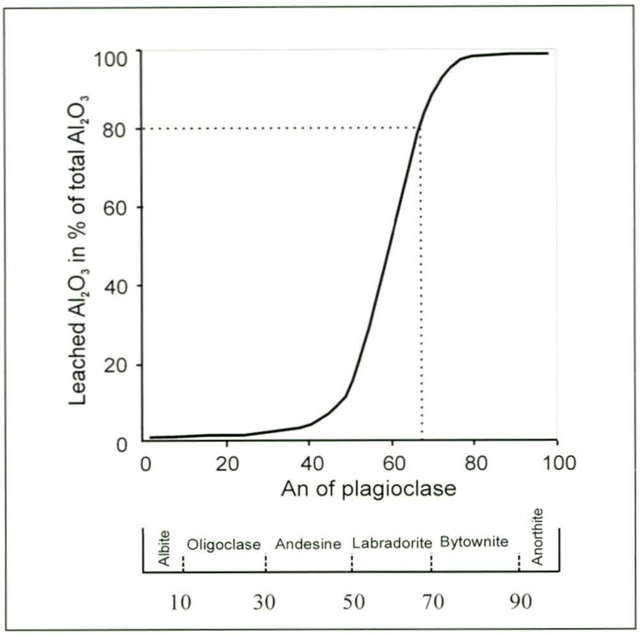

Fig. 2. Plot of solubility vs. anorthite content of plagioclase. Modified after Graff (1981) and Qvale (1982a).

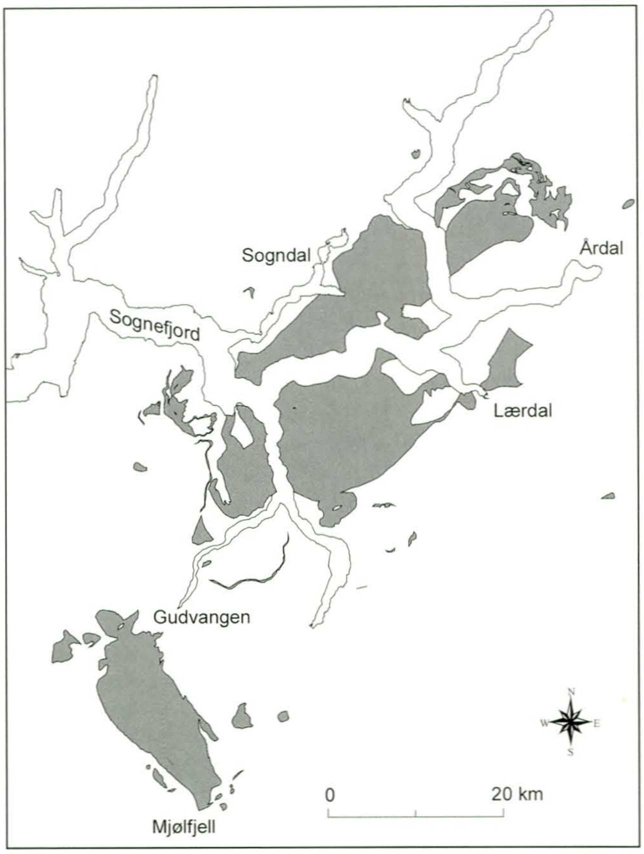

Fig. 3. Anorthositic rocks of Inner Sogn and Voss.

has several industrial applications. The altered, white variety is mined for aggregate and filler purposes, and an attractive, massive brown variety with blue labradorescence in some plagioclase crystals is quarried as dimension stone (Heldal & Lund 1995).

A summary of the anorthosite occurrences in Norway has been given by Qvale (1982a). In this report Qvale also gives a comprehensive overview of the geology and mineralogy of the Sogn-Voss anorthosite provinces. Wanvik (1999) presented an overview of the same area with emphasis on the criteria and geographical variations regarding potential industrial use.

Norwegian investigations and developments

Historical perspective

The potential for exploitation of the anorthosite for various purposes has been evaluated at different times since the beginning of the 20th century. Goldschmidt (1919) was the first to propose the idea of utilising anorthosite as a raw material for the production of aluminium and aluminium in combination with other elements. Two years earlier, he introduced his idea to A/S Elektrokemisk Industri and also carried out the first regional investigation of the anorthosites of the Inner Sogn area (Goldschmidt 1917). Goldschmidt found that the massif in the Nærøydal area contained the best quality of easily soluble anorthosite. He also located a deposit in Kinsedal, east of Lustrafjord, which was suitable for a leaching process to liberate the aluminium component. Investigations in Kinsedal continued until 1920.

