

# Overview of talc resources in the Altermark talc province, northern Norway, and possible uses of the talc ore

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Active prospecting during the past 10 years has proved that the Altermark area contains much more talc than previously recognised. In the Nakkan-Esjeklumpen area, 10 M tonnes or more of talc-carbonate ore are probably present, distributed in ultramafic bodies. The ore, which occurs as one of several layers within compositionally zoned ultramafic lenses dominated by antigorite serpentinites, has the following general mineralogy: talc (45-65 %), carbonate (30-50 %), chlorite (0-4 %) and magnetite (0-3 %). Relative to other known similar deposits, the ore is rather coarse-grained, and the minerals tend to be idioblastic. Several products can be made from the talc-carbonate ore. By applying flotation or other kinds of mineral separation techniques, it is likely that high-quality talc-concentrate could be made in addition to talc-carbonate mixtures. A concentrate of by-product breunnerite would possibly be of economic value.

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## Introduction

Economic talc<sup>1</sup> mineralisation is normally associated either with dolomite or with ultramafic rocks (i.e. 'ultramafic' talc). All known major occurrences of talc in Norway are of the ultramafic type, and are associated with serpentinitised ophiolitic ultramafites, ultramafic conglomerates or solitary ultramafic lenses.

Norwegian Talc AS, owned by Plüss Staufer AG, is the major talc company in Norway, and produces talc from ultramafic rocks in Altermark, Nordland county, northern Norway (Fig. 1). In the Altermark area, the ultramafic lenses are found to be particularly well talcified, and the area is described as a talc province. Due to a shortage of ore reserves in the late 1980s, a prospecting campaign was carried out during the following years (1989-1995). Work started with drilling and investigation of the Straumdalen talc deposit (Holter 1990), and was followed up by a more intensive survey including airborne geophysics (Mogaard & Walker 1991, Karlsen & Olesen 1991), regional mapping, detailed deposit mapping, and comprehensive mineralogical studies (Karlsen 1995). This campaign, which has been followed up by drilling, turned out to be successful, and several millions of tons of talc-carbonate rocks were detected, both within and outside the existing talc mine. The Nakkan deposit was detected by airborne geophysical exploration (Mogaard & Walker 1991, Karlsen & Olesen 1991, 1996), and is today the major target for future exploitation. In the present paper, the general geology and prospects in the Altermark area are presented.

1. Talc – both pure mineralogical talc and industrial talc which may contain variable amounts of magnesite, chlorite etc.

## Geological setting

The Altermark area is situated about 20 km west of Mo i Rana, northern Norway (Fig. 1). The rocks belong to the Rödingsfjället Nappe Complex (Gustavson & Gjelle 1991) of the Uppermost Allochthon (Roberts & Gee 1985) of the Caledonides.

The Rödingsfjället Nappe Complex and the overlying Helgeland Nappe Complex are the two dominating nappe complexes along the Nordland coast. These nappe complexes contain numerous ultramafic lenses of somewhat disputed origin (Karlsen 1995). Immediately to the south of Helgeland, ophiolitic ultramafite with associated talc occurs on the island of Leka in Nord-Trøndelag. North of Rødøy (Bang 1985), ophiolite complexes as such have not been recognised, and the ultramafites occur as solitary lenses. Around the basement windows Sjøna, Høgtuva and Svartisen, solitary ultramafic or ultramafic/mafic lenses are widespread, situated predominantly within the Rödingsfjället Nappe Complex (Fig. 1).

## Tectonostratigraphy

In the investigated area, the Rödingsfjället Nappe Complex consists of three tectonic units: the Tjørnrasta Nappe, the Straumbotn Nappe (Søvegjarto et al. 1988) and the Slettefjället Unit (Fig. 2). The Tjørnrasta Nappe is dominated by quartzo-feldspathic gneisses and quartz-rich mica schists while the Straumbotn Nappe comprises kyanite-staurolite bearing garnet-mica schists, marbles and amphibolites. The tectonised transition from the Tjørnrasta Nappe to the overlying Straumbotn Nappe is marked by occurrences of strongly deformed graphitic schists, which outline the thrust zone of the 'Straumbotn Nappe floor thrust' (SNft). The Slet-

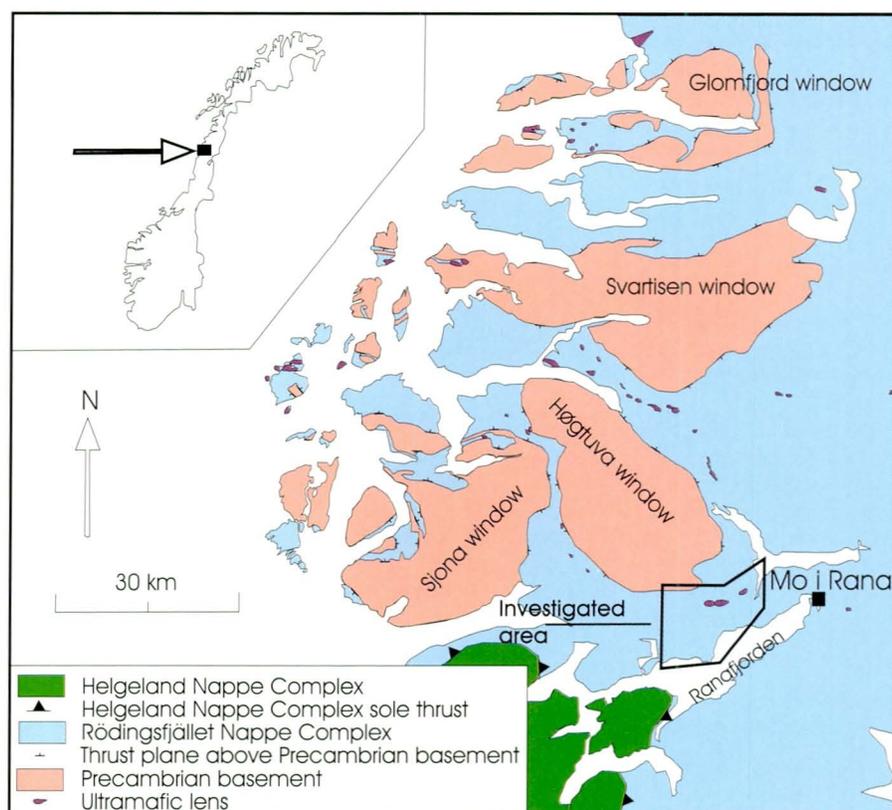


Fig. 1. Tectonostratigraphic map of western Helgeland and occurrences of ultramafic rocks. Scale of ultramafic rocks is exaggerated by around 100%. The investigated area is outlined. Compiled from Søvegjarto (1977), Johnsen (1983), Søvegjarto et al. (1988, 1989) and Gustavson & Gjelle (1991).

tefjellet Unit, which is situated above the Straumbotn Nappe, is interpreted to be a structural repetition of the Tjørnrastra Nappe, and contains similar rock types (Karlsen 1995).

