A regional study of the dimension-stone potential in labradorite-bearing anorthositic rocks in the Rogaland Igneous Complex

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Introduction

The occurrence of anorthositic rocks containing irridescent feldspar in the Rogaland Igneous Complex has been known for almost a century. Until recently, however, no study of the economic potential of these rocks as dimension-stone resources has been carried out, even though such rocks are highly valued on the international market due to their attractive play of colours.

The scope of the present regional study was to identify and characterise rock-types and units containing such feldspar and make an inventory of the dimension-stone potential in the igneous complex (Heldal & Lund 1994). The project was initiated by NGU, Rogaland Næringstjeneste A/S and the local authorities of Dalane, and carried out by NGU in 1993/94 with financial support from local and regional governments.

The anorthositic rocks of the Rogaland Igneous Complex comprise four anorthositic massifs (Egersund-Ogna, Håland, Helleren and Åna-Sira), a layered lopolith (Bjerkreim-Sokndal) and two smaller intrusive bodies (Garsaknat and Hidra; Fig. 1). The massif-type anorthosites are essentially composed of monotonous anorthosite and leuconorite in various proportions (Michot

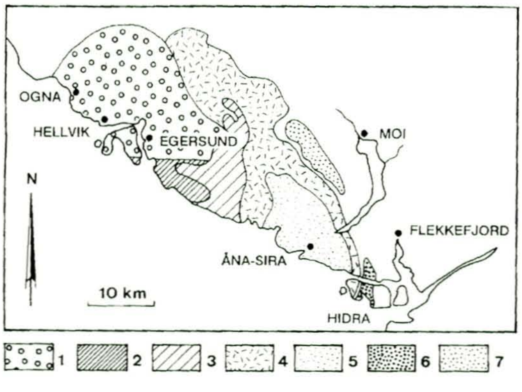


Fig. 1. Anorthositic rocks in the Rogaland Igneous Complex (simplified after Duchesne & Michot 1987). 1 Egersund-Ogna massif; 2 Håland massif; 3 Helleren massif; 4 Bjerkreim-Sokndal lopolith/monzonoritic intrusions; 5 Åna-Sira massif; 6 Hidra intrusion; 7 Garsaknat intrusion.

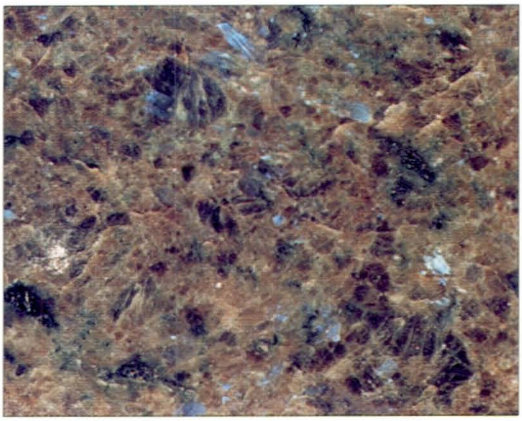
1961, Duchesne & Maquil 1987, Duchesne & Michot 1987). The Bjerkreim-Sokndal layered lopolith comprises a suite of anorthositic-mangeritic rocks (Duchesne 1987), while the Garsaknat and Hidra intrusions are massive anorthosites with leuconoritic margins (Demaiffe & Hertogen 1981, Duchesne & Michot 1987).

General aspects

From an industrial point of view, the main potential for dimension-stone in the Rogaland Igneous Complex is where massive bodies of anorthosite and leuconorite containing labradorescent plagioclase are found. This view is strictly related to subjective preferences in the dimension-stone market, where rock-types showing unique colour or a play of colours have higher value than less unique rock types.

In anorthosites the play of colour (labradorescence) is produced by lamellar structure in labradorite, known as Bøggild intergrowths (Bøggild 1924). These consist of lamellae (0.1 - 0.25 microns) of two plagioclases which may differ in composition by perhaps 12% An (Smith 1974). The compositional range of plagioclase in which labradorescence occurs is believed to be between An_{47} and An_{58}, and the colour of irridescence may vary from blue (An_{47-55}) to green/yellow (An_{50-55}) and red (An_{55-58}) (Smith 1974, Zeino-Mahmalat 1972).