Interest for anorthosite as an alternative raw material for aluminium production was revived during the second world war. Extensive field investigations, sampling and diamond drilling were carried out in Kinsedal by Norsk Hydro (Carstens 1942). The work culminated in the building of a complete plant for underground mining, transport and shipping of anorthosite. Up to 300 men were employed there and some 15,000 tonnes of rock were produced before sabotage ended the work in 1945.

In the mid 1960s, underground mining of white anorthosite began in Nærøydal (Figs. 4, 7 and 8) in the altered zone along the thrust at the base of the Gudvangen-Mjølfjell massif. Production has continued since that time. Products have included white road aggregate, white concrete elements, and abrasives for use in toothpaste and cleaning agents. Annual production has varied between 10,000 and 100,000 tonnes of anorthosite. Part of the production has been exported, and the most recent development is the shipping of anorthosite to a Swedish producer of mineral wool.

Throughout most of the 20th century, the major potential end-use of the Sogn-type anorthosite has been considered to be as an alternative aluminium raw material to bauxite, based on the solubility of this anorthosite type in mineral acids. Leaching with acids, such as HCl and H_2SO_4 is very well established in the Norwegian Anortal process (Kvande 1987, Braaten 1991). In the mid 1970s, the formation of the International Bauxite Association (IBA) triggered Elkem A/S and Årdal og Sunndal Verk A/S into renewing their interest in anorthosite as an alternative aluminium raw material. During the period 1976-1982, major geological investigations and process development were carried out on the Sogn

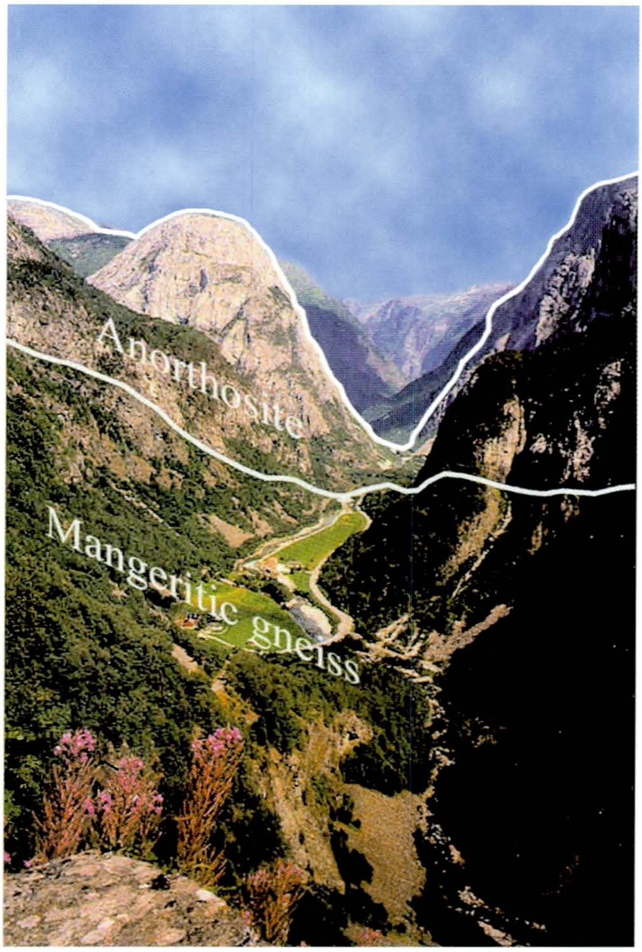

Fig. 4. Anorthosite in Nærøydalen near Gudvangen, as seen from Stalheim. Mangeritic gneisses are located below the anorthosite of the well-known Jordalsnut.

anorthosite by the joint venture company I/S Anortal (Wanvik 1981, Braaten 1991). The main objective of the fieldwork was to locate a deposit containing at least 100 million tonnes of readily soluble anorthosite, which contains only minor amounts of mafic minerals. Areas with top-quality rock were located and drilled at two separate locations; the Hylland field and the Kaldafjell field, south of Nærøydal (Fig. 7). The Geological Survey of Norway has contributed to the project with important field investigations on a regional scale (Qvale 1982b).

The Anortal project was successful concerning adequate raw material and the development of a technically viable process, and thus the main issues of establishing a possible Norwegian alternative to imported bauxite was solved. The project, however, was terminated, as the concept was not found to be commercially compatible with existing bauxite-based alumina production.

