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Assessment of the anorthosite at Gudvangen Stein's property in Nærøydalen Aurland from a resource geology perspective

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Title:
Assessment of the anorthosite at Gudvangen Stein's property in Nærøydalen Aurland from a resource geology perspective

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Summary:

An evaluation of the anorthosite resource at the property of Gudvangen Stein gives the following conclusions:

- Large quantities of an unusually aluminium-calcium rich anorthosite are present at the property of Gudvangen Stein A/S in Nærøydalen. The property forms part of a 100km^2 large anorthosite massif extending 25 km southeastwards towards Mjølfjell at the Bergen railroad.
- Two main varieties of anorthosite are present within the mining area of Nærøydalen. One type is a primary anorthosite where the almost monomineralic feldspar content is soluble in acids and thus well suited for processing that requires dissolving of the minerals. The second type is altered and fine-grained, with a white colour well suited for applications requiring light or white materials. Both types are well-suited material for rock wool production.
- This aluminium-calcium-rich anorthosite is hard to find both in Norway and worldwide in large and homogenous quantities as in Nærøydalen. The Gudvangen deposit is world class in this category.
- Millions of tons of anorthosite occur within Gudvangen Stein's property, and additional immense quantities are present in adjoining areas of the large Gudvangen-Mjølfjell anorthosite-massif. Thus raw material resources are practically unlimited.
- Anorthosite has a wide range of potential uses, and the aluminium-calcium rich variety of the Gudvangen area has especially varied possible applications in addition to the present established markets of rock wool, asphalt and concrete.
- The regulations of the Protected Landscape area and the recently acquired status of the Nærøyfjord region as a World Heritage Site gives room for further developments underground, based on the current mining areas of Gudvangen Stein. Environmental concerns are important, and future workings must not come in conflict with the protection regulations and any World Heritage status for the area.
- The newly upgraded mining system at Jordalsnuten provides flexibility to handle both present production capacity and medium scale future expansion.

Keywords: Industrial mineral	Anorthosite	Mining

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1. INTRODUCTION

The large areas of anorthositic rocks situated in the most picturesque parts of Inner Sognefjord in Western Norway have been well known amongst geologists for more than a century. Locally the anorthosite is referred to as 'kvitberg', i.e. 'white rock' since it develops a white weathering crust, and the light-colored mountain-areas add greatly to the grandiose scenery of this region.

The high aluminium content of these rocks has made them interesting for industrial purposes in several periods since shortly after WW1, and varied potential applications gives interesting future perspectives for the large volumes of this rare and close to mono-mineralic rock.

In relation to Nordic Mining ASA's agreement to consider purchasing 85% of Gudvangen Stein AS, Nordic Mining has made an agreement with NGU to provide a geological evaluation of the anorthosite deposit in the area of Gudvangen Stein's property in Nærøydalen. This report is the resulting assessment.

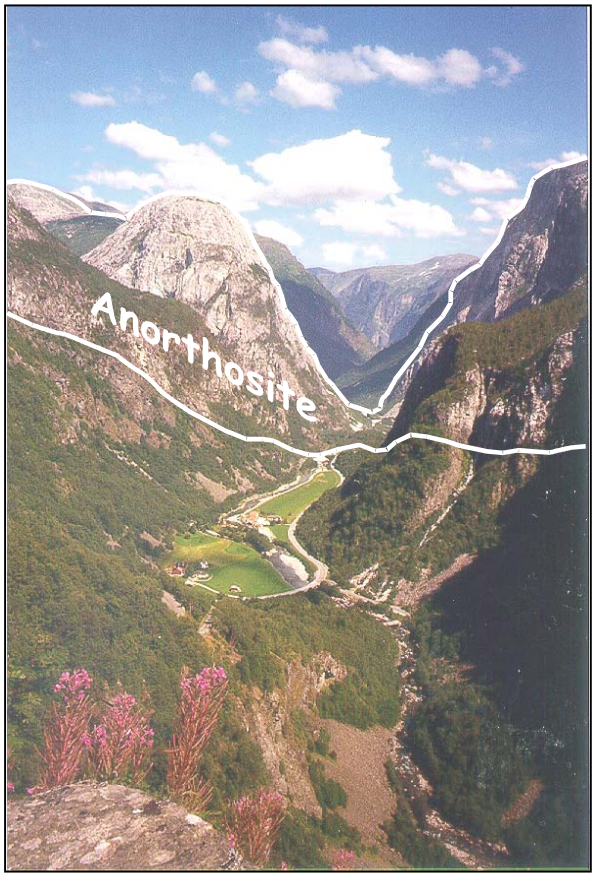

Fig.1. *The white anorthosite mountainsides are impressive in Nærøydalen. Jordalsnuten to the left.*

2. WHAT IS ANORTHOSITE

Anorthosite is an intrusive rock that constitutes at least 90% of the feldspar mineral plagioclase. Besides plagioclase the anorthosites contain dark minerals such as pyroxene, amphibole and epidote. Feldspar is a very common mineral worldwide, making up more than 50% of the earth's crust, but a variety with as high aluminium-calcium content as the Gudvangen type is rare in large and homogenous quantities. Plagioclase occurs in nature as a mixture of the sodium-rich type albite and the calcium-rich type anorthite (Fig. 5), and all grades of mixture are possible. The Inner Sogn type consists of about 60-80% anorthite and is thus especially rich in aluminium.

Of special interest in industrial applications is the fact that the plagioclase feldspar has a variable solubility in mineral acids, dependent on the anorthite content (Fig. 6). Plagioclases with 60-70% anorthite and above are soluble, while content below 50% results in a non-soluble plagioclase. This fact is vital when uses of anorthosite are considered in relation to processes involving acid leaching of the rock. However the main product at the present extractions by Gudvangen Stein is an altered anorthosite-type that is almost non-soluble in acids.

3. LOCATION OF THE ANORTHOSITIC MASSIFS IN INNER SOGN AND VOSS

The anorthosites in the inner part of the Sognefjord region cover a total area of 700 km^2 and compose the largest anorthosite complex in Western Europe. The light-coloured anorthosite massifs form larger parts of outer Aurlandsfjord and areas between Sogndal and Lærdal. (Fig. 8).

The Gudvangen Stein property is situated within the impressive massif that extends from Gudvangen in Nærøydalen and south-eastwards to Mjølfjell by the Bergen railroad line. The most spectacular parts of the steep cliff sides in Nærøydalen is the white-coloured anorthosite of this massif (Fig. 1, 2, 3 and 4).

4. EXPLORATION AND MINING HISTORY

The first investigations of the anorthosites in Sogn for industrial use were made in 1916 by the renowned geologist V. Goldschmidt. Aluminium-production based on acid leaching of anorthosite was an innovative idea, and during WW2 a mine for that purpose was opened in the northern part of Inner Sogn. The shipments were sabotaged and the operations ended. Thirty years later the Anortal-project with the companies Elkem and Årdal og Sunndal verk did thorough investigations including core-drilling program and larger processing experiments with the similar intent of using the anorthosite as a raw material for aluminium production. This effort lasted for about 5 years and established a broad knowledge base of the occurrences of anorthosite in Inner Sogn and Voss; especially the first class massif between Gudvangen and Mjølfjell by the Bergen railroad line.

Late last century the Gudvangen anorthosite was the main target for companies that evaluated the rock as raw material in applications as water cleaning agents and smelter oven linings.

Since around 1960 the white anorthosite at the bottom of Nærøydalen has been mined for various purposes, such as road aggregate, concrete elements, laundry detergent powder and toothpaste. A larger boost has come during the last ten years as the rock has become attractive as a new ingredient in producing rock wool isolation material. This end use has expanded steadily, and at present Gudvangen Stein ships to nine different rook wool plants in Europe.

5. CHEMICAL AND MINERALOGICAL QUALITY OF THE GUDVANGEN STEIN ANORTHOSITE IN NÆRØYDALEN

The Gudvangen-Mjølfjell massif that crosses Nærøydalen has as its main constituent the primary, coarse-grained violet to grey anorthosite with anorthite-content of 65-78%. Major volumes of the Gudvangen Stein property consist of this type that is easily soluble in mineral acids.

However, the existing mines in the valley (Glashammaren at the south side and Jordalsnuten at the north side) have been operating primarily on the other anorthosite variety present there. This is the white, fine-grained type that is altered from the primary, coarse-grained type (Fig. 7). The bulk chemistry of both types is about the same (see table 1), but the alteration process has replaced the primary calcium-rich feldspar with an assemblage of sodium-rich plagioclase (albite) and various other minerals such as zoisite, epidote and chlorite. This altered type is to be found at the base of the Gudvangen-Mjølfjell massif (Fig. 12, 14) and in a vertical zone along Nærøydalen (Fig. 12, 14, 15). This vertical zone is the primary geometrical factor for the presence of white anorthosite produced in the existing mines in Nærøydalen.

