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Kyanite investigations in Tverrådalen, Surnadal

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REPORT

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Title:
Kyanite investigations in Tverrådalen, Surnadal

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Map-sheet name (M=1:250.000) Ålesund	Map-sheet no. and -name (M=1:50.000) 1420 -1 Snota
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Summary:

A kyanite-quartzite south-east of Skei in Surnadal has been investigated by field sampling and core drilling with Pack Sack equipment. The 5-6 m thick layer, identified only in a single outcrop, has an average kyanite content of 30% according to analyses of the drill cores. The deposit has a near vertical plunge and the lateral extension is unknown, due to lack of outcrops.

The kyanite is small-grained (minus 0.5 mm) and looks pure in microscope. A good kyanite concentrate with 61.6% Al_2O_3 has been obtained in a small laboratory test using heavy liquids.

Further investigations would necessitate flotation testing to evaluate the product potential, and conventional diamond drilling to verify the volume potential of the deposit.

Keywords:

industrimineraler	kyanitt	kvarts
muskovitt	kjerneboring	fagrapport

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1 INTRODUCTION

NGU was contacted by Olav Sæter from Surnadal in late 1996. He presented us with some samples of quartzite that he had localised at his property in Tverrådalen. Previous to this specimens had been investigated by Lisbeth Alnæs (SINTEF), Inge Bryhni (Geological Museum in Oslo) and Nils E. Johannessen (North Cape Minerals A/S at Lillesand) at the initiative of Mr. Sæter. They all stated that the rock contained major amounts of kyanite, content varying from 27 to 40%. Sæter now wanted NGU to investigate the potential of the deposit with a field survey.

After testing a sample by a laboratory method using fluoric acid documenting 36% kyanite as a result, we agreed on carrying out field work in Surnadal.

Further sampling of the deposit by NGU showed an average kyanite content of 31%. Olav Sæter then contacted Ola Øverlie at A/S Olivin and an agreement of co-operation was established making some diamond drilling possible.

The field geologist was Jan Egil Wanvik, the diamond drilling has been done by Norodd Meisfjord and Rolf Lynum

2 LOCALITY

The deposit is situated about 11 km by road SE of the community centre Skei at the innermost part of Østbødalen. (Fig.1). The valley is here called Tverrådalen and the kyanite is found on the southern slope of the rather steep valley at a level 100m above the river that here lies at 200 m. above sea level. The outcrop of kyanite-quartzite is about 10x5m in size (see figures 2 and 3). The distance to possible seaport is about 15 km.

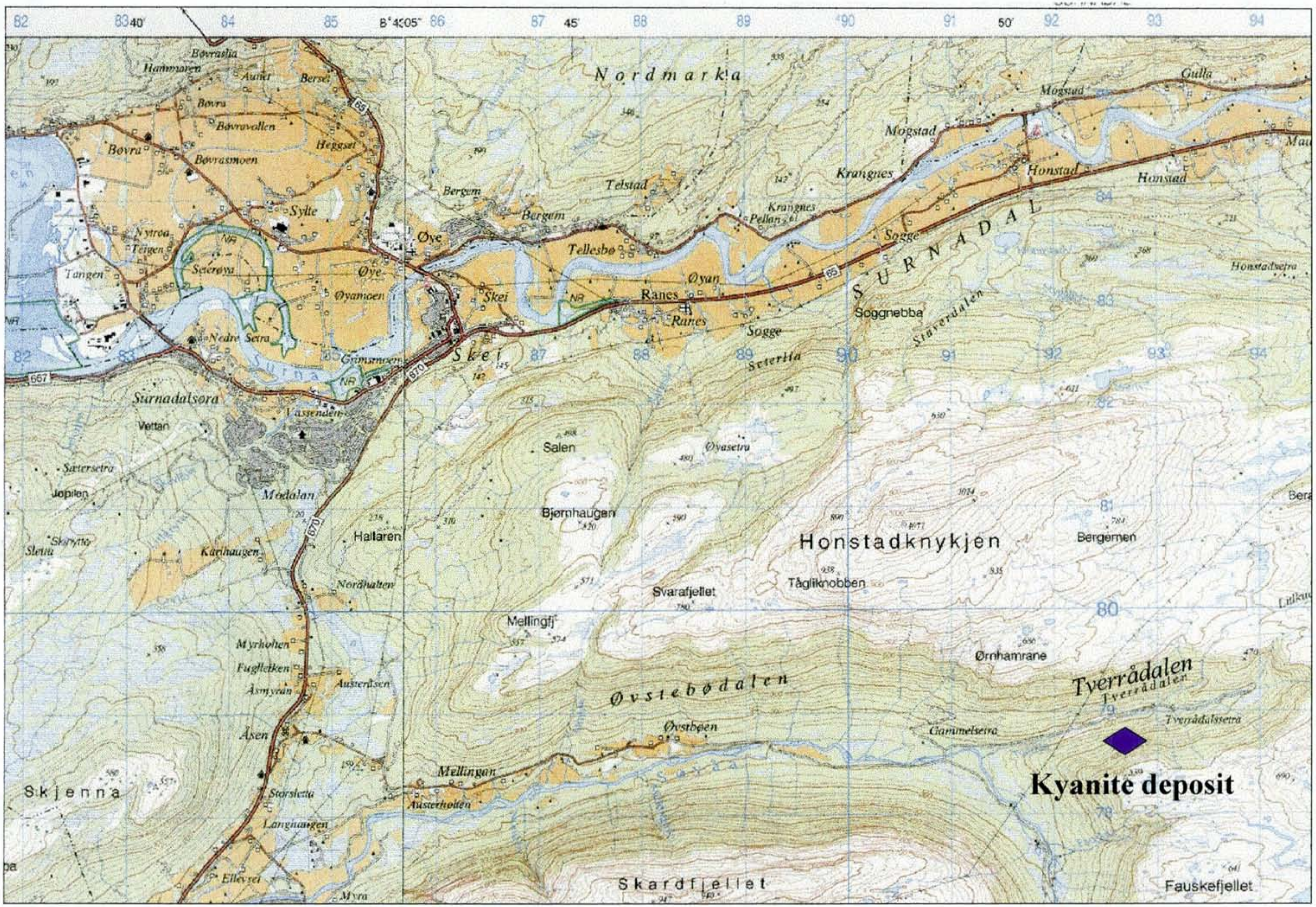

Figure 1 Locality of the kyanite deposit. 1:50.000.

Figure 2 Kyanite outcrop, seen from NW. Pack Sack drilling.

Figure 3 The outcrop, seen from NE.

3 GEOLOGICAL SETTING

The deposit is situated in the border area between the basal gneiss units and the Caledonian nappe rocks that extends from the Trondheim region along Surnadal and further westwards to the Molde area.

The most detailed mapping in the area has been done by Tørudbakken (1982), and on his 1:50.000 map, a fairly narrow meta-arkose/quartzite extends along the Tverrådalen and eastwards over Kufjellet and into Vinddøldalen. On both the southern and northern side, this arkose borders to a granitic gneiss. The kyanite outcrop is situated about 100-200m south of the arkose unit as mapped by Tørudbakken. See geological map, figure 4.

