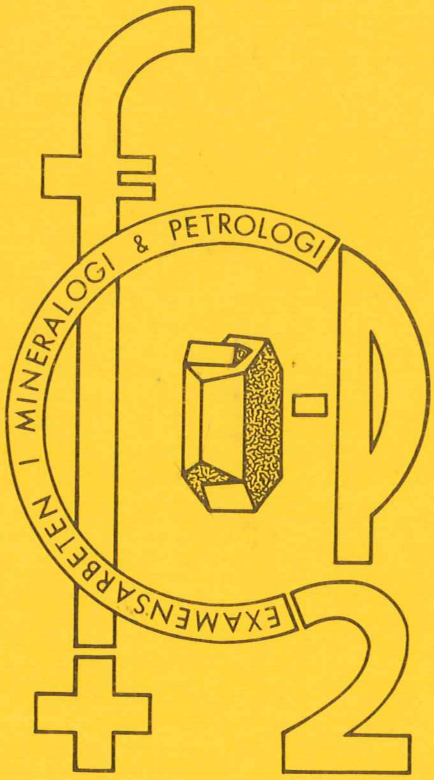
EXAMENSARBETEN I GEOLOGI VID LUNDS UNIVERSITET

Mineralogi och petrologi



INVESTIGATION OF A WOLLASTONITE OCCURRENCE IN CENTRAL SWEDEN

Anett Elg

Lunds univ. Geobiblioteket
15000 600954145

GEOLOGISKA
INSTITUTIONENS BIBLIOTEK
LUND pev

NR 17

ITUTIONEN LUNDS UNIVERSITET

CODEN: LUNBDS/(NBGO-5017)/1-139/(1987)

EXAMENSARBETEN I GEOLOGI VID LUNDS UNIVERSITET

Mineralogi och petrologi

INVESTIGATION OF A WOLLASTONITE OCCURRENCE IN CENTRAL SWEDEN

Anett Elg

LUND 1987

GEOLOGISKA
INSTITUTIONENS BIBLIOTEK
LUND

NR 17

GEOLOGISKA INSTITUTIONEN LUNDS UNIVERSITET

Table of Content

Appendices

List of Tables

List of Figures

ACKNOWLEDGEMENTS

I would like to thank staff and students in the Department of Geology at the University of Hull for help and advice, in particular my supervisor, Dr. P.W. Scott. And also Mr. F.C.F. Wilkinson for microprobe work, Mr. R. Middleton for XRF and Mr. J. Garner who photographed the hand specimens for this thesis. I would also like to thank Dr. A.G. Fraser who gave assistance and constructive advice in XRD and mineral identification.

Mr. K. Gatedal and Mr. J.O. Larsson (LKAB) provided me with material for this work.

Thank you also to Mrs. C. Mallet who typed this thesis.

My parents, who always have encouraged and supported me concerning my studies, deserve my special thanks.

I would also like to express my gratitude to Dr. A.Lindh for helpful advise for the final writing of this thesis.

ABSTRACT

The wollastonite occurrence at Hulta is a skarn deposit associated with iron ore within the Leptite Formation of central Sweden. Wollastonite is found in carbonate layers within the leptite and the rocks have been subject to regional metamorphism. These layers are normally approximately 10 cm thick. Corelogging, microscopic studies and X-ray diffraction show a varied composition of the rock, with minerals of different chemical and physical properties. These are microcline and quartz, which are the main constituents of the leptite, and also garnet, calcic pyroxene, wollastonite, vesuvianite and calcite. Minor phases are albite, sphene, allanite, fluorspar, zircon, and scheelite. The average wollastonite in the wollastonite-bearing sections is 10-15 wt%. This conforms with the XRF results which show a high content of Si (35.10-63.26 wt% SiO_2) and a low to moderate Ca-content (10.94-34.06 wt% CaO). The highest Ca-content is found in an impure limestone, and is thus accompanied by a high LOI (13.11 wt%). Microprobe studies show that the calcic pyroxene is salite and the garnet is a solid solution of varying proportions of grossular and andradite. The wollastonite itself is almost pure $CaSiO_3$ with only minor Mn (0.35-0.95 wt% MnO) and a LOI which is less than 1 wt%. The aspect ratio is approximately 1:4.4, the brightness and reflectance is similar to that of commercially used wollastonite. These properties give the wollastonite many potential uses in industry, if efficiently concentrated. Preliminary froth flotation work using amine collectors only separated garnet to some extent from the material.

ABSTRACT

En wollastonitförekomst vid Stor Hulta gruvor i närheten av Nora har undersökts. I den nedlagda gruvan har tidigare skarnjärnmalm tillhörande leptitformationen brutits. I jämförande syfte har även wollastonit från Akatjvare i Tjåmotisområdet undersökts. Detta är LKAB:s prospekteringsobjekt och är beläget i Jokkmokks kommun. Resultaten för detta material, som utgörs av fyra stuffer av dubbel knytnävsstorlek, redovisas i respektive kapitel.

Wollastoniten i Hulta finns i regionalt omvandlade karbonatlager, som i regel är ca. 10 cm tjocka, växellagrade med leptit. Vid borrkärnekartering framkom att bergarten är mycket inhomogen och att de wollastonitförande lagren förekommer ojämnt fördelade i leptiten. Undersökningarna har koncentrerats på de partier i borrkärnorna där dessa lager är mest frekventa.

Mineralogin i dessa partier har studerats med hjälp av petrografiskt mikroskop och röntgendiffraktion. Röntgendiffraktometri utfördes på fyra olika prover. De vanligaste mineralen är kvarts och mikroklin, som utgör huvudbeståndsdelarna i leptiten, samt granat, kalciumpyroxen, wollastonit, vesuvian och kalcit. Dessutom har albit, titanit, allanit, flusspat, zirkon och scheelit påträffats i mindre mängder. Inom de wollastonitförande enheterna är den genomsnittsliga wollastonithalten 10-15 vikts %.

Den kemiska sammansättningen hos de genom röntgendiffraktometri undersökta proverna har analyserats med hjälp av röntgenfluorescens. Analyserna visade en Si-halt på 35,10-63,26 vikts % SiO_2 och en Ca-halt på 10.94-34,06 vikts % CaO. Den högre CaO-halten uppmättes i en oren kristallin kalksten, som således också uppvisade en hög glödgningsförlust (13,11 vikts %).

Mikrosondstudier har gjorts för att fastställa den kemiska sammansättningen hos de ingående mineralfaserna. Dessa visar att pyroxenen är salit, och att granaten är fast lösning av i huvudsak grossular och andradit i varierande proportioner. Wollastoniten är nästan ren $CaSiO_3$ med små mängder av Mn (0.35-0.95 vikts% MnO) och en glödgningsförlust som är mindre än 1 vikts%.

Wollastonitkornens längd/bredd-förhållande har undersökts i ljusmikroskop. Det genomsnittsliga förhållandet hos material 63-125 um är 4.4/1. De optiska egenskaperna hos wollastoniten undersöktes med hjälp av en reflektionsspektrofotometer. Detta gjordes också på ett prov på wollastonit som utvinns kommersiellt i Lake Bonaparte i New York State, USA. Värdena för både wollastoniten från Hulta och Tjåmotis visade sig ligga mycket nära de för den amerikanska wollastoniten uppmätta värdena.

Dessa inledande undersökningar av wollastoniten från Hultagruvorna visar att den har tillräcklig hög kvalitet för att kunna användas i en rad olika industrianvändningar där det inte krävs så högt längd/breddförhållande. Förutsättningen är dock att man kan separera ut mineralet på ett effektivt och lönsamt sätt. Preliminära flotationsförsök med aminsamlare gjordes, som resulterade i en viss frånskiljning av granaterna.

INTRODUCTION

Wollastonite is a relative newcomer as an Industrial Mineral. As such, it has potential uses not yet fully developed, and therefore demand for it can be expected to increase in future. In this work a wollastonite occurrence called Hulta, in the centre of Sweden has been investigated. It is located on the topographic and Swedish Geological Survey map 11F Lindesberg SV, some 200 km west of Stockholm (see accompanying map).

For comparative purpose, a sample from Tjåmotis, 125 km south-west of Kiruna, has been included in the work. This is a wollastonite deposit that is being developed by the mining company LKAB (Luossavaara-Kiirunavaara Aktiebolag).

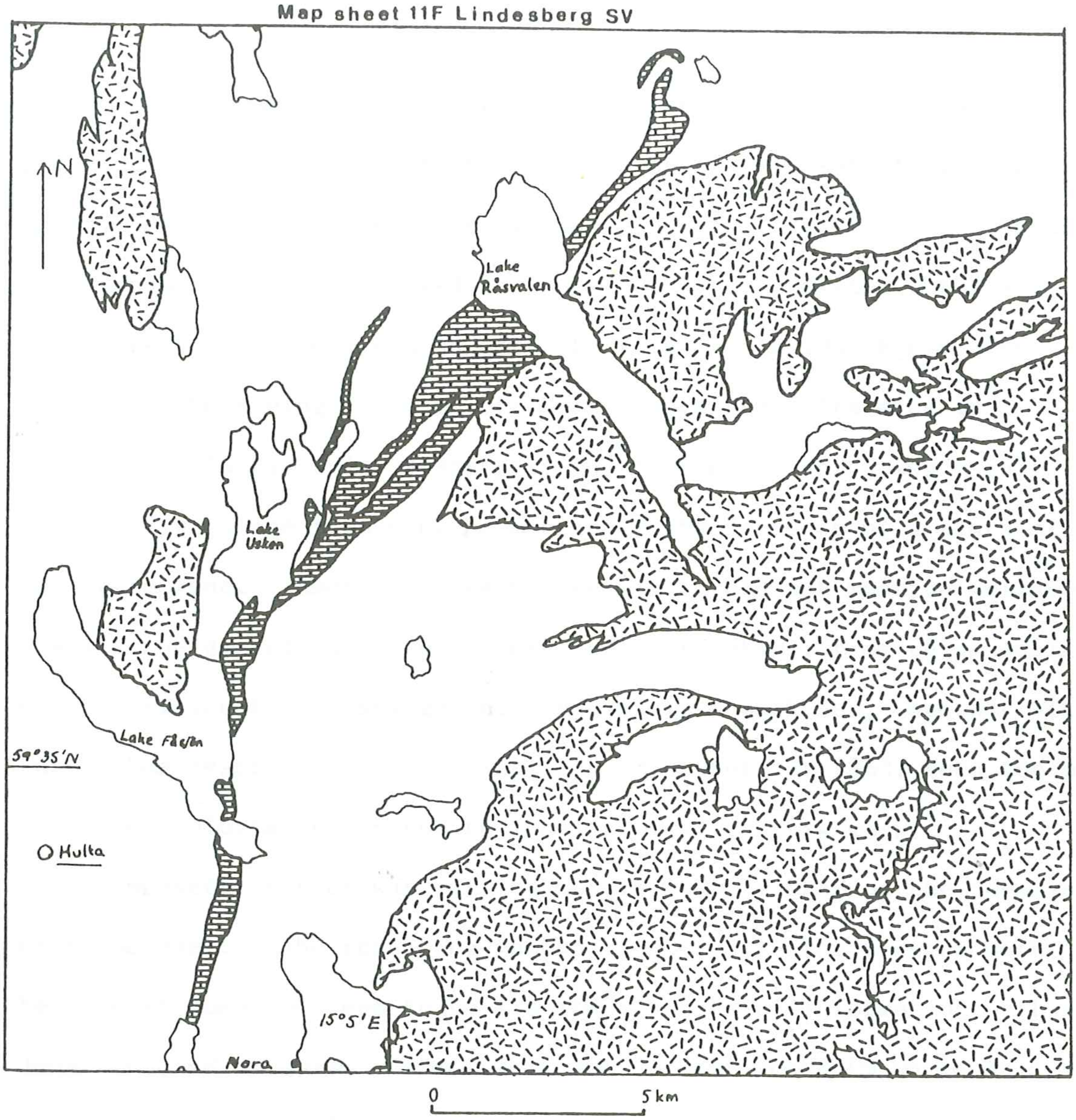
Both wollastonite occurrences are found in rocks of the Sveccofennian Orogeny. This consists mainly of rocks that are 1800-2000 million years old, and make up a large part of Sweden . The wollastonite of Hulta is found in a skarn, which is associated with an iron ore, within the Leptite Formation (1950-2200 Ma) of central Sweden. This formation is well-known for its relative richness in metal ores, such as iron, copper, lead, zinc and silver.

Leptites, that give name to the formation, are metamorphosed rocks of volcanic origin. They are fine-grained and have alkalirhyolitic to rhyolitic composition. They are divided into lower sodium-rich and upper potassium-rich varieties. This is, according to Arvanitidis and Richard (1981), due to temperature dependent selective fixation of the alkalies in feldspar molecules, during early metasomatic alteration. Thus, the formation of sodium feldspar is favoured by higher temperatures that prevail at depth in the crust, and that of potassium feldspar occurs closer to the surface, where temperatures are lower.

Metasediments, such as micaschists, breccias and conglomerates in more or less continuous layers also occur on the Geological Survey map. Crystalline limestone and skarn are found as thicker units, or as thin intercalations in the leptite. Rocks in the area also include syn- and anorogenic granites, and dolerites. There are two different directions of dolerite dykes, namely older ones going from east to west and younger north-south striking dykes.

Folding in the area has taken place in two steps. Firstly there was an east-westerly compression, which gave north-south trending horizontal fold axes. The second phase was caused by a compression in north-southerly direction, which resulted in refolding along easterly plunging axes.

Metamorphic alteration has occurred in three events. The first event was synvolcanic and took place before the first folding. It involved intense alteration of the supracrustal sequence, in particular alkali ion exchange, which has been mentioned before. The second event was the regional low pressure metamorphism, with its peak after the deformation of the area. It reached high amphibolite facies, and was the cause of the autometasomatism that formed the skarn in Hulta. The third event of metamorphism could be a retrograde phenomenon immediately following the amphibolite facies metamorphism. However, according to Lundström (1983), it is more likely to be a separate later event, since traces of it have been found in postorogenic intrusions. It includes alteration of biotite to chlorite, of plagioclase to sericite and of cordierite to pinnite.



Distribution of the rock types in the region.

After Ingmar Lundström 1979

▨ Plutonic rocks, larger massifs

☐ Supracrustal rocks, volcanic and sedimentary

▤ Carbonate rocks in larger occurrences

/ Geological boundary / Lake shoreline.

PREVIOUS WORK

Quite a number of both published and unpublished work has been produced about the district in which the deposit is situated. This is mainly because of its relative richness in metal ore, and the literature also tends to be concentrated on that. And so, previous works are mostly restricted to areas adjacent to mines. In 1942 Hjelmquist described the mining field of Striberg, where the Hulta mine is included. In his brief description on this mine, which was mainly concerned with the iron ore, he mentioned the presence of a skarn altered carbonate zone. Among the skarn minerals he did not mention wollastonite. However, he described fibrous tremolite (stralsten), from which wollastonite can be difficult to distinguish. Hjelmquists work has, together with Lundströms description to the map 11 F Lindesberg SV 1983, been the main source of information on the regional geology in this work.

A magnetic survey was carried out in 1985 by LKAB on the commission of K. Gatedal. The resulting map was not used in the present work, because it does not seem to be a suitable source of information with its large scale, and being over an area rich in iron ore, when looking for wollastonite.

Older geological literature consists of regional summaries by Törnebohm (1880) and Santesson (1883), and descriptions to older Swedish Geological Survey maps, such as those by Hummel (1873), Karlsson (1873), Gumaelius (1875) and Blomberg (1879).

PRESENT WORK

The aim of this work was to characterize the wollastonite occurrence mineralogically, and assess its value as a source of wollastonite. Field work consisted of reconnaissance mapping and corelogging with sampling. Qualitative mineralogical studies were carried out using a polarization microscope and X-ray diffraction.

A semi-quantitative assessment of the wollastonite content in representative bulk samples was done by XRD. Chemical composition of these bulk samples was obtained by X-ray fluorescence.

The chemical composition of each mineral was investigated by electron microprobe with special interest on the purity of the wollastonite.

Attempts were made to separate the wollastonite from impurities using froth flotation.

CHAPTER 1

Review of Wollastonite uses and the related key properties of the mineral

Wollastonite is a relative newcomer in industry. It remained practically unexploited until the 1930s. In 1933 the earliest mining of the mineral was reported, at Randsburg in California, where it was used for the manufacture of mineral wool.

Large scale operation was first started in Willsboro, New York State in the 1950s. Because of the relative youth of the industrial mineral wollastonite, its full potential is not yet exploited in industry.

1.1 Properties of wollastonite and its applications in industry

Wollastonite, $CaSiO_3$ has the theoretical composition 48.3% CaO and 51.7% SiO_2. In nature, it has a rather constant chemical composition, but some substitution of iron, manganese and, to a lesser extent, magnesium for calcium may occur. So, for example, mangoan wollastonite has been found in the Oslo district of Norway and wollastonites with 15-20% $FeSiO_3$ are known in Britain (R.W. Andrews, 1970). Iron rich wollastonite inverts to calcic pyroxene at temperatures of 940-980°C. The colour of wollastonite is usually white, but can sometimes be cream, grey, or very pale green. It is often found in coarse bladed masses, that rarely show good crystal form. The particle shape is usually acicular or fibrous, even for small particles, a property on which much of its usefulness depends. Fibre lengths are commonly 7-8 times their diameter, but the length to width ratio may be as much as 13-15. The inverse value of that number is called the aspect ratio. The applications of wollastonite can be divided into two groups according to the aspect ratio (width:length) of the wollastonite used (T. Power 1986):

Aspect ratio	Applications
1:3 - 1:5	Ceramics, metallurgical fluxes, simple filler and coating.
1:15- 1:20	Asbestos replacement, performance filler in various plastic and resin systems.