Table 1 Main element chemistry in wt% of the two anorthosite varieties in Nærøydalen, plus an example from the Rogaland anorthosite

Variety	SiO2	Al2O3	Fe2O3	TiO2	MgO	CaO	Na2O	K2O	LOI
Unaltered, Nærøydal	49,0	30,7	0,7	0,1	0,4	14,2	3,0	0,2	0,8
Altered, Jordalsnuten	48,2	29,9	1,5	0,2	0,7	14,0	2,9	0,3	2,2
Rogaland anorthosite	56	26	1,5		0,5	8			

6. HOMOGENEITY OF THE ANORTHOSITE DEPOSIT

The extensive investigations by the Anortal project and more recent works have showed that the major parts of the large Gudvangen-Mjølfjell massif consist of acid-soluble anorthosite. The content of dark iron-containing minerals varies somewhat within the massif; though as a whole it is fairly low. Results from previous investigations with geological mapping and core drillings from surface and underground indicate clearly that the anorthosite within the property of Gudvangen Stein is of good quality and has a fair low amount of contaminating ferrous-containing minerals.

The same evaluation of homogeneity and consistent good quality can be made in connection with the occurrence of altered fine-grained white anorthosite in the present mining area of Jordalsnuten.

It must be noted that only very minor amounts of core drilling has been undertaken in the underground areas that makes up the future reserves of anorthosite. If market and product developments results in a call for large scale mining, then a dedicated core drilling program ought to be undertaken to assure that the adequate rock qualities are available at an optimal extraction site.

7. AVAILABLE QUANTITIES AND MINING SUITABILITY

The mountains in the Nærøydalen area are steep and rise to over 1000 m. In total, about 1 billion tons of anorthosite are present above river level at the 900.000 m^2 Gudvangen Stein property on both sides of the valley. How much of this is feasible to mine is not a topic to speculate about in this report, though high internal rock pressure might be a challenge when mining with several hundred meters of overburden. Anyhow the vast volumes of anorthosite present in the adjoining areas southwards secures that billions of tons of good quality anorthosite are available in the Nærøydalen area.

7.1 Unaltered, primary anorthosite

At present the primary product of Gudvangen Stein is as rock wool raw material, and for this purpose both altered and unaltered anorthosite is usable. This is advantageous in evaluation of future mining possibilities as the unaltered anorthosite is occupying the main volume of the anorthosite at the 900.000 m^2 Gudvangen Stein property on both sides of the valley (Fig. 12).

Knowledge about the geometric positions of the two main anorthosite varieties is based on core drilling and geological mapping and sampling of the lower mountainsides above the mining areas at both sides of the valley.

Surface investigations have revealed that unaltered anorthosite is present from the back top of Glashammaren and then further upward in the mountainside. At Jordalsnuten, surface mapping and sampling has shown that altered anorthosite is present up to about 100 m above the present mining levels, and that unaltered anorthosite is present at higher levels of the mountainside (Fig. 12).

An extensive core drilling program and other geological surveys of the anorthosite at the mountain plateau during the Anortal-project in 1977-79 showed that primary, acid-soluble anorthosite is totally dominating the large massif southwards from Nærøydalen. The massif as a whole covers an area of approximately 150 km^2, and with a thickness of up to 2000 m the anorthosite volumes contain hundred of billions of tons of such primary anorthosite. Practically unlimited volumes of this quality are considered to be available for mining underground from Nærøydalen.

Core drilling from the inner part of the mines (Fig 12, 13, 15)), shows that primary, unaltered anorthosite is highly dominating also inwards from the altered zone at both sides of the valley.

7.2 Altered, white anorthosite zones

Fine-grained, altered white anorthosite is present alongside Nærøydalen in a zone with horizontal thickness of about 150 m from the surface of the base of the mountainside of Jordalsnuten (Fig.12, 15). This is the observed situation in the present mining area. From the mining drifts there is still some 500 m's of anorthosite to go at the company's own property alongside the valley in the direction of Gudvangen (Fig. 4), and even though there has not

been detailed geological mapping and sampling along this part of the zone yet, the altered anorthosite is expected to be present there.

Initial surface mapping and sampling has shown that the altered zone extends to almost 100 m above present mine levels in Jordalsnuten (Fig. 12). Supplemental surface mapping needs to be done to acquire more details on the eastward extent of the zone, but present information indicate that around 10 million tons of altered white anorthosite is probably present within Gudvangen Stein's property in Jordalsnuten above valley bottom level. Up to 40% of this might be possible to extract from the mine.

The altered white anorthosite extends both upward and downward from the existing mining areas. The base of the Gudvangen-Mjølfjell massif consists of a tectonically altered zone with white anorthosite (Fig. 12 and 14). In Nærøydalen this zone is considered to be present immediately below the mining levels, and based on the observed anorthosite borders in Nærøydalen, white anorthosite can be expected to extend about 200 m below the existing mine in Jordalsnuten. At the base this altered zone extends laterally in all directions, and thus large volumes of white anorthosite is present. Tens of millions of tons of this quality is expected to be available there.

At Glashammaren area only limited amounts of altered anorthosite seems to be left in the existing mining level. Besides the location is today used as a tourist mine. Below the valley bottom level though, the same white anorthosite extends downward, and the tectonically altered base zone is to be expected underneath as at Jordalsnuten. The geometric location of this base-sole is not investigated at the south side of the valley either, and only diamond drilling downwards can give exact data about this. Probably this altered zone is available close below the mine-level, and larger volumes of this type are expected to be present for future mining there as at Jordalsnuten.

7.3 Mining conditions.

At a recent inspection of the Jordalsnuten mine, the modern and well-planned mining operations was observed. In the earlier years of mining during the second half of last century, the mining operation was of minor scale. Tunnel dimensions were small and the mining plans and layout of the mining was unsystematic.

As the new phase emerged early this century where larger quantities started to be purchased by the European rock wool industry, the Gudvangen Stein Company upgraded and modernized the mining planning to the well-functioning drift system that is in full operation today. A horizontal cross-section with both old and new mine drifts is illustrated in Fig. 15. There are now several adits at the base of the anorthosite mountainside facilitating mining at several locations simultaneously. Thus mixing of various anorthosite qualities is possible when needed to obtain the proper product in accordance with the customers' specifications. The mining method is room and pillar with drift dimensions of 19x16 m in the crosscuts.

The present mining in the Jordalsnuten is primarily done in the altered zone of the large anorthosite body (Fig. 15), where the characteristic fine-grained dull white and light-grey anorthosite dominates. This quality is preferable to asphalt purposes and well suitable for other markets such as the rock wool industries.

The main new transport drift for the mining area in Jordalsnuten is placed in the border area towards unaltered primary anorthosite (Fig. 15), and for potential purposes that require soluble anorthosite this provides easy admission to start mining northwards from this same transport drift. Future operations are planned eastwards maintaining this same ideal placement of main transport drifts along the border zone between altered and unaltered rock.

If extraction of large quantities of unaltered anorthosite proves attractive in the future, then mining well inside the mountains in the valley is necessary. The large overburden might then give some challenges to handle in relation to rock pressure. The anorthosite has good rock mechanical properties though, and large-scale mining is considered to be a viable future option.

Concerning the altered anorthosite, much mass is available in more surface-near parts with moderate rock pressure at both sides of the valley. If future demand makes extraction of larger volumes of the altered variety needed, then one might want to go downward and inward in the altered base zone and similar issues regarding high rock pressure will have to be considered and handled.

8. PRESENT AND POTENTIAL USES OF THE ANORTHOSITE IN THE GUDVANGEN AREA

Traditionally the anorthosite of the Gudvangen area has been mined for applications where the whiteness of the material is of high importance. Uses such as toothpaste, washing powder, aggregate for road surfaces and light coloured concrete elements are examples of the scope of products that has given the owners some profit during the years.

These applications have thus mainly been based on the physical properties of the feldspar rock.

In the rock wool application the colour is not important, and this main product area today is based on the chemical constituency of the anorthosite rock, with the high aluminium-content being the primary ingredient as a cost-competitive substitute of otherwise used expensive aluminium additives.

The high aluminium content of the Inner Sogn anorthosite is well known, and to use the rock as a possible alternative raw material for aluminium production has been the target for various companies during dedicated periods throughout nearly a century.