Recent developments

At the start of the 1990s, the company A/S Polymer (now Polymer Norge AS) introduced the concept of producing a polymeric coagulant (polyaluminium chloride) for cleaning drinking water and waste water, employing anorthosite as the raw material. The process involves acid leaching of the raw material and thus adopts parts of the processing results developed in the Anortal project. New alternative sites for quarrying suitable anorthosite have, in this connection been located by the Geological Survey of Norway (Wanvik 1997, 1999). The company is at present carrying out a pilot-scale processing development in Poland. Results so far have been very encouraging. The highly polluted waste water from Polish and East European industry is seen as the main target for the product.

In 1993, a Norwegian company (Borgestad Fabrikker A.S.) wished to test the high Al and Ca Sogn anorthosite as a raw material for a new refractory product designed as a sealant of aluminium electrolytic cells in the aluminium industry (Brantzæg et al. 1993, Færøyvik 1994). The high melting point of the calcic plagioclase from the Sogn anorthosite is, in this case, advantageous compared to the lower melting point of the more Na-rich anorthosite of the Egersund region. Although the project initially seemed very promising, it has met with problems relating to the viscosity of the sealant product and is thus so far only partially successful.

Liberation of the aluminium component is still the main issue of a process (Fig. 5) that has recently been developed by the Norwegian Institute for Energy Technology (IFE) (Råheim et al. 1998, Råheim 1999). IFE was responsible for the processing development in the Anortal project. In this new refined concept, more or less all components (Al, Ca and Si) of the rock are utilised, yielding products such as calcium carbonate, ammonium nitrate and silica-products in addition to the aluminium oxide. In addition, the process incorporates the consumption of CO_2, and since this can be obtained from the emissions of natural gas power plants, such a clean, 'total-utilisation' process can be considered to have a very good environmental profile. At present the institute is seeking an industry partner in order to be able to develop this project further.

The leach residue from an acid process is a white, highly porous, low-density, amorphous silica gel. The residue has a potential use as a filler and extender in the paint, plastics and paper industries, as well as a binding material in cement production. The very high porosity might also make it suitable as an absorbant of various products, including radioactive particles.

This high-Si residue is also interesting as an alternative raw material in a new innovative industrial process, which at present is being developed by the company Norwegian Silicon Refinery AS. Both Al and Si are being produced in a refined, continuous, electrical melting operation with feldspar as the raw material (Stubergh 1994, 1996). The silicon product is of solar cell quality and the high silicon content of the plagioclase of the Egersund anorthosite is suitable for such a process, as well as the residue of leached Sogn anorthosite.

As a raw material for the production of ceramics and sanitary porcelain, a low melting point is advantageous. For this application, white anorthosite from Hellvik, near Egersund, is shipped to European customers (internet reference: http://www.edelsplitt.no).

Sintering processes have also been attempted with

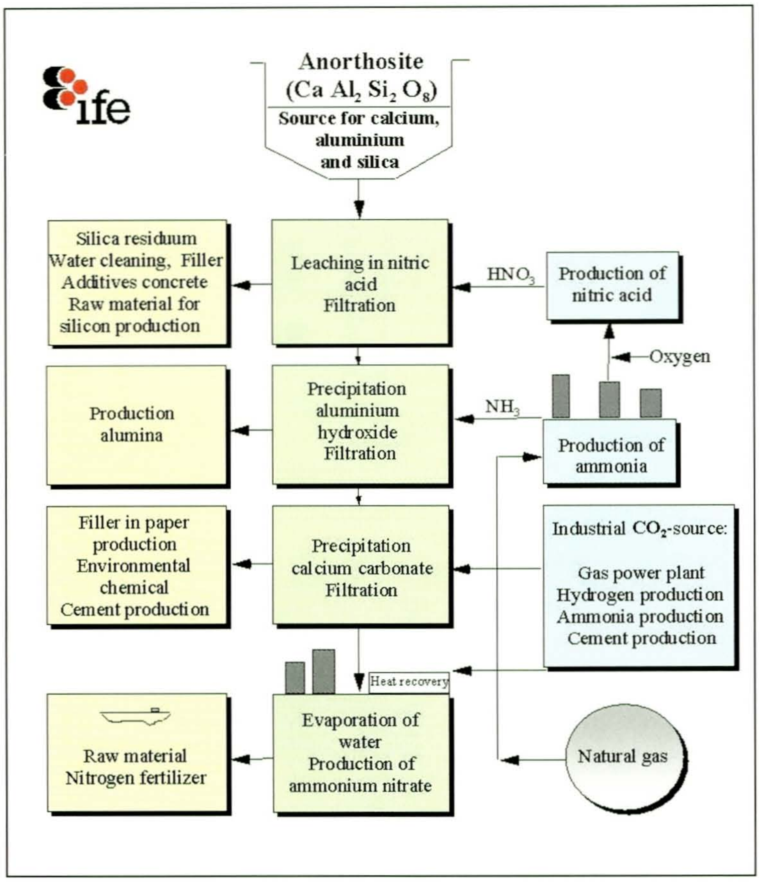

Fig. 5. The Norwegian Institute for Energy Technology has developed a new CO_2-based concept of utilising several components of the Sogn anorthosite.