The ultramafic rocks, which can be classified as so-called *solitary* alpine-type ultramafites (Quale & Stigh 1985), occur as lenses within the Straumbotn Nappe and are usually associated with the SNft (Fig. 2). It is possible that certain revisions will have to be made to the standard tectonostratigraphy of the region.

The structural history of the area is complex, and will be described in detail in a separate paper; only a summary is given here. Four deformation events have been recognised,  $D_1$ ,  $D_2$ ,  $D_3$  and  $D_4$  (Karlsen 1995). The first deformation event,  $D_1$ , created the well-developed metamorphic foliation,  $S_1$ , which is the dominant micro-/mesoscopic structure, and defined by mica, hornblende, kyanite, staurolite, graphite, epidote and elongated aggregates of quartz and feldspars.  $D_1$  also created microscopic to macroscopic  $F_1$  folds, which are moderately inclined, and weakly plunging isoclinal folds with a strongly developed penetrative axial plane cleavage ( $S_1$ ). Most of the  $F_1$  fold axes parallel the main E-plunging,  $L_1$  stretching lineation.  $L_{1a}$  is a micro-/mesoscopic stretching lineation defined by strongly elongated aggregates of quartz and/or feldspars and by a parallel orientation of the minerals kyanite, staurolite and hornblende. The  $L_{1a}$  lineation generally plunges at about 0-30° towards E or ESE.  $L_{1b}$  is a meso-/macroscopic stretching lineation defined by the longest axes of meso- and macroscale boudins of serpentinites and locally amphibolites plunging at around 20-30° towards E. All of the interpreted nappe boundaries within the Rödingsfjället Nappe Complex are interpreted to be of early  $D_1$  age.

Deformation events post-dating the peak of metamorphism are represented by  $D_2$  and  $D_3$ , which created meso- to macroscopic scale folds that deform the  $D_1$  structures. The Slettefjellet fold, which is the dominant macroscopic structure in the area, is interpreted to be an overturned, tight,  $F_2$  antiform with an axial surface dipping at about 40° towards SE. The Slettefjellet fold changes trend when traced westward along the Sjøna gneiss dome (interpreted from Gustavson & Gjelle 1991), probably as a result of the dome geometry of the Precambrian window.

Décollement thrusting is observed along the outermost parts of the ultramafic rocks where the enveloping rocks have been intensively folded by  $F_2/F_3$  and slid along the border of the ultramafites.

Geothermobarometric investigations have indicated that all the rocks of the Rödingsfjället Nappe Complex in the investigated area were metamorphosed at amphibolite facies at high-pressure conditions during  $D_1$  (Karlsen 1995).

## Compositional zoning of the ultramafic lenses

The ultramafic lenses are actually parts of composite mafic/ultramafic lenses, although the mafic parts, now represented by amphibolite, are not always easy to recognise. The ultramafic parts of the lenses are mineralogically zoned, and three major zones occur (Fig. 3): (1) Serpentinitic core, (2) Talc-carbonate zone, (3) Monomineralic rocks in the rim. The *serpentinite* consists predominantly of interpenetrating textured antigorite and 5-20% magnetite. Especially ferrite-chromite, but locally also relics of olivine and clinopyroxene, are