The plagioclases of the anorthosite massifs in Rogaland generally range in composition from An_{40} to An_{56} (Zeino-Mahmalat 1972, Duchesne & Maquil 1987), but the labradorescent type ($An>47$) only occurs within limited parts. Although occurrences are found in all the described massifs and intrusions, the potential for workable deposits seems to be limited to the Egersund-Ogna Massif and the Hidra and Garsaknat intrusions. This limitation is based mainly on other industrial and geological factors of importance, e.g. accessibility, homogeneity and fracturing. Generally, the existence of labradorite is closely associated with pyroxene, as megacrysts or evenly distributed grains, and rock composition varies from anorthosite to leuconorite.



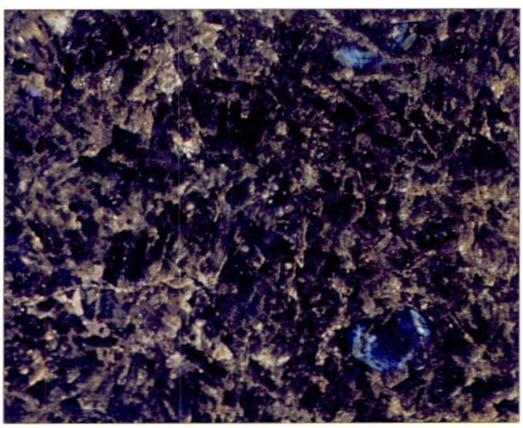


Fig. 2 (Upper photo). Polished sample of Hellvik-type anorthosite (prospect 5). Scale 1:1. (Lower photo). Polished sample of Hidra-type anorthosite (prospect 9). Scale 1:1.

On the basis of colour, it is convenient to distinguish two types of labradorite-bearing anorthosite/leuconorite: the *Hellvik type* and the *Hidra type*. The former is brownish red with a clear blue to green play of colour, while the latter is dark grey with a deep blue labradorescense and is rich in iron oxides (Fig. 2). An important factor regarding the variation in colour is probably the oxidation state of the rocks (Smith 1974), which again may be related to cooling mechanisms and metamorphism.

The Hellvik type occurs in the central part of the Egersund-Ogna Massif close to the coast near Hellvik, as irregular bodies surrounded by homogeneous, andesine-bearing anorthosite (Fig. 3). Contacts are intrusive, sharp or transitional, and the irregular bodies are believed by some authors to represent fragments from an early stage in the evolution of the complex, enclosed in the surrounding melt during the final emplacement of the massif (Robins pers. comm. 1994).

Grain size varies from medium to coarse to very coarse, and the plagioclase generally shows a bimodal distribution with large, subhedral crystals up to 5cm in size in a finer grained matrix. Between 10% and 30% of the plagioclase crystals show blue to green labradorescence. Pyroxene (<20%) commonly occurs as evenly distributed grains or as megacrysts, in places concentrated in boudinaged layers. The content of opaques (scattered, small grains of pyrite and magnetite) is generally less than 0.5%, indicating that the rock would be well suited for most building stone purposes. This view is supported by the nature of the weathering profile, which is very shallow and almost without staining.

Saussuritisation and kaolinisation are common phenomena in anorthosites, and the degree and nature of such alteration are of great importance for exploitation as for use of dimension stone. Generally, highly altered rocks are not commercially interesting. In the Hellvik area it is possible to distinguish between regional and local alteration. The former is mainly seen in the monotonous anorthosites, as small white and green spots on a mesoscopic scale, and as 'dusty' plagioclase microscopically. The labradorite-bearing anorthosites, however, are remarkably unaltered.