4 FIELD WORK

Field work started by examining and sampling the kyanite-quartzite outcrop that Olav Sæter had found. The rock is massive fine-grained and has a grey colour. There also appear marked spots and bands with reddish colour. This colour was the reason why Olav Sæter took samples. He thought the colour was caused by a rutile content. By microscopy, the high kyanite content was revealed, but the presence of rutile was also confirmed. The red colour is indeed caused by rutile, and the content, according to chemical analyses is slightly above 0.5%.

The kyanite of the rock is visible on the outcrop at fresh surface by a slightly bluish-grey colour, and the kyanite seems to be rather evenly scattered in the part of the deposit that is visible in the outcrop. In table 1 the kyanite content of some samples collected from various parts of the outcrop is given.

Tabell 1 Kyanite content of various samples from the outcrop

Sample	5	6	7	8	9	Average
Kyanite %	24,8	45,6	19,0	43,68	22,18	31,05

The outcrop is not large, and finding more outcrops was naturally of high priority. The foliation of the outcrop is parallel to the neighbouring gneisses and the valley itself, and the dip is almost vertical (80° S). A search for additional outcrops, both eastwards and westwards, was then carried out.

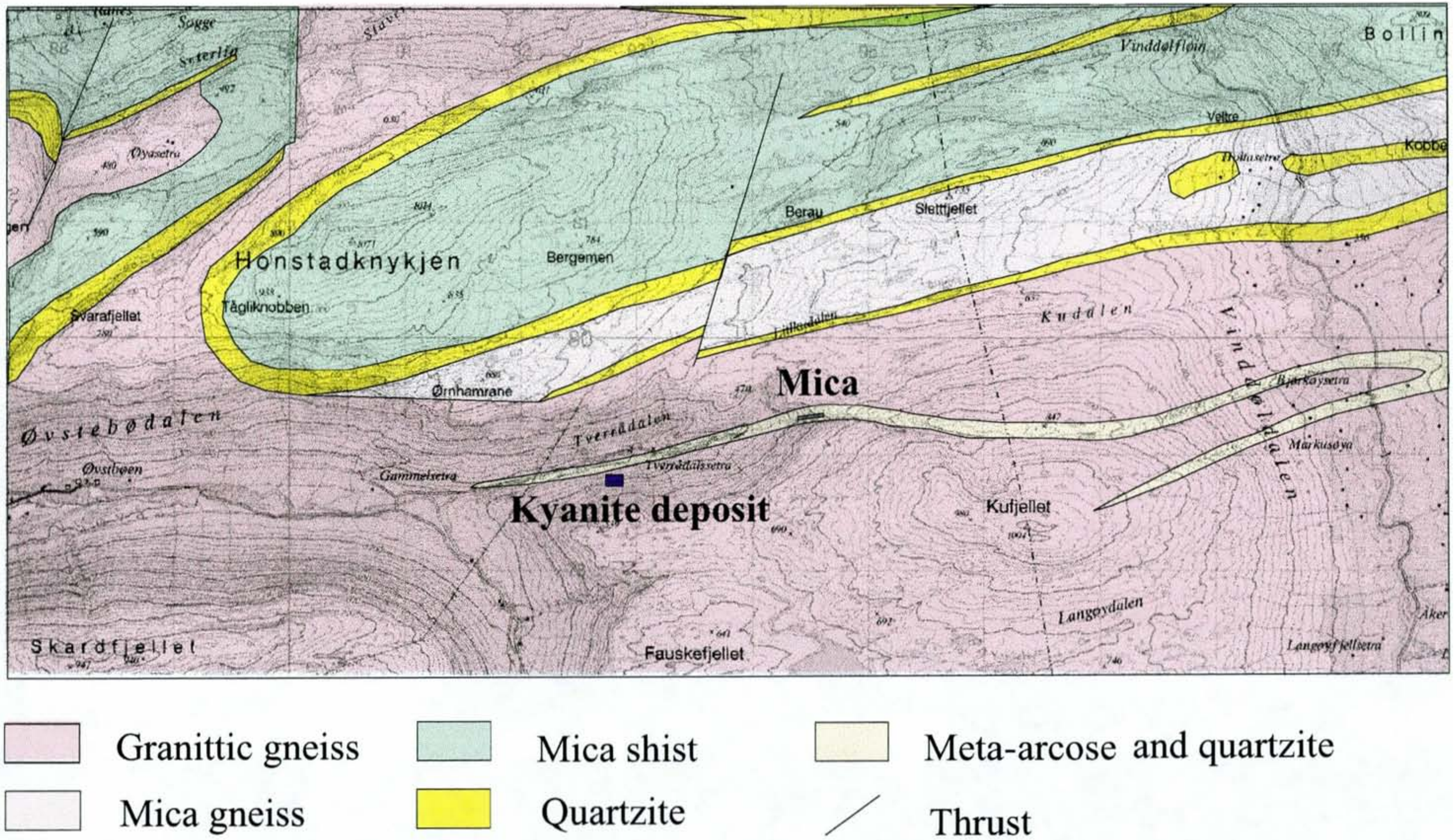

Figure 4 Geological map, 1:50.000 *Modified after Tveten and Lutro 1998*

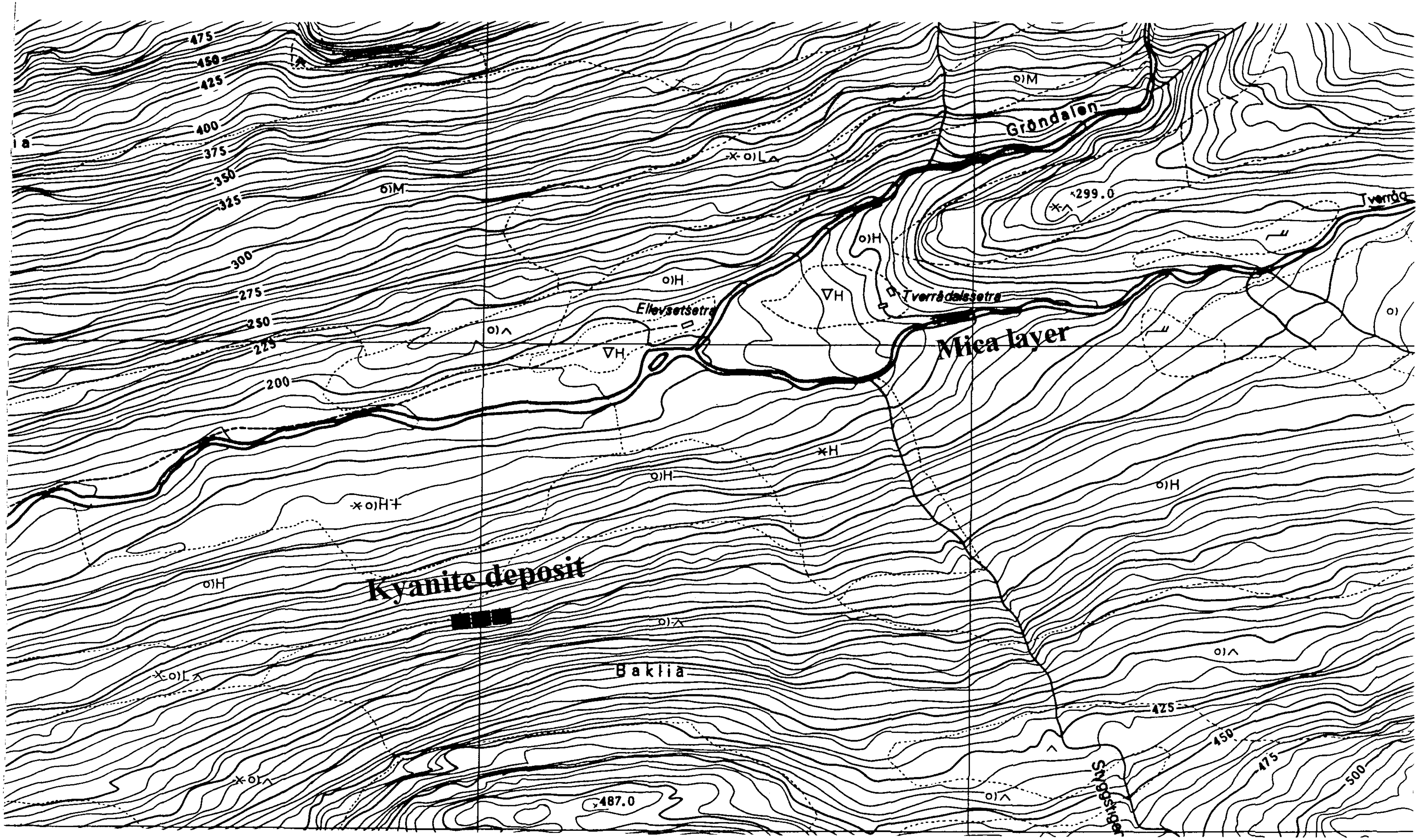

Figure 5 1:5.000 map with kyanite deposit and muscovite locality.

Tverrådal is dominated by overburden, resulting in relatively few outcrops. This definitely presented a problem, in so far that we did not succeed to localise any further outcrops of the kyanite-quartzite in addition to the one found by Olav Sæter.