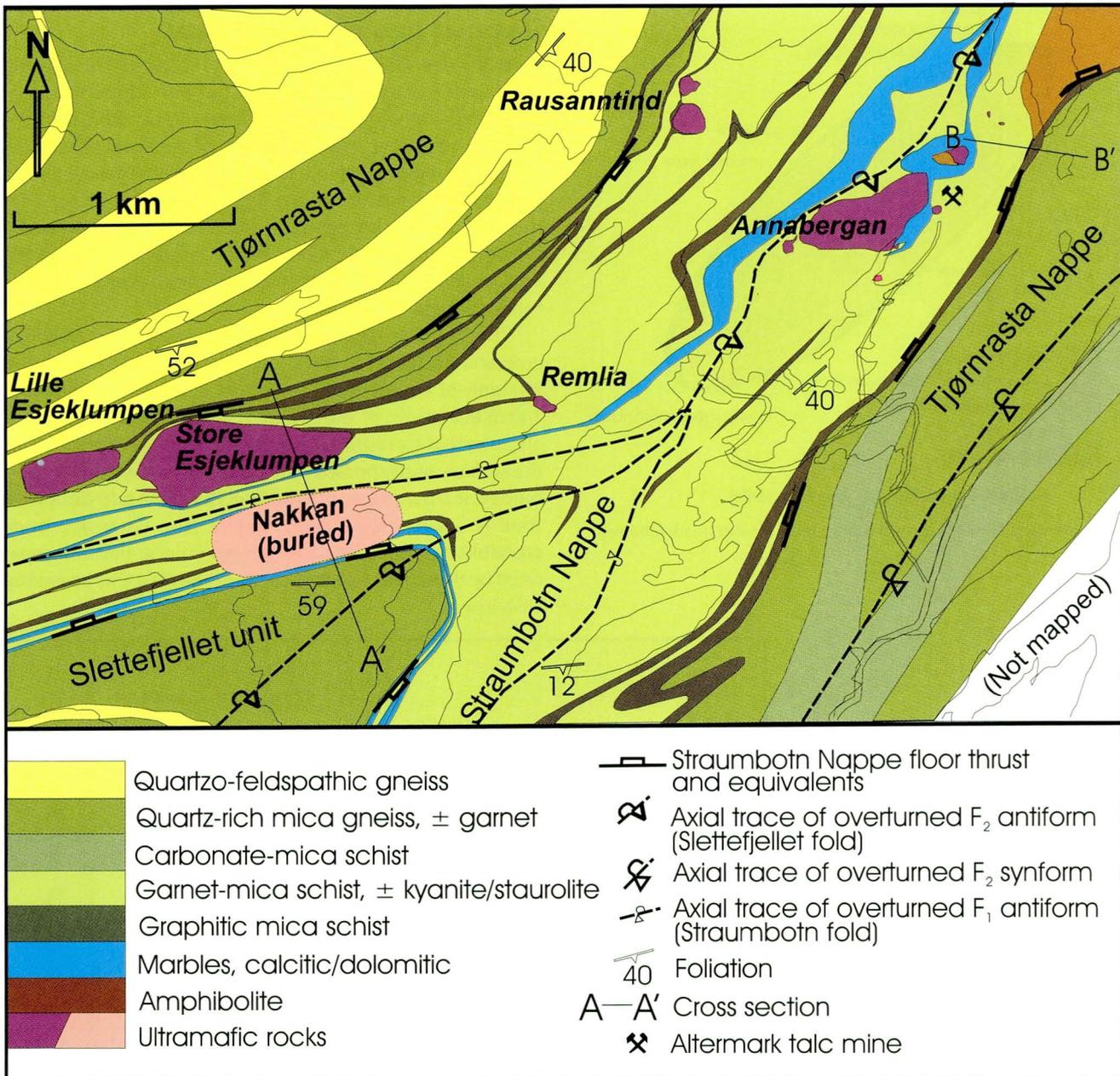


Fig. 2. Simplified geological map of the investigated area with names of the ultramafic lenses and localities of cross-sections. Abbreviations: A = Annabergan ultramafite, SE = Store Esjeklumpen, LE = Lille Esjeklumpen, R = Remlia. N = Nakkan (situated about 150 m below surface). Nappes: Tj.Na = Tjørnrasta Nappe, Tj.Na2 = Tjørnrasta Nappe inverted, Str.Na = Straumbotn Nappe. Cross-sections are shown in Figs. 4 & 6.

present in subordinate amounts. Some of the ultramafic cores carry lenses of primary clinopyroxenite, dunite, chromite and also rodingite. The *rodingite*, which probably represent metasomatised mafic rocks, has been described only once previously in Norwegian ultramafites (Bøe 1985) and consists of the assemblage: epidote + amphibole + chlorite ± hydrogrossular ± serpentine. The *talc-carbonate zone* consists of about 40-70% talc, 30-45% carbonate and trace amounts of chlorite, magnetite and chromite. In the innermost parts of the zone, trace amounts of antigorite occur, commonly as porphyroclasts pre-dating the talc-carbonate formation, but also as porphyroblasts post-dating the talc-carbonate. The carbonate is dominated by texturally and

chemically zoned breunnerite, while dolomite may be present locally in subordinate amounts. A more detailed description of this rock, which is the primary ore, is given below. The *monomineralic rocks in the rim* consist of talc schist, (± tremolite), chloritite and biotitite. The talc schist is also a part of the ore, but in general it is much thinner and more chlorite rich than the talc-carbonate rock, and therefore of less interest. The tremolite in the tremolite occurs predominantly as green-coloured, idioblastic grains. The ultramafic lenses are isofacial with the metamorphic envelope. The compositional zoning pattern was created by prograde metamorphism during D<sub>1</sub> (Karlsen 1995).

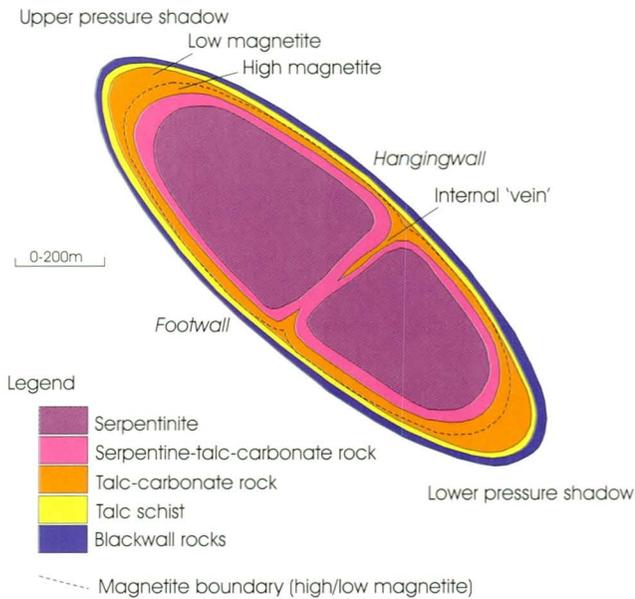


Fig. 3. Idealised lithological zoning pattern of the Altermark ultramafic lenses.

### Deposit geometry and size

All of the described deposits, except for the Remlia deposit, occur as rims around serpentinites, but with different serpentine/talc-carbonate ratios. In some of the talc bodies in the mine, there are only small remnants of serpentinite, while in others it is the dominating lithology. A short introduction to the geometry and size of the deposits is given below. Estimates of tonnage are based on different premises due to different levels of investigation, and the terms *proven*, *probable* and *possible* are used. In the present paper, however, only the total estimations are given.

The *Store Esjeklumpen ultramafite* (Figs. 2 & 4) is an 800 m long and up to 180 m thick, exposed ultramafite consisting primarily of antigorite. Its maximum depth below surface is 140 m at a height of 240 m above sea level. The talc-carbonate zone that surrounds the serpentinite is not easy to see on the surface, partly because the boundary is covered by overburden and partly because the majority of the talc-carbonate zone is situated well below surface. The ultramafic body probably consists of 4 cores of serpentinite that are separated by thin zones of talc-carbonate and, to a limited extent, chloritite.