Local alteration occurs along fracture zones (commonly WNW-ESE and N-S), and a gradual transition from unaltered rock to white meta-anorthosite is seen when approaching these. The frequency of fracture zones also controls the jointing of the rocks in between, and wide spacing of fracture zones implies large deposits of massive anorthosite/leuconorite. Thus, the exploitable parts of the bodies occur as individual, irregular blocks of 'fresh' rock between the fracture zones and bordered by homogeneous anorthosite. In the lowlands close to the sea, the frequency of fracture zones is generally higher than in the hills in the northern part of the area, resulting in a better potential for large block production in the north. At several places, spacing of fracture zones is more than 50 m, and of visible joints 5 m or more.

In all the deposits, however, the occurrence of pyroxene megacrysts and clusters of thin greenish veins influences around 20-50% of the rock volume, contributing to a higher quarrying waste ratio than the joint and fracture pattern alone would indicate.

Five prospects are located in the Hellvik area (1-5 on Fig. 3). Prospects 1 and 2 are large deposits with potential for large-scale extraction

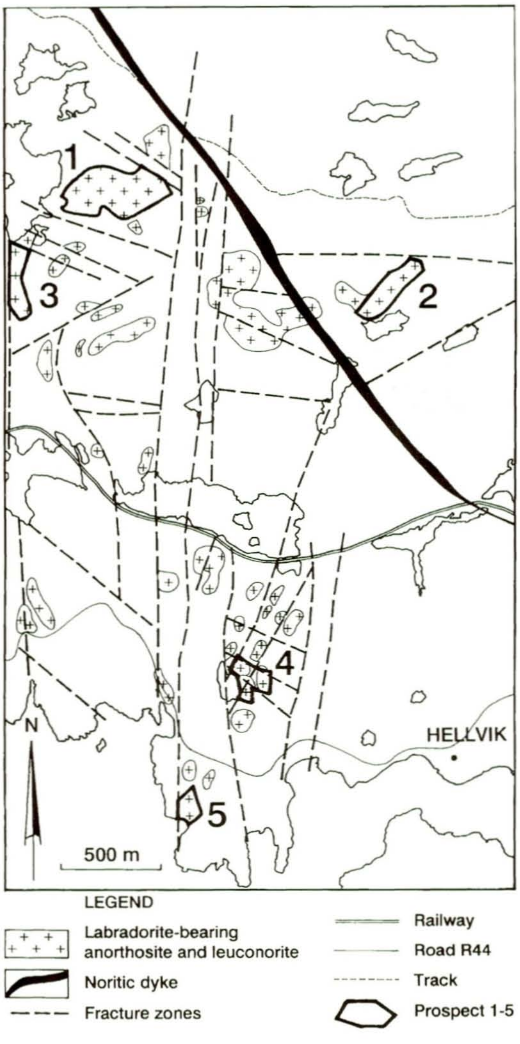


Fig. 3. Distribution of exploitable deposits of anorthositic rocks with labradorescent plagioclase in the Hellvik area, central part of the Egersund-Ogna Massif. See Fig. 1 for localisation of map. Prospects are numbered.

of large blocks of overall good quality. Prospects 3, 4 and 5 are more easily accessible, but smaller in size and generally more fractured, and it is most likely that these are suited only for small-scale quarry operations. Several other deposits exist in the area, but these are considered to be of poorer quality than the prospects, especially regarding content of veins, accessibility and uniformity.

The Hidra type occurs mainly in the Hidra and Garsaknat intrusions (Fig. 4). Both these consist of anorthosite with a leuconoritic margin. The pegmatites, which contain large 'spectrolite' crystals on the island of Hidra, are well known among collectors, but probably not suitable as dimension stone resources. For that purpose, large and homogeneous deposits of finer grained material would be of greater interest.

The Hidra type is characterised by an overall dark grey colour with scattered labradorite crystals. The bimodal distribution of the feldspar is even more significant than in the Hellvik type, with labradorite megacrysts surrounded by a medium- to coarse-grained matrix. The content of labradorescent plagioclase varies between 1% and 10% in the homogeneous anorthosites and slightly more in the pegmatites. The play of colours is mainly towards deep blue.