Use	Acid solubi-lity	Al	Fe	Ca	LOI	Other criteria	Quantity needed
Al production	high	high	low				large
Al +Si +Ca (CO_2-free gas power process)	high	high	low				large
Water cleaning	high	high	low			not quartz	medium
Si + Al production (electrolysis)		high	low			high Si, low P, B and K	large
Refractory		high	low	high	low	not quartz	small
Ceramics			low		low	low melting point	medium
Mineral wool		high		high		low Si	medium
Aggregates						whiteness, mechanical qualities	medium/ large
Dimension stone						fracturing, block size, colour	small

Table 2. Important characterisation criteria for anorthosite used in different applications.

anorthosite (Dolan et. al. 1991). However, these have proven to be energy intensive, and testing using the Norwegian Pedersen process (Kvande 1987) has not been found to be of commercial interest.

The most recent application of anorthosite in a high-thermal process is for mineral wool production. The Swedish company Paroc AB, operating 3 rockwool factories, has now started using Norwegian anorthosite in their production. In this case, it is the high-Al variety, which is interesting; thus favouring the Sogn type.

Concerning more direct applications, the white altered variety of both the Sogn and the Rogaland anorthosite has been mined/quarried for aggregate for some decades. Macadam, for use in the top layer of asphalt, in Norway and abroad, is the primary product, with its white colour and good mechanical properties as the main advantage. In addition, concrete elements, for exterior walls as well as street/traffic applications, have been produced with this white anorthosite as a vital ingredient. The white variety from both regions has also been used as an additive in washing powder and as a grinding agent in toothpaste.

Unaltered anorthosite is attractive both as dimension stone and aggregate. Mellegren & Dalseg (1981) have described future plans for the opening of a giant aggregate quarry near Jøssingfjord. Production from this quarry, in the southernmost part of the massif, is principally designated for direct export. Export is also the main issue with the successful, new, dimension stone quarry operated by the company Granit-1893 AS in brown anorthosite west of Egersund.

Table 2 gives an indicative overview of the main criteria of anorthosite as the raw material in various relevant industrial applications. Further detailed information on the industrial uses of anorthosites has been given by Dolan et al. (1991) in the context of their thorough study of Canadian anorthosites.

The Sogn-Voss occurrences

Geology

The anorthositic rocks of the Inner Sogn-Voss region belong to the Jotun Nappe, a thick block of Proterozoic crystalline rocks lying in a NE-SW trending faulted trench. Below the basal thrust there are younger schists, phyllites, quartzites and gneisses overlying Precambrian basement gneisses. The Jotun Nappe itself is subdivided into several separate sheets. The anorthositic rocks are situated within an upper unit together with gabbroic rocks and, in northern areas, also granodioritic rocks. They belong to the Middle Allochthon of the Caledonides. The calcic character of the Sogn anorthosite is a common feature of Archaean anorthosites (Ashwal 1993). However, the Sogn anorthosite is generally considered to be of Proterozoic age, probably ca. 1700 Ma (Sigmond 1988).