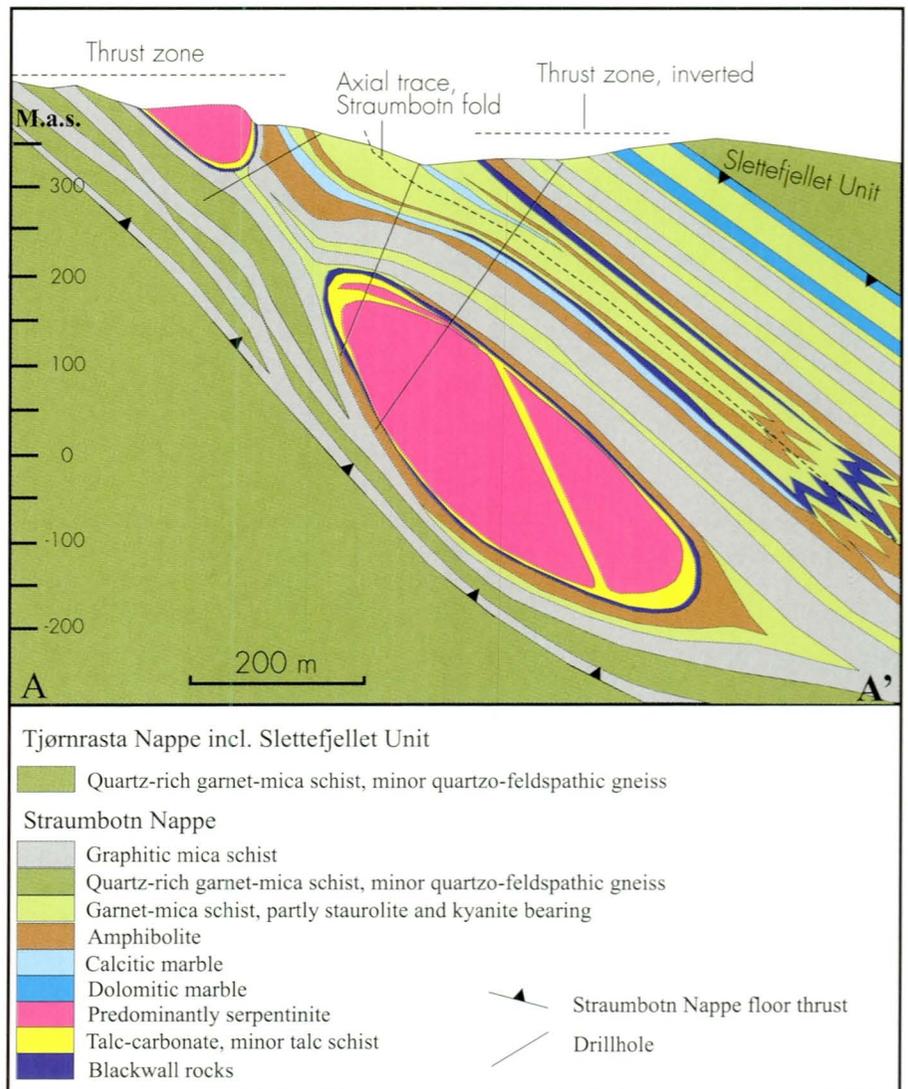


Fig. 4. Cross section A-A' (Fig. 2) showing the Store Esjeklumpen and Nakkan ultramafites.

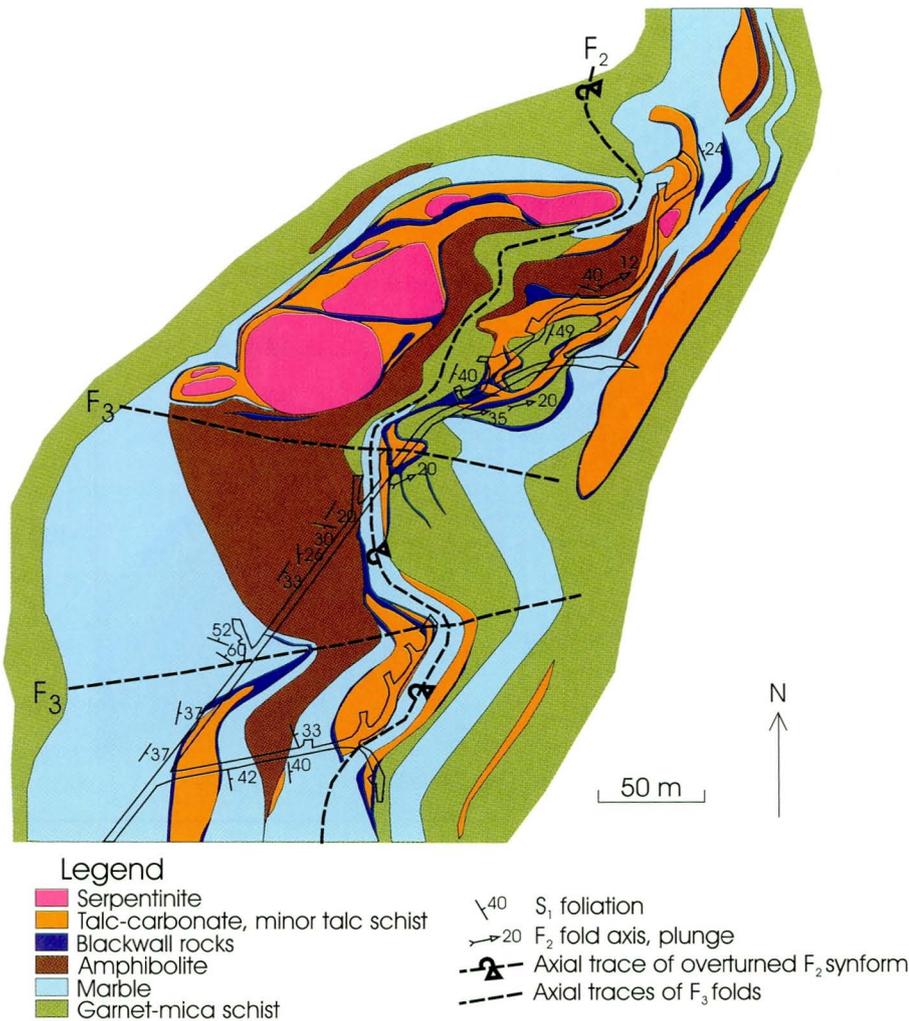


Fig. 5. Simplified geological map of the Main Level, Altermark talc mine. Mine layout from 1995.

During the years 1932-1934, an inclined shaft was driven in a talc-carbonate rock in the southwestern part of Store Esjeklumpen in order to investigate the ore, but the work was subsequently stopped at the time of opening of the Altermark talc mine (1934). In 1990 and 1991, Store Esjeklumpen was the subject of drilling, and 1460 m and 2260 m were drilled, respectively, in 16 cross-sections. The prospecting work was supplemented by surface mapping in 1991 (Karlsen 1995).