The most important uses of wollastonite and related key properties of the mineral are listed in Table 1-1.

Key Property	Applications A	B	C	D	E	F	G
Acicular shape	X	X	X		X		
Chemical purity	X	X	X				
Hardness (4.5 - 5 on Moh's scale)			X			X	
pH (9.9 in a 10% slurry)		X					
White colour, high reflectance	X	X	X				
Low loss on ignition (<1%)	X			X			
Low absorption of oil and water		X	X				
Low fluxing temperature	X			X		X	X
Good heat resistance					X		X
Low thermal expansion (5.6×10^{-6} mm/mm/°C)	X						X

Table 1-1. Key properties and applications of wollastonite. A = ceramics, B = paint, C = performance filler in plastics and rubber, D = metallurgical industry, E = asbestos replacement, F = abrasive industry, G = mineral wool.

1.1.1 Ceramics industry

The major consumer of wollastonite is the ceramics industry, where it is mainly used in fast firing processes. In these, thin ceramics such as semivitreous art ware, dinner ware and especially wall tiles are produced. The addition of wollastonite makes it possible to bring down the length of the firing cycle quite considerably. This is due to several factors:

Only a short pre-heat phase is required since water is easily removed along the wollastonite fibres;

No gas is produced;

The wollastonite has high fluxing action;

The thermal expansion is low;

The material has high resistance to thermal shock;

Green strength (the strength of unfired product) is high enough to withstand the application of glaze so that single firing can be used.

Other applications within ceramics industry are in glazes, glaze frits, fluxes, colour stains and low loss electrical insulation ware.

Some requirements for the ceramics industry:

The wollastonite must be free of, or very low in, iron to avoid discoloration.

Particle size requirements for wollastonite for the fast firing process:

all material	<60 mesh (250 um)
most material	<200 mesh (75 um)
more than half of the material	<325 mesh (50 um)

Loss on ignition must be less than 1%.

1.1.2 Paint industry.

It is mainly for specialist paint manufacture that wollastonite is used. For simple paint systems, other materials, which are normally more readily and cheaply available, are used.

Wollastonite is used in paint for exterior house coatings, latex paints, paints for road markings, caulking compounds and as replacement for asphalt based coatings. The needle-like particles give a flat surface, and the interlocking particles improve toughness and durability of the coat. Pigment costs are brought down because of the high brightness and whiteness of wollastonite, which reduces the amount of pigment needed. Low oil absorption also contributes to reduced costs since less binder is needed. Wollastonite based paint cannot be used in acid environments, because of the high pH it produces in a slurry. However, this feature is advantageous, in that it gives a buffering effect, when polyvinyl acetate paints decompose to vinyl alcohol and acetic acid. In neutralizing the acid, the wollastonite prevents corrosion.

Some requirements for the paint industry:

residue on sieve, max. %	63 um: 1.0
	45 um: 3.0
particle size distribution, % min., cumulative	20 um: 90
	10 um: 70
	5 um: 40
loss on ignition, % max.	8
pH of aqueous suspension	8 - 12.5
matter volatile, 105°C	12

(British Standard BS 1795: 1976 (1985))

1.1.3 Performance filler in plastics and rubbers

This industrial sector utilizes the acicularity of the wollastonite particle, that imparts strength to the product. Certain techniques have been developed in mineral processing to maintain high aspect ratios also after grinding. This development increases the number of possible uses of wollastonite in plastics and rubber.

Wollastonite is used in thermoplastics (PVC, nylon, polypropylene) and thermo-setting resin systems (epoxy, phenolic, polyester). It is also used in a variety of non-black rubber goods.

Some of the benefits of the wollastonite addition in rubber and plastics are:

It reduces the amount of expensive media consumed;

It reduces shrinkage and increases thermal conductivity and heat deflection temperature;

The mineral is thermally stable and chemically resistant;

It improves tensile and flexural strength (surface treated material, see below).

Wollastonite also gives a mat finish and an opaque product.

In recent years chemical surface treatment of particles has been developed to further improve performance of wollastonite. Silanese is the most commonly used compound. It acts as a coupling agent in that the organic part of the molecule reacts with the resin and the inorganic functional group reacts with the siliceous material (P. Harben 1986), in this case wollastonite.

The effects of surface coating are:
greatly improved strength, due to parallel arrangement of wollastonite particles to the flow of resin, and reduced abrasiveness of the wollastonite on manufacture equipment.

Some of the requirements for the plastics and rubber industry are: low impurity content, small particle size with uniform distribution, high aspect ratio of the crystal, and high whiteness and brightness.

1.1.4 Other uses of wollastonite

In metallurgical industry there has arisen an increasing demand for wollastonite with the establishment of the continuous casting process. The flux composite powder containing wollastonite is applied to the stream of molten metal. This is to maintain the surface in a molten state, when it is poured from the bottom of the refining ladel into the refractory tundish. This procedure minimises surface defects, such as scratching, that could arise during the pour. It is the low fluxing temperature of wollastonite that is beneficial in this procedure.

The application of wollastonite in mineral wool and as a replacement for asbestos utilizes its heat resistant properties and, in the latter case, its acicular nature. In the abrasive industry wollastonite is used for the production of ceramic bonded abrasives and of abrasive wheels, where it gives a strong bond without increasing the density.

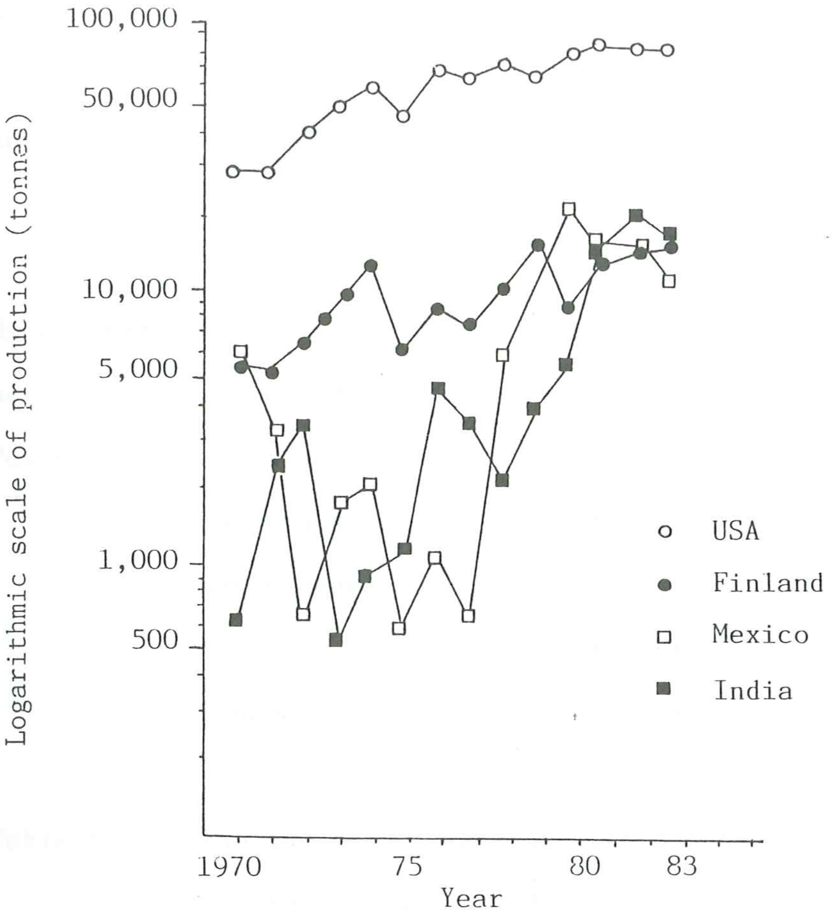
Wollastonite has many properties which would make it suitable as a filler in paper (including high brightness and the particle shape) but the main problem is the high abrasiveness of the material that causes wear of manufacturing equipment.

1.2 Main wollastonite producing countries

As fig. 1-1 shows, the leading world producer of wollastonite is USA. There are two deposits that are operated in New York State, which is the main source area. These are the Willsboro deposit in Essex county and the Gouverneur mine in the Gouverneur district. The Willsboro material from the Lewis mine consists of 60% wollastonite, 30% garnet and 10% diopside. Material from Gouverneur district differs from the Willsboro material in that it contains no garnet.

The wollastonite is found in a contact-metamorphosed, pre-Cambrian Grenville limestone that has been intruded by anorthosite.

The Laapenranta deposit of SE Finland is the main European source of wollastonite. It is found in a regionally metamorphosed pre-Cambrian limestone which is interbedded with leptite. Average wollastonite content is 18-20% and the mineral is accompanied by calcite, dolomite, leptite, quartz and diopside.



Source: BGS World Mineral Statistics

Fig. 1-1. The major wollastonite producing countries of the world.

Other countries that supply wollastonite are Mexico, India and most recently China. More sporadic production is operated in Kenya and Namibia. Additionally, synthetic wollastonite is manufactured in Denmark.

Applications of wollastonite from the different sources are presented in table 1-2.

Grade	Source	Applications					
		A	B	C	D	E	F
Acicular	Willsboro		O	X		X	
	India		O	X		X	
Micronised, acicular	Willsboro		X	X			X
	Lappeenranta		X	X			X
Powder	Willsboro	X	X		O		X
	Lappeenranta	X	X		X		X
	Gouverneur	X	X		X		X
	China	X	X				X
	Synthetic	X	X		X		O

Table 1-2. The sources of wollastonite and their markets in Europe.

X = major application
O = minor application
A = ceramics, B = paint, C = performance filler in plastics and rubber, D = metallurgical industry, E = asbestos replacement, F = general filler.

CHAPTER 2

GEOLOGY

2.1 Field work

Field work was carried out in an area around an abandoned iron mine, Hulta gruvor, 1 km. north of the little village Striberg and 12 km northwest of the small town Nora.

The degree of exposure is very low, but in the area adjacent to the Hulta mines there were numerous trenches, established by K. Gatedal in 1985, which contained rock exposures. At the time for the field work (end of April - beginning of May) the ground was still partly covered with snow, and large quantities of meltwater was accumulated in depressions. Therefore, access to wollastonite-bearing outcrops was restricted. However, reconnaissance mapping and sampling of surface exposures was carried out (fig. 2-1).

In connection with the trenching in 1985, K. Gatedal also drilled 15 deep drillholes (fig. 2-2). The cores from this drilling program were logged (appendix 1) and sampled. The main part of this project is based on that material. A complete list of samples is given in Table 2-1.

2.2 Geology of the wollastonite deposit

The dominating rock in the area is potassic leptite. In this rock wollastonite occurs in carbonate layers, which are concentrated in zones.

Thicknesses of carbonate layers vary from a few centimetres to several metres. There has been a complete replacement of calcite by wollastonite, where the thickness of a layer is small. In thicker carbonate layers, the rock is still mainly consisting of calcite, with minor wollastonite, being an impure crystalline limestone. This distribution of wollastonite is probably connected with the way in which it was formed. As previously mentioned the rocks have been subject to regional metamorphism. The rise in pressure and temperature have caused reaction between the mineralogically and chemically different units, to form wollastonite and other skarn minerals. In a thin layer of carbonate the calcite is more readily available to form wollastonite in reaction with quartz, than in a thick one. Therefore thin layers of carbonate have no remaining calcite.

Other skarn minerals are garnet, calcic pyroxene, vesuvianite and hornblende. Different kinds of skarn have been recognized depending on the dominating mineral. They have been named accordingly garnet skarn, pyroxene skarn and wollastonite skarn. Additionally, there are sections within the leptite that have been altered to chlorite and biotite. Magnetite is found associated with pyroxene and mica.

The rocks have, according to S. Hjelmquist (1942), been folded along an axis plunging 20° towards ENE. According to the same author, an east-west trending dolerite cut through the sequence with a dip of 70° towards south. This was observed in one outcrop. Detailed descriptions of selected samples and thin sections from surrounding rocks are found, together with those from wollastonite skarn, in appendix 2.
Fig. 2-3 shows two examples of the succession of the rocks in the core. Boundaries between rock units are often transitional. For example, leptite can become gradually enriched in pyroxene as the distance to a compact pyroxene layer becomes smaller. Generally, units of pyroxene skarn are thicker than those of the two other skarn types. Pyroxene skarn can have thicknesses up to 10 m., while the maximum thickness of garnet skarn is 4 m., normally being around 1 m. Wollastonite is found only in low concentrations in units more than 10 cm. thick.