The anorthositic rocks mainly occur in two distinct geo-

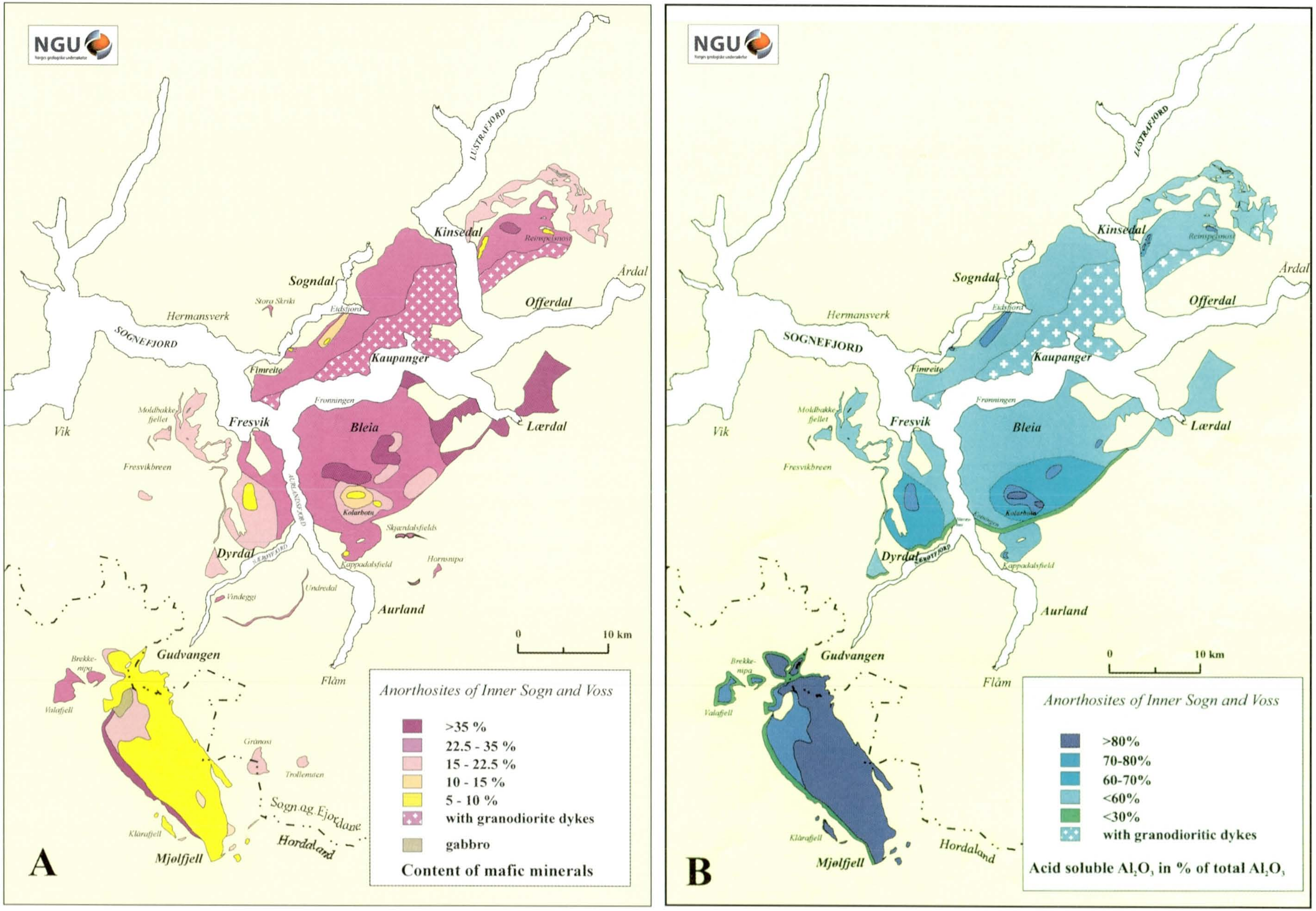

Fig. 6. Variation in content of (a) dark minerals and (b) acid solubility in the various areas of the Sogn anorthositic massifs.

Location	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Acid solub.
Kaldafjell, drillcores	50.0	29.6	1.4	0.15	0.7	13.7	3.1	0.27	0.02		
1982, 202 samples	50.05	30.53	0.65	0.16	0.82	13.70	3.46	0.25	0.02		
Fresh, Nærøydal	48.99	30.70	0.68	0.10	0.42	14.22	3.00	0.16	0.08	0.77	42.05
Fresh, Brandsetdal	49.75	31.02	0.43	0.07	0.08	14.18	2.94	0.14	0.08	0.55	41.69
Fresh, Øvsthusdal	49,39	30.55	1.05	0.14	0.63	14.09	3.15	0.16	0.03	0.59	42.63
Altered white, Jordalsnut	48.15	29.43	0.41	0.08	0.02	15.65	2.21	0.19	0.06	2.24	12.1
Altered white, Fyrde	48.69	29.77	0.60	0.10	0.12	13.83	3.25	0.31	0.06	1.69	32.9
Mine fines, Nærøydal	48.19	29.4	1.46	0.24	0.83	13.58	3.02	0.27	0.08	2.40	15.3

Table 3. Major elements and acid solubility of typical samples from the Gudvangen-Mjølfjell massif (wt %, XRF).

graphical areas (Figs. 3 and 6). The southern area, between Gudvangen and Mjølfjell, consists of a single large massif and several smaller satellite bodies. The northern area, which extends from Dyrdal in outer Nærøyfjord to Kinsedal in Lustrafjord, is dominated by one large massif, separated into 4-5 separate bodies by the Sognefjord. Several satellite bodies are also present. In addition to Qvale (1982b) and Wanvik (1999), information on parts of the southern areas have been published by Hødal (1945), Dugstad (1965) and Bryhni et al. (1983).