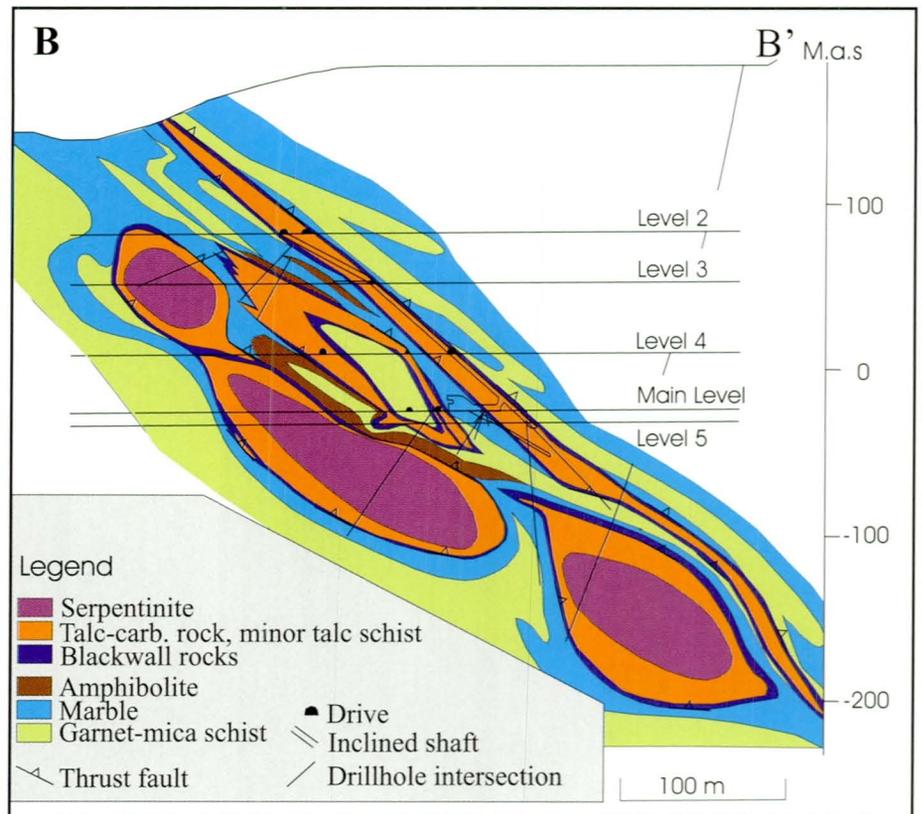
The geometry of the talc-carbonate deposit is relatively simple as it occurs mainly as a regular zone around the serpentinite core. The thickness of the talc zone varies according to the structural occurrence; it is always much thicker in the 'nose', pointing towards S-SE in the dip direction, i.e. in the direction of the lineation L<sub>1b</sub>, and up to 40 m of talc-intersections are present in drillholes. Along the hanging- and foot-wall of the serpentinite, the talc-carbonate ore is much thinner (< 2-3 m thick). The thickness of the talc rocks also varies along the E-W trend: it is generally much thicker in its western parts than in the east where the thickness gradually decreases to less than 2-3 m. In spite of the relatively simple geometry of the Store Esjeklumpen talc deposit, some few zones of chloritite crosscut the orebody.

The *Lille Esjeklumpen ultramafite* has not been investigated by drilling, but detailed surface mapping has proved

that talc mineralisation also occurs in this ultramafic lens. Thin talc-carbonate layers are present in the northern, eastern and western parts of the body, while the southern part is not exposed (Karlsen 1995). Based on our knowledge of the geometry of other talc deposits in the area, most of the talc-carbonate is probably present in a pressure shadow (Fig. 9) at the S-SE, deep-seated end of the body. Magnetic modelling (Karlsen & Olesen 1997) indicates that the magnetic part of the body does not continue deeper than 150 m below the surface. Investigations carried out so far indicate that 4 M tonnes or more of talc ore are present in the Store/Lille Esjeklumpen area.

The *Nakkan ultramafite* (Figs. 2 & 4) was discovered by geophysical exploration (Karlsen & Olesen 1991, 1996) and subsequent (1992) core drilling (Karlsen 1995). The ultramafic body is situated in the S-SE continuation of the Store Esjeklumpen ultramafite, with a minimum distance between them of approximately 150 m. Its uppermost part is situated approximately 215 m above sea level and minimum 130 m below the surface. The ultramafic body is approximately 800 m wide along the E-W trending strike, and has a general dip of 40-45° towards S-SE, as at Store Esjeklumpen. Its maximum thickness is more than 200 m. The length of the body in the dip direction is unknown, but it is probably more than 500-600 m. The ultramafic body is composed of at least three dif-

Fig. 6. Simplified cross-section B-B' (Fig. 2) of the northern part of the Altermark Talc mine. The interpreted thrust faults are primarily of D<sub>1</sub> age but were strongly reactivated during D<sub>2</sub>.



ferent serpentinite cores separated by thin zones of talc-carbonate rocks and, in some cases, black wall rocks such as chloritite and biotitite. The upper part of the Nakkan ultramafite has been investigated by drilling in 1992, 1996, 1997, 1998 and 1999 with a total length of drillcore of 16,260 m.

As in the other large ultramafic lenses in Altermark, the talc rocks occur primarily as rims around the serpentinite cores. The thickest parts of the talc-carbonate zone (~ 20 m) are found on the hanging-wall, not far from the 'nose' pointing N-NW towards Store Esjeklumpen. Based on the common occurrence of pressure shadows around competent units, as well as on our knowledge of the geometry of similar ultramafites in the talc mine, it is probable that a similar pressure shadow exists at the opposite, deeply buried southeastern end of the lens (cf. Fig. 6). This area, however, has not been investigated due to the great depth below surface and the high drilling costs involved. Investigation of this part of the lens can only be done from an entrance drive. Internal cross-cutting 'veins' (up to 10 m wide) of talc-carbonate can, at least to some extent, be regarded as additional resources, though they partly carry unusually high amounts of magnetite leading to lower recovery. In total, the Nakkan ultramafite is believed to contain a tonnage of 5 M tonnes or more.

The total length of the *Altermark talc mine* is approximately 800 m from NE to SW. The mine is operated at 5 different levels (Fig. 6). Today, the Main Level (Fig. 5) is used as the access and transport drive, and the ore is being mined in inclined (20-50°) stopes between the Main Level and the Level 2.

The northern half of the mine is geometrically complex

with numerous talc-bearing lenses (Figs. 5 & 6) which commonly have relatively high ratios of talc rock to serpentinite. The majority of these bodies consists mainly of talc-carbonate rocks with small cores of serpentinite lenses 'floating' within them. The serpentinite bodies are generally cigar-shaped with their longest axes oriented E-W and with a plunge of about 20° towards east. Frequently, décollement thrusting has occurred along the contact between the ultramafites and the country rocks, leading to intensively folded country rocks being placed on top of non-folded ultramafic assemblages. In the Altermark talc mine, reserves for several years have been mapped.

### Ore quality

In the industry, several criteria are used to describe the quality of industrial talc, e.g. whiteness, oil absorption, content of damaging minerals, hardness and smoothness, and electrical and thermal properties. All such criteria, which are measured in the final products, are controlled by the mineralogy of the ore and the beneficiation processes used. The mineralogy of the ore is described below, focusing on the possible end products. Whiteness, which is also discussed, is a very important parameter for the present day production of talc-carbonate products, but has a limited value when other potential products of the talc-carbonate mixture are evaluated. This is because the whiteness would be changed if other processes were applied.

Examples of the chemistry of the Altermark talc ores is given in Table 1. Except for the content of Ni and Cr, the ore

Table 1. Selected whole-rock analyses of the talc-carbonate ore.