These anorthosites and leuconorites have a high content of opaques (mainly haematite but also magnetite and pyrite), locally up to 10%. This results in a deep, stained, weathering profile and clearly limits suitability for outdoor use of the stone. Furthermore, the weathered surface makes correct quantitative evaluation of labradorescence difficult, and for detailed investigation core-drilling or blasting will be necessary to obtain fresh samples.

Four prospects are localised - 6-7 in the Garsaknat intrusion and 8-9 in the Hidra intrusion (Fig. 4). Prospects 6 and 9 are relatively heterogeneous, with irregular pegmatite bodies commonly occurring in finer grained anorthosite and leuconorite. The appearance in several places is very good, with a high content of deep blue labradorescent crystals. However, due to lithological variations and fracturing, large blocks of uniform quality are not likely to be obtained.

Larger deposits of homogeneous, massive anorthosite are found at prospects 7 and 8. Labradorescent crystals occur throughout these areas, but the quantity seems to be lower than at prospects 6 and 9; and possibly too low for gaining a good market value. Furthermore, thin greenish veins occur in many places. However, the potential for large-scale extraction of large blocks in these deposits provides good reason for further prospecting.

Discussion

For industrial exploitation of dimension stone deposits some basic criteria must be fulfilled. First of all, a deposit should be able to supply large, uniform blocks with a minimum of waste. Secondly, the quality of the rock for use as a building material should be at least as good as similar rock-types on the market, and the market price must be high enough to match the costs of quarrying.

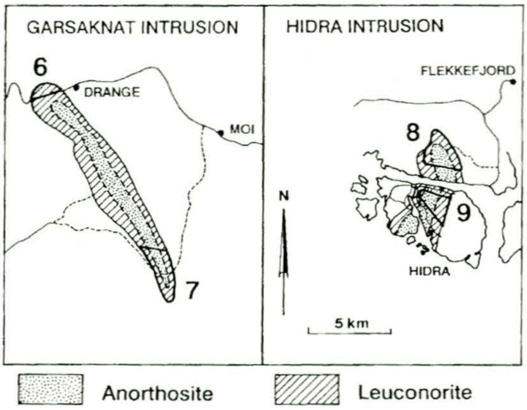


Fig. 4. The Hidra and Garsaknat intrusions (simplified after Falkum 1982). Prospects are marked with heavy lines and numbered (6-9). Paved roads are marked with thin line, dirt roads with dotted line. See Fig. 1 for localisation of maps.

There is no doubt that extraction of large blocks is possible both of the Hellvik type (prospects 1 and 2) and the Hidra type (prospects 6 and 7). On the other hand, the occurrence of veins and pyroxene megacrysts contributes to an increased waste ratio. Approximately 20% of the rock volume at these prospects is affected by these features. Concerning costs of quarrying in general, topography, fabric and mineralogy suggest similar relations as for larvikite, which means overall higher extraction costs than the average for granitoids. However, the rocks are well suited for diamond-wire sawing due to lack of quartz.

Quality-in-use of anorthosites is mainly dependent on the content of easy-oxidising minerals, the degree of feldspar alteration and content of open pores and microfractures (Alnæs 1995). Both types of deposits are little or only slightly altered, and rapid deterioration of rocks in use is not considered to be a problem.However, deep weathering profile in the Hidra type indicate a possibility for rusty staining and discolourting if used in exteriors.

The market value of dimension-stone is always difficult to evaluate, since this strongly depends on the taste of the end-users and on fashion. The price difference ratio for raw blocks between an ordinary, grey granite and a unique, attractive rock-type may be 1:10. In this study, conclusions regarding the market value of the anorthosites have been drawn on the basis of supply, uniqueness and price of similar rock-types on the market. This comparison shows that the Hellvik type seems to be the most interesting of the two. Similar anorthosite is quarried at only one other place in the world, in the Nain anorthosite, Canada . Deposits of dark grey anorthosites with labradorescent plagioclase similar to the Hidra type are, on the other hand, known from Finland, Ukraine, Siberia and southern Africa. The assumed lower content of labradorite in the massive varieties of the Hidra type could also lead to the rock being less atractive on the market than competing types.

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