In the Fresvik area (west of the northern part of the Aurlandsfjord), the upper sheet of the Jotun Nappe displays a primary intrusive layering seen on a regional scale (Bryhni et al. 1977); with alternating anorthosite and gabbro layers with thicknesses from tens to hundreds of metres. The anorthosites themselves are internally isoclinally folded, and thus the total thickness of the massifs can be as much as 2000 m, as observed, for example, on the eastern side of the Aurlandsfjord.

The anorthositic massifs display large variations in their content of mafic minerals (Fig. 6). Areas with proper anorthosite (< 10 % mafic minerals) are totally dominant in the southern Nærøydal-Mjølfjell area. In the northern areas, leucogabbro (10-35% mafic minerals) predominates, anorthosite-gabbro (22.5-35 % mafics) is also prominent, whereas anorthosite is restricted to only minor local occurrences. In the more pure, and most commercially interesting anorthosite areas, the dark minerals consist of epidote and brown amphibole with minor amounts of garnet, biotite and sericite. The leucogabbro contains less epidote, but clinopyroxene, in places altered to green amphibole, as well as some garnet, are common constituents. The latter minerals form patches, spots and bands, depending on the type and generation of the anorthositic rock.

The Sogn anorthosite is characterised by a high-An plagioclase (An_{55-80}). The southern Gudvangen-Mjølfjell Massif has been shown to be particularly calcic (An_{65-78}) while the northern regions are less calcic (An_{40-60} dominates) (Qvale 1982b). Based on regional field studies, Qvale (1982b) divided the Sogn anorthositic rocks into 9 sub-types, representing four different generations. Of these only the second generation with granular coarse- to medium-grained anorthosite is attractive for industrial uses. The Gudvangen-Mjølfjell massif is dominated by this sub-type. The other varieties, dominant in the other massifs, generally show too high contents of dark minerals to be considered as commercially attractive.

One of the more geologically (but not commercially) interesting types is a late-generation corona anorthosite that occurs in several parts of the massifs. Lens-shaped aggregates of mafic minerals, up to 10 cm in size, commonly appear as well developed corona textures. Primary olivine reacted with plagioclase, resulting in a dunite core surrounded by zones of orthopyroxene, clinopyroxene, amphibole, garnet and spinel in the outer rim (Griffin & Heier 1970, Griffin 1971).

Along the thrust base of the upper Jotun Nappe sheet (Fig. 8), the rocks are strongly deformed. Where anorthosite is present in this thrust zone, as in the Gudvangen-Mjølfjell Massif, the primary rock has been saussuritised, resulting in the formation of albitic plagioclase and epidote minerals. Since the An content is low (An_{20}), this anorthosite is not acid soluble. This low solubility, 12-15% (of total rock) as opposed to 41-42% in unaltered rock, is indicated in Table 3. This table also shows that alteration does not produce a significant change in the major element composition of the anorthosite.

Geological criteria in relation to industrial applications

The types of mineralogical and geological factors to look for when evaluating an anorthosite deposit depends on the end use. Apart from the plagioclase composition, the low content of dark minerals and a minimal number of dykes of other rocks within the anorthosites are favourable factors in all cases.

In view of the high content of mafic minerals in major parts of the Sogn anorthosites (Fig. 6), only restricted areas are of industrial interest. In the Gudvangen-Mjølfjell Massif though, a content of 5-10 % dark minerals dominates, and the best areas have only 3-5 % mafics.