The proximity of the kyanite outcrop to the arkose- unit on the geological map made it worthwhile to take a tour eastwards to Vinddøldal where the terrain presents us with good outcrops of this unit. This quartzite-arkose proves to be an ordinary arkosic quartzite, containing 10-30% K-feldspar. We found no trace of kyanite along the zone, neither in the Vinddøldal or across Kufjell. The kyanite-quartzite thus does not seem to belong to this unit.

The kyanite-rock probably extends laterally as a layer parallel to the direction of the valley, but lack of outcrops gives us so far no evidence for this so far. It is also possible that the deposit might consist of only one or several smaller lenses along a defined layer.

To place the kyanite deposit in a more regional perspective, three geologists that have done bedrock mapping in the region were contacted. None of them (Alan Krill, Ole Lutro and Einar Tveten) have registered kyanite in similar quartzite/arkose units in the Møre-Trollheimen-Oppdal region. Thus the outcrop is so far still unique.

5 DIAMOND DRILLING

In order to investigate the thickness of the kyanite-zone, a small drilling program was carried out. The drilling was done with a lightweight Pack-Sack equipment from NGU (Fig. 2). Due to a difficult terrain at the outcrop, two holes were necessary to be able to make a cross section of the body. The holes were drilled as shown in figure 5. Core logs are given in tables 2 and 3.

Table 2 Core log, drillhole 1.

DH1	**towards S with**	**50°dip**	
zone	rock unit	description	comment
0-1.6m	kyanite zone	Kyanite	kyanite-poorer from 0-0.6m
1.6-1.75m		core loss	
1.75-2.8m		Kyanite	
2.8-3.0m		core loss	30-45°
3.0-3.7m		Kyanite	kyanite-poorer from 3.1-3.3m
3.7-4.4m		core loss	
4.4-4.8m		Kyanite	kyanite-rich
4.8-5.5m	granitic gneiss		45° foliation angle

Table 3 Core log, drillhole 2

DH 2	**towards N with**	**80°dip**
zone	description	comments
0-1.1m	kyanite	lower kyanite content
1.1-3.5m		
3.5-5.5m		lower kyanite content
5.5-9.4		
9.4-10.1	core loss	
10.1-10.7	dark mica-gneiss	20° foliation angle