The scope of potential uses of anorthosite is large, and table 2 gives an overview of many alternative applications. The list is divided in four main categories according to type of processing:

1 Crushed/milled; uses based on physical characteristics.
2 Chemically treated by acid or other dissolving agents.
3 Melting of the anorthosite.

Table 2 Overview of various potential uses of anorthosites.

Processing	**Products**	**Uses**	Specifics
Physical. (dry or wet mineral processing)	Plagioclase grains with crystal structure intact	Aggregates	Light coloured road surfaces, gardens
		Building materials	Concrete elements, dimension stone, industrial floors
		Abrasives	Scouring powder, toothpaste, sand blasting
		Fillers, Extenders, coatings	Paint, plastics, rubber, paper
Chemical (acid or alkaline leaching)	Aluminium chloride	Aluminium metal	
	Aluminium oxide (alumina)	Flocculent	Water and waste water treatment
	Aluminium sulphate (alum)	Flocculent/sizing	Paper manufacture
	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
		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	Rock wool
		Welding fluxes	
		Al-production cells	Cryolite bath insulation
		Slag conditioner	Ferrosilicon and silicon-metal
	Direct reduction	Al-Si-alloys, Al- and Si- metal	

As a special remark regarding the potential applications of anorthosite one might mention that the light-coloured areas of the Moon's surface consists mainly of anorthite. At a web-site of NASA (Mining and Manufacturing on the Moon) this fact is highlighted as a possible source for mining and utilizing the rock as raw material for producing aluminium, calcium and silica for metal-production and major ingredients in manufacturing of fibreglass and other glass and ceramic products.

9. THE ANORTHOSITE DEPOSITS IN NÆRØYDALEN COMPARED TO OTHER ANORTHOSITE BODIES IN THE INNER SOGN AREA

The anorthosite bodies of the Inner Sogn region have as their main characteristic and asset, this calcium-aluminium rich plagioclase feldspar that is relatively rare both in Norway and worldwide. The composition of the anorthosite varies somewhat also within the Inner Sogn anorthosites, and except for smaller pockets of Ca-Al-rich areas in the middle and northern parts of the complex, the major part of the Gudvangen-Mjølfjell body stands out as being thoroughly dominated by the most Ca-Al-rich anorthosite (Fig. 9). The anorthosite within the property of Gudvangen Stein is situated in the northern part of this large body and contains thus the easily soluble type in addition to the altered white variety within the present mining area.

The Gudvangen-Mjølfjell anorthosite body is also proven to be especially low in its content of contaminating dark ferrous-mineral, compared to the areas further north in the large anorthosite complex of Inner Sogn (Fig. 10).

10. COMPARISON WITH OTHER NORWEGIAN ANORTHOSITE OCCURRENCES

Norway has a rich variety of anorthosite bodies in various parts of the country (Fig. 8). The largest complex is the Inner Sogn–Voss with Nærøydalen, but also in the Bergen-area and Rogaland south of Stavanger, large occurrences of anorthosite deposits occur. In contrast to the Inner Sogn anorthosites, all these other anorthosite occurrences (with minor exceptions) have a feldspar that is distinctly lower in aluminium and calcium. Thus, only the Inner Sogn anorthosite is soluble in acids and its higher aluminium content makes it definitely preferable for rock wool production.

Regarding physical properties and whiteness, the white anorthosites near Egersund in the south westernmost part of Norway have their established marked shares in some ceramics and road top-layer applications. However the white altered anorthosite of Gudvangen Stein has a distinct better PSV (polished stone value) and is thus preferred in special asphalt applications where a non-slip road surface is wanted. This same advantage seems to be the case compared to other known Norwegian white anorthosite deposits. Some of the other have a better proximity to the sea compared to the Jordalsnuten mine and have accordingly some more advantageous transport costs.

11. COMPARISON WITH ANORTHOSITES WORLDWIDE

The anorthosite complex in Inner Sogn is the largest in Western Europe. (The massifs in Rogaland, Norway being the second largest). Worldwide larger massifs occur, but the combination of large homogenous volumes of high aluminium, low iron anorthosite close to the coast is hard to find elsewhere. No occurrences are known today that is compatible with the Gudvangen anorthosite with respect to the above-mentioned criteria.

12. MINING WITHIN A WORLD HERITAGE AND PROTECTED LANDSCAPE AREA?

In 2005 the Nærøyfjord area was added to UNESCO's World Heritage List. Prior to this, in 2002, main part of the Nærøyfjord and surrounding areas were made a protected landscape area; though the inhabited areas in the valley are exempt. This includes the present outside workings and adits of Gudvangen Stein. There is made room in the regulation rules of the landscape area for the existing underground mining to continue. Open quarrying is not allowed but further underground developments are feasible as long as accommodation to the environment is prioritised, concerning outside facilities, transport and shipments. World Heritage status for the area would be possible to maintain in a balanced combination with environmentally cautious anorthosite extraction procedures.

13. SUMMARY

- Large quantities of an unusually aluminium-calcium rich anorthosite are present at the property of Gudvangen Stein A/S in Nærøydalen. The property forms part of a 100km^2 large anorthosite massif extending 25 km south-eastwards towards Mjølfjell at the Bergen railroad.

- Two main varieties of anorthosite are present within the mining area of Nærøydalen. One type is a primary anorthosite where the almost monomineralic feldspar content is soluble in acids and thus well suited for processing that requires dissolving of the minerals. The second type is altered and fine-grained, with a white colour well suited for applications requiring light or white materials. Both types are well-suited material for rock wool production.

- This aluminium-calcium-rich anorthosite is hard to find both in Norway and worldwide in large and homogenous quantities as in Nærøydalen. The Gudvangen deposit is world class in this category.

- Millions of tons of anorthosite occur within Gudvangen Stein's property, and additional immense quantities are present in adjoining areas of the large Gudvangen-Mjølfjell anorthosite-massif. Thus raw material resources are practically unlimited.

- Anorthosite has a wide range of potential uses, and the aluminium-calcium rich variety of the Gudvangen area has especially varied possible applications in addition to the present established markets of rock wool, asphalt and concrete.

- The regulations of the Protected Landscape area and the recently acquired status of the Nærøyfjord region as a World Heritage Site gives room for further developments underground, based on the current mining areas of Gudvangen Stein. Environmental concerns are important, and future workings must not come in conflict with the protection regulations and any World Heritage status for the area.

- The newly upgraded mining system at Jordalsnuten provides flexibility to handle both present production capacity and medium scale future expansion.

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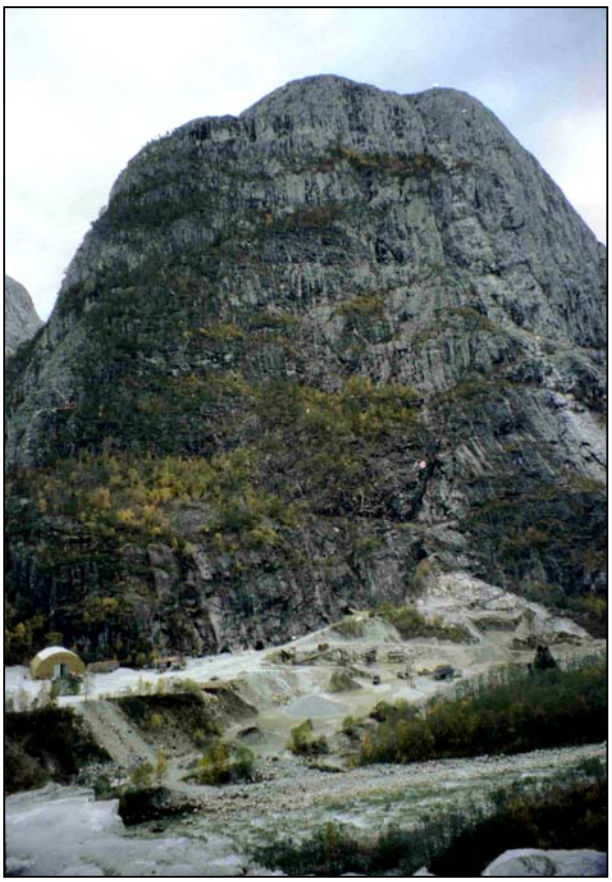