Dykes of other rocks are very common within the anorthosites of the Jotun Nappe. The most prominent are early gabbro and garnet-amphibolite dykes occurring as lay-

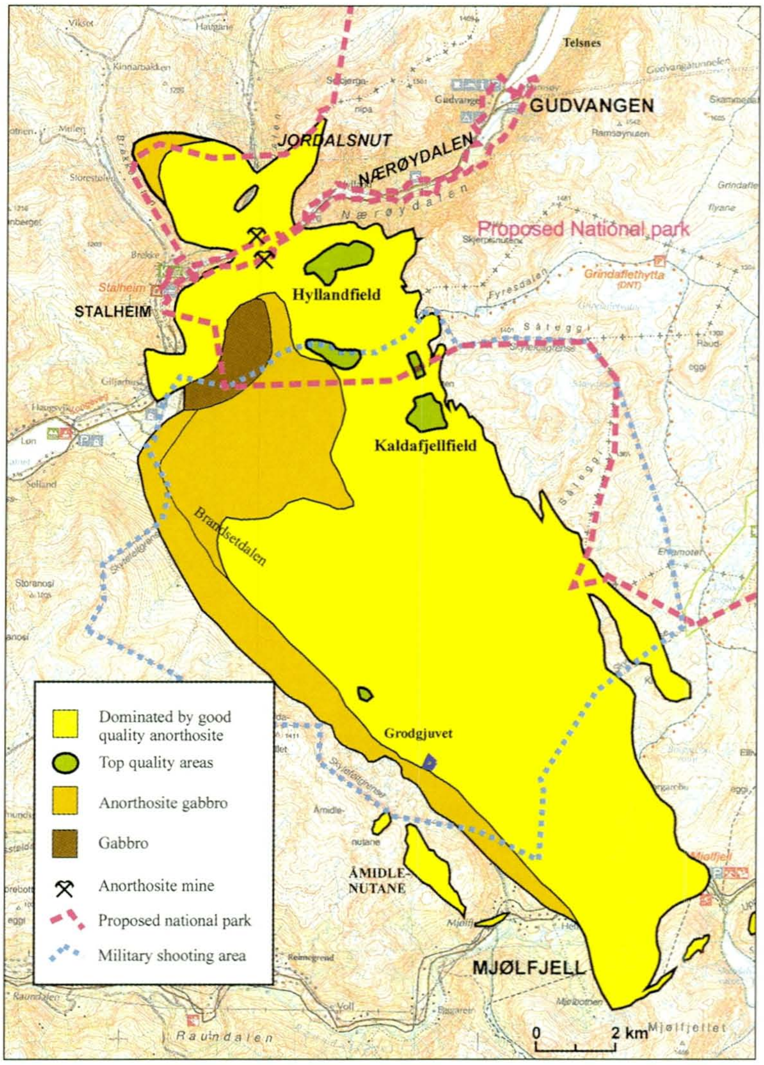

Fig. 7. Location of the high quality Gudvangen-Mjølfjell massif.

ers and lenses of varying thickness and frequency. These are a major negative factor against exploitation in many areas. Their widespread occurrence, for example in the Gudvangen-Mjølfjell massif, excludes many areas for exploitation which otherwise are of optimum anorthosite quality. Mapping of swarms of these dykes (Ottesen 1979) has shown that the anorthosite massifs are intensely folded. Among other dykes, granodioritic intrusions are the most common. Ordinarily they are not frequent and thus do not greatly affect anorthosite quality, but in northern and northeastern areas, they are very common (Fig. 6). Thinner, granitic pegmatite dykes also occur, but they are sporadic and do not influence anorthosite quality.

The high An content of the plagioclase is characteristic of the Sogn anorthosite, and is the most important factor making these deposits especially attractive. Since Goldschmidt's days it has been known that only high-An plagioclase is soluble in mineral acids. Such high-An plagioclase is thus essential for applications requiring liberation of Al and other elements from anorthosite. During the Anortal project Gjelsvik (1980) stated that leachability is a function of the Si:Al ratio, which must be below about 1.5:1 to prevent the dissolution of Al ions being masked by an insoluble silicate structure. The condition that appears to be necessary for acceptable dissolution is the collapse of the silicate structure as Al ions are leached from it.

Due to the regional variations of the An content of the Sogn anorthosite, only smaller areas in the central and northern regions have optimum solubility characteristics. The remainder is only moderately to poorly soluble (Fig. 6); anorthite contents between 40 and 60 dominate in these areas. The plagioclase in the Gudvangen-Mjølfjell massif, on the other hand, is dominated by An_{65-78} and most parts of this massif are of very high solubility. The altered anorthosite at the thrust base of the massif is a clear exception.

Alteration of the anorthosite is a common phenomenon, caused by local deformation of the anorthosite massifs. The plagioclase is crushed and saussuritised, with alteration to a more albitic plagioclase. Amphibole, clinopyroxene and garnet have been partly replaced by epidote, biotite, chlorite and muscovite. Some quartz and calcite may also be present. This gneissic, altered variety is easy to recognise and has a dull, fine-grained whitish appearance. The most intense alteration took place within the thrust zones at the base of the anorthosite massifs, where up to hundreds of metres might have been affected (Fig. 8). Higher up in the anorthosites, deformation and alteration is primarily restricted to narrow shear zones, up to a few m thick. Outside of such zones, saussuritisation is restricted to grain boundaries in massive anorthosites, and has resulted in a beehive texture on weathered outcrops. The low-An rims of the grains protrude at the surface, while the more calcic cores are weathered and eroded.