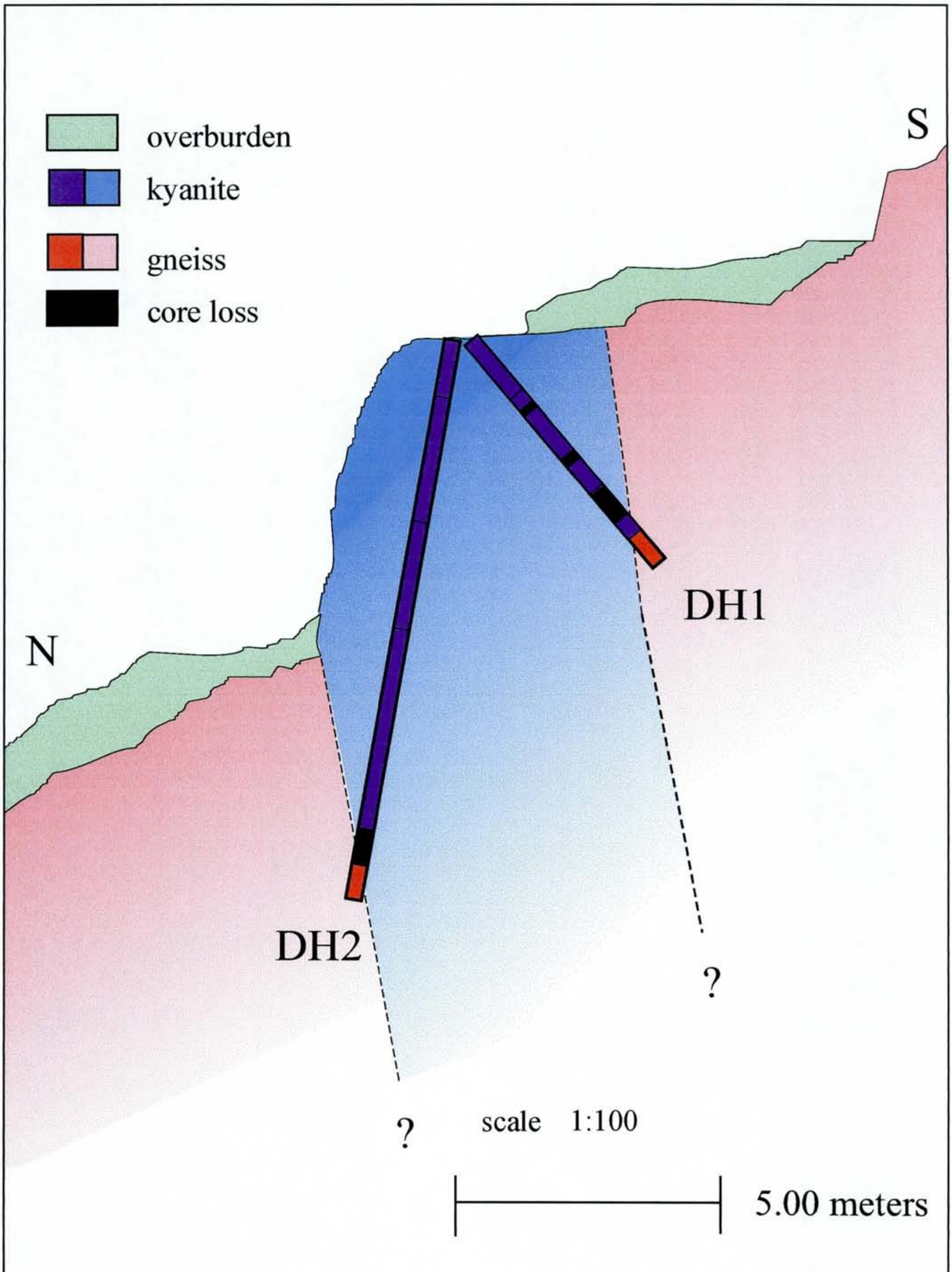

Figure 6 Vertical NS section with drill holes

Figure 7 Drill core, hole 1

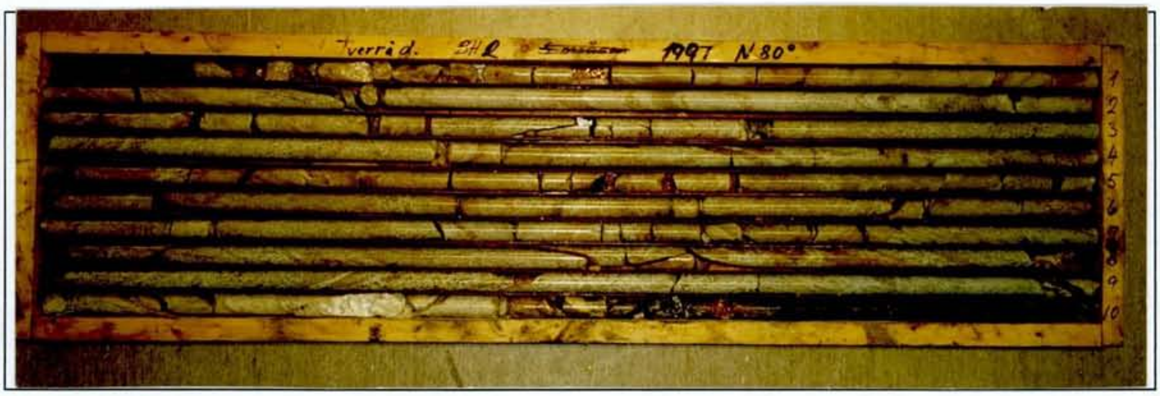

Figure 8 Drill core, hole 2

The thickness of the kyanite-quartzite zone is between 5 and 6 m, depending on the true dip of the zone. Foliation of the gneiss of the drill cores indicates a near vertical dip (85-90° S). Foliation of the outcrop and nearby gneisses indicate a dip of about 80-85°S. A dip of 85° will give a thickness of almost exactly 5.5m.

Chemical analyses are given in table 4, and they show that the kyanite content varies between 20 and 44%, with 30,6% as an average for the intersections in the two drillholes. A graphic presentation of the kyanite content in the two holes is given in figure 9.

Table 4 Chemical analyses of the drill cores

Sample		**Kyanite**	SiO2	Al2O3	Fe2O3	TiO2	MgO	CaO	Na2O	K2O	MnO	P2O5	LOI	Total
		%	%	%	%	%	%	%	%	%	%	%	%	%
DH1	0-3.5m	**20,4**	78,64	16,96	0,31	0,45	0,11	0,05	0,32	0,71	<0.01	0,05	1,89	99,48
	3.5-4.8m	**33,1**	75,49	21,81	0,10	0,47	0,11	0,02	<0.10	0,20	<0.01	0,03	1,14	99,38
	average	**30,6**		19.00										
DH2	0-1.1m	**33,7**	80,26	18,15	0,19	0,35	0,09	0,02	<0.10	0,22	<0.01	0,02	0,93	100,28
	1.1-3.5m	**43,7**	69,38	27,88	0,27	0,46	0,11	0,07	<0.10	0,18	<0.01	0,07	1,02	99,47
	3.5-5.5m	**29,6**	78,35	18,82	0,24	0,38	0,10	0,05	<0.10	0,19	<0.01	0,04	0,70	98,90
	5.5-9.1m	**30,6**	75,83	20,62	0,20	0,39	0,11	0,04	0,16	0,28	<0.01	0,04	1,21	98,88
	average	**34,2**		21,8										
Total	average	**30,6**		20,8										