SAMPLE	A, Egt.5		NAK 9201	ESK 9008A	ESK 9008A	ESK 9008A	ESK 9008A	NAK 9201
	321 m		321 m	133 m	163.2 m	180.3 m	371 m	
SITE IN ULTRAM.	Rim	Vein/joint	Rim	Rim	Rim	Rim	Rim	Vein/joint
<b>Major elements (%)</b>								
SiO <sub>2</sub>	32,04	36,08	30,45	35,27	29,71	29,90	34,25	
TiO <sub>2</sub>	0,02	0,05	0,02	0,02	0,01	0,01	0,02	
Al <sub>2</sub> O <sub>3</sub>	0,38	1,58	0,33	0,48	< 0.3	0,37	< 0.3	
Fe <sub>2</sub> O <sub>3</sub> (tot.)	7,36	11,36	8,18	8,93	7,50	8,20	7,05	
MnO	0,10	0,15	0,15	0,19	0,16	0,16	0,13	
MgO	35,82	33,54	36,35	34,42	35,42	35,04	37,10	
CaO	0,13	0,12	0,25	1,29	1,15	0,63	0,17	
Na <sub>2</sub> O	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	
K <sub>2</sub> O	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	
P <sub>2</sub> O <sub>5</sub>	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	
L.O.I.	23,57	17,05	24,26	19,19	25,63	25,36	21,84	
<b>Sum</b>	<b>99,42</b>	<b>99,93</b>	<b>99,98</b>	<b>99,79</b>	<b>99,59</b>	<b>99,69</b>	<b>100,55</b>	
<b>Trace elements (ppm)</b>								
Rb	0	0	0	0	0	0	0	
Sr	21	22	23	53	51	33	21	
Y	11	8	10	8	11	7	10	
Zr	19	16	15	18	22	12	19	
V	40	58	33	35	22	24	31	
Cr	1735	3634	1860	2085	1054	1450	1733	
Co	63	74	55	51	41	62	52	
Ni	3644	3766	2612	2297	1927	2771	3337	
Cu	0	0	0	7	0	8	0	
Zn	40	96	59	66	40	71	37	
Ba	0	0	0	0	0	0	0	
Pb	2	0	0	0	0	2	0	
S	0	0	40	1250	0	840	0	

is very pure and elements regarded as being damaging to the environment or health are at concentrations below analytical detection limits.

The mineralogy of four selected ultramafites has been investigated; Store Esjeklumpen, Nakkán, Remlia and Altermark talc mine. The Remlia ultramafite (Fig. 2) is quite different from the others because parts of the talc-carbonate rock carry anthophyllite, a mineral not wanted in mineral products because of its fibrous habit. The Remlia body is therefore not

regarded as a deposit, and is not discussed further. The deposits at Store Esjeklumpen, Nakkán and at the Altermark talc mine (Fig. 2), however, have quite similar mineralogies.

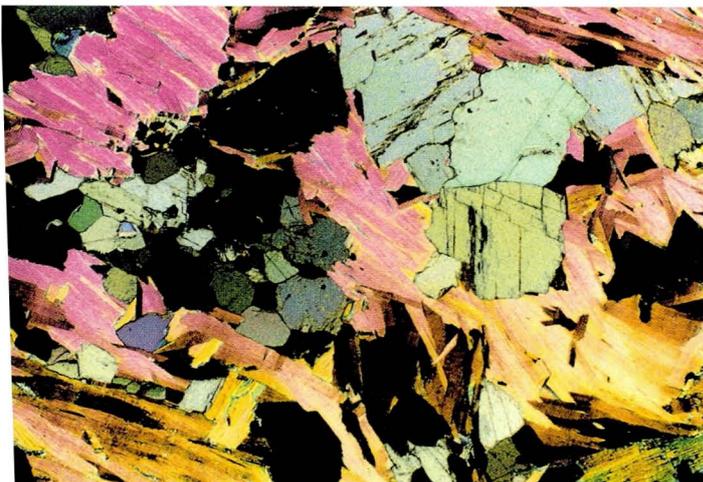
The talc-carbonate ore (Fig. 7) consists mainly of talc (about 45-65 %) and carbonates (30-50 %). Additional constituents are chlorite (typically 0-4 %, locally higher) and magnetite / chromite / ferrite-chromite (0-3 %, locally higher). Tremolite and anthophyllite are usually absent in the ore, but have been identified locally in distinct zones in the talc-carbonate rock. Zones containing amphibole are not regarded as ore. Antigorite is present close to the serpentinitic cores. Sulphides are present in very small amounts (<0.5 %) and are dominated by pyrite, pyrrhotite and pentlandite. The carbonates are commonly chemically zoned breunnerites with an increasing content of FeCO<sub>3</sub> from the core towards the rim (up to about 21 mol. %) (Fig. 8). In places, the FeCO<sub>3</sub> content in the core is less than 5 mol. % (~2.1 wt. % FeO) and the carbonate may be termed magnesite. There is a break in carbonate composition in the area between 10.3 and 12.6 %

FeCO<sub>3</sub>, a feature also recognised in the Raudberget deposit in Stølsheimen (Karlsen 1990), but at a lower level. Dolomite is present locally in subordinate amounts. The talc crystals carry 0-4 wt. % FeO (total) and 0-0.3 wt. % NiO in their lattices (Table 2), a common feature in talc associated with ultramafites. Two types of magnetite occur: a) chemically zoned large grains with cores of chromites or altered chromites; and b) more seldom, small, unzoned, pure magnetite grains. Chlorite occurs with a wide range of compositions, the most common being a clinocllore composition. Chlorite in the talc-carbonate rock may carry up to about 3 wt. % Cr<sub>2</sub>O<sub>3</sub> and 0.15 wt. % NiO in the lattice (Table 2).

The mineralogy of the ore varies somewhat between the different deposits, and also within each of the deposits; Most of the variations are, however, systematically related to the structure of the ultramafic lenses (Fig. 9);

- 1 Antigorite occurs only close to the serpentinite core, either as remnants of pre-existing serpentinite, as inclusions within carbonate, or as late-growth porphyroblasts that crosscut the talc-carbonate assemblage.
- 2 Chlorite is more abundant close to the black wall rocks than elsewhere.

Fig. 7. Photomicrograph of the talc-carbonate ore, showing the idiomorphic grain shape of talc (green) and carbonate (grey). Horizontal scale of field of view: 1 cm.