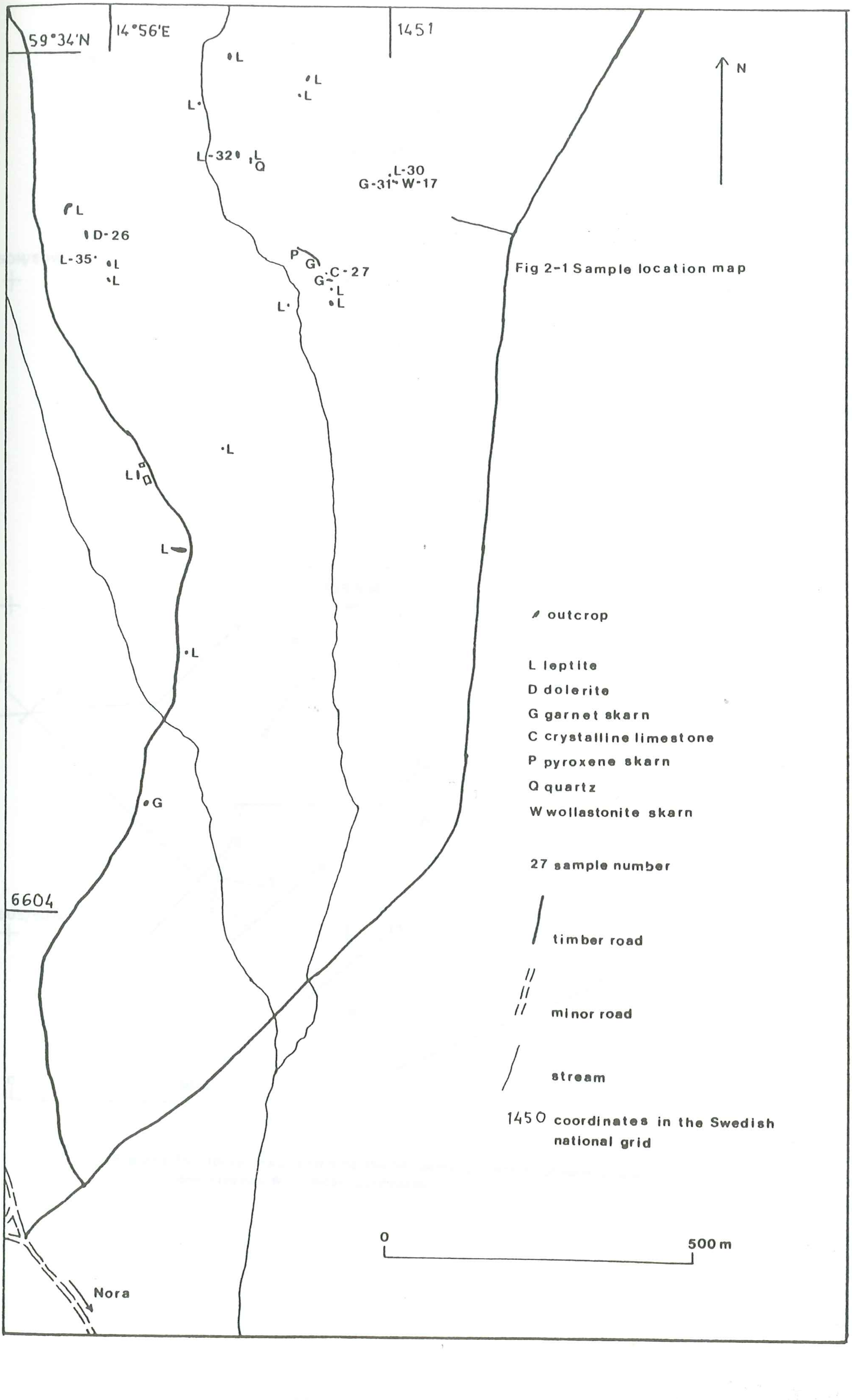


Fig 2-1 Sample location map

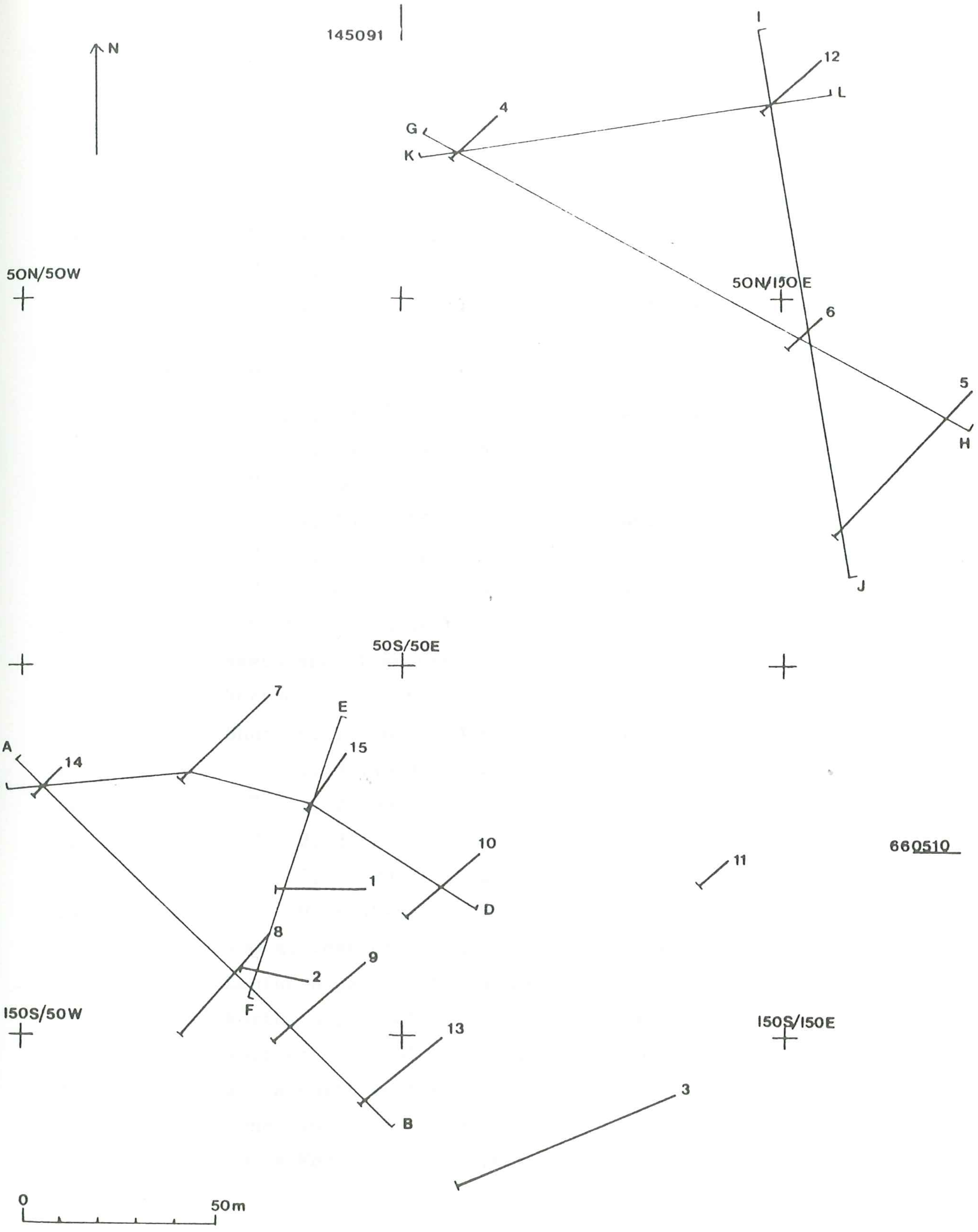
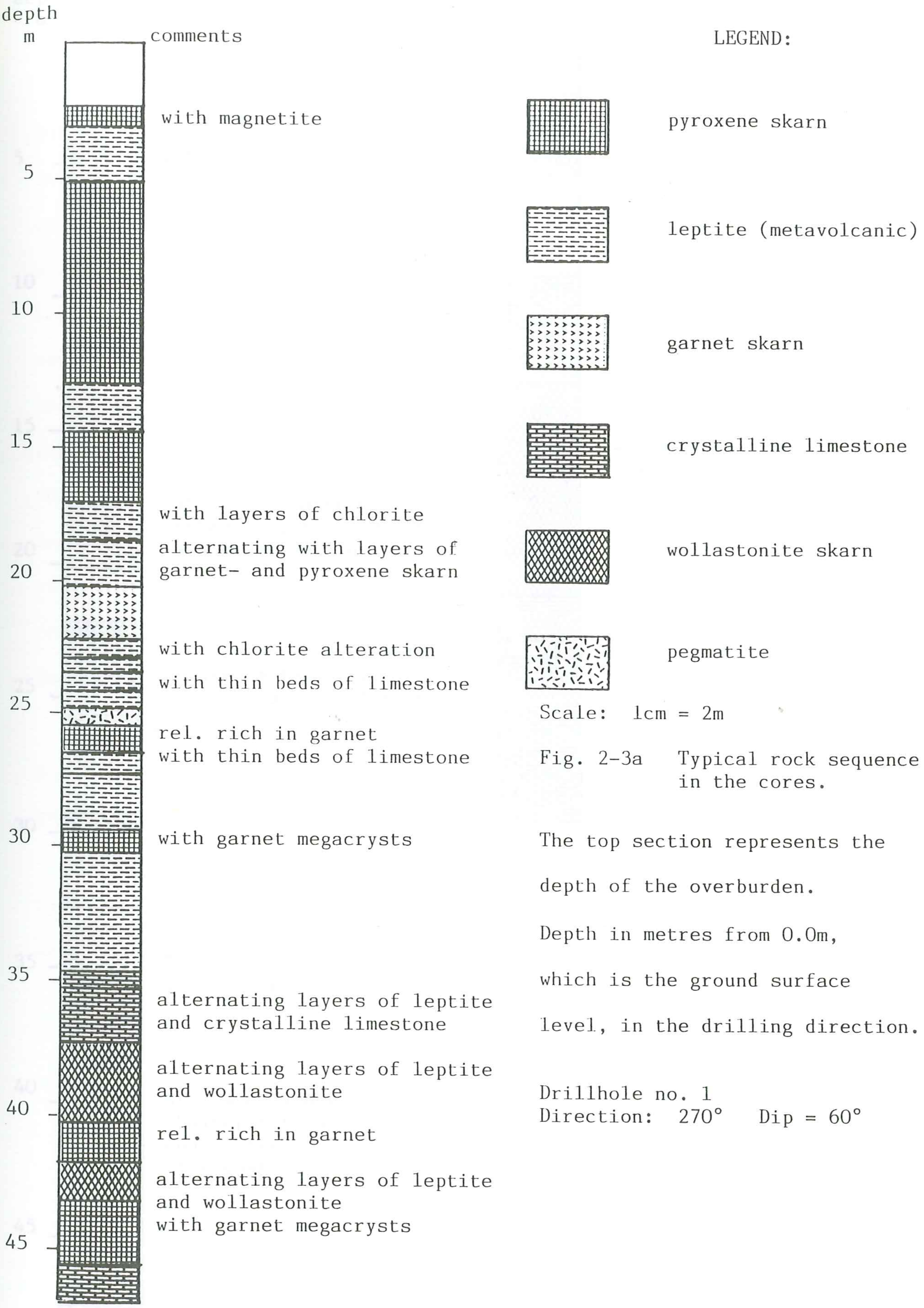


Fig.2-2 Drillhole map showing the horizontal projection of each borehole, and profiles. With local coordinates.

Sample No.	Locality	Rock type
1	Dhno. 1, 38.00-38.10 m	Wollastonite skarn
2	" 1, 42.00-42.05 m	Skarn
3	" 4, 37.00-37.05 m	Wollastonite skarn
4	" 4, 42.75-43.20 m	Wollastonite skarn
5	" 4, 45.60-45.75 m	Wollastonite skarn
6	" 4, 33.95-34.10 m	Wollastonite skarn
7	" 2, 26.90-27.10 m	Wollastonite skarn
8	" 2, 33.00-33.07 m	Metaleptite
9	" 2, 33.07-33.15 m	Wollastonite skarn
10	" 2, 34.35-34.45 m	Wollastonite skarn
11	" 8, 40.75-41.75 m	Impure limestone
12	" 14, 15.70-15.75 m	Wollastonite skarn
13	" 14, 21.85-22.00 m	Crystalline limestone
14	" 10, 65.15-65.20 m	Wollastonite skarn
15	" 10, 65.10-65.15 m	Metaleptite
16	Akatjvare, Tjåmotis	Wollastonite skarn
17	Northern part of Hulta mines	Wollastonite skarn
19	Dhno. 8, 21.50-22.30 m	Wollastonite skarn
20	" 1, 39.40-39.50 m	Wollastonite skarn
21	" 2, 29.00-29.10 m	Wollastonite skarn
22	" 2, 31.00-31.15 m	Wollastonite skarn
23	" 5, 71.80-71.90 m	Biotite rock
24	" 9, 8.45-8.50 m	Pyroxene skarn
26	430 m. west of Hulta	Dolerite
27	Southern part of Hulta mines	Crystalline limestone
30	Northern part of Hulta mines	Leptite
31	Northern part of Hulta mines	Garnet skarn
32	220 m north-west of Hulta	Leptite
34	Dhno. 16, 72.40-72.50 m	Leptite gneiss
35	390 m West of Hulta mines	Leptite

Table 2-1 List of samples. Dhno = Drillhole number.



Scale: 1cm = 2m

Fig. 2-3a Typical rock sequence in the cores.

The top section represents the depth of the overburden.

Depth in metres from 0.0m, which is the ground surface level, in the drilling direction.

Drillhole no. 1
Direction: 270° Dip = 60°

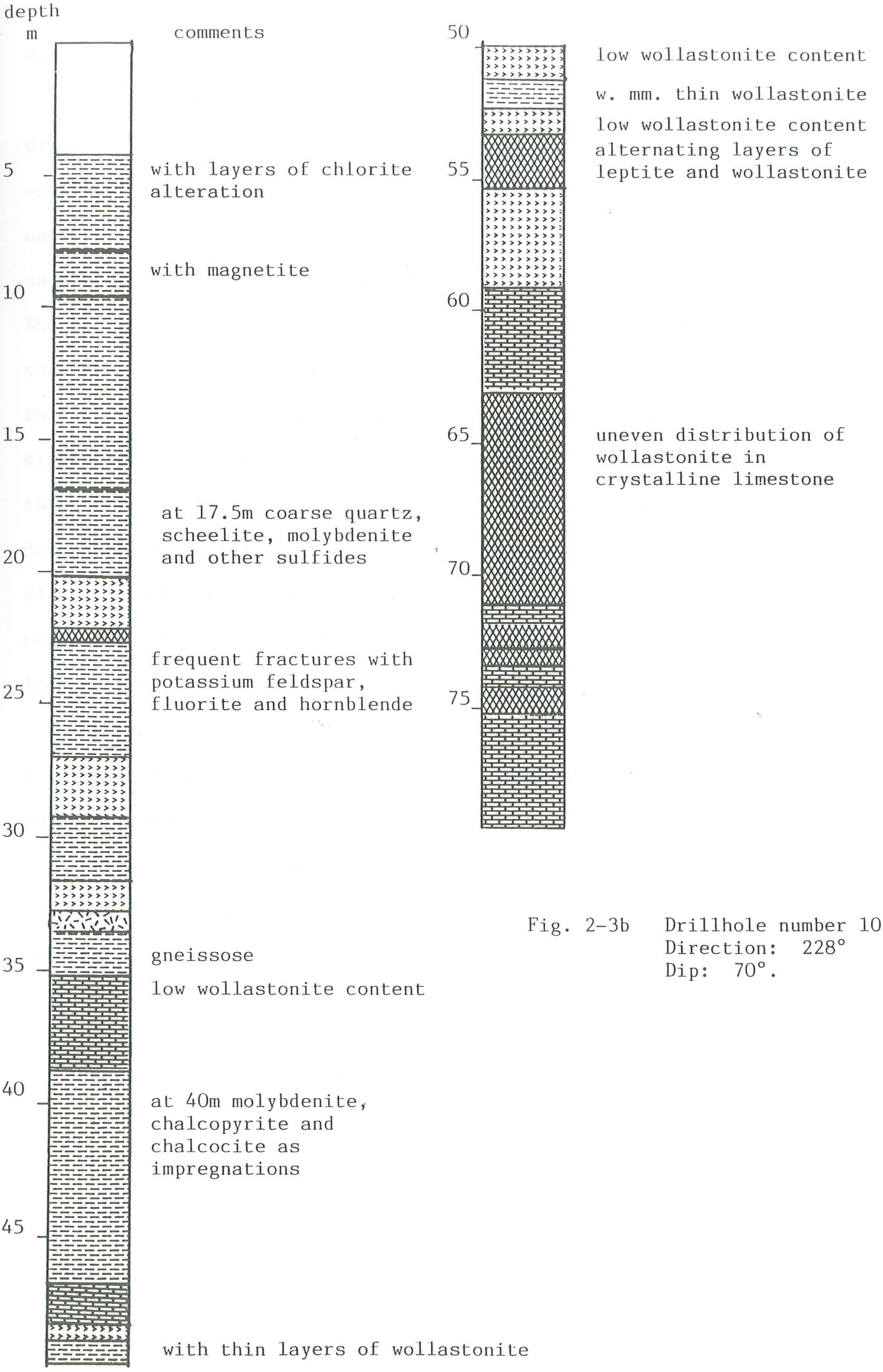


Fig. 2-3b Drillhole number 10
Direction: 228°
Dip: 70°.

2.3 Shape of the wollastonite body

As mentioned before, a dolerite cut through the strata, and divides the wollastonite occurrence into two units, a northern and a southern part. Using the borehole data, an attempt has been made to outline the shape of the deposit. This was done by projecting boreholes on the vertical planes represented by the lines AB-KL in fig. 2-2. The result is presented in fig. 2-4 a-c, figure 2-4a showing the southern part. Combining profiles AB and EF together gives an indication that the deposit has a lenticular shape. It becomes thinner and is dipping towards north to northeast. Adding profile CD to this shows that the deposit is not continuous. This could be due to the folding described by S. Hjelmquist (1942), or an uneven distribution of the alteration of the carbonate layers. A carbonate layer that in one drillhole contains wollastonite could then in another drillhole be thicker and lack wollastonite.

The northern part of the deposit has, according to profiles GH-KL, a less complicated outline. It forms a lense or sheet which is dipping towards northwest or west.

These conclusions are based on the drillhole data available, and in order to estimate the volume of the deposit, further drilling has to be made.

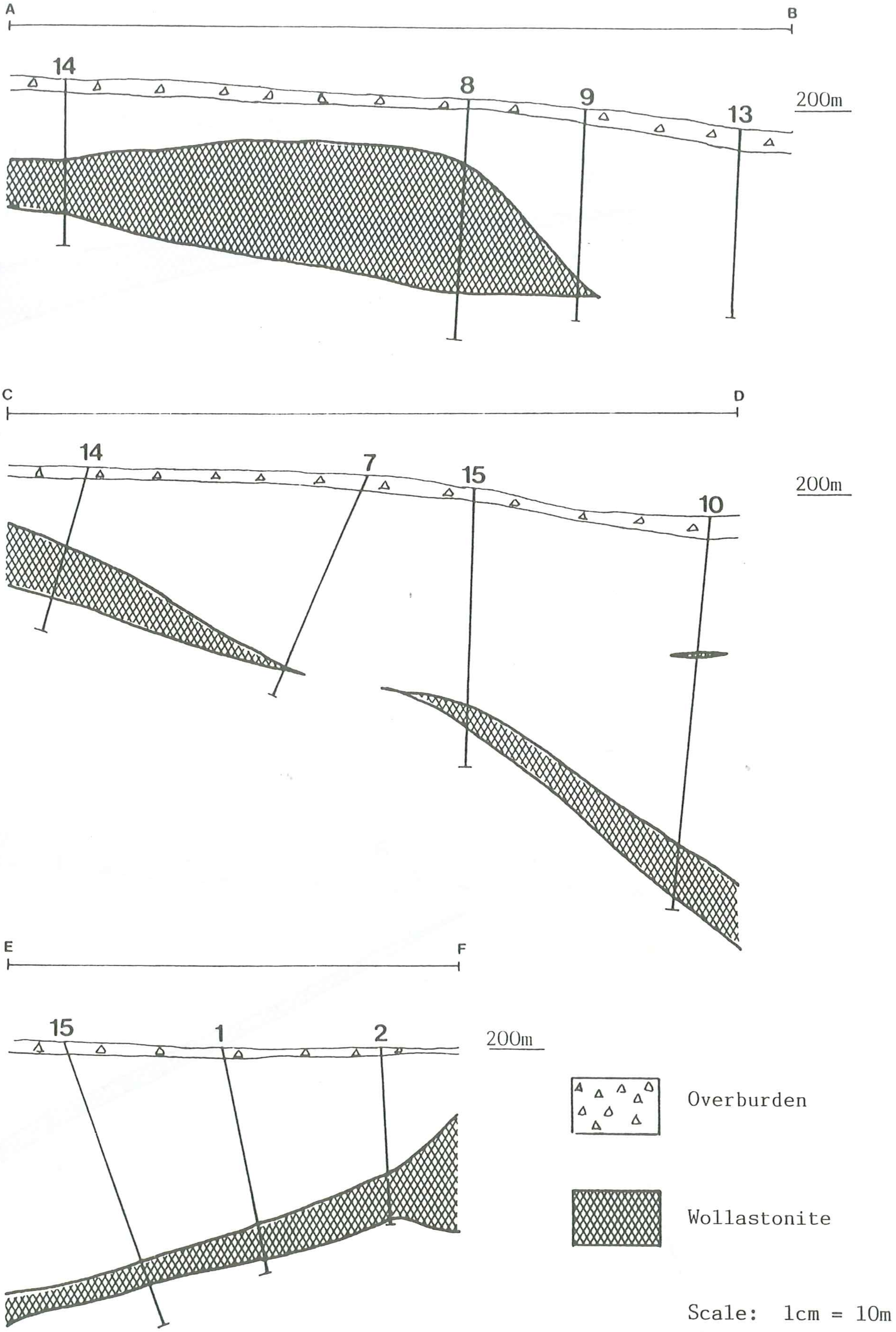


Fig. 2-4a. Possible outline of the wollastonite occurrence as projected on the profiles A-B, C-D and E-F. 200m. above sealevel indicated.