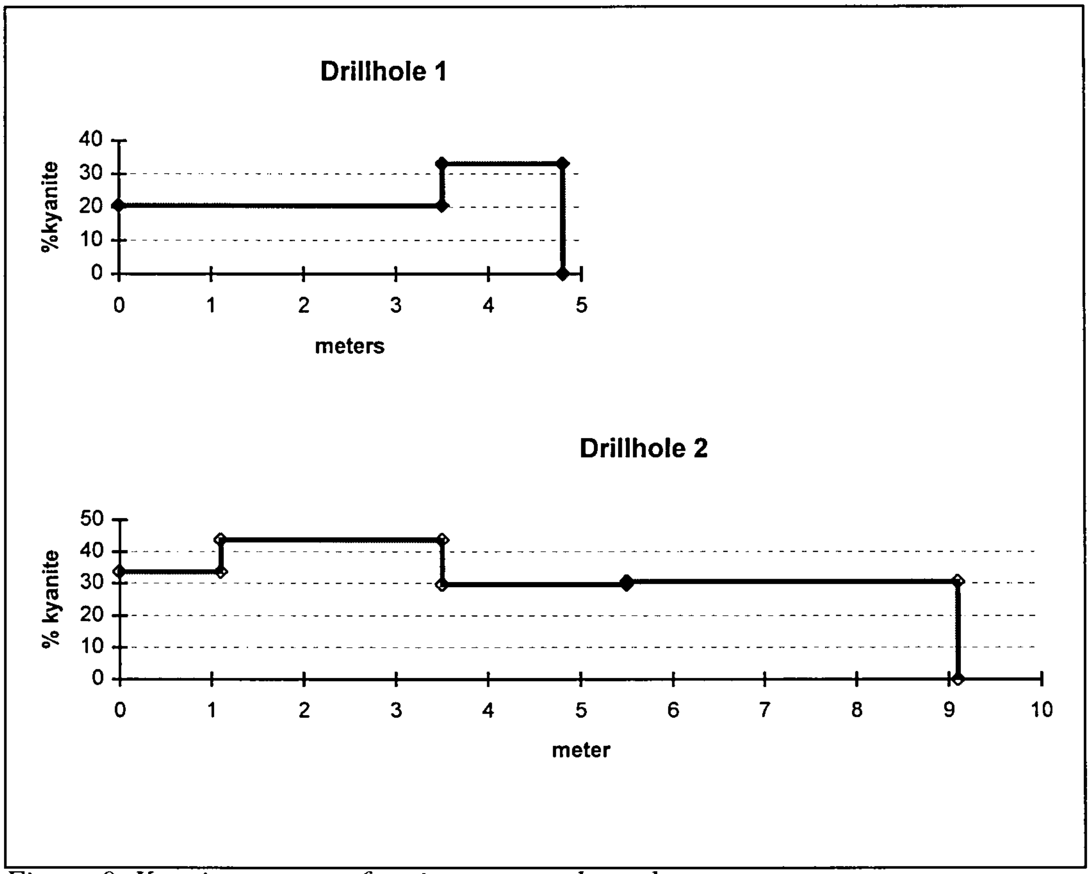

Figure 9 Kyanite content of various zones along the cores.

6 MINERALOGY AND CHEMISTRY OF THE KYANITE-QUARZITE ROCK

The outcrop and cores show us that the kyanite is scattered rather evenly throughout the rock, but on a smaller scale we can see lenses in which quartz is more dominant, as shown in figure 13.

Microscopy shows that the rock consists of approximately:
65% quartz, 30% kyanite, 3-5% muscovite and 0.5% rutile

The *kyanite* has a grain size up to 2mm, but the dominant size is rather 0.5mm and less (Figs. 10, 11 and 12). The mineral seems to be relatively free from dominant inclusions. Some inclusions of quartz are, however, visible. The kyanite grains are sometimes fragmented, and partly overgrown by recrystallised aggregates of muscovite and some chlorite. The kyanite is largely oriented parallel to the foliation of the rock.

The *quartz* is a mixture of distinct separate grains with size up to 0.5mm and more small-grained aggregates.

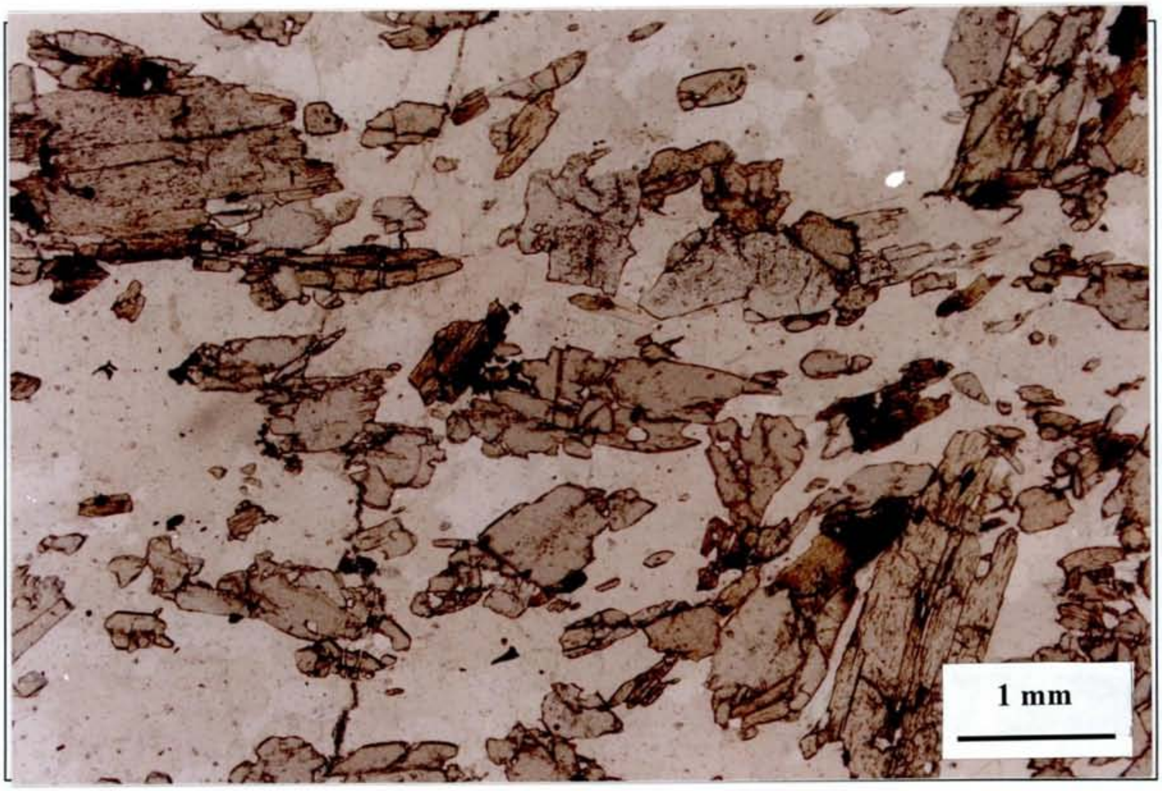

Figure 10 Thin section showing kyanite grains and a few dark rutile grains. Plane polarised light.