Fig. 2. Jordalsnuten

Fig.3. Glashammaren

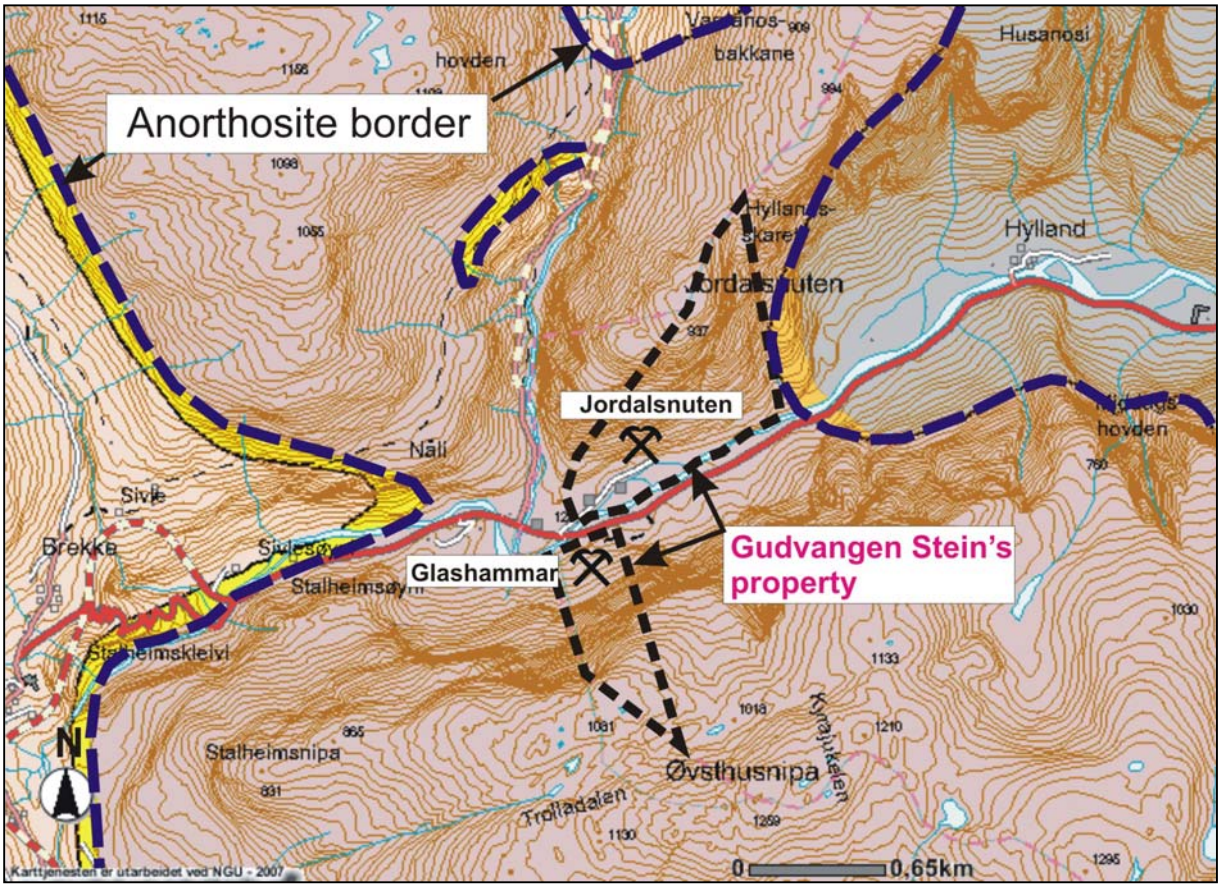


Fig. 4. Gudvangen Stein's property and distribution of anorthosite in Nærøydalen

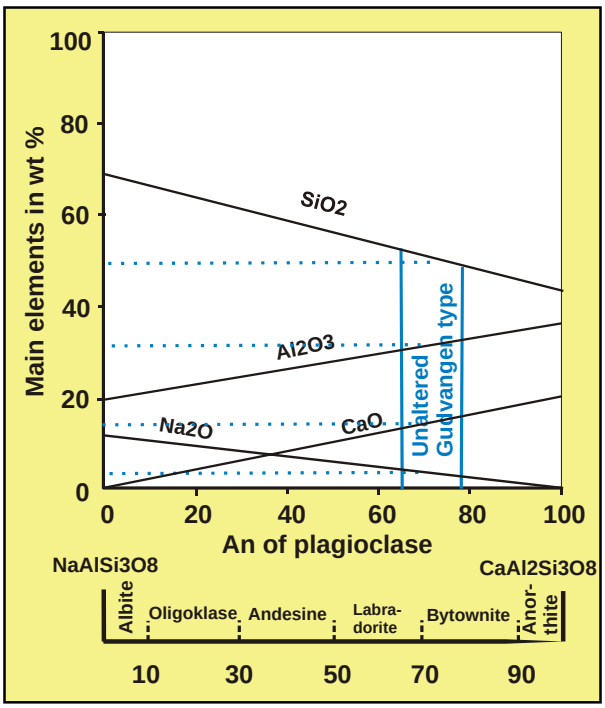


Fig. 5. Chemical composition of various plagiclases

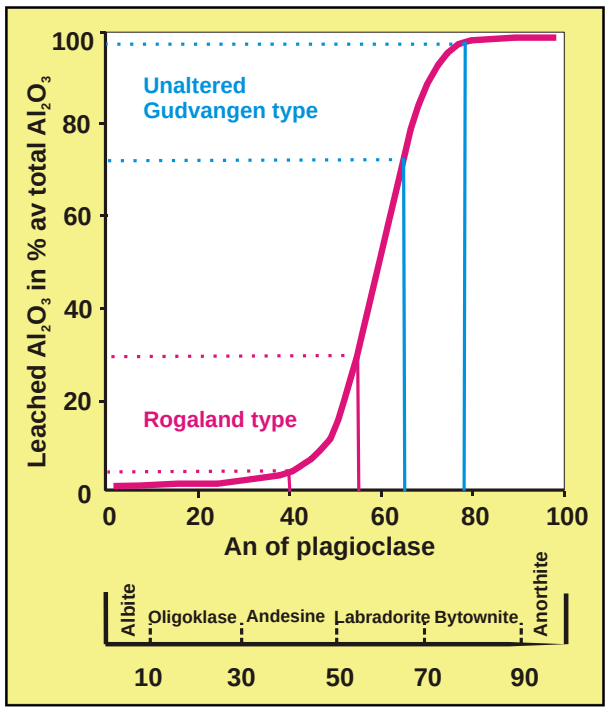


Fig. 6. Variable acid solubility of plagioclases

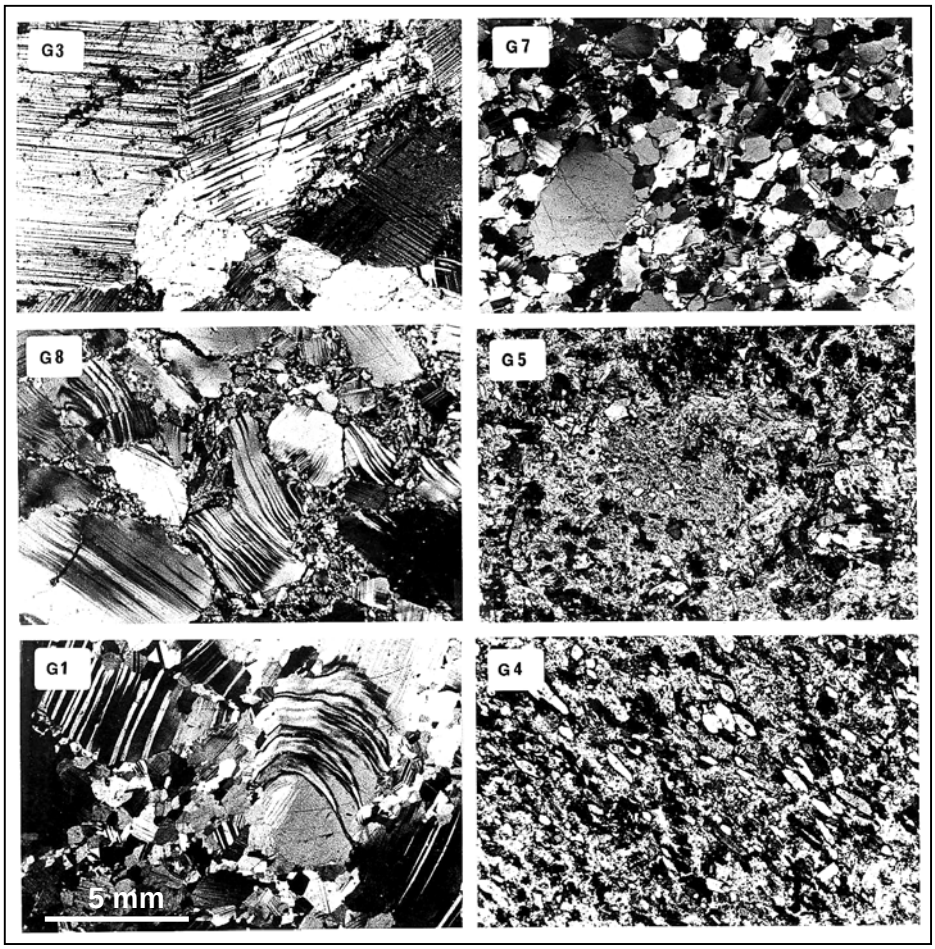


Fig. 7. Microscope photos of various grades of alteration of primary anorthosite. Unaltered top left; heavy altered, bottom right.