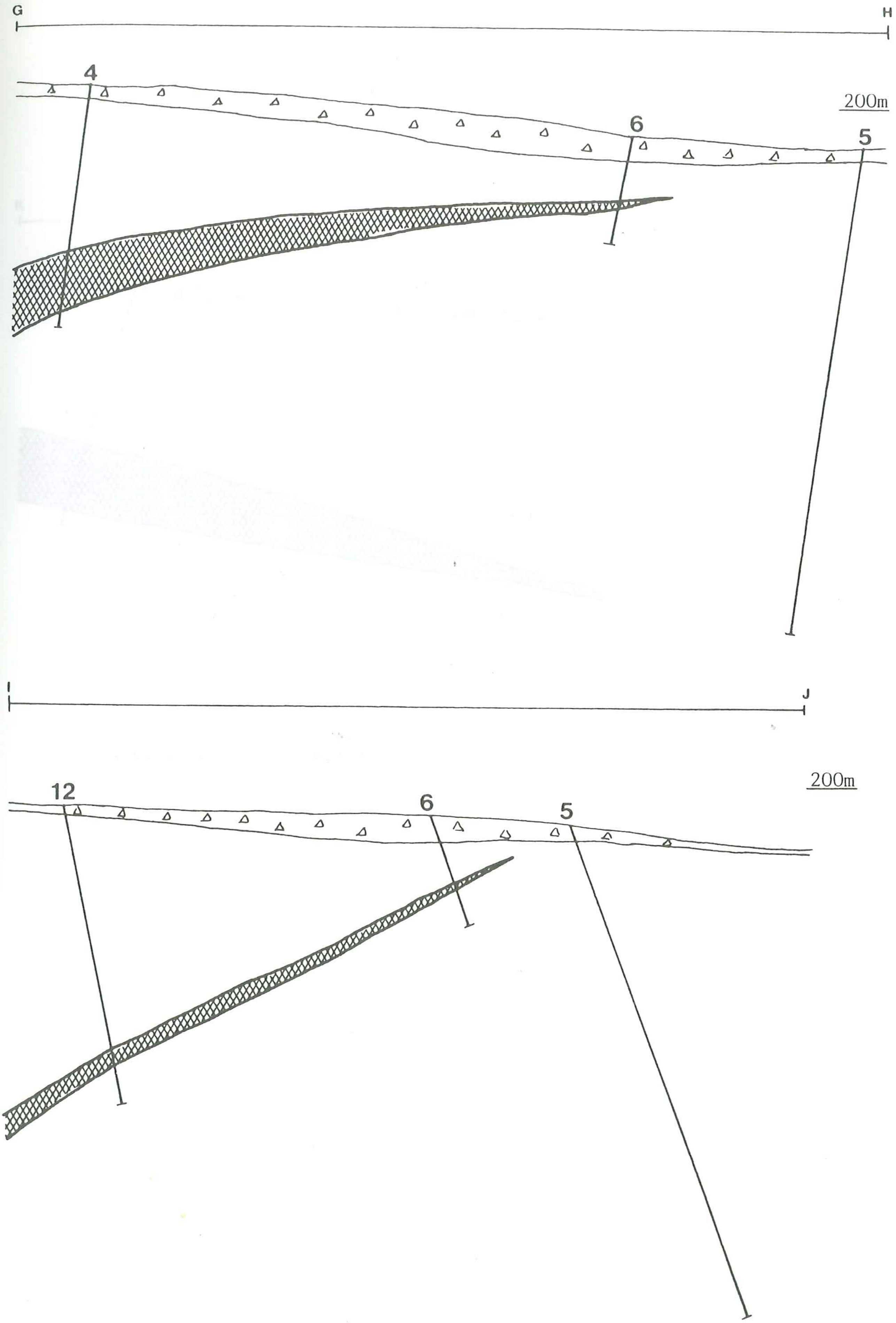


Fig. 2-4b Profiles G-H and I-J

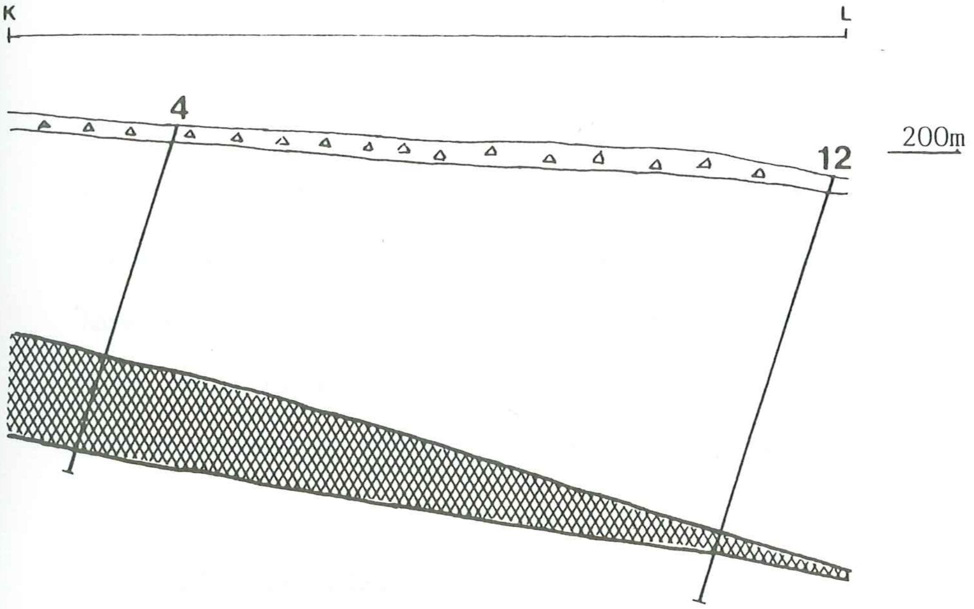


Fig. 2-4c Profile K-L

CHAPTER 3

Mineralogy and petrography

The mineralogy of the rocks has been investigated by using hand lens, polarization microscope and X-ray powder diffractometry.

Samples from drillhole cores and outcrops were collected to cover the mineralogical and textural variations within the wollastonite bearing units. The descriptions of hand specimens and thin sections are given in Appendix 2. A summary of these are found in the sections on macroscopic and microscopic appearance. X-ray diffraction analyses have been carried out on three larger core sections, one fistsized sample from outcrop, and one sample from the Tjămotis deposit. The results are discussed in the section on X-ray diffraction.

3.1 Macroscopic appearance

The wollastonite most commonly occurs in white veil-like sections, normally less than 10 cm in thickness. These form alternating layers with a fine-grained to aphanitic feldspar-quartz rich rock of volcanic origin, called leptite. These layers are unevenly distributed in the leptite.

The colour of the metavolcanic sections vary with the mineralogical composition. So, for example the pink colouration that have been seen on part of sample 17 is caused by pure potassium feldspar. The thin wollastonite sections are metasomatically altered limestone layers in the leptite, with no remaining calcite. Carbonate rich layers of larger thicknesses are still mainly composed of calcite, constituting an impure crystalline limestone. In these, wollastonite is present in smaller amounts, forming white feather-like patches in a greyish calcite ground mass.

Other main skarn minerals are calcic pyroxene, garnet and vesuvianite. The pyroxene forms very small crystals with green colour. This can be seen as a green toning of the fine-grained ground mass or as green speckles in a white ground mass. Pyroxene sometimes occurs in clusters with preferred orientation, forming a lineation, as in sample 5, where the ground mass consists of quartz, potassium feldspar, albite and wollastonite. Garnet is also found as scattered minute grains, rendering leptite layers a pale pinkish colour. Most commonly it forms up to 5 cm large, pinkish brown to dark brown poikiloblasts. Examples of this are found in samples 5, 17 and 19.

Vesuvianite is dark, brownish green in colour, and normally forms rather large crystals. These tend to cluster together forming aggregates, often in close association with garnet.

3.2 Microscopic appearance

Detailed descriptions of hand specimens and thin sections are given in Appendix 2.

Modal percentages are visually estimated values, which in many cases can vary quite considerably between hand specimen and thin section. This is due to compositional layering with rapid changes over small distances, that most of the samples exhibit. When this is the case, both mineral mode for the hand specimen as a whole, and for the thin section is given.

Three different kinds of mineral assemblages have been recognized, and will be dealt with separately in the following sections. They are:

1. Leptite assemblage - mainly feldspar and quartz in varying proportions;
2. Wollastonite assemblage - wollastonite is the major constituent, often accompanied by garnet, vesuvianite and calcic pyroxene. Minor amounts of quartz and feldspar are normally also present;
3. Calcite assemblage - consists mainly of calcite. Garnet is the most common skarn mineral, but vesuvianite, calcic pyroxene and

wollastonite may also be present.

The thicknesses of these portions are sometimes very small, so that more than one type can occur within the same thin section. Transitional rock types are also found.

3.2.1 Leptite assemblage

The following samples are included in this category: 1, 2, 4, 8, 15, 17b, 20 and 35.

Normally at least 90% of these sections consist of quartz and feldspar in a granular texture.

The relative proportions of quartz and feldspar vary from 100% potassium feldspar (sample 17b) to 75-90% quartz and 5-10% feldspar (samples 1 and 35).

The feldspar is dominantly potassic, and when plagioclase is present it only makes up a small part of the sample (sample 4).

Calcic pyroxene is present in 3-8%, mainly as intergranular space filling. Garnet can be absent or present in amounts up to 15%. It forms poikiloblasts or anhedral intergranular space fillings. In sample number 2, however, it constitutes 60% of the sample, because the section has been cut so that a large poikiloblast forms the main part of the sample. Fluorspar is less common, but when it occurs it forms intergranular space filling, making up about 10% of the section (sample 8). Accessory calcite can be present filling in intergranular spaces, more rarely in larger quantities.

When it makes up more than one percent of a sample, calcite forms frequent inclusions in garnet.

Additionally minute euhedral grains of sphene, allanite and zircon are sometimes present in amounts less than one percent.

3.2.2 Wollastonite assemblage

In this group all samples that contain wollastonite, and are not crystalline limestone, have been included. These are the majority of the thin sections: samples number 3, 5, 6, 7, 9, 10, 14, 17a, 21 and 22, 12.

As can be expected the samples vary considerably in composition. The percentage of wollastonite range from 15 to 60, but is generally around 30-35%. When occurring in larger amounts,wollastonite forms a ground mass of randomly orientated crystals with needle-like shape . If the wollastonite makes up a smaller part of the sample it is found in patches. More rarely it is found as scattered individual grains. Wollastonite needles are frequently found partially embedded in crystals of feldspar, quartz and calcic pyroxene. A common mode of occurrence is as abundant inclusions in garnet and vesuvianite. The amount of quartz varies from 0-50%, and together with feldspar it makes up a granular texture. Feldspar also varies greatly in amounts between 5-45%. When it only makes up a small part of the sample, and no quartz is present, it occurs in patches or as intergranular space fillings.

Calcic pyroxene is always present in amounts up to 10%. It forms anhedra filling in intergranular spaces. It can also form aggregates, together with garnet. Garnet is generally associated with wollastonite, which tend to nucleate on the former. Garnet can contain so large amounts of wollastonite inclusions, that its outlines are completely masked. It forms poikiloblasts or small anhedra that is found in aggregates or in intergranular spaces. Garnet has been found in all slides except one, and the amount of garnet varies between 1-25%.

Vesuvianite is less common than garnet, with which it is often associated. It is found in less than half the samples, and the modal percentages vary between 1-20%. Vesuvianite forms up to a cm large euhedral to subhedral crystals. These often contain wollastonite inclusions, that can become so abundant that they mask the outlines of the vesuvianite.

Calcite is present in almost half of the samples, but do not make up more than max. 4% of the samples. It is found as scattered anhedra filling in intergranular spaces, as minute needle-shaped inclusions in garnets or as vein fillings.

Sphene and allanite occur as minute euhedra constituting less than 1% of the sample.

Scattered minute opaques may also be present in quantities less than 1%.

3.2.3. Calcite assemblage

Samples 11, 13 and 28 constitute this group.

Calcite makes up at least 65% of the rock in these sections.

Wollastonite, if present, forms needles that occur randomly orientated in patches.

Calcic pyroxene and feldspar, if present, form intergranular space fillings, and constitute 5-10% each of the sample. Garnet occurs as poikiloblasts, and is very variable in amount.

3.3 X-ray diffraction

The mineralogy of four samples from Hulta, and one sample from Tjåmotis was investigated using X-ray diffractometry.

The samples were crushed using jawcrusher and micronised to a homogeneous powder with suitable grain size, and the powders were mounted in pressed cavity mounts.

In fig. 3-1 a typical X-ray diffraction pattern for the Hulta samples is shown. The minerals present in this sample are also identified in the three other samples, but in varying proportions. The minerals in each sample, including the Tjåmotis sample (fig. 3-2), have been divided into three groups; major, minor and accessory phases, on the basis of the height of selected peak. The results are presented in table 3-1. The minerals were identified on the basis of the whole scan (4-60 degrees 2Θ). The strongest or, because of overlap, another strong peak was selected for each mineral. Their intensities were compared for estimation of relative proportions of the phases. The minerals, with the 2Θ angles for the selected peaks are listed in table 3-2.

Sample number	main phases	minor phases	accessory phases
4	microcline quartz garnet	wollastonite diopside albite	vesuvianite fluorspar vesuvianite
11	calcite microcline	garnet vesuvianite wollastonite quartz	diopside fluorspar
16	wollastonite	calcite	garnet
17	microcline wollastonite garnet	quartz	calcite diopside (vesuvianite)
19	microcline quartz	diopside wollastonite garnet vesuvianite	clacite

Table 3-1. The major, minor and accessory phases in each sample, as interpreted from X-ray diffraction analysis.

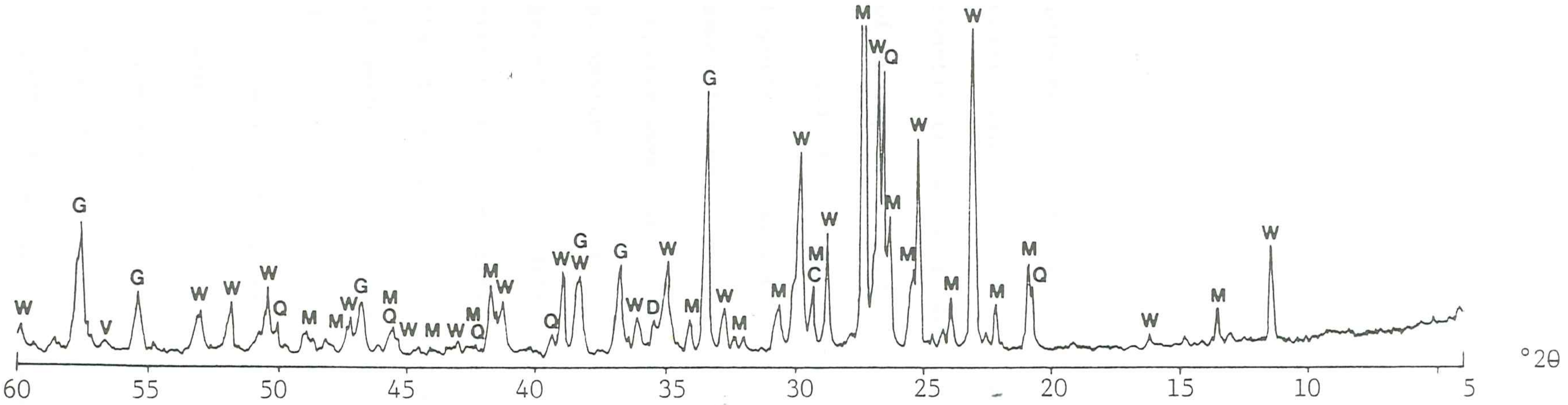


Fig. 3-1 X-ray diffraction chart for sample 17. W = wollastonite, M = microcline, G = garnet, D = diopside, Q = quartz, C = calcite, V = vesuvianite

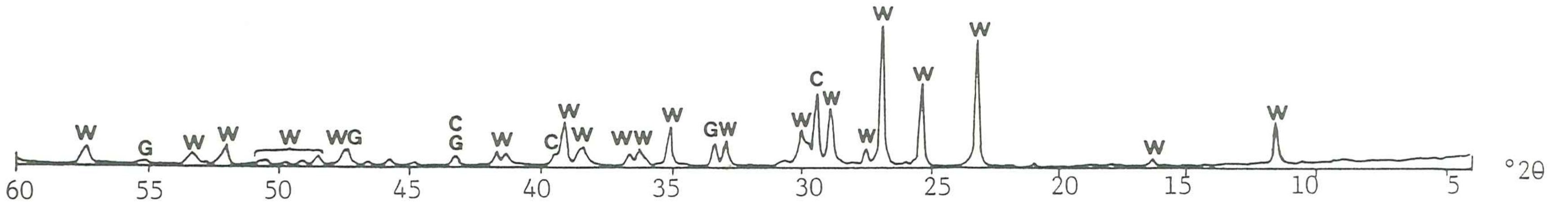


Fig. 3-2 X-ray diffraction chart for the Tjåmotis sample. For abbreviations, see fig. 3-1.