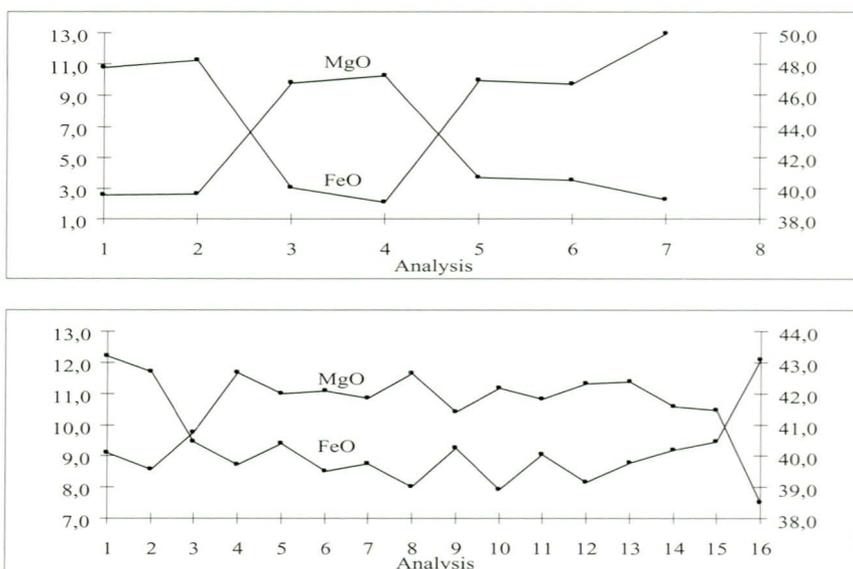


Fig. 8. Zoning profile across two zoned magnesite/breunnerite grains of about 1 cm diameter.

3 Magnetite is more abundant in the inner parts of the talc-carbonate zone.

The content of magnetite, which is formed by the process of serpentinisation, is a measure of maturity of talc-carbonate alteration. During the formation of the talc-carbonate assemblage from serpentinite, serpentine is rapidly broken down, while magnetite/ferrite-chromite takes longer. For this reason, internal parts of the ore might contain high amounts of magnetite (up to 10 % in extreme cases) while the outer part normally contains < 1 %. When magnetite is broken down, Fe enters the carbonate, thus causing the chemical zoning with increased Fe content from core to rim. The change from a low magnetite content to a high content takes place in a narrow

zone. The distribution of magnetite, as described above, has the following general implications for the ore:

- Ore excavated from nearby the serpentinites has high amounts of magnetite, while ore excavated from more distal parts has low amounts of magnetite.
- When the talc-carbonate zone is thin, the amount of magnetite present is always high due to the short distance from the serpentinite core.

Because of this relationship and geometrical differences, the amount of magnetite in the different deposits is variable. In the Altermark talc mine, contents in the range 0-8 % magnetite are recorded. The Store Esjeklumpen deposit generally contains < 1 % magnetite. In the Nakkan deposit, the magnetite content is in general higher than elsewhere, and on

Table 2. Selected microprobe analyses of the minerals present in the talc-carbonate ore.

Sample	63	77	44	64	78	45	74	75	F6	F1
Area	Talc mine	St.Esjekl.	Nakkan	Talc mine	St.Esjekl.	Nakkan	St.Esjekl.	St.Esjekl.	Talc mine	Talc mine vein
SiO <sub>2</sub>	62,24	62,24	61,26	30,08	30,40	32,84	n.a.	n.a.	0,05	0,00
TiO <sub>2</sub>	0,00	0,00	0,00	0,18	0,00	0,00	n.a.	n.a.	0,47	0,35
Al <sub>2</sub> O <sub>3</sub>	0,06	0,06	0,04	16,71	17,11	12,92	n.a.	n.a.	6,58	4,51
FeO	3,32	3,11	0,73	7,32	6,30	3,98	2,02	10,34	32,36	40,67
MnO	0,00	0,00	0,05	0,00	0,06	0,04	0,18	0,20	0,07	0,22
MgO	30,58	29,93	31,87	29,88	31,31	36,06	46,55	40,36	1,78	0,85
CaO	0,00	0,03	0,00	0,01	0,03	0,03	0,29	0,28	0,02	0,01
Na <sub>2</sub> O	0,03	0,00	0,00	0,00	0,00	0,07	n.a.	n.a.	0,06	0,10
K <sub>2</sub> O	0,00	0,01	0,00	0,00	0,01	0,00	n.a.	n.a.	0,00	0,00
Cr <sub>2</sub> O <sub>3</sub>	0,04	0,03	0,04	1,98	2,75	1,28	n.a.	n.a.	61,03	53,31
NiO	0,23	0,08	0,28	0,08	0,11	0,25	n.a.	n.a.	0,09	0,00
Total	96,50	95,49	94,27	86,24	88,08	87,47	49,04	51,18	102,51	100,02
Mineral	Talc	Talc	Talc	Chlorite	Chlorite	Chlorite	Core Magnesite	Rim Breunnerite	Core Fe-chromite	Rim Fe-chromite

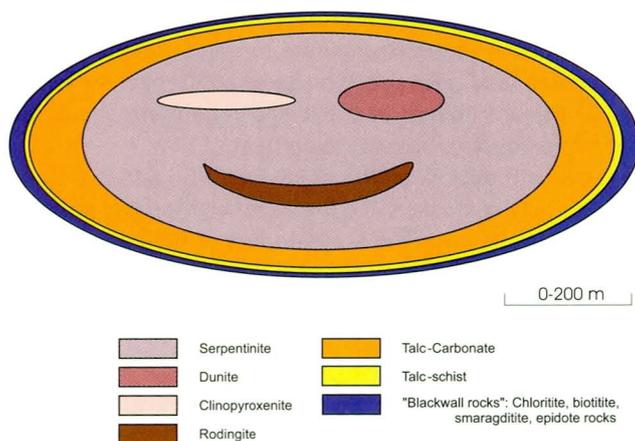


Fig. 9. Generalised zoning pattern showing some important features related to the quality of the ore (see text).

average it may contain around 2 % magnetite, while the local content may be higher. When the ore is magnetically separated, the magnetic fraction tends to contain other minerals in addition to magnetite. For this reason there might be a lower recovery of the ore when the content of magnetite is high. In the evaluation of the Nakkan deposit, this aspect has to be considered.

*Whiteness* is a measure of reflectance at three different wavelengths, here designated Rx, Ry and Rz, where the wavelengths are 600  $\mu\text{m}$ , 560  $\mu\text{m}$  and 450  $\mu\text{m}$ , respectively. A high whiteness % means a white colour. The statistics from whiteness measurements in Altermark show that the variations between the Rx, Ry and Rz are small (Karlsen 1995). For this reason, only Rx is referred to below. The degree of whiteness of the final products depends on 1) mineralogy, 2) grain size of the sample when measured (grade of crushing and micronisation), and 3) blacking from technical equipment like the crusher and the microniser. In the investigation of the ore quality the grain size is kept constant, and the blacking from instruments is neglected (micronisation has not been applied). The whiteness values given below are therefore assumed to be essentially related to mineralogy. In practice, the values will increase by around 2 % when micronised.