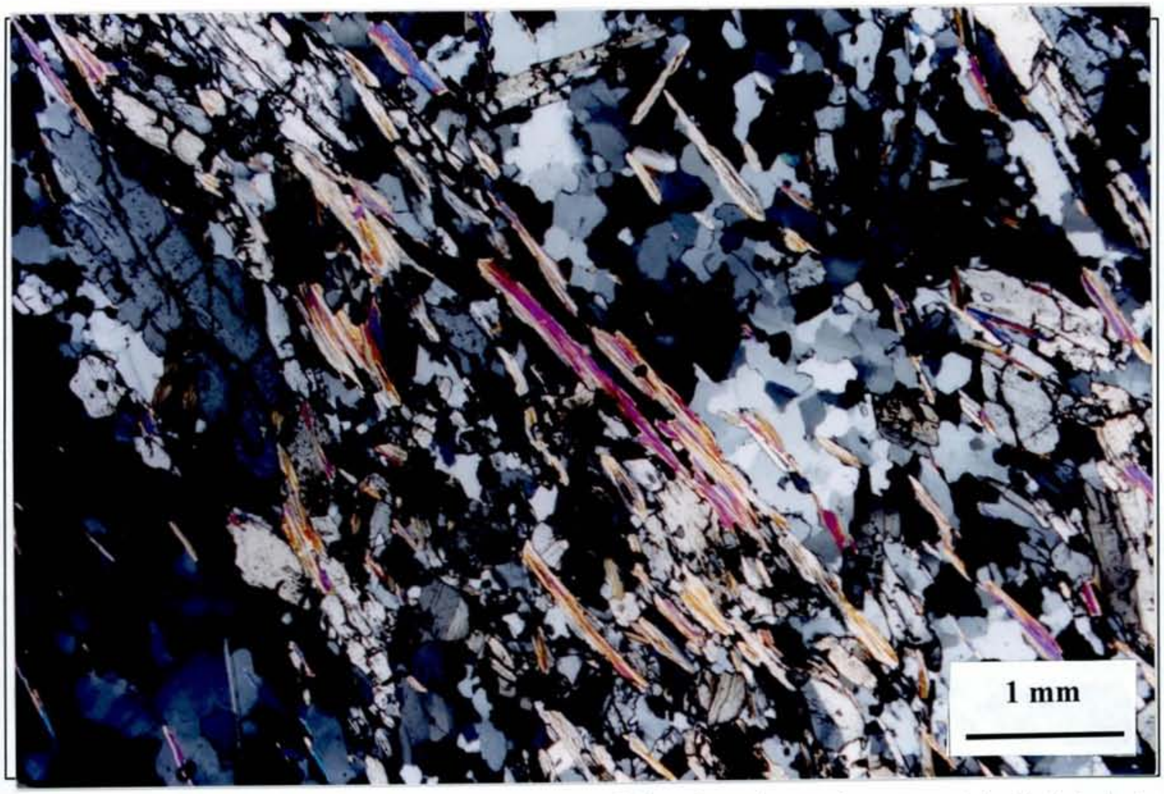

Figure 11 Thin section showing muscovite with bright colours, kyanite with slightly beige tones and quartz grains as white and black. Cross polarised light.

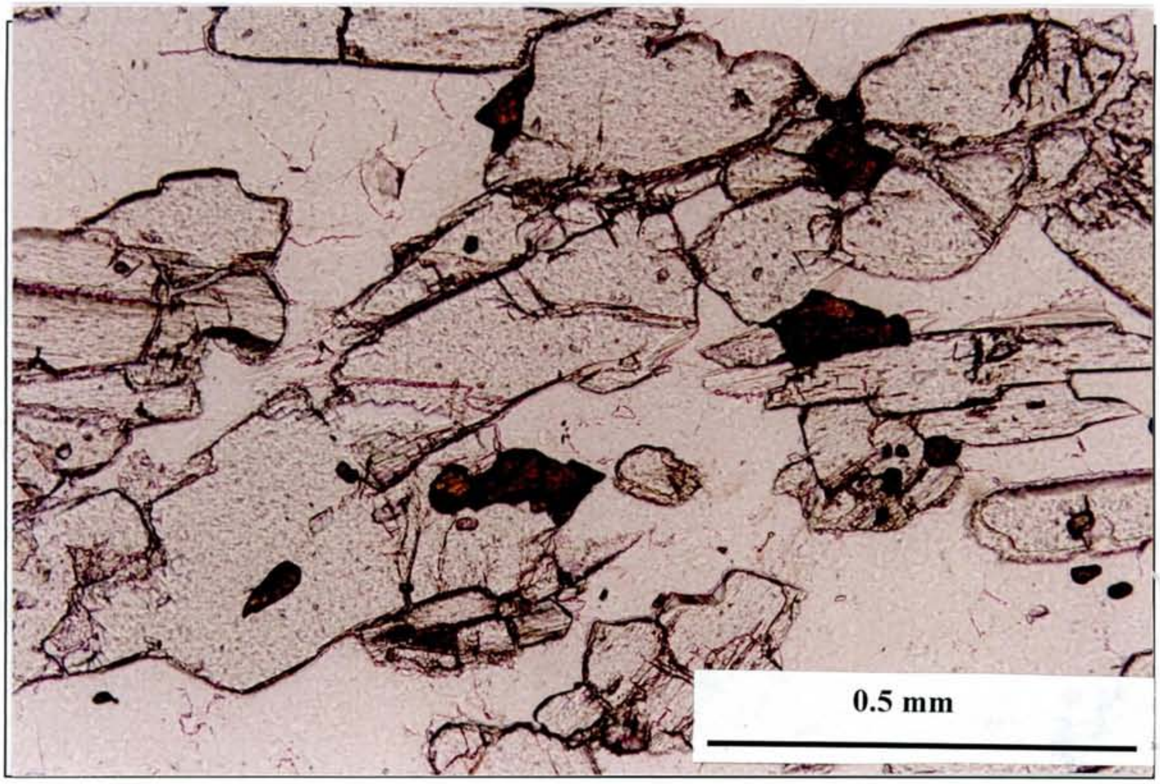

Figure 12 Brovn rutile grains together with kyanite in thin section. Plane polarised light.

Figure 13 Polished section of kyanite-quartzite. Kyanite with bluish grey colour, quartz with more reddish colour.

The *muscovite* occurs as aggregates that are parallel to the foliation of the rock, and the grain size is mainly about 0.5mm. See fig. 10.

The *rutile* occurs mainly as separate grains, with a grain size of 0.1-0.2mm. See fig. 11.

The samples from the outcrop described in chapter 4 was analysed by XRF to obtain the contents of major elements:

Table 5 XRF analyses showing chemical composition of some samples from the kyanite outcrop

Sample	Kyanite	SiO2	Al2O3	Fe2O3	TiO2	MgO	CaO	Na2O	K2O	MnO	P2O5	LOI	Total
	%	%	%	%	%	%	%	%	%	%	%	%	%
5	24,8	80,23	17,90	0,22	0,44	0,14	0,03	<0.10	0,38	<0.01	0,03	0,97	100,45
6	45,6	67,62	30,75	0,26	0,35	0,14	0,04	<0.10	0,23	<0.01	0,05	0,75	100,25
7	19,0	83,09	13,19	0,23	0,50	0,11	0,16	0,18	0,47	<0.01	0,12	0,84	98,89
8	43,68	70,19	26,50	0,22	0,45	0,13	0,03	<0.10	0,18	<0.01	0,05	0,81	98,59
9	22,18	81,76	15,10	0,15	0,51	0,09	<0.01	<0.10	0,20	<0.01	0,01	0,61	98,48
Average	31,0		18,7										

7 LABORATORY CONCENTRATE

In order to test the maximum purity of a kyanite product from the deposit, a small concentrate was produced at our laboratory.

To have a good liberation of the individual kyanite grains, a ground sample from the drill cores was sieved using 120 and 200 mesh sieves. This corresponds to a grain fraction of 0.074-0.125mm.

A kyanite concentrate was produced using:

1. Heavy liquid separation, using a liquid with a density of 3.3.
2. High intensity magnetic separation, using a Franz separator.

XRF analysis of the pure kyanite concentrate gave:

Al_2O_3	SiO_2	Fe_2O_3	MgO	TiO_2	$Å_2O_5$	CaO	Na_2O	K_2O	MnO	LOI	Tot.
61.62	36.47	0.42	0.23	0.05	0.05	0.02	<0.10	<0.01	<0.01	0.71	99.65

This is a fine result. The chemistry is satisfactory for a pure kyanite concentrate, and shows that production of a concentrate might be feasible.

Which purity it is possible to achieve in an industrial process remains, on the other hand, to be seen. An acceptable share of the kyanite content has then to be liberated and produced.