Mineral	Peak (°2θ)
microcline	27.36
quartz	26.66
wollastonite	11.50
garnet	33.30
vesuvianite	56.79
calcite	29.43
diopside	35.51
fluorspar	47.06
albite	27.88

Table 3-2. The minerals, with their peaks, used for interpretation of the X-ray diffraction charts.

Microcline is the main phase in the Hulta samples. However, its presence in sample 11 is due to an 8 cm thick section of pure coarse crystalline microcline. This sample differs from the others in that calcite constitutes a major phase. The rock in this section is mainly composed of an impure crystalline limestone.

Quartz is a major phase in two of the samples, where the mineral together with microcline makes up the leptite portion. Its absence among the major phases in sample 17 conforms with the observation that the leptite assemblage in thin section 17b, is almost entirely composed of potassium feldspar. In sample number 16, wollastonite, calcite and garnet have been detected. No distinct diopside peak was registered, even though its presence is known from thin section work. This shows that diopside is overrepresented in the described thin section, and that its mode of occurrence there is unusual for the rock as a whole.

3.3.1 Semiquantitative X-ray diffraction

A semiquantitative assessment of the wollastonite content in the samples was carried out in the following way:

From a section of almost pure wollastonite in one of the cores (drillhole no. 10, 70.20 m.), wollastonite was hand picked in order to obtain a 100% wollastonite sample. An X-ray diffraction scan was done on this sample using the same conditions as for the other samples. A peak that did not have any interference with any other mineral in the samples, was selected for a comparison of peak heights. For this purpose the peak at 11.5° 2θ was chosen.

At the selected peak position the peak height was measured in terms of divisions on the chart (max. 100) and the background was subtracted from this. This was done for each of the samples and the pure wollastonite standard.

By using the count rate, the peak height was converted into number of counts. So, for example, at a count rate of 2000 cps, each division on the chart is equal to 20 counts, and 12 divisions equals 240 counts.

For each sample, the number of counts obtained in this way was divided by the corresponding number of counts for the pure wollastonite. Multiplication of this ratio by 100 gave the approximate wollastonite content in weight percents. The results are presented in table 3-3.

sample	cps.	peak height - background	counts	% wollastonite
6	2000	21	420	100
4	400	10.5	42	10
11	400	9	36	9
16	2000	12.5	250	60
17	400	28	112	27
19	400	9.5	38	9

Table 3-3. Results of semiquantitative X-ray diffraction

3.3.2 Comments on the X-ray diffraction method.

No minerals were discovered that had not already been found optically. The extensive overlapping of peaks made it very difficult to distinguish them from each other.

Minerals whose presence, however in low concentrations, were known from other methods were not detected.

For these reasons, X-ray diffraction was not a suitable method for mineral identification in these samples. However, it was a useful tool to confirm or contradict observations about relative mineral proportions made in thin section.

The semiquantitative analysis was a quick and convenient way to get a rough estimate of the weight-percentages of wollastonite. This method, however, assumes that the mass-absorption coefficients of the samples are similar to that of the standard.

3.4 Conclusions

In the Hulta samples several minerals with different chemical and physical properties are present. Because of this a beneficiation process would have to be composed of several steps, in order to remove impurities. Alternatively wollastonite must be the mineral being removed in, for example, froth flotation. The commonly observed occurrence of wollastonite as inclusions in garnet and vesuvianite makes it necessary to crush the rock very finely in order to release all wollastonite in the material.

CHAPTER 4

Chemical Composition

4.1 Bulk chemistry

The chemical composition of the rock was determined by X-ray fluorescence spectromery using the fusion disc method of Norrish and Hutton (1969) except for Na where pressed powder pellets were use.

Three larger core samples (45, 100 and 80 cm long), and one outcrop sample were selected to provide an overall chemical composition of the wollastonite bearing units. The results are presented in table 4-1.

	Sample Number			
Oxide	4	11	17	19
SiO_2	63.26	35.10	55.52	68.77
TiO_2	0.12	0.06	0.16	0.08
Al_2O_3	11.13	8.21	9.70	10.29
Fe_2O_3	2.90	3.24	4.10	1.56
MnO	0.26	0.46	0.19	0.18
MgO	0.49	0.39	0.54	0.36
CaO	14.45	34.06	24.04	10.94
Na_2O	2.02	0.30	0.20	0.86
K_2O	4.56	3.65	5.32	6.22
SO_3	nd	nd	nd	nd
P_2O_5	nd	nd	nd	nd
LOI	0.46	13.11	0.80	0.24
Total	99.65	98.58	100.57	99.50

Table 4-1 The chemical composition of samples 4 (drillhole no. 4, 42.75-43.20), 11 (drillhole no. 8, 40.75-41.75m), 17 (outcrop no. 17) and 19 (drillhole no. 8, 21.50-22.30m) nd = not detected.

The low totals in some of the analyses reflect the presence of elements that have not been analysed, These are fluorine (in fluorspar), and to a smaller extent REE (in allanite). The main element in three of the four analyses is silicon. Together with the relatively high aluminium content, that conforms with the abundance of quartz and feldspar in the leptite portions. Sample number 11 is low in silica, and is rather high in calcium, which together with high LOI reflects a high calcite content. No positive conclusions of the wollastonite content can be drawn from the CaO percentages, because of the presence of calcium in most other silicate phases identified. However, calculations show that even if all the calcium was bound in wollastonite, the most wollastonite rich sample would not contain more than 50% of the mineral. Fluctuation in the iron and manganese concentrations are mainly caused by the variations of garnet and vesuvianite content.

The higher concentration of potassium compared with sodium conforms with the observation that the feldspars are almost only potassium feldspars. The exception to this is sample 4, in which the proportion of albite in the feldspar portion is higher than average.

Magnesium shows a low, but constant, concentration in the analyses. This reflects the even distribution of calcium pyroxene.

Titanium is present in all the analyses, but in low concentrations, illustrating the distribution of scattered crystals of sphene.

4.2 Mineral chemistry

Analyses of the crystals in each sample were made using a Link Systems 290-2KX energy dispersive spectrometer fitted to a Cambridge Geoscan Electron Microprobe. Other conditions are as follows: 15 kV accelerating potential, 2.7 nA specimen current, 100 live-seconds counting time, 75° take-off angle. Data correction was made using Link systems ZAF4 software. Detection limits for the silicate phases are as follows:

SiO_2	0.21	TiO_2	0.18	Al_2O_3	0.26
FeO	0.19	MnO	0.18	MgO	0.21
CaO	0.14	Na_2O	0.27	ZnO	0.24
K_2O	0.13				

The following samples were selected for microprobe analyses: numbers 2, 5, 6, 8, 9, 11, 12, 16 and 17.

The chemistry for each mineral from Tjåmotis (sample 16), is described briefly at the end of each section.

4.2.1 Wollastonite

Chemical compositions of some of the wollastonite crystals are presented in table 4-2. The formulae have been calculated on the basis of 6 oxygens.

They show a constant chemical composition, the calcium being replaced by manganese in most of the crystals, in amounts ranging from 0.37 to 0.95% MnO. This corresponds to 0.012 - 0.031 ions of Mn in the formula.

The wollastonites are generally iron-free, but a few analyses show the presence of 0.36 - 0.37%, which is equal to 0.012 Fe^{3+} in the recalculation.

The compositions of the wollastonites from Tjåmotis, are very similar, but the manganese-content tends to be slightly higher in these crystals.

There is no detectable magnesium substitution for calcium in any of the wollastonites.

4.2.2 Calcic pyroxene

Analyses for selected pyroxenes are presented in table 4-3, together with their formulae calculated on the basis of 6 oxygens.

The calcic pyroxene from Hulta shows a wide compositional range between diopside and hedenbergite (fig 4-1).

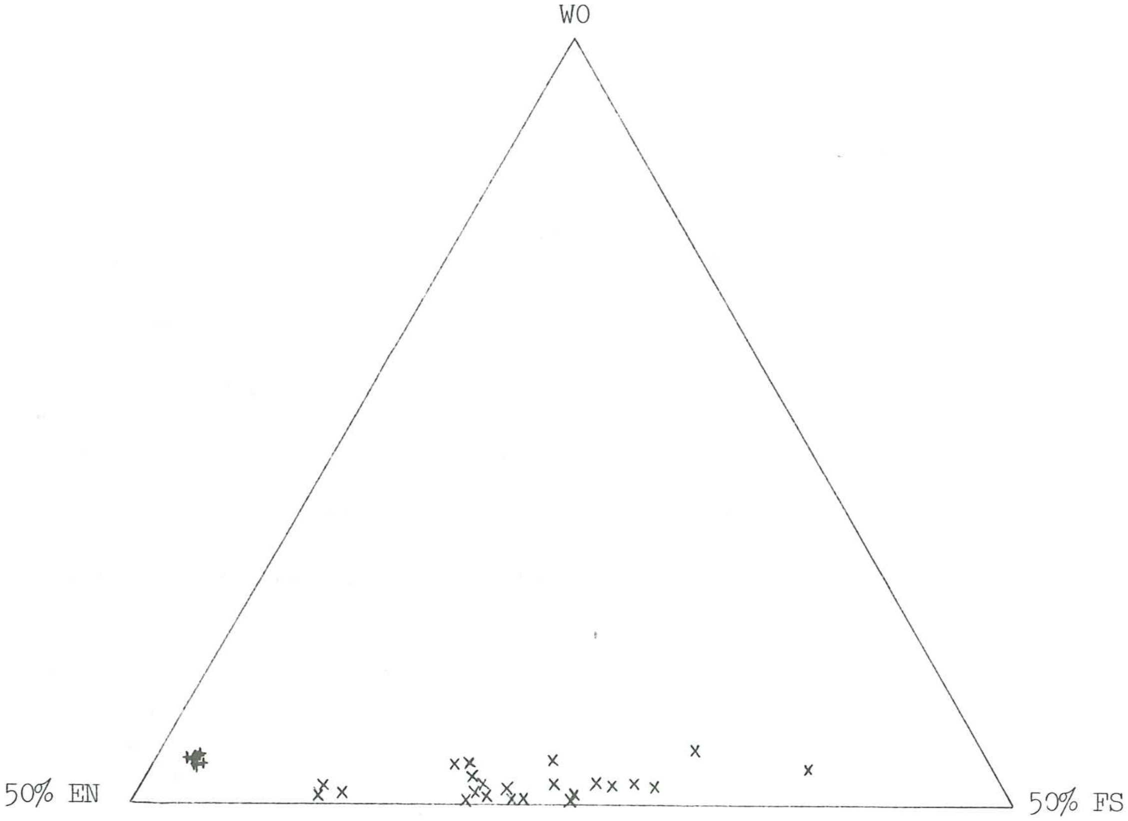


Fig. 4-1 Triangular plot showing the chemical variation of the pyroxenes from Hulta and Tjåmotis, in terms of molecular percentages of the end members wollastonite, enstatite and ferrosilite. x=Hulta +=Tjåmotis. Mol.%.

The share of the wollastonite component in the pyroxene molecules is close to 50 mol.% and the most calcium rich pyroxene has 53.10 mol.% wollastonite in the formula (spot 2, sample 11).

The content of the enstatite end member ($MgSiO_3$) ranges between 10.77 and 39.33 mol.% and the ferrosilite component ($(Fe,Mn)SiO_3$) makes up 10.07-37.12 mol.% of the pyroxene molecules. Therefore is the correct name of the calcic pyroxene salite.

Sodium is present in appr. one third of the crystals, but in amounts smaller than 0.05 ions of Na in the formulae. There is no substitution for silica by aluminium or iron.

Within the same crystal, there is no chemical variation.

The pyroxenes in the Tjåmotis sample are pure diopside, with a slight enrichment in calcium (fig. 4-1). In addition, they contain approximately 1% Na_2O, and 1.0 - 1.5% MnO.

4.2.3 Garnet

A selection of chemical analyses are presented in table 4-4. The mineral formula calculation was done on the basis of 24 oxygens. The garnets show a varied composition, with andradite and grossular being the main end members in solid solution. Their proportions vary between 25.16 and 56.32% for andradite and from 41.38 to 72.64% for grossular (fig. 4-2). The chemical variation is just as wide within the same sample as between samples.

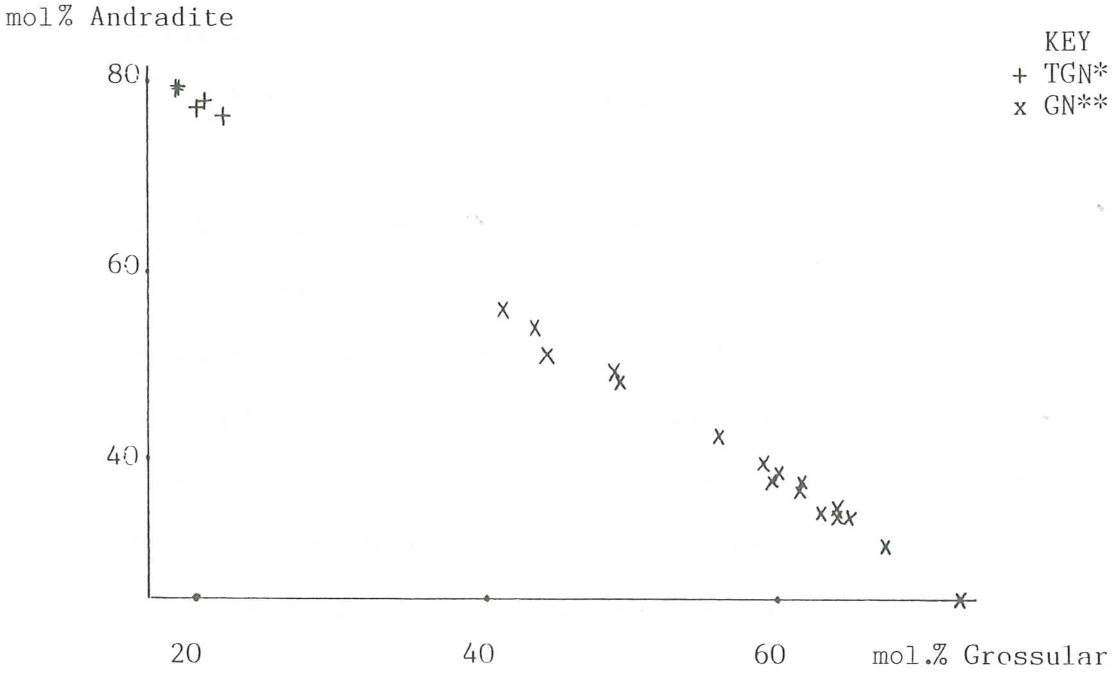


Fig. 4-2 The chemical variation of the garnets (TGN = Tjåmotis garnet, GN = Hulta garnet)

In all but one sample, small amounts of manganese are present, which gives 0.64 - 2.31% of spessartine end member in the solid solution. Almandine end member is present in four of the 17 samples, and only in minor amounts, 0.48 - 2.42%.

No chemical zoning has been observed.

The garnets in sample 16 show a more constant chemistry, with andradite being the main end member, in solid solution with grossular (fig. 4-2). Their end member proportions vary between 76.92 and 81.83% for andradite and from 16.87 to 22.09% for grossular.

In addition these garnets contain 0.99 - 1.88% of the spessartine end member. They show no compositional zoning.

4.2.4 Vesuvianite

In table 4-5 a selection of chemical analyses for some vesuvianites is presented. The mineral formulae have been calculated on the basis of 72 oxygens, to fit the general formula:

$$X_{19}\ Y_{13}\ Z_{18}\ O_{68}\ (OH,F)_8$$

where X = Ca (Na, K)

Y = (Al, Fe2, Fe3, Mg, Ti, Mn)

Z = Si

The Y-position is mainly occupied by aluminium, with a cation content in the formula ranging from 7.54 - 10.34. The iron is all divalent, and 1.47 - 5.28 ions are present in the formulae. Vesuvianites with a high iron content have brown colour, as described for sample 12 (spot 1 and 4). These are as a consequence poorer in aluminium.

Magnesium is present in all but four of the analysed crystals, three of these being the brown variety, and it makes up 0.53 - 1.53 of the cations.

Manganese was detected in 18 of 21 analyses and has a cation proportion range of 0.10 - 0.94.

Titanium has been found in half of the crystals, in amounts less than 0.5 cations.

The structure of vesuvianite is not fully understood (Deer et al, 1975), and several formulae have been suggested to best fit the chemical composition of the mineral. It has certain parts of its structure in common with garnet, to which it is both chemically and physically similar. The chemical similarity becomes evident in a comparison between the table 4-4 and table 4-5. The totals for vesuvianite are lower than for garnet because of the presence of hydroxyl or fluorine in vesuvianite. The controlling factor as to which mineral will crystallize may, according to Deer et al, 1975, be related to the presence of fluorine or other volatile constituents.

In general, however, the vesuvianites are poorer in iron than the garnets. They also contain magnesium in contrast to garnets, which are completely lacking MgO. This indicates that if the vesuvianites only formed in the presence of volatiles, then these were enriched in magnesium.

4.2.5 Feldspar

Feldspar analyses, with cation proportions calculated for 8 oxygens, and the end member proportions are presented in table 5-6.

The vast majority of the feldspars are pure potassium feldspars. Sodium have, however been determined in some of the potassium feldspars. In these feldspars the margins are richer in sodium than the cores. Only a few plagioclase crystals have been found. The plagioclases have albitic composition, with the anorthite content ranging from 1.53 - 13.87. In these crystals, the cores are richer in anorthite than the margins.