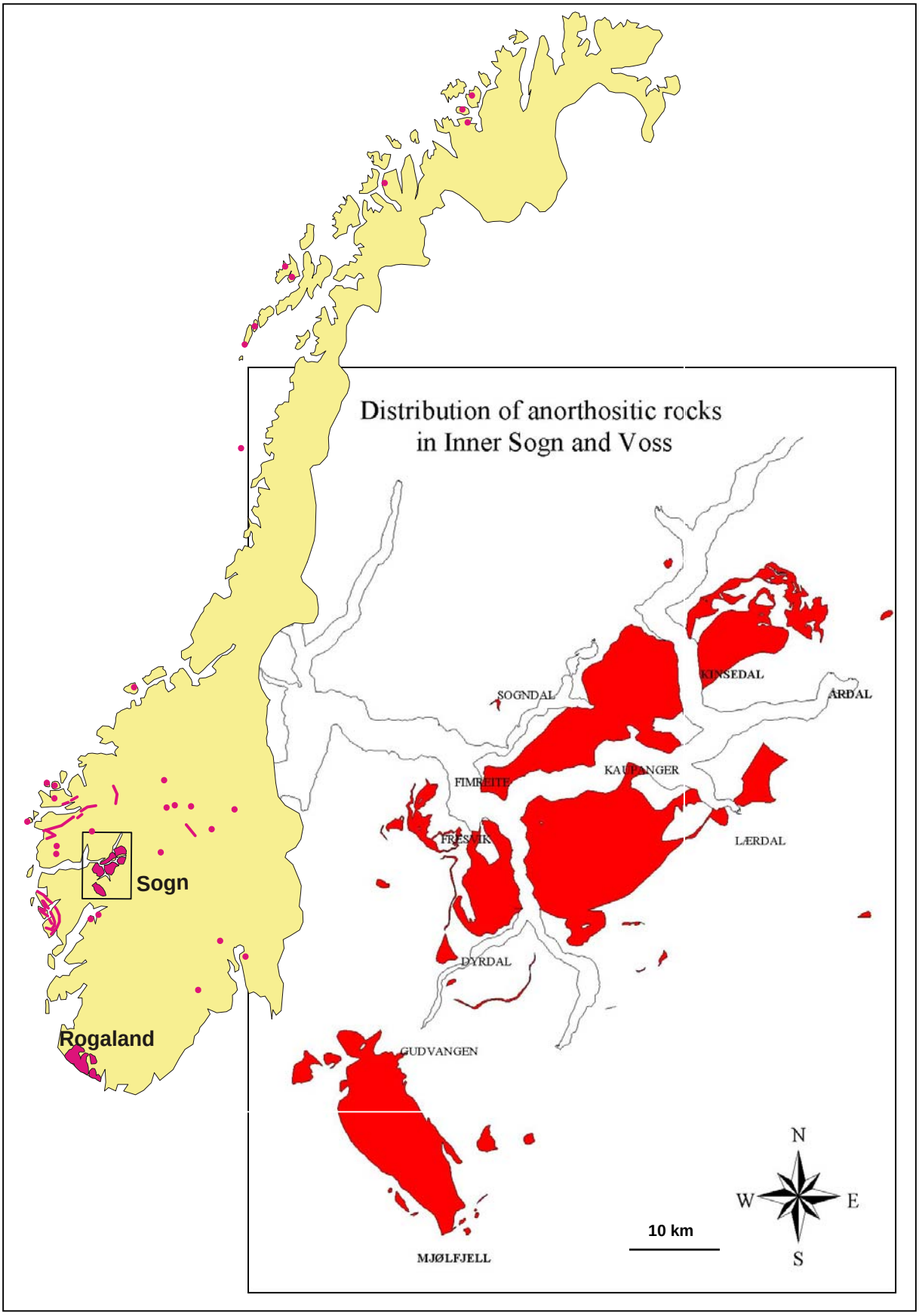


Fig. 8. Distribution of anorthositic rocks in the Inner Sogn and Voss area in perspective to other anorthosite localities in Norway.