N. E. Johannessen at North Cape Minerals has already carried out a processing test with material from the deposit provided by Olav Sæter (Johannessen 1996). The tests were very preliminary, and the low Al_2O_3 content of 25% achieved is hopefully no relevant guide to what is realistic in an optimised industrial process.

8 COMPARISION WITH OTHER DEPOSITS

For a Norwegian kyanite deposit - it is appropriate to compare facts with the Halsjõberg kyanite deposit that was mined in Vãrmland in Sweden during the period 1985-1992. This deposit has a kyanite content of 25-40%, with 30% in average (Graesberg 1986). Grain size also seems to be about the same as the Surna deposit, as a particle size of 0-0.25mm is given for the final product. The chemistry of the Halsjõberg deposit is also similar,

Table 6 Chemical and mineralogical comparison with the Swedish kyanite deposit

	Halsjö	Surna		Halsjö	Surna
Element	%	%	Mineral	%	%
Al_2O_3	13-25	15-30	Kyanite	20-40	20-44
SiO_2	65-80	70-80	Quartz	55-70	50-75
TiO_2	0.3-0.7	0.35-0.5	Rutile	0.2-0.7	0.5-0.6
Fe_2O_3	0.8-2.0	0.1-0.3	FeTi.Oxides,Pyrite		
K_2O	0.1-0.4	0.2-0.5	Muscovite &	3-4	5
P_2O_5	0.1	0.01-0.12	Al-phosphates		

The Swedish deposit is about 850m long and has a maximum width of about 150 m. Reserves of more than 5 mill. tons are available. The company had an average sale of 5-6.000 tons a year when it was in production. A clear advantage for the Surna deposit is its closeness to the sea, 20 km, compared to the Halsjöberg which lies far inland.

United States is the major producer in the world with very large quartz-kyanite deposits containing 30-40% kyanite. The producing deposits in USA have a coarser grained kyanite than the Surna deposit, as it is reported that the ore is ground to minus 35 mesh (0.4mm) prior to flotation (2), and several grain fractions are produced (minus 35, 48,100, 200 and 325 mesh sizes - corresponding to 0.4, 0.3, 0.01, 0.07 and 0.04mm (Skillen 1993). In 1992, a large deposit in Arizona with over 30% kyanite was discovered. The coarse grain size (10 mm) will produce a concentrate in the 0.5-1.0 mm range - ideally for monolithic refractories. (Skillen 1993).

In Spain there is production of coarse-grained kyanite from gravel beds of rivers that contain only up to 20% kyanite.

It is also relevant to compare the deposit in Surnadal with the well known quartz-kyanite deposits at Saltfjellet near the polar circle. In a personal comment from Svein Gjelle at NGU, he describes that kyanite rich lenses occur sporadically within the extensive quartz-muscovite unit prominent on the bedrock map Lønsdal (Gjelle 1985). One ore more of these lenses were drilled by A/S Sydvaranger around 1983, but we do not have any of the information available relevant to this exploration activity.

9 USES, CONSUMPTION AND WORLD RESERVES

The kyanite mineral is high temperature resistant (1800°C), and is used in refractory materials, mainly for special kiln linings in the metallurgical- and glass industry. The mineral is also used for electrical and chemical porcelains, and some is used as insulating materials of sparking plugs.

Raw kyanite can be used advantageously in refractories to counteract shrinkage of other ingredients. This is therefore the main area for the use of fine grained flotation enriched kyanite (Graesberg 1986)

According to US Bureau of Mines (Potter, 1985), finely ground kyanite, such as minus 200 mesh (0.074mm), is used in sanitary porcelains and wall tile. In the refractories a coarser size (minus 35-48 mesh, corresponding to minus 0.3-0.4mm) is used. With a grain size below 0.5mm for the Surna kyanite, the major part of the kyanite grains will be liberated at a finer grain size, making the potential market more limited.

Mr Graesberg (1986) from Swedish Kyanite commented: "The production of refractory material is the only commercial field of application for kyanite in Europe today."

Yearly consumption in the western world is about 150.000t.

Kyanite demand from western Europe varies between 15.000 and 30.000 tons per year, depending on market conditions for the steel industry Graesberg (1986) and Skillen (1993). The refractory market in the USA is estimated to be about 90.000 tpa. (Skillen 1993).

Worlds total known kyanite reserves is estimated to be several hundred million tons. U.S. Geological Survey uses the term "immense" to describe the recourses in the United States. The kyanite marked is thus not the easiest to be competitive in.

10 A SEPARATE MICA DEPOSIT IN TVERRÅDALEN

About 1.5 km east of the kyanite outcrop, Olav Sæter has localised a layer rich in muscovite-mica in the bottom of the eastern part of the Tverrådal. (See figure 4 and 5 and 13) The layer is vertical and has a maximum thickness of 5 m. Microscopic analyses show a relatively pure muscovite mica with a grain-size of 1-5mm. The rock contains ca. 40% muscovite and the rest is predominately fine-grained quartz. See figure 14.

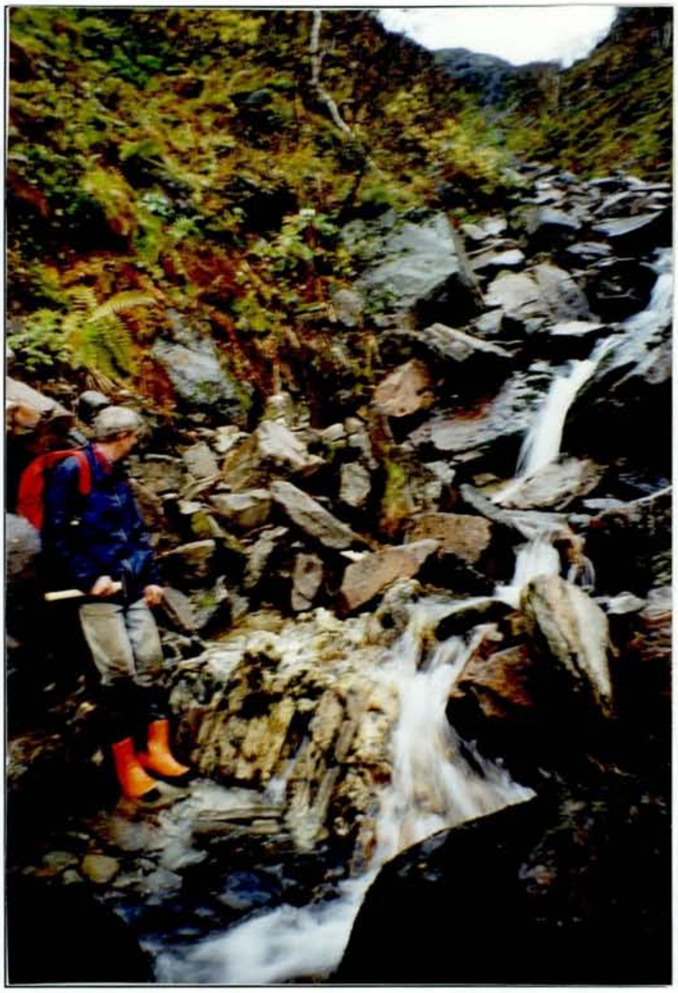

Figure 14 Mica-rich quartzite layer in the river at the bottom of Tverrådal. Olav Sæter is standing on the layer.