4.2.6 Allanite

The chemical compositions of selected allanites are presented in table 4-7. No mineral formula calculation was done, because not all elements present in the mineral had been analysed quantitatively. These elements are cerium and lanthanum, as shown in the X-ray spectrum for one of the allanites in sample no. 5 (fig. 4-3).

Rare earth elements substitute for calcium in the general formula:

$$X_2\ Y_3\ Z_3\ O_{12}(OH)$$

Where X = Ca, Mn, REE

Y = Al, Fe, Mg, Ti

Z = Si, (Be)

Radioactive components are present in most cerium epidotes (Deer et al 1975) substituting for Ca in amounts of 0.35 - 2.23%.

The analyses of the allanites were compared with those given in Deer et al, 1975. It was then found that, not taking into account the elements not analysed, analysis 3 in table 4-7 have a rather "normal" composition of allanites. The allanites in analyses 1 and 2 are however low in aluminium and iron. These elements occupy the Y-position, and their shortage can thus not be explained by substitution by REE.

The X-ray spectra for the crystals where this was observed, showed more intense peaks for Ce, than that for the allanite in sample 17. This indicates that the crystals are richer in radioactive components, since the presence of thorium follows that of cerium.

Radioactive components produce alpha particle emission, which destroy the structure of the crystal lattice, and allows water to enter. Therefore allanites with high content of thorium do not conform to the ideal structural formula. This is probably the reason for the deficiency of iron and aluminium in spot 18 and 19 in sample 5.

4.2.7 Sphene

Analysis of a sphene is presented in table 4-8. The mineral formula was calculated on the basis of 20 oxygens. In addition to the elements shown, niobium was detected, but could not be quantified. Aluminium, iron and niobium substitutes for titanium in about a quarter of the places for titanium.

Table 4-2 Selected Wollastonite Analyses

Sample	9	12	12	12	5	17	16	16
Code	WM	WC	WC	WM	WC	WC	WC	WM
Spot	12	3	19	20	9	8	1	2
SIO2	50.57	51.09	51.35	51.16	51.34	51.50	51.33	51.28
TIO2	--	--	--	--	--	--	--	--
AL2O3	--	--	--	--	--	--	--	--
FEO	--	0.37	--	--	--	--	--	--
MNO	0.95	0.51	0.56	0.65	0.38	--	0.72	0.83
MGO	--	--	--	--	--	--	--	--
CAO	48.01	47.88	47.71	48.22	47.97	48.35	48.85	47.80
NA2O	0.31	--	--	--	--	--	--	--
K2O	--	--	--	--	--	--	--	--
NIO	--	--	--	--	--	--	--	--
ZNO	--	--	--	--	--	--	--	--
TOTAL	99.84	99.85	99.62	100.03	99.69	99.85	100.90	99.91
						Formula		
SI	1.956	1.981	1.995	1.980	1.993	1.994	1.969	1.988
FE2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE3	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000
MN	0.031	0.017	0.018	0.021	0.012	0.000	0.023	0.027
CA	1.990	1.990	1.986	1.999	1.995	2.006	2.008	1.985
NA	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000

WC = Wollastonite core, WM = wollastonite margin

Formula calculated for 6 oxygens and 4 cations.

Table 4-3 Selected Pyroxene Analyses

Sample	9	9	5	5	11	11	16	16
Code	PCC	PCM	PCC	PCM	PCC	PCM	PCC	PCM
Spot	18	19	14	15	1	2	17	18
SIO2	54.31	54.56	52.40	52.95	49.83	50.18	54.43	53.92
TIO2	--	--	--	--	--	--	--	--
AL2O3	--	--	0.49	--	--	--	0.36	0.41
FEO	5.31	5.62	11.99	11.87	20.42	16.05	1.74	1.59
MNO	2.18	0.85	1.12	1.24	2.86	3.53	0.99	1.29
MGO	13.89	14.06	9.86	10.00	3.43	5.32	15.98	15.71
CAO	25.54	25.54	24.25	24.84	23.11	23.65	25.57	25.61
NA2O	--	--	--	--	0.60	0.63	1.51	1.17
K2O	--	--	--	--	--	--	--	--
ZNO	--	--	--	--	--	--	--	--
NIO	--	--	--	--	--	--	--	--
TOTAL	101.23	100.62	100.10	100.89	100.26	99.36	100.58	99.72
					Formula			
SI	1.999	2.015	2.003	2.009	1.986	1.986	1.957	1.961
AL	0.000	0.000	0.022	0.000	0.000	0.000	0.015	0.018
FE2	0.162	0.174	0.383	0.376	0.606	0.454	0.000	0.000
FE3	0.002	0.000	0.000	0.000	0.075	0.077	0.052	0.048
MN	0.068	0.027	0.036	0.040	0.097	0.118	0.030	0.040
MG	0.762	0.774	0.562	0.566	0.204	0.314	0.856	0.852
CA	1.007	1.011	0.993	1.010	0.987	1.003	0.985	0.998
NA	0.000	0.000	0.000	0.000	0.046	0.048	0.105	0.083
					End Members			
FS	11.50	10.12	21.23	20.88	37.12	30.28	1.60	2.12
EN	38.12	38.97	28.47	28.41	10.77	16.62	45.75	45.08
WO	50.38	50.91	50.30	50.70	52.11	53.10	52.65	52.80

PCC = clinopyroxene core, PCM = clinopyroxene margin

Formula recalculated on the basis of 6 oxygens, and 4 cations.

Table 4-4 Selected Garnet Analyses

Sample	12	17	17	2	11	8	16	16
Code	GNC	GNC	GNM	GNC	GNC	GNM	GNC	GNM
Spot	16	4	5	7	9	11	9	12
SIO2	38.19	36.59	37.26	38.06	37.12	37.33	35.93	36.26
TIO2	--	1.40	--	--	--	--	0.40	0.51
AL2O3	14.39	13.45	11.95	16.94	9.30	14.10	3.28	4.07
FEO	10.32	10.48	12.86	7.77	17.11	10.52	23.26	21.95
MNO	0.52	0.28	0.45	1.01	0.62	1.04	0.55	0.43
MGO	--	--	--	--	--	--	--	--
CAO	35.28	35.55	35.35	35.39	33.84	35.69	34.11	34.82
NA2O	--	--	--	--	--	--	--	--
K2O	--	--	--	--	--	--	--	--
ZNO	--	--	--	--	--	--	--	--
NIO	--	--	--	--	--	--	--	--
TOTAL	98.71	97.76	97.87	99.16	97.99	98.68	97.53	98.04
					Formula			
SI	5.989	5.820	5.940	5.896	5.989	5.863	5.954	5.953
AL	2.660	2.522	2.245	3.092	1.769	2.610	0.640	0.787
TI	0.000	0.168	0.000	0.000	0.000	0.000	0.050	0.063
FE3	1.353	1.394	1.715	1.006	2.253	1.382	3.223	3.014
FE2	0.000	0.000	0.000	0.000	0.056	0.000	0.000	0.000
MN	0.069	0.038	0.061	0.132	0.084	0.139	0.078	0.060
MG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CA	5.928	6.058	6.039	5.873	5.849	6.006	6.055	6.124
					End Members			
PYROPE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALMANDINE	0.00	0.00	0.00	0.00	0.93	0.00	0.00	0.00
SPESSTN	1.16	0.64	1.01	2.20	1.40	2.31	1.30	0.99
ANDRADITE	33.83	39.04	42.88	25.16	56.32	34.55	81.83	76.92
GROSS	65.02	60.32	56.11	72.64	41.34	63.14	16.87	22.09

GNC = Garnet core, GNM = garnet margin.

Formula calculated for 24 oxygens, and 16 cations.

Table 4-5 Selected Vesuvianite Analyses

Sample	9	9	12	12	12	2	8	8
Code	IC	IM	IC	IM	IM	IC	IC	IM
Spot	13	14	1	4	9	4	3	4
SIO2	36.79	37.23	36.75	37.76	35.60	35.13	35.99	35.64
TIO2	--	--	--	--	0.26	0.86	0.43	0.41
AL2O3	16.87	18.07	12.86	13.83	13.98	12.54	16.06	15.99
FEO	3.88	3.61	12.70	10.74	5.09	5.95	5.25	4.74
MNO	0.42	0.65	0.59	0.69	1.18	2.05	0.50	--
MGO	1.75	0.77	--	--	1.11	0.65	0.98	0.92
CAO	35.80	36.46	35.01	35.19	32.66	31.56	34.57	34.40
NA2O	--	0.33	--	--	--	--	--	--
K2O	--	--	--	--	--	--	--	--
ZNO	--	--	--	--	--	--	--	--
NIO	--	--	--	--	--	--	--	--
TOTAL	95.50	97.12	97.91	98.20	89.88	88.74	93.78	92.10

Formula

SI	18.172	18.079	18.274	18.633	18.900	19.084	18.260	18.373
AL	9.822	10.343	7.538	8.044	8.750	8.025	9.603	9.717
FE3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE2	1.601	1.467	5.282	4.431	2.260	2.701	2.227	2.044
TI	0.000	0.000	0.000	0.000	0.105	0.350	0.164	0.159
MG	1.285	0.560	0.000	0.000	0.876	0.528	0.743	0.707
MN	0.174	0.267	0.251	0.288	0.530	0.945	0.213	0.000
CA	18.946	18.972	18.655	18.604	18.578	18.367	18.790	19.001
NA	0.000	0.313	0.000	0.000	0.000	0.000	0.000	0.000
X	18.946	19.284	18.655	18.604	18.578	18.367	18.790	19.001
Y	12.882	12.637	13.071	12.763	12.522	12.549	12.951	12.626

IC = idocrase (vesuvianite) core, IM = idocrase (vesuvianite) core.

Formula calculated on the basis of 72 oxygens and 50 cations.

Table 4-6 Selected Feldspar Analyses

Sample	9	9	9	5	5	6	6
Code	FKC	FKM	FKC	FPC	FPM	FKC	FKM
Spot	1	2	15	1	2	7	8
SIO2	64.68	66.62	65.76	66.27	67.41	65.57	66.09
TIO2	--	--	--	--	--	--	--
AL2O3	18.06	18.47	18.13	21.34	19.08	17.71	18.05
FEO	--	--	--	--	--	--	0.31
MNO	--	--	--	--	--	--	--
MGO	--	--	--	--	--	--	--
CAO	--	0.22	--	2.55	0.75	--	0.27
NA2O	0.51	5.13	--	10.59	11.90	--	0.39
K2O	15.75	8.99	15.80	--	--	16.00	15.99
ZNO	--	--	--	--	--	--	--
NIO	--	--	--	--	--	--	--
TOTAL	99.00	99.43	99.70	100.75	99.14	99.28	101.10
						Formula	
SI	3.011	3.014	3.029	2.893	2.981	3.038	3.017
AL	0.991	0.985	0.985	1.098	0.994	0.967	0.971
FE2	0.000	0.000	0.000	0.000	0.000	0.000	0.012
CA	0.000	0.011	0.000	0.119	0.035	0.000	0.013
NA	0.046	0.450	0.000	0.896	1.021	0.000	0.035
K	0.935	0.519	0.929	0.000	0.000	0.946	0.931
						End Members	
OR	95.27	52.98	100.00	0.00	0.00	100.00	95.13
AB	4.73	45.94	0.00	88.26	96.64	0.00	3.53
AN	0.00	1.08	0.00	11.74	3.36	0.00	1.34

FKC = potassium feldspar core, FKM = potassium feldspar margin,
FPC = plagioclase feldspar core, FPM = plagioclase feldspar margin.

Formula calculated for 8 oxygens.

Table 4-7 Selected Allanite Analyses

Analysis	1	2	3
Sample	5	5	17
Code	ALN	ALN	ALN
Spot	18	19	1
SIO2	33.07	30.37	31.82
TIO2	--	--	--
AL2O3	3.92	7.09	13.23
FEO	7.04	4.53	12.50
MNO	2.86	0.96	--
MGO	--	0.40	--
CAO	13.83	10.20	15.81
NA2O	--	--	--
K2O	--	--	--
ZNO	--	--	--
NIO	--	--	--
TOTAL	60.72	53.55	73.36

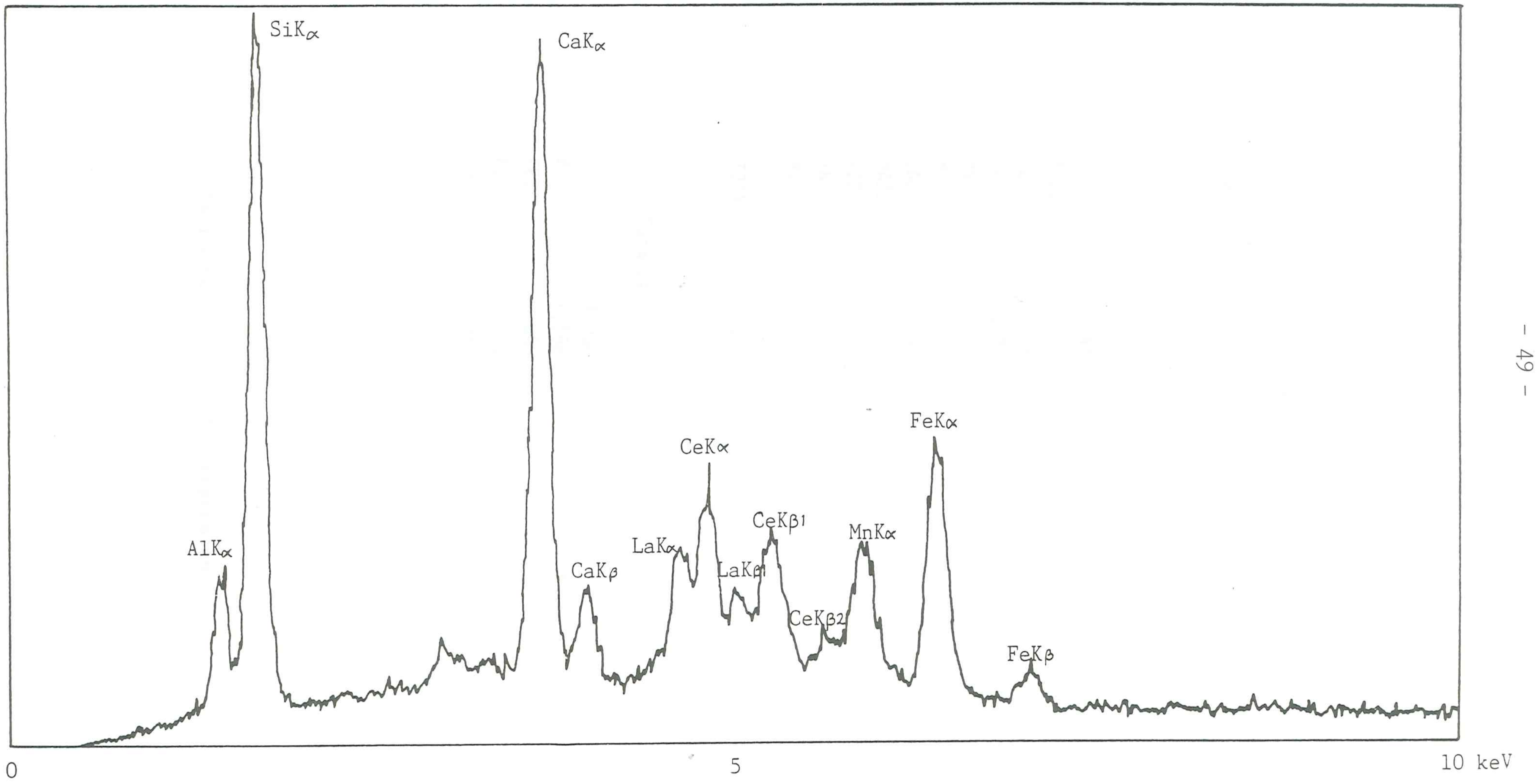


Fig. 4-3. X-ray spectrum for allanite, sample 5 spot 18

Table 4-8 Sphene Analysis

Sample	5
Code	TI
Spot	12
SIO2	30.41
TIO2	30.37
AL2O3	3.78
FEO	2.87
MNO	--
MGO	--
CAO	28.31
NA2O	--
K2O	--
ZNO	--
NIO	--
TOTAL	95.75

Formula

SI	4.000
AL	0.586
FE3	0.000
FE2	0.316
CA	3.990

Formula calculated for 20 oxygens and Si = 4

CHAPTER 5

Mineral Processing

Experiments aiming to separate the wollastonite from impurities were carried out using froth flotation.

5.1 Sample preparation

Material used were samples number 11, 17 and 19. These were crushed in fly press and jawcrusher. Further grinding was done using tema mill in small time increments until all material passed through a 250 um sieve. Two particle size fractions were obtained, namely material 125-250 um and 63-125 um, by dry sieving. The samples were then deslimed to remove ultra fine particles.

5.2 Experimental conditions

The experiments were carried out using a model D-12 Denver laboratory flotation machine, with internal air supplier in 250 and 500g stainless steel tanks.

As reagent one of the Jafaflots AA106, AA107 or AA117, obtained from Steetley Chemicals, Basingstoke, was used. These are modified amines based on alkyl groups mainly between $C_{14} - C_{22}$.

The reagents were used in aqueous solution as hydrochlorides prepared according to a recipe provided (appendix 5). As frothing agent Aerofroths frother 65 was used. This is a polyglycol type frother, which is completely water soluble.

Hydrofluoric acid was used as pH-modifier.

Local Hull tap water, pH = 7, was used for the pulp.