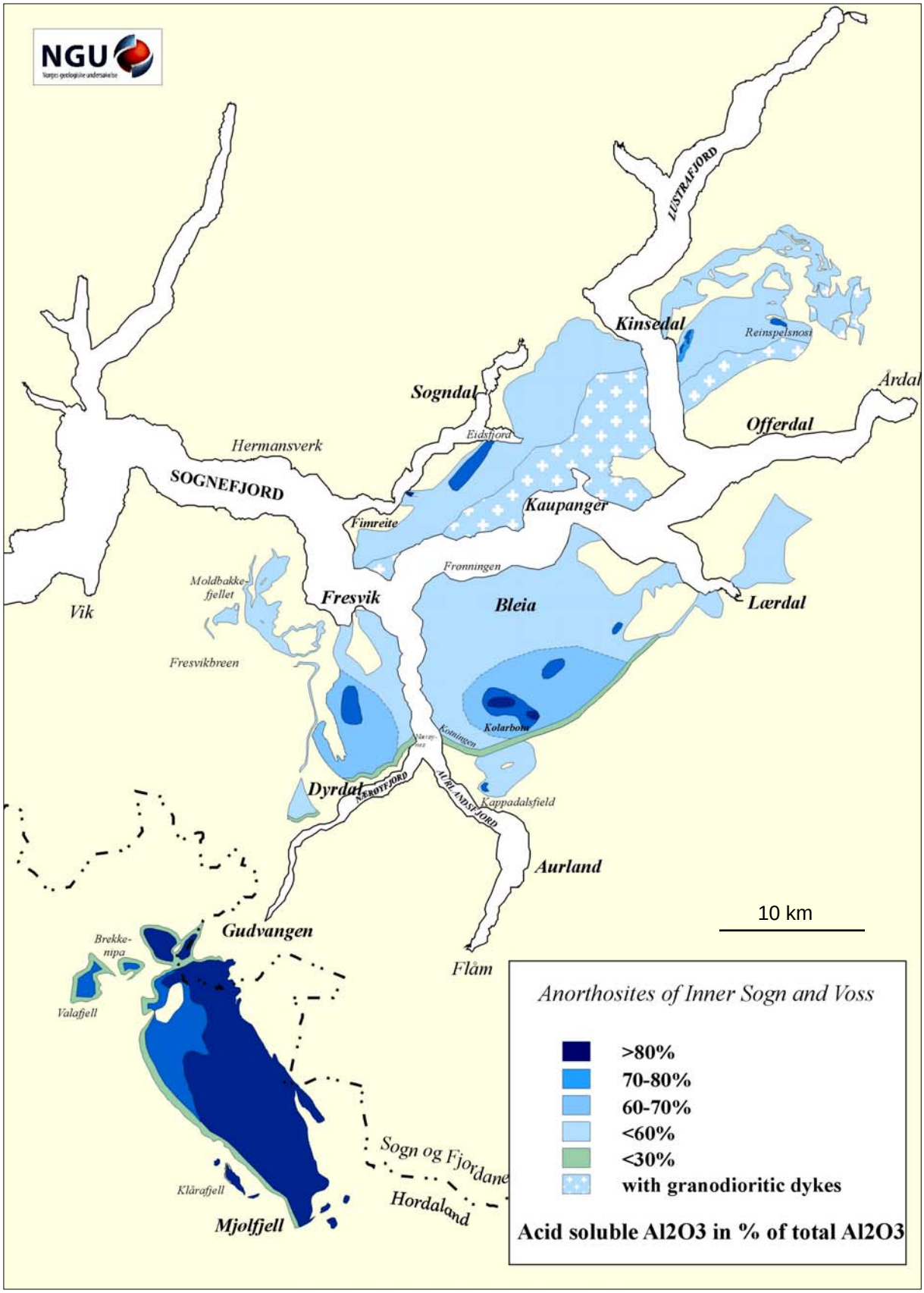


Fig. 9. Acid solubility of the anorthosite bodies of Inner Sogn and Voss

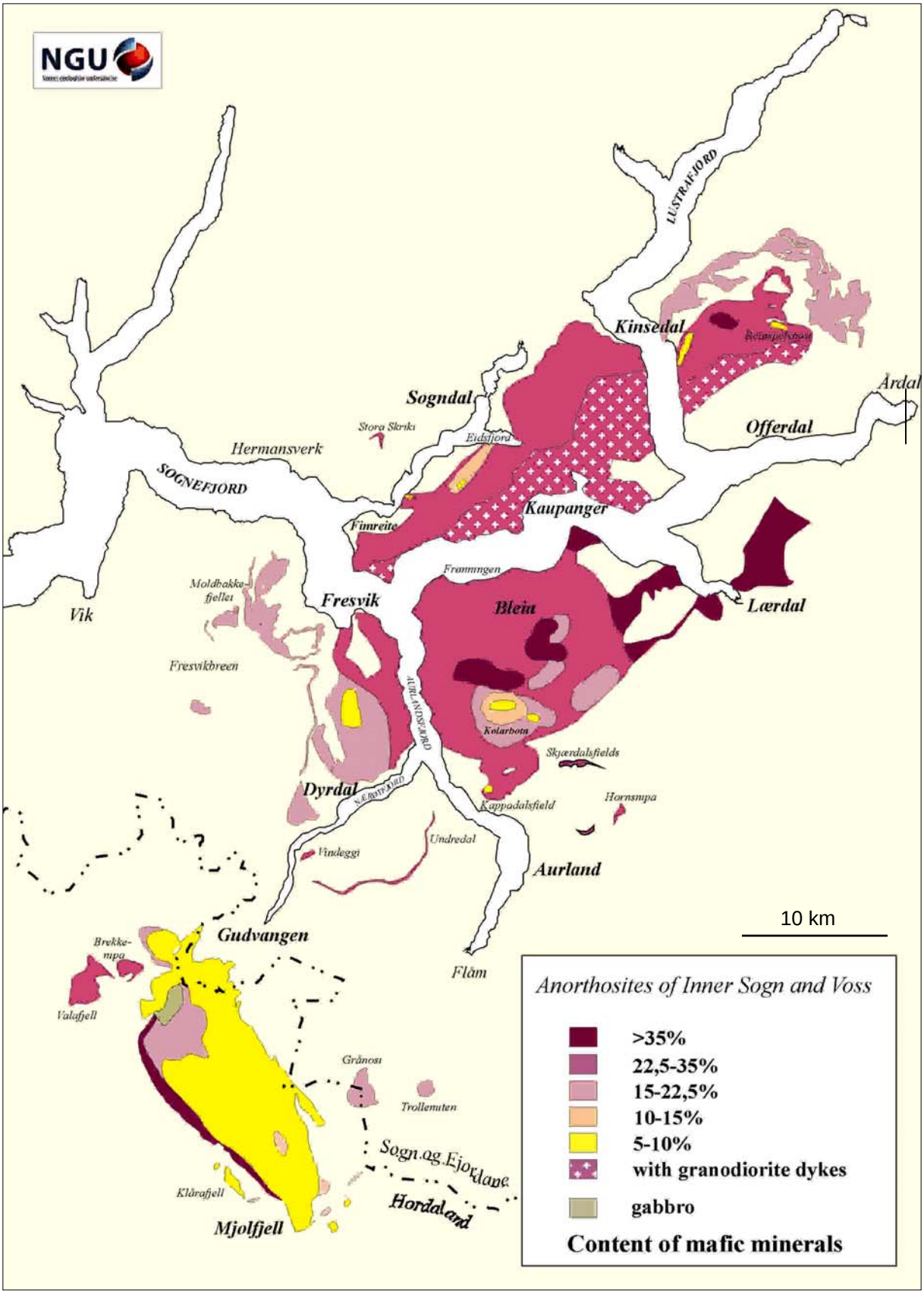


Fig. 10. Dark mineral content of anorthosites in Inner Sogn and Voss