A 2-5m thick vertical layer would necessitate underground mining. Bearing in mind that the competition in the mica market world wide is tough with several new operations in the pipeline (Sims 1997), operation of this deposit is difficult to envision as being competitive.

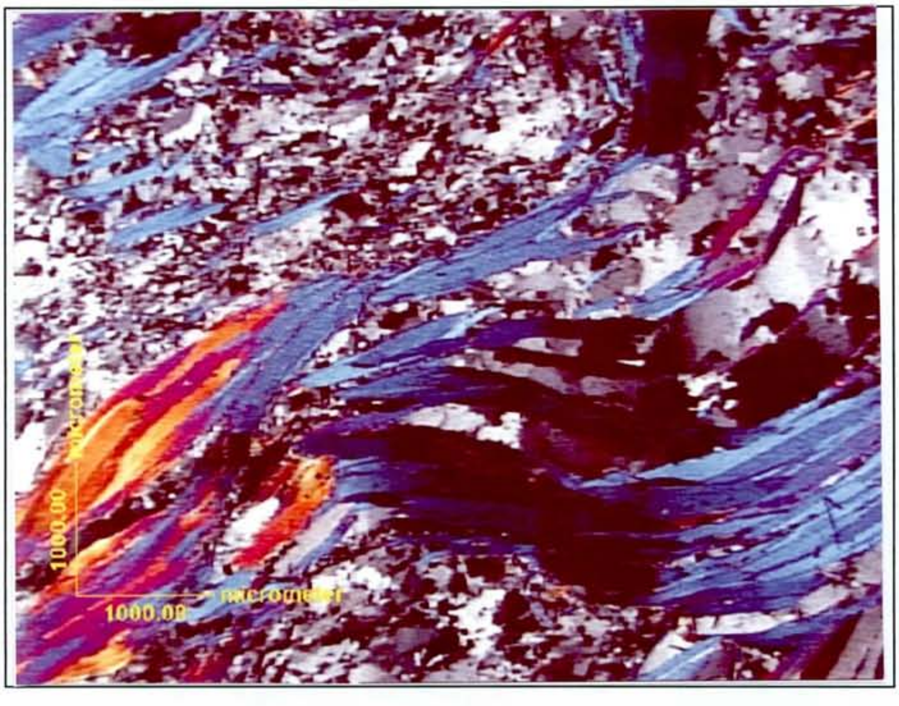

Figure 15 Thin section showing muscovite with bright colours, quartz grains as white and black. cross polarised light.

11 CONCLUSION AND DISCUSSION

The kyanite-quartz deposit in the Tverrådal has been drilled with lightweight equipment that successfully made a cross section of the deposit by the outcrop. The drilling shows that the layer has a thickness of 5-6 m. The cores indicate that the kyanite content across the layer varies between 20 and 43%, with an average of 30.6%.

Searching for more outcrops of similar rock in the area was disappointing and produced no results. The lateral extension of the deposit is therefore unknown, and we do not know if the body is part of a layer with considerable extension or only a smaller lens. The foliation at the outcrop indicates that the body has a direction parallel to the other rock units in the area and if the outcrop represents a lens, more lenses along the strike would be expected to exist.

The lack of more outcrops leaves us with the fact that the extension and volume of the kyanite deposit can only be verified by further drilling with conventional equipment.

A heavy liquid laboratory concentration test gave a kyanite concentrate with satisfactory chemical composition. Al_2O_3=61.6%, FeO=0.4% and TiO_2=0.05% gives us an indication that an interesting product might be produced in an optimised industrial purification process. To investigate this further some tests (e.g. at SINTEF/NTNU) would be necessary.

The comparatively small grain size (minus 0.5 mm) of the kyanite indicates a product that might be somewhat below the wanted grain sizes of the most common uses of kyanite in refractories. The grain size is however comparable to the kyanite of the Swedish Halsjöberg that produced and sold about 5000-6000 tons annually.

In contrast to the Swedish deposit the Tverrådal deposit is favourably located, not far from the sea (20km).

As a final comment, it is appropriate to have in mind that all other kyanite deposits in operation in the world are worked as open pit mines. A 5-6m thick steep body as in Tverrådalen has to be mined underground, and Mr. Sæter is planning to partly counteract this disadvantage by building a small hydroelectric plant in the valley - supplying operations with cheap electrical power.

12 REFERENCES AND LITERATURE

Gjelle. S. 1985: Berggrunnskart Lønsdal 2128 3, 1:50000, foreløpig utgave. *Norges geologiske undersøkelse*

Graesberg, M., 1986: Swedish Kyanite - new source of alumina for refractories and ceramics. *7th "Industrial Minerals"International Congress*

Industrial Minerals January 1985. Sillimanite minerals - Europe places demands on andalusite. P.41-63.

Industrial Minerals, February 1986. Svenska Kyanite - Europe's new producer of kyanite.

Johannessen, N.E. 1996: Re.: Evaluering kyanittholdig bergart fra Surnadal. *Internt notat North Cape minerals AS*

Potter, M.J., 1985: Kyanite and related minerals. In Mineral facts and problems, *US Bureau of Mines.*

Sims, C. 1997: Mica. Building a future on dry ground. *Industrial Minerals*. January 1997.

Skillen, A. 1993: Sillimanite minerals. Simplicity the key. *Industrial minerals Consumes Survey. Raw materials for the Refractories Industry*

Strand. T, 1952: The relation between the basal gneiss and the overlying meta-sediments in the Surnadal district. *Norges geologiske undersøkelse 184.*

Tveten, E. And Lutro, O. 1998: Berggrunnskart Ålesund 1:250.000, foreløpig.. *Norges geologiske undersøkelse.*

Tørudbakken, B. O. 1982: En geologisk undersøkelse av nordre Trollheimen ved Surnadal, med hovedvekt på sammenhengen mellom strukturer, metamorfose og aldersforhold *Hovedoppgave i geologi -Universitetet i Oslo.*

U.S. Geological Survey. *Mineral Commodity Summaries, January 1997*

APPENDIX 1

The HF/$HClO_4$ - method of kyanite-content determination

There is no officially accepted chemical/instrumental method to determine the kyanite content of a rock. NGU has however tested a chemical method of finding the kyanite content. The content is determined by means of dissolving the non-kyanite minerals with hydrofluoric acid (HF) and perchloric acid (HClO4). The method was tested some years ago with samples from a kyanite-deposit in Finnmark, and the results proved to be very reliable.

The method is as follows:

Weigh about 1 gram. Add 20 drops of $HClO_4$ + 10 ml HF. Evaporate until dry. (For drying use 1-2 hours). Repeat the process. Add 10 ml HCl. Evaporate until dry. Add 20 ml HCl (1:1) and boil the suspension for about 30 minutes. Filter through blue ribbon filter. Wash with water, dry and ignite. ($HClO_4$ can be substituted with H_2SO_4).