After adding reagent, conditioning time of 10 minutes was allowed, for each addition. Collecting time was 5-10 minutes.

5.3 Evaluation of results

Material obtained in the froth was investigated in binocular microscope. Results are presented in table 5-1 for each sample and experimental condition.

An attempt was also made to do a semiquantitative evaluation of the wollastonite content by X-ray diffraction, as described in section 3.3.2. This method is not suitable here because of the drastic change of mass absorption coefficient when changing the composition of the sample.

5.4 Results

Table 5-1 shows that the only positive result was the removal of a large proportion of ferromagnesian minerals, giving a concentrate consisting of wollastonite, feldspar and quartz. Quantification of the relative proportions of quartz, feldspar and wollastonite was not possible in the time available. Addition of only small amounts of excessive reagent cause all minerals to float.

5.5 Conclusions

From this preliminary work it seems that the wollastonite in the samples cannot be concentrated completely with the reagents used. However some of the experimental conditions gave a removal of ferromagnesian minerals.

It is probable that further work would result in a more efficient purification than attained, especially for mineralogically less complex material. This would include variation of temperature, pH and addition of suitable depressants or activators. However it is not likely that this material, with its varying nature of impurities, can give highly concentrated wollastonite with the method used.

A multistage mineral processing would have to be employed for purification of wollastonite in the samples.

Sample number	Appearance of starting material	Experimental conditions		Appearance of material in froth
		Material	Conditions	
17	pale brown, heterogeneous mixture of garnet, quartz, feldspar, wollastonite and minor pyroxene and vesuvianite	150.0g sample 125 - 250 um 600 ml water	pH=8, 4 drops frother 4 ml AA106, 1500 RPM	same appearance as the starting material
		150.9g sample 125-250 um 1200 ml water	pH=8, 4 drops frother 0.5 ml AA106, 1500 RPM	same as that of the starting material
		52.4 g sample 125-250 um 850 ml water	pH=7, 12 drops frother 1500 RPM 0.1ml AA106	white colour very few garnets, pyroxenes and vesuvianites
			0.2 ml AA106	
			0.3 ml AA106	
			0.4 ml AA106	
			0.5 ml AA106	
			0.6 ml AA106	same as that of the starting material
		51.4 g sample 125-250 um 850 ml water	pH=7, 10 drops frother 1500 RPM 0.2 ml AA107	white colour, very few garnets, pyroxenes and vesuvianites.
			0.3 ml AA107	
			0.5 ml AA107	same as that of starting material, but paler colour

Table 5-1. Froth flotation experiments. Unless otherwise indicated, a 250 g stainless steel tank is used.

/continued

Sample number	Appearance of starting material	Experimental conditions		Appearance of material in froth
		Material	Conditions	
17	pale brown, heterogeneous mixture of garnet, quartz, feldspar, wollastonite and minor pyroxene	50.5 g sample 125-250 um 800 ml water	pH=7, 17 drops frother, 1500 RPM 0.05 ml AA117	white colour, very few pyroxenes and vesuvianites
			0.2 ml AA117	
			0.35 ml AA117	
			0.5 ml AA117	same as that of the starting material.
		100.2g sample 63-125 um 1600 ml water	pH=7, 8 drops frother, 1500 RPM, 0.2 ml AA106, 500g stainless steel tank	same as that of starting material
		101.4g sample, 125-250 um 1600 ml water	pH=7, 8 drops frother, 0.3 ml AA106, 1500 RPM, 500 g stainless steel tank	same as that of starting material
		52.57g sample 63-125 um 800 ml water	pH=3, 5 drops of frother, 0.2 ml AA106 1200 RPM	same as that of starting material
19	pale brown, heterogeneous mixture of garnet, quartz, feldspar, wollasstonite and minor pyroxene	51.72g sample 125-250 um 800 ml water	pH=3, 4 drops of frother 0.2 ml AA106 1200 RPM	same as that of starting material but paler colour.
11	pale grey heterogeneous mixture of calcite, garnet, minor wollastonite and feldspar	101.9g sample 125-250 um 1600 ml water	pH=7, 8 drops of frother 0.2 ml AA106, 1500 RPM, 500g stainless steel tank	same as that of starting material

Table 5-1. continued

CHAPTER 6

PHYSICAL PROPERTIES

6.1 Acicularity

A visual estimate of the aspect ratio was done using binocular microscope. For this purpose the particle size fraction 63-125 um was used, from samples 16 and 17.

It was found that the material from Hulta has an average aspect ratio of 1:4.4 and the value for the material from Tjåmotis (sample 16) is 1:5.8.

6.2 Colour measurements

Colour measurements were carried out using a reflectance spectrophotometer. This was done on three samples, of which one was from Hulta consisting of practically pure wollastonite that had been handpicked under binocular microscope. One sample was from Tjåmotis with impurities partly removed under binocular microscope. The third one was wollastonite that is being commercially used, from Lake Bonaparte, New York State, USA.

A ceramic tile was used as a standard. Reflectance (in %) was measured using 9 different filters (wavelengths) for each sample, in order to obtain spectrophotometric curves. Additionally, measurements according to the Commission Internationale de l'Eclairage colour system were done. This is used to calculate hue, purity and brightness, and for this purpose the tristumulus values X, Y and Z are obtained. These correspond to red, green and blue, respectively, but, in addition the colours are adjusted to the stimulus response of the normal eye.

The results are listed in table 6-1, and in fig. 6-1 the spectrophotometric curves are presented.

	Hulta	Tjåmotis	L.Bonaparte
Wavelength (Å)		Reflectance (%)	
4260	81.8	80.9	83.4
4700	89.0	89.1	90.6
4900	89.7	90.5	91.5
5200	90.5	91.1	91.8
5500	91.4	92.5	93.0
5800	92.6	93.6	93.3
6000	95.6	96.4	95.6
6600	96.0	97.4	96.1
6840	94.0	96.0	94.7
X	94.4	95.3	95.0
Y	72.0	72.6	72.4
Z	30.1	30.3	30.4
Hue	-5300 Å	-5300 Å	-5300 Å
Purity	22.2%	22.2	22.2%
Brightness	72.0%	72.6%	72.4%

Table 6-1. Results of colour measurements.

The results show that there is very little difference between the three samples. The only difference is that the results for the American samples were slightly higher on the spectrophotometric curve than for the two Swedish samples. The shape of the three curves are very similar to each other, with the higher reflectance on the red side of the spectrum.

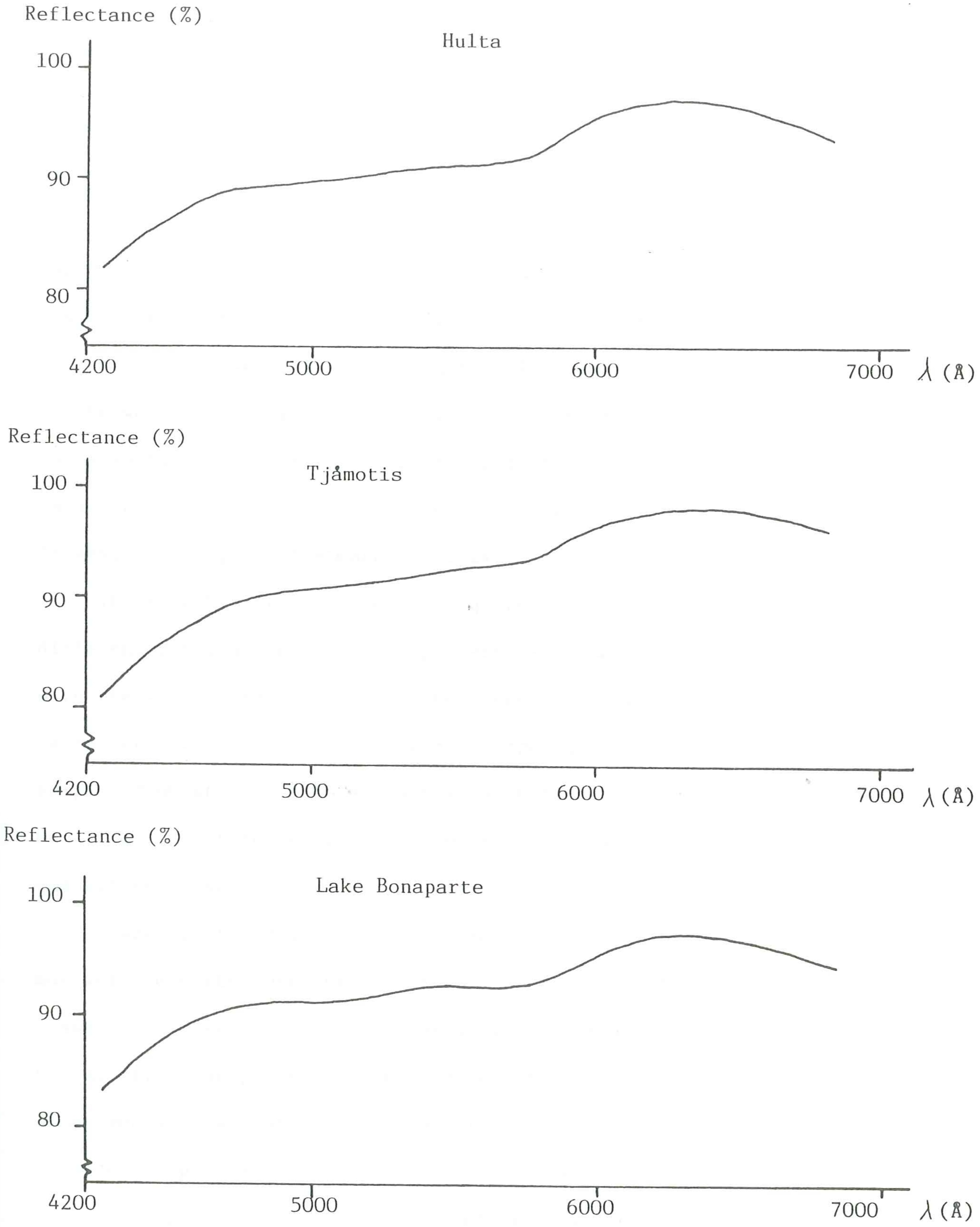


Fig. 6-1 Spectrophotometric curves for the sample from Hulta, Tjåmotis and L. Bonaparte.

CHAPTER 7

CONCLUSIONS

The chemical composition of the wollastonite is practically pure $CaSiO_3$, its aspect ratio is approx. 1:4.4 and the colour properties compare well with currently used wollastonite. The totals of the microprobe analyses closely approach 100%, indicating that the LOI of the wollastonite is less than 1%. This makes the wollastonite of Hulta suitable for many industrial applications, where high acicularity is not required. These are for example ceramics, metallurgical fluxes, and simple fillers and coatings.

The rock has proven to contain quite a variety of minerals with different physical and chemical properties, especially in comparison with the sample from Tjamotis. Furthermore the wollastonite content is rather low (10-15 wt% on average) compared with that of the Tjamotis sample (~60 wt%). This means that an efficient beneficiation process may be difficult to design, and the extraction would lead to large quantities of waste.

However, if the mineral can be satisfactorily concentrated it may well be worth considering for further development. If it is possible to make use of any of the gangue minerals, garnet for example, the material can prove to be even more interesting. The froth flotation experiments show that more work has to be done on the separation process in order to give a definite assessment of the deposit.

These wollastonite rocks have interesting and pretty texture, and pleasant colouration. They are also very hard, as experienced when using a geological hammer for sampling purposes, and observations made during corelogging show a low frequence of fractures. Therefore, if the reserve does not turn out to be a good source of wollastonite for industry, the material should be considered for ornamental or building stone.

Results of drilling show an irregular shape to the body and further drilling must be carried out for quantitification of the reserve. This should primarily be concentrated in the area west of drillhole no. 14. Traces of wollastonite have been found in outcrop sample number 35 (see fig. 2-1). This indicates that the wollastonite body is close to the surface in this area.

Theoretically the wollastonite occurrence is a potential source of wollastonite as an Industrial Mineral. However, further work must be done, as indicated above. Surrounding areas should also be investigated.

APPENDIX 1

Core Logs

Logged drillhole cores nos. 1-15.

Drillhole No.	Local co-ord.	Ground level, m.above sea level	Direction	Incl.	Tot. length	Wollastonite m.
1	110S/40E	200	270°	60°	40.75	37.35-43.40
2	135S/25E	200	282°	60°	35.95	26.30-35.50
3	165S/121E	192	247°	45°	88.15	-
4	100N/75E	203	226°	70°	49.30	33.30-46.60
5	25N/200E	192	223°	60°	106.80	-
6	45N/60E	194	226°	60°	24.05	14.30-16.10
7	58S/15E	203	225°	50°	51.65	45.00-45.65
8	122S/15E	202	270°	50°	56.70	15.30-52.45
9	130S/40E	200	228°	50°	50.45	39.70-44.40
10	100S/70E	196	228°	70°	79.55	63.10-79.55
11	102S/135E	192	228°	70°	30.60	-
12	115N/160E	196	228°	70°	59.95	49.85-53.15
13	150S/60E	196	230°	50°	44.30	-
14	78S/40W	205	224°	70°	31.85	15.10-25.55
15	74S/35E	201	214°	70°	53.80	41.90-45.85

Depth is given in metres measured from ground level in the drilling direction.

Drillhole no. 1

Direction: 270° Inclination: 60°

Depth (m)	Rock description
0 -2.40	Overburden
2.40-3.15	Pyroxene skarn With magnetite.
3.15-5.20	Leptite Grey,fine-grained.
5.20 - 12.70	Pyroxene skarn
12.70-14.50	Leptite Grey, fine-grained.
14.50-16.70	Pyroxene skarn
16.70- 16.85	Leptite
16.85 - 17.10	Pyroxene skarn
17.10-18.60	Leptite With chlorite intercalations,
18.60-19.30	Pyroxene skarn
19.30-19.40	Garnet skarn
19.40-20.30	Pyroxene skarn Lower part becomes enriched in garnet downwards.
20.30-22.30	Garnet skarn The top 40cm contain intercalations of pyroxene skarn.
22.30-23.00	Leptite
23.00-23.50	Leptite Red, fine-grained
23.50-23.85	Crystalline limestone
23.85-24.30	Leptite Red, with intercalations of limestone.
24.30-24.70	Leptite gneiss With impregnations of pyroxene.
24.70-24.95	Leptite Grey, fine-grained.

24.95-25.55	Pegmatite
25.55-25.90	Pyroxene skarn Contains abundant garnet
25.90-26.50	Leptite and pyroxene skarn Alternating layers.
26.50-27.30	Leptite Red,with interlayering limestone.
27.30-29.40	Leptite Red, with pyroxene impregnations.
29.40-30.30	Pyroxene skarn Contains 1 cm. large garnet porphyroblasts.
30.30-34.20	Leptite Red, fine-grained, with impregnations of pyroxene. Other minerals: scheelite, calcite and garnet.
34.20-34.50	Crystalline limestone
34.50-34.70	Leptite Red, fine-grained.
34.70-35.25	Crystalline limestone
35.250-35.55	Leptite
35.55-37.35	Leptite and crystalline limestone. Alternating layers. Minerals: calcite, feldspar, quartz, pyroxene and garnet.
37.35-40.25	Wollastonite skarn. Layers of wollastonite alternating with grey leptite. Wollastonite occurs as masses of small needles embedding 1-5 cm large poikiloblasts and porphyroblasts of garnet. Other minerals: pyroxene, quartz, feldspar. Sample 38.00-38.10, 39.40-39.50.
40.25-41.80	Pyroxene skarn With garnet.

41.80-43.25	Wollastonite skarn Same as above. Minerals: garnet, fluorite, vesuvianite, pyroxene, quartz, wollastonite, calcite. Sample 42.00-42.05
43.25-45.55	Pyroxene skarn With garnet porphyroblasts. Other minerals: epidote, calcite, biotite .
45.55-47.05	Crystalline limestone Coarse grained, with chlorite impregnations

END

Drillhole no. 2

Direction: 282° Inclination: 60°

Depth (m)	Rock description
0 - 1.40	Overburden
1.40 - 6.50	Pyroxene skarn Other minerals: quartz, biotite, some epidote.
6.50 - 12.20	Pyroxene skarn With partial chlorite alteration.
12.20-13.10	Pyroxene skarn Zone which becomes gradually enriched in quartz, calcite, epidote downwards.
13.10-14.70	Pyroxene skarn With garnet.
14.70-15.10	Leptite Red, fine-grained. Apparent dip = 45°
15.10-15.55	Crystalline limestone Apparent dip = 30°
15.55-17.00	Pyroxene skarn Other minerals: quartz, calcite.
17.00-18.65	Garnet skarn Other minerals: epidote, vesuvianite.