Tests show that there is a negative correlation between the whiteness and the content of magnetite and chlorite (Karlsen 1995). In samples that not have been magnetically separated, the content of magnetite will determine the whiteness. For example, a sample containing 10-15 % magnetite gives a whiteness of around 60-70 %, while a sample containing 0.6 % magnetite gives a whiteness of 78.7 %. By removing magnetite by magnetic separation, the whiteness is increased considerably. The highest measured whiteness in magnetically separated samples is approximately 84 %. Chlorite is the major mineral determining the whiteness when magnetite has been removed. Since the content of chlorite varies, so will the whiteness.

The talc-carbonate rocks at Nakkan and in the Altermark talc mine have the highest recorded magnetically separated whiteness, 76-83 % and 72-84 %, respectively, whilst that at the Store Esjeklumpen deposit has a whiteness of around 76-80 %.

## Possible products

Talc is an extremely versatile mineral, and has applications in the following sectors: paints, paper, ceramics, cosmetics, plastics, roofing, agriculture, and in the rubber industry. Its many uses partly reflect the fact that the properties of talc are highly valued by industry. It also indicates that there is a great variety of different talc products on the market. Talc products may be classified in several ways. One way is by their content of talc, e.g. talc >95 %, talc 75-95 %, talc 60-75 %, talc < 60 %. Alternatively, the origin of the talc is used as a criteria: e.g., ultramafite-derived talc and dolomite-derived talc.

High-purity talc (talc content >95 %) is used in cosmetics, steatite, cordierite ceramics, paper and plastics. Medium-purity talc (e.g., talc content 75-95 %) is used in paper, plastics, wall tiling, paint and rubber. Low-purity talc (e.g., <75 %) is used in paint, roofing materials, flooring and fertilisers.

There are certain distinctions between ultramafite-derived talc and dolomite-derived talc, in that some small amounts of Fe and Ni are sited in the crystal lattice of the former, while the dolomitic talc is an almost pure Mg-silicate. This is important for some applications; for example, ultramafic talc is not used in plastics where a low Fe content is required.

There are several product possibilities for the talc raw material from Altermark (Fig. 10): 1) talc-carbonate product, 2) talc concentrate, 3) carbonate concentrate. The first of these is the easiest one to produce and involves crushing, grinding and magnetic separation. This is the method applied by Norwegian Talc AS today, but in addition, micronising techniques are applied. Their products, 'AT1' & 'ATX', contain around 60 % talc and 40 % magnesite. The other two possible products noted above would all have to be made by flotation or other kinds of mineral separation methods. Flotation is the method employed by Mondo Minerals in Finland, which produces talc concentrates with more than 90% talc from talc-carbonate rocks. A sulphide concentrate and a carbonate concentrate are produced as by-products. The sulphide product is Ni-rich, because the primary sulphide is pentlandite. The carbonate concentrate contains mostly breunnerite, i.e. the Fe-rich variety of magnesite. There is a great difference between the Finnish raw material and the raw material from Altermark. In Finland, two quite different ultramafic talc-carbonate ores exist: 1) sulphide-rich, magnetite-poor and 2) sulphide-poor, magnetite-rich. The raw material is taken from the first type, while the second type is the one that most closely resembles the ores in Altermark.

By applying flotation techniques to the Altermark talc-carbonate ore, it is probable that high-grade pure talc products could be produced. Coarse grain size and idioblastic crystal shapes are advantageous for such a mineral separation. It is expected that pure talc concentrates will have considerably higher whiteness than the talc-carbonate product produced today. The reason for this is that whiteness-reducing minerals like magnetite and chlorite would be more thoroughly removed in such a process. A carbonate product from flotation would have a chemistry close to the average composition of magnesite/breunnerite with an FeO content

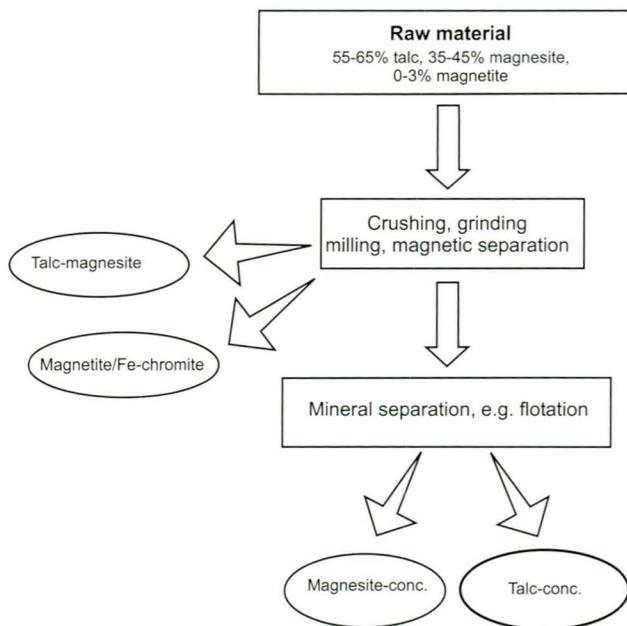


Fig. 10. Possible processing routes for the talc-carbonate ore (see text).

around 8-10 %. While pure magnesite products are common on the market, the Fe-bearing breunnerite products are not. Such Fe-bearing Mg products are not easily sold, or are sold at low prices (Olerud 1990). Since almost all carbonates contain substantial amounts of Fe, it would not be possible to make a pure Mg product by further physical separation methods. However, it might perhaps be possible to achieve a purer Mg product by applying some methods to change the chemistry of the carbonates. Anyhow, more research on such a carbonate product with respect to both properties and market possibilities would have to be carried out. Since the sulphides occur only in very limited amounts (< 1 %) and consist of a mixture of pyrite, pyrrhotite and pentlandite, an economic sulphide product is not possible to achieve. A similar conclusion can probably be made for the magnetite/ferrite chromite content removed by magnetic separation.

## Conclusions

Active prospecting during the last 8 years has proved that the Altermark area contains much more talc than previously known. In the Nakkan-Esjeklumpen area, there are probably around 10 million tonnes or more of talc-carbonate ore, distributed in three ultramafic bodies. In the present mining area, a considerable reserve has been added to the previously known tonnage.

The ore, which occurs as one of several layers within compositionally zoned ultramafic lenses dominated by antigorite serpentinites, has the following general mineralogy: talc (45-65 %), carbonate (30-50 %), chlorite (0-4 %), magnetite (0-3 %). Relative to other similar known deposits, the ore is rather coarse-grained, and the minerals tend to be idioblastic.

There are variations in the mineralogical content, both within and between the deposits. Variations in magnetite

and chlorite are systematically related to the position of the sample relative to the serpentinite core and the external rim. The content and grain size of magnetite will effect the recovery of the ore during magnetic separation and should be focused on during future development.

Several products can be made from the talc-carbonate ore. By applying flotation it is likely that high-quality talc concentrate could be made. A by-product of breunnerite concentrate might also be economic, but more research and development need to be carried out to find applications.

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