The colour of the anorthosite varies and gives no definite indication of quality. Even though altered low-An anorthosite is white (fine-grained and with dull lustre), unaltered types might also be white (medium- to coarse-grained and crystalline). Grey and violet-grey varieties are most common, but dark violet and dark brown varieties also occur. These two latter types are normally high in An, and for most industrial uses they are excellent; but they are found to often contain large amounts of microscopic inclusions of iron oxides and this might be disadvantageous in some applications.

Environmental issues

The Sogn anorthosites are situated in a very picturesque part of Norway. The Nærøyfjord region in particular is considered to be very special with its narrow fjord and steep mountains, and is visited by numerous tourists every year. Large parts of this area are thus now proposed as a new national park, including some of the most interesting parts of the Gudvangen-Mjølfjell massif (Fig. 7). This poses definite restrictions on

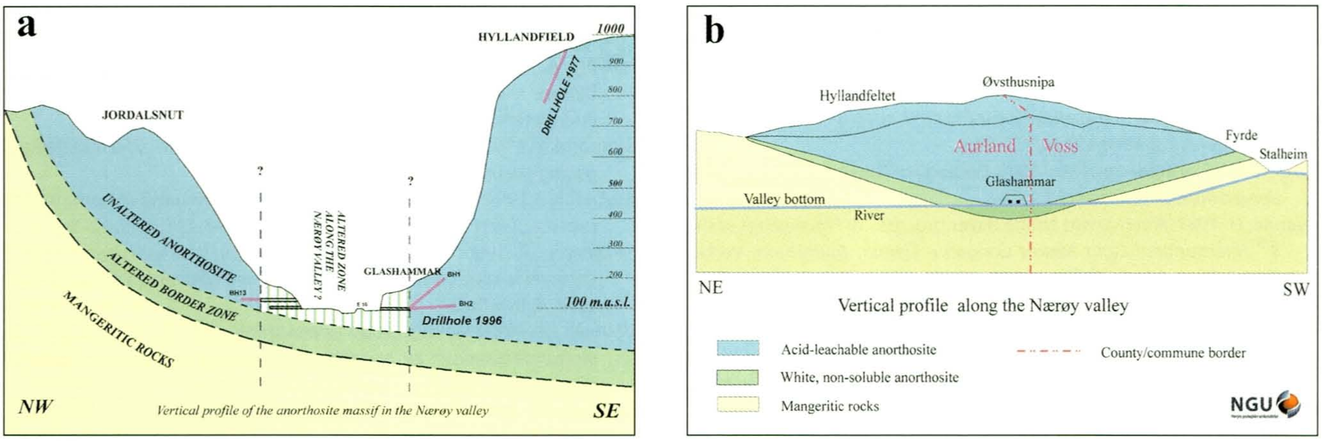

Fig. 8. Vertical sections (a) across and (b) along the Nærøydal, showing the altered thrust (border) zone at the base of the anorthosite massif. Diamond drillholes of investigated areas are marked with red lines in sections.

open mine quarrying, and the locations selected as being most favourable for mining during the Anortal project might then become inaccessible in the future. Furthermore, the anorthosite area to the south of the proposed park is already occupied as a military training area (Fig. 7). Thus, the Sogn anorthosite provides a 'good' example of the difficulties one often is confronted with today when prospecting for new mineral deposits. Luckily, more recent investigations have revealed that high-quality, acid-soluble anorthosite is accessible even with regular underground mining from the Nærøydal valley, and that such mines are possible to operate in a narrow 'open' zone along the bottom of the valley.

Conclusions and future perspectives

As an almost monomineralic feldspar resource, anorthosite has a varied spectrum of industrial applications. Especially the Sogn anorthosite has a long and interesting history of various companies involved in investigations to utilise this large resource. Industrial applications of anorthosite are expected to increase in scope and possibilities in the future. The very large deposits in Sogn and Rogaland are situated close to the coast, and are thus favourable for boat transport. The acid-soluble, high-An Sogn anorthosite and the medium-An Rogaland anorthosite thus provide Norway with an excellent base for various commercially interesting future industrial applications.

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