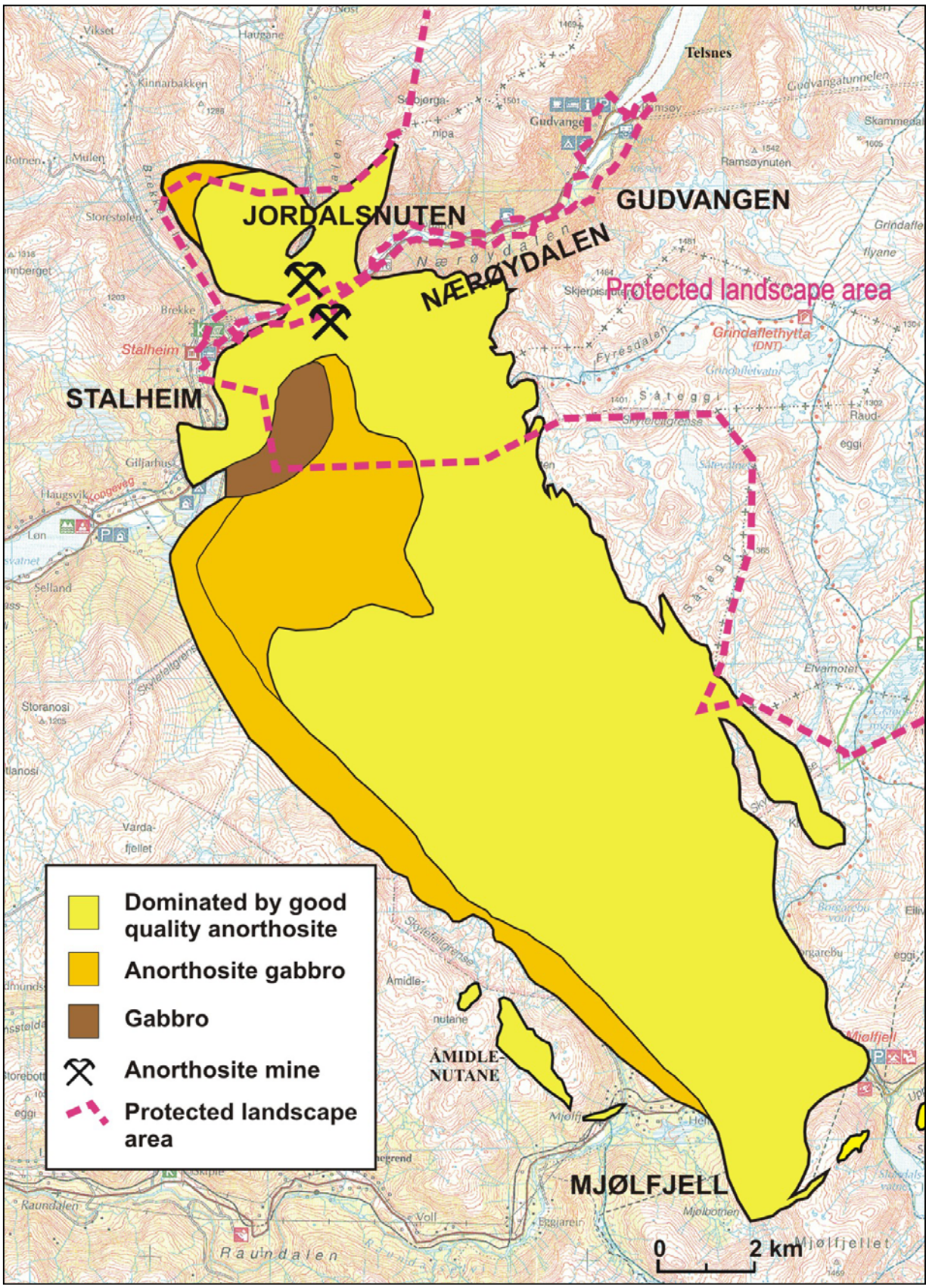


Fig. 11. The Gudvangen-Mjølfjell anorthosite massif

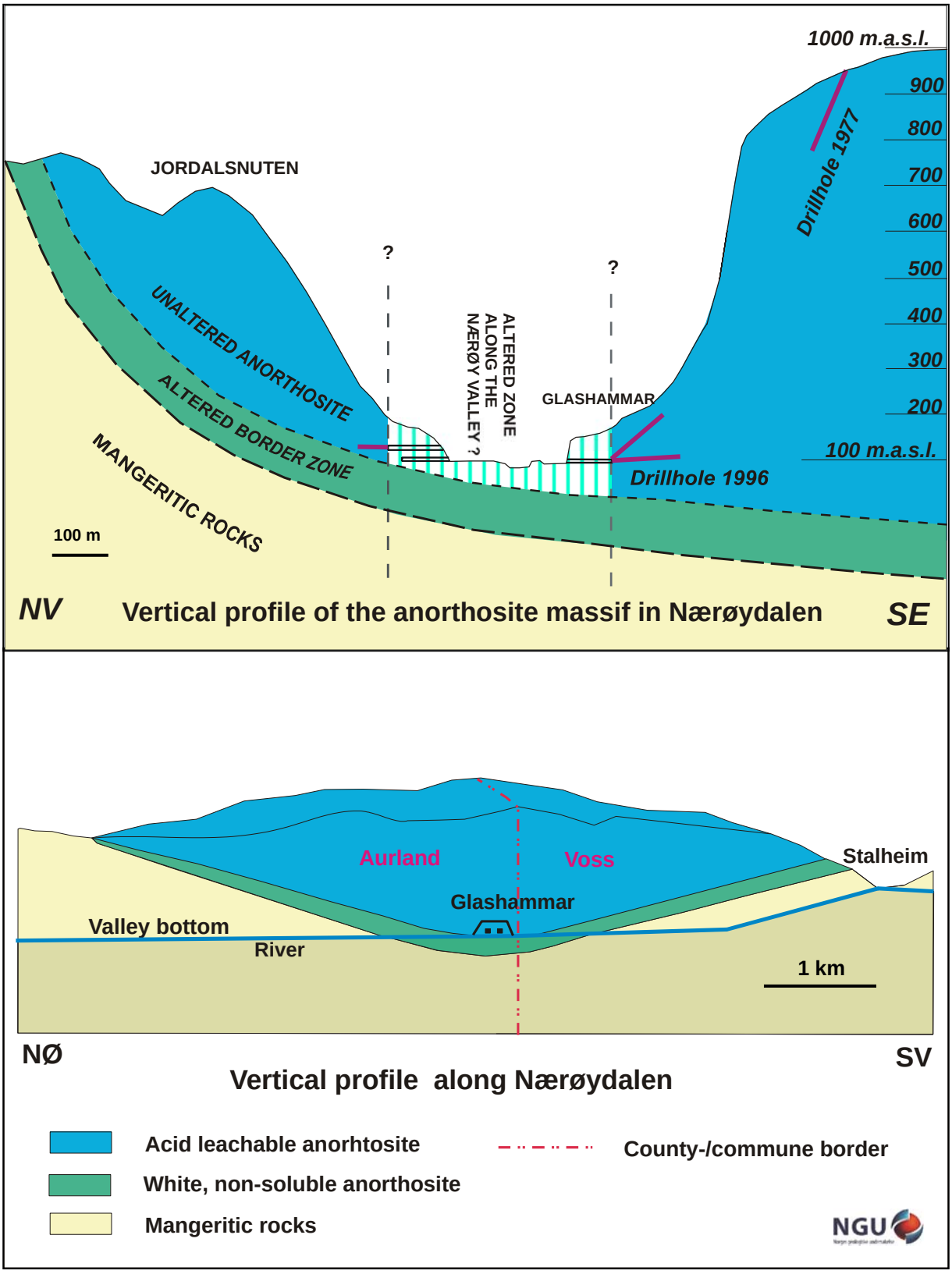
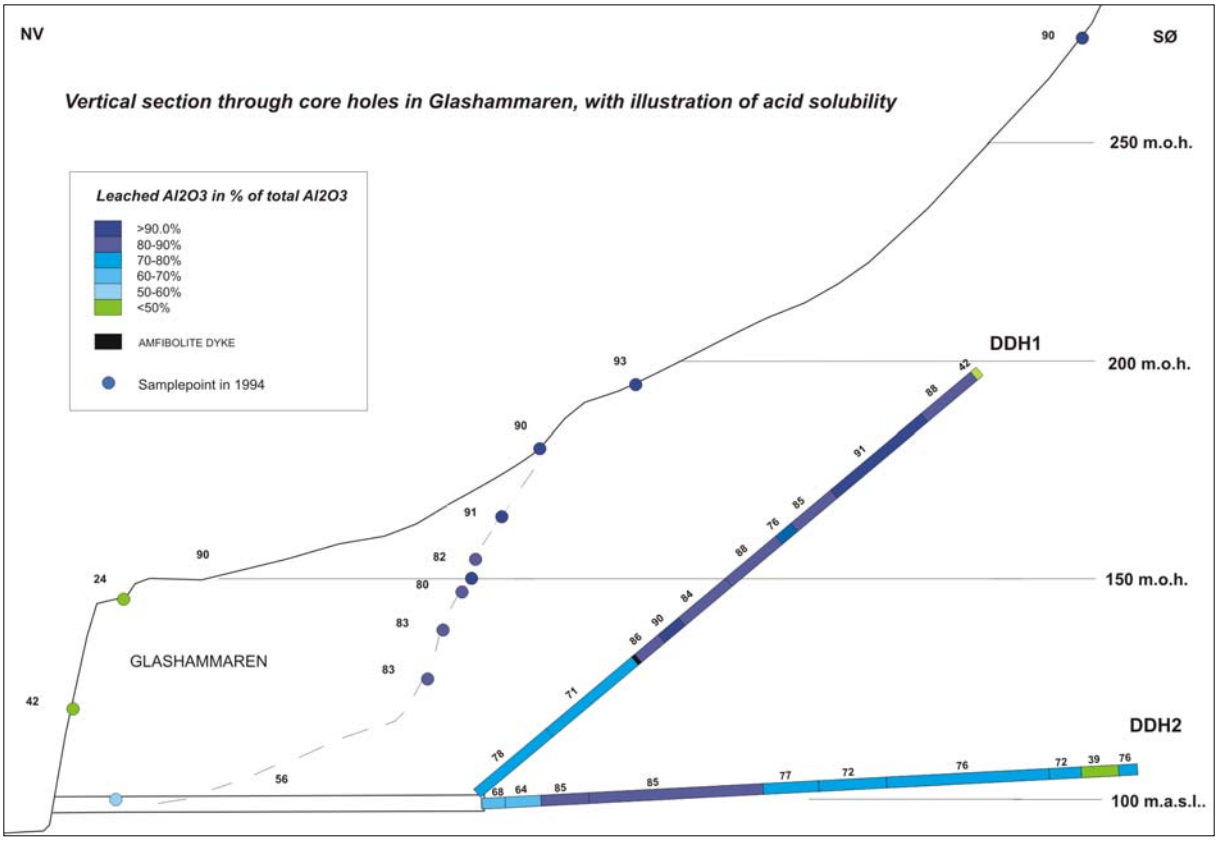


Fig. 12. Vertical sections of the anorthosite massif in Nærøydalen



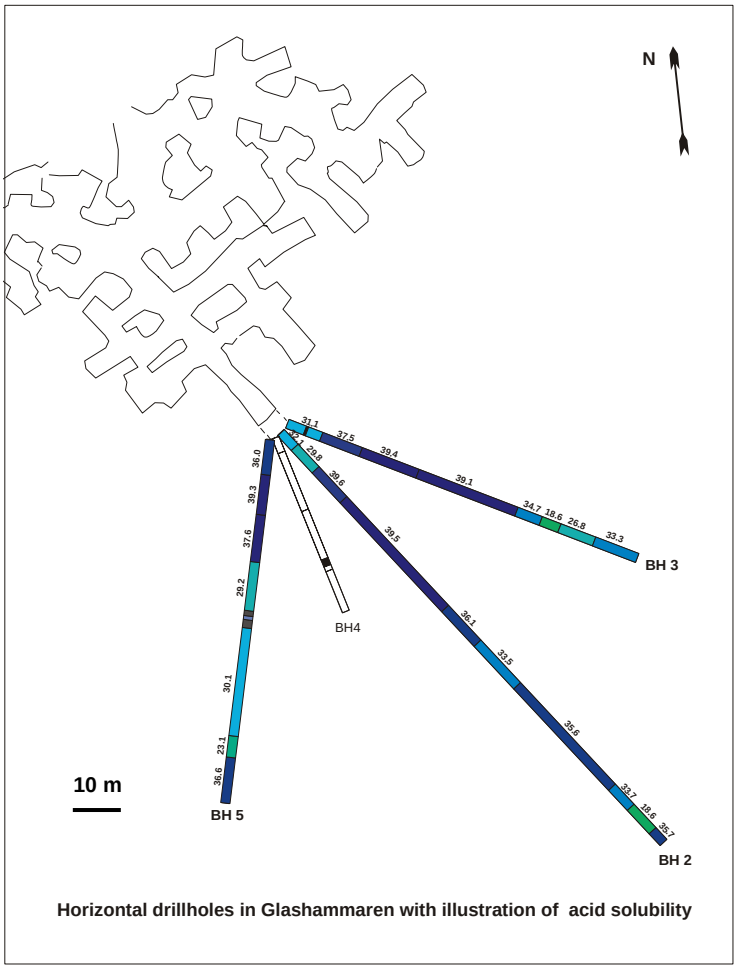


Figure 13 Section trough core drill holes in Glashammaren

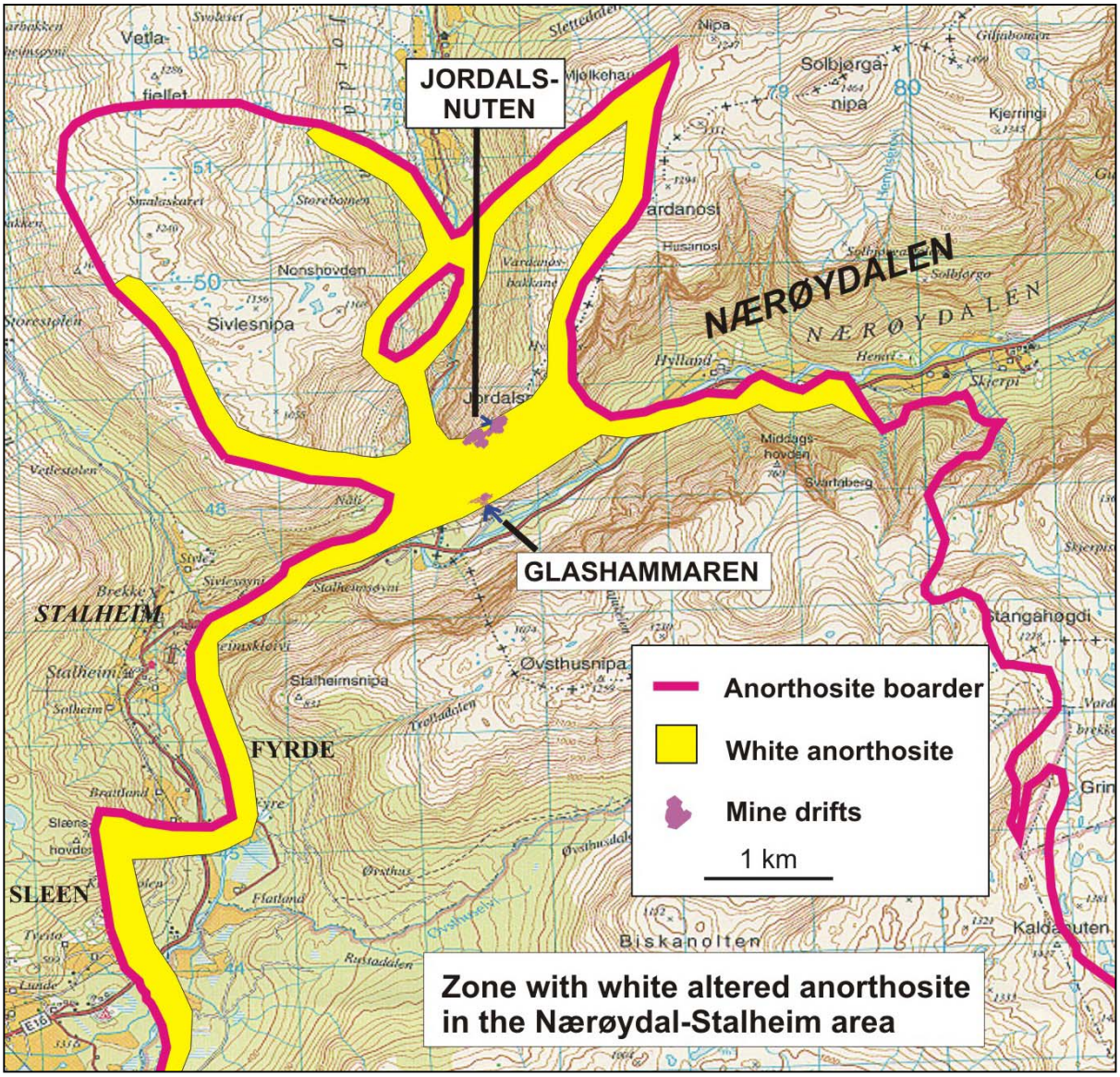


Fig.14. Zone with white altered anorthosite along border of the Gudvangen-Mjølfjell massif and along Nærøydalen

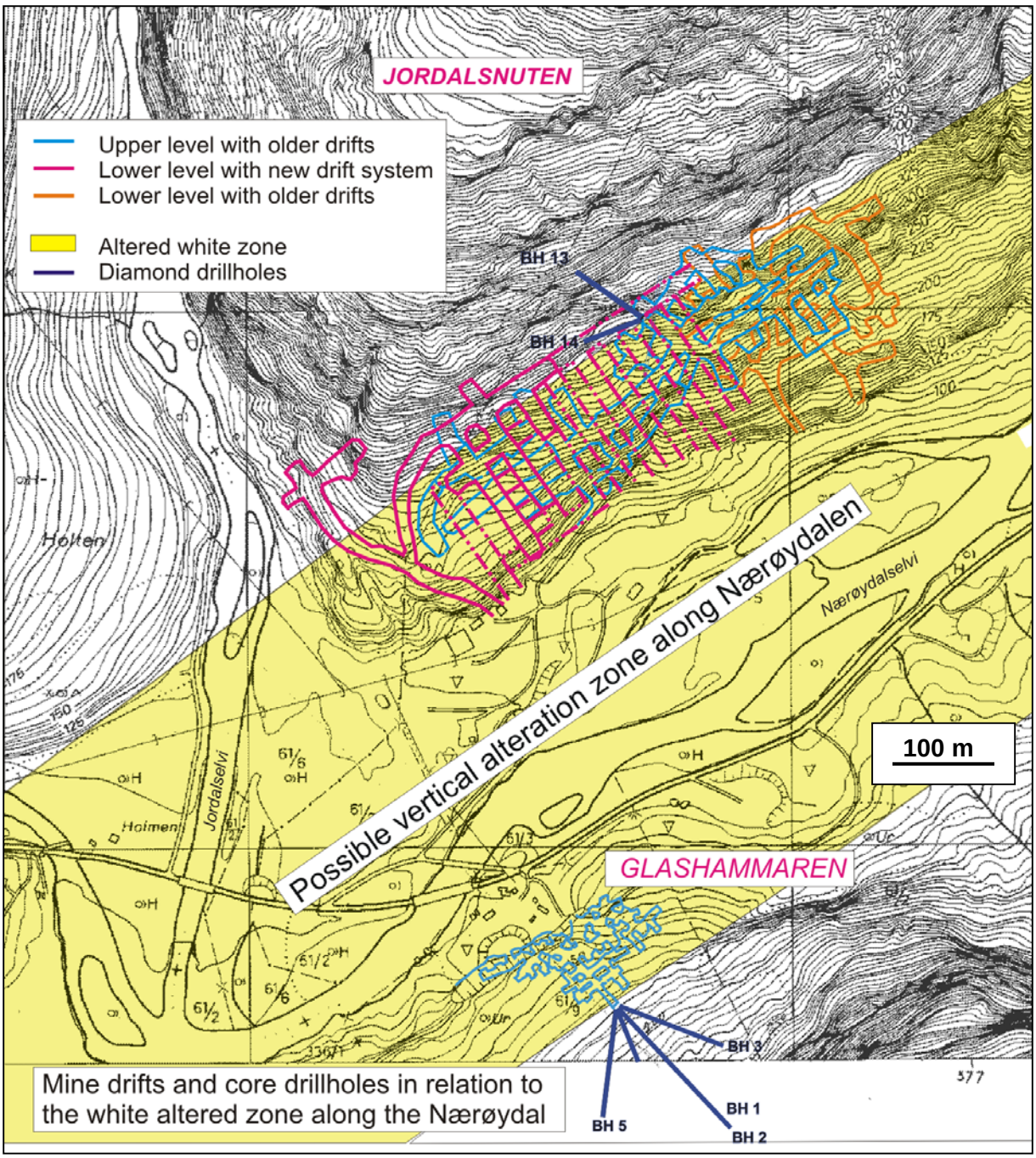


Fig. 15. Location of the observed vertical alteration zone in the mining area in Nærøydalen.