18.65-19.30	Garnet skarn and leptite Transitional zone.
19.30-26.30	Leptite gneiss Becomes enriched in carbonate in the lower 1.20m.
26.30-28.80	Wollastonite skarn Alternating layers of wollastonite and leptite. Wollastonite content increases downwards. Other minerals: Quartz, garnet, vesuvianite. Sample 26.90-27.10
28.80-29.00	Leptite
29.00-35.50	Wollastonite skarn Same as above Sample 29.00-29.10, 31.00-31.15, 33.00-33.15, 34.35-34.45.
35.50-35.95	Crystalline limestone

END

Drillhole no. 3

Direction: 247° Inclination: 45°

Depth (m)	Rock description
0 - 4.85	Overburden
4.85-15.20	Pyroxene skarn Other minerals: biotite, calcite, magnetite and sulphides.
15.20-15.55	Leptite Grey, fine-grained
15.55-19.35	Pyroxene skarn As above. On both sides of the leptite there are 5 cm thick chlorite sections.. Sulphides in fractures at 17.95-18.20

19.35-36.05	Leptite Greyish red. At 19.35-26.00 the leptite is interlayered with chlorite.
36.05-37.05	Pegmatite/ aplite Mainly pot. feldspar. Sulphide impregnations.
37.05-57.20	Leptite gneiss Red recrystallized material in grey groundmass.
57.20-58.50	Leptite Extensively altered. With aggregates of vesuvianite.
58.50-59.50	Leptite gneiss
59.50-60.00	Leptite Extensively altered, as above.
60.00-61.80	Leptite Extensive fracturing with quartz and epidote in the fractures, varying size, up to 9 cm. Fractures are perpendicular to each other and form 30° angle with the core axis.
61.80-72.55	Leptite gneiss
72.55-73.60	Pyroxene skarn. With garnet, transition towards leptite.
73.60-77.80	Leptite gneiss
77.80-78.10	Pyroxene skarn
78.10-79.20	Leptite gneiss
79.20-85.55	Pyroxene skarn Contains aggregates of magnetite surrounded by veins of chlorite.
85.55-88.15	Leptite gneiss Diffuse transition towards dark grey leptite. Pegmatite veins in lower part.

END

Drillhole no. 4

Direction: 226° Inclincation: 70°

Depth (m)	Rock description
0 - 2.55	Overburden
2.55-10.70	Leptite Grey, with 1-2 mm large phenocrysts of potassium feldspar. Diffuse foliation 80° against core axis.
10.70-10.85	Crystalline limestone
10.85-14.30	Leptite
14.30-15.00	Pegmatite
15.00-19.55	Leptite Dark grey, with occasional interlayering carbonate.
19.55-24.50	Pyroxene skarn Minerals: pyroxene, epidote, chlorite and sulphides in fractures.
24.50-25.00	Leptite
25.00-25.85	Pyroxene skarn
25.85-28.50	Leptite
28.50-30.20	Pyroxene skarn Other minerals: chlorite, magnetite.
30.20-30.55	Leptite
30.55-32.90	Pyroxene skarn With chlorite, and intercalations of leptite. Apparent dip of foliation: 45° against core axis.
32.90-33.30	Leptite gneiss
33.30-35.30	Wollastonite skarn Alternating layers of leptite and almost pure wollastonite. Minerals: quartz, k-feldspar, garnet, vesuvianite, wollastonite. Sample 33.95-34.10

35.30-36.35	Pyroxene skarn With chlorite.
36.35-39.60	Wollastonite skarn Same as above, with porphyroblasts of garnet. Sample 37.00-37.05
39.60-40.10	Leptite
40.10-43.25	Wollastonite skarn As above. Sample 42.75-43.20
43.25-44.10	Leptite gneiss
44.10-45.30	Leptite gneiss Interlayered with limestone, fractures with pegmatite and epidote.
45.30-46.55	Wollsatonite skarn This section has no distinct layering. Wollastonite is rather evenly distributed as feather-like impregnations in leptite, together with aggregates of pyroxene. Sample 45.60-45.75
46.55-49.30	Leptite gneiss Occasional interlayering of limestone.

END

Drillhole no. 5

Direction: 223°

Inclination: 60°

Depth (m)	Rock description
0-2.95	Overburden
2.95-27.95	Leptite Grey, with diffuse foliation 90° against core axis. Increasing extent of chlorite alteration downwards.
27.95-28.15	Pyroxene skarn Rich in quartz.

28.15-67.15	Leptite Around 31m., there is a 1.5 m broad chlorite zone.
67.15-73.95	Biotite rock with magnetite and chlorite. Sample 71.80-71.90
73.95-90.15	Leptite Grey, with zones up to a metre thick of chlorite.
90.15-93.10	Impure limestone Mineralogy: calcite, garnet, pyroxene, quartz.
93.10-106.80	Leptite at 95.80-97.95 intercalations of garnet-bearing limestone. Pegmatite w. MoS_2 at 102.5 .

END

Drillhole no. 6

Direction: 226° Inclination: 60°

Depth (m)	Rock description
0-5.40	Overburden
5.40-6.50	Leptite
6.50-8.00	Chlorite rock
8.00-13.75	Leptite Grey; foliation with apparent dip 75° against core axis.
13.75-14.30	Garnet skarn
14.30-16.10	Wollastonite skarn Fuzzy layering. Other minerals: garnet, pyroxene, quartz.
16.10-18.65	Leptite gneiss Grey with red recrystallised material.
18.65-19.50	Garnet skarn
19.50-24.05	Leptite gneiss With granitic veins, at 75° against core axis.

END

Drillhole no. 7

Direction: 225° Inclination: 50°

Depth (m)	Rock description:
0-3.25	Overburden
3.25-4.95	Leptite Grey; with thin quartz veins.
4.95-6.70	Leptite With magnetite and chlorite in zones.
6.70-10.70	Leptite
10.70-17.50	Pyroxene skarn With magnetite; a quartz vein at 15.60-16.70 with leptite in the centre.
17.50-32.90	Leptite
32.90-41.90	Pyroxene skarn Other mienrals: chlorite, garnet.
41.90-45.00	Pyroxene skarn Abundant garnet.
45.00-45.65	Wollastonite skarn
45.65-48.35	Crystalline limestone Low content of wollastonite.
48.35-51.65	Leptite Transitional boundary.

END

Drillhole no. 8

Direction: 270° Inclination: 50°

Depth (m)	Rock description
0-2.85	Overburden
2.85-10.70	Pyroxene skarn With chlorite and aggregates of magnetite.
10.70-11.50	Garnet skarn Extensively fractured.

11.50-13.10	Garnet skarn With pyroxene.
13.10-14.60	Crystalline limestone Mineralogy: Calcite, garnet, wollastonite, vesuvianite.
14.60-15.30	Leptite
15.30-25.65	Wollastonite skarn Layers with fuzzy outlines in leptite. Sample 21.50-22.30
25.65-26.50	Leptite
26.50-34.85	Wollastonite skarn As above.
34.85-35.20	Leptite
35.20-35.40	Wollastonite skarn
35.40-37.30	Leptite
37.30-44.80	Crystalline limestone Low wollastonite content Sample 40.75-41.75
44.80-46.45	Crystalline limestone Mineralogy: calcite, fluorite, garnet, vesuvianite forming a pretty pattern.
46.45-47.50	Crystalline limestone With wollastonite.
47.50-50.75	Crystalline limestone No wollastonite.
50.75-52.45	Wollastonite skarn The upper metre contains 40% wollastonite, decreasing downwards.
52.45-56.70	Crystalline limestone Mineralogy: calcite, pyroxene, quartz.

END

Drillhole no. 9

Direction: 228°   Inclination: 50°

Depth (m)	Rock description
0-3.45	Overburden
3.45-5.70	Chlorite rock
5.70-6.45	Leptite
6.45-15.25	Pyroxene skarn Pegmatite and chlorite alteration. Sample 8.45
15.25-15.80	Pegmatite
15.80-18.95	Leptite
18.95-22.20	Leptite With garnet skarn layers.
22.20-23.30	Crystalline limestone.
23.30-23.95	Leptite
23.95-24.60	Crystalline limestone
24.60-33.30	Limestone and leptite Alternating layers. Minerals: quartz, feldspar, biotite, garnet, pyroxene, vesuvianite, scheelite.
33.30-34.25	Leptite
34.25-36.35	Pegmatite
36.35-36.50	Leptite
36.50-37.25	Pegmatite
37.25-37.70	Leptite
37.70-39.70	Leptite and limestone Alternating layers.
39.70-40.50	Wollastonite skarn
40.50-41.40	Leptite
41.40-43.40	Wollastonite skarn Layering with apparent dip 65° against core axis.

43.40-43.80	Leptite
43.80-44.40	Wollastonite skarn Alternating layers of leptite and wollastonite.
44.40-47.95	Crystalline limestone Mineralogy: calcite, garnet, fluorspar, vesuvianite.
47.95-48.85	Pegmatite
48.85-50.45	Impure limestone Impregnations of pyroxene and fluorspar.

END

Drillhole no. 10

Driection: 228°

Inclination: 70°

Depth (m)	Rock description
0-4.25	Overburden
4.25-5.75	Chlorite rock
5.75-7.90	Leptite Foliation 90° against core axis.
7.90-9.60	Leptite Chlorite alteration in 1cm - 10cm sections. Impregnations of magnetite.
9.60-20.20	Leptite Grey, with chlorite alteration in sections. At 17.50 scheelite with coarse grained quartz, MoS_2 and other sulphides.
20.20-21.00	Garnet skarn Other minerals: vesuvianite and quartz.
21.00-21.30	Pegmatite
21.30-21.85	Garnet skarn
21.85-22.00	Wollastonite skarn
22.00-22.20	Garnet skarn
22.20-22.70	Wollastonite skarn Other minerals: garnet, vesuvianite, quartz, pyroxene, K-feldspar.

22.70-23.50	Leptite Grey, with frequent small fractures filled with k-feldspar.
23.50-23.70	Garnet skarn
23.70-27.00	Leptite Grey, as above, with fluorspar and hornblende in fractures.
27.00-29.25	Garnet skarn Other minerals: vesuvianite, pyroxene, quartz, k-feldspar.
29.25-30.90	Leptite
30.90-31.25	Garnet skarn
31.25-31.70	Leptite
31.70-32.50	Garnet skarn
32.50-32.80	Leptite
32.80-33.60	Pegmatite
33.60-35.20	Leptite gneiss
35.20-37.60	Wollastonite skarn Mineralogy: garnet, calcite, tremolite (?), quartz
37.60-37.90	Leptite gneiss
37.90-38.80	Wollastonite skarn. As above.
38.80-46.80	Leptite Foliated, with alternating red and grey layers. At 40.05 impregnations of chalcopyrite, chalcocite and molybdenite.
46.80-48.30	Crystalline limestone Mineralogy: garnet, calcite, quartz, pyroxene
48.30-49.00	Garnet skarn
49.00-49.90	Leptite gneiss With some layers of wollastonite
49.90-51.30	Garnet skarn Contains some wollastonite.

51.30-52.30	Leptite Grey, foliated with some beds of wollastonite.
52.30-53.25	Garnet skarn Contains some wollastonite.
53.25-55.35	Wollastonite skarn Alternating layers of leptite and wollastonite, with apparent dip 75° against the core axis.
55.35-59.15	Garnet skarn Diffusely layered in the upper part. Other minerals: pyroxene, scheelite, quartz and felspar. The lowest 10cm consist of almost only pyroxene.
59.15-61.80	Crystalline limestone Contains some garnet and pyroxene.
61.80-62.20	Garnet skarn As above.
62.20-63.10	Crystalline limestone As above.
63.10-69.55	Wollastonite skarn Mineralogy: wollastonite, quartz, garnet, calcite and impregnations of fluorite. Strongly varying wollastonite content. Diffuse layering, with dip 65° against the core axis. Sample 65.10-65.20
69.55-70.00	Crystalline limestone No wollastonite.
70.00-71.05	Wollastonite skarn Rich in wollastonite, other minerals: garnet, vesuvianite. Sample 70.20
71.05-71.80	Impure limestone. No wollastonite, contains fluorspar.
71.80-72.20	Crystalline limestone Contains some wollastonite.
72.20-72.80	Crystalline limestone No wollastonite.
72.80-73.40	Crystalline limestone With wollastonite.

73.40-74.20	Crystalline limestone No wollastonite.
74.20-74.40	Wollastonite skarn
74.40-74.80	Crystalline limestone
74.80-75.10	Crystalline limestone With wollastonite
75.10-79.55	Wollastonite skarn Thin beds of wollastonite in leptite.

END

Drillhole no. 11

Direction: 228° Inclination: 70°

Depth (m)	Rock description
0-1.10	Overburden
1.10-14.45	Leptite Grey, with pegmatite.
14.45-19.25	Chlorite rock
19.25-30.60	Leptite Extensive fracturing below 27.40.

END

Drillhole no. 12

Direction: 228° Inclination: 70°

Depth (m)	Rock description
0-2.00	Overburden
2.00-38.20	Leptite Grey,becoming darker and more fractured downwards.
38.20-39.60	Chlorite rock
39.60-49.85	Leptite
49.85-53.15	Wollastonite skarn Foliation 60° against core axis.

53.15-56.50	Leptite
56.50-59.20	Leptite With chlorite.
59.20-59.95	Leptite

END

Drillhole no. 13

Direction: 230°   Inclination: 50°

Depth (m)	Rock description
0-4.60	Overburden
4.60-35.90	Leptite gneiss Grey with red recrystallised material. Scattered impregnations of garnet and chlorite sections. Pegmatites at 6.00-6.20, 24.25-25.00, 30.00. Extensive fracturing at 24.25-25.00 Diffuse foliation 60° against core axis.
35.90-37.40	Leptite Grey, with scheelite.
37.40-44.30	Leptite

END

Drillhole no. 14

Direction: 224°   Inclination: 70°

Depth (m)	Rock description
0-2.25	Overburden
2.25-6.50	Leptite Grey, with some chlorite and quartz veins.
6.50-7.50	Garnet skarn
7.50-10.10	Crystalline limestone With some garnet.

10.10-11.55	Pyroxene skarn With chlorite, and a 1.5 cm thick pegmatite.
11.55-15.10	Leptite Grey, with pyroxene and chlorite.
15.10-17.10	Wollastonite skarn Other minerals: garnet, pyroxene, vesuvianite. Sample 15.70-15.75.
17.10-17.45	Crystalline limestone
17.45-18.20	Leptite gneiss
18.20-19.90	Crystalline limestone Contains some wollastonite.
19.90-20.80	Leptite
20.80-24.45	Crystalline limestone Low content of wollastonite. Sample 21.85-22.00
24.45-24.85	Crystalline limestone No wollastonite.
24.85- 25.55	Wollastonite skarn
25.55-31.85	Crystalline limestone

END

Drillhole no. 15

Direction: 214°

Inclination: 70°

Depth (m)	Rock description
0-2.45	Overburden
2.45-23.75	Leptite Grey, with sections of chlorite. Magnetite impregnations at 10-12.
23.75-24.55	Garnet skarn
24.55-41.90	Leptite Grey, some impregnations of scheelite. Quartz veins surrounded by garnet. At 31.50 pegmatite.
41.90-43.10	Wollastonite skarn

43.10-43.88	Leptite
43.88-48.50	Wollastonite skarn 1 cm thick beds of wollastonite in leptite. Transitional boundary towards next section.
48.50-51.70	Pyroxene skarn With garnet.
51.70-53.80	Crystalline limestone The lowest 3 cm contain some wollastonite.

END

APPENDIX 2

THIN SECTION DESCRIPTIONS

Estimated mineral mode = modal percentages that are estimated by visual inspection. Where these differ considerably between thin section and handspecimen, both values are given.

Samples 1-22 = wollastonite skarn
Samples 23-35 = surrounding rocks.

Grain sizes in handspecimen:
Aphanitic = not visible for the naked eye.

Fine-grained	< 1 mm
Medium-grained	1-5 mm
Coarse-grained	> 5 mm

Sample number: 1

Location: Drillhole no. 1, 38.00-38.10 m.

Rock type: Wollastonite skarn

Estimated mineral mode;

Hand specimen:

Quartz + K-feldspar	40
Garnet	30-40
Wollastonite	20-25
Diopside	5

Thin section:

Quartz	75
K-feldspar	10
Garnet	6
Calcic pyroxene	8
Wollastonite	<1
Sphene	<1
Allanite	<1

Handspecimen:

The sample consists of a fine to medium-grained, pale green ground-mass with misty patches of white wollastonite, making up a diffuse layering. The pale green portion consists of quartz and feldspar. Garnet is found as pinkish brown, 3-4 cm. large, rounded poikiloblasts embedded in the wollastonite. It also forms pink speckles in the quartz-feldspar portion. Green crystals of diopside are found evenly distributed throughout the sample. Scattered spots of dark brown allanite are found in the quartz-feldspar dominated part.

Thin Section:

This section is taken from the quartz-feldspathic part of the sample. The quartz and feldspar form an equigranular (0.1-0.4 mm) ground mass, in which pyroxene (0.05-2 mm) and garnet (0.5-5 mm) form anhedral particles that occur in intergranular spaces. Quartz shows undulose extinction. Potassium feldspars show sericitic alteration.

Poikilitic garnets with inclusions of quartz, feldspar and wollastonite occur in some places. Some of the smaller garnets are altered to a mineral which is pleocroic green to greenish yellow to brown. Garnet and diopside often form aggregates together.

Sample number: 2

Location: Drillhole number 1, 42.00-42.05m.

Rock type: Skarn

Estimated mineral mode (%)

Hand specimen:		Thin section:	
Quartz and K-feldspar	70	Quartz	15
Garnet	10-15	K-Feldspar	10
Vesuvianite	8	Garnet	60
Wollastonite	5	Calcite	10
Diopside	5	Diopside	5
Allanite	<1	Sphene	<1

Hand specimen:

The sample is fine grained to aphanitic and has a mottled appearance with the dominating colour being green. The sample exhibits compositional layering, so it has a 0.5 cm broad band of wollastonite, and a pink elongated patch of garnet alternating with pale grey bands of quartz and feldspar. Olive green irregular patches of vesuvianite are found throughout and crystals of green pyroxene tend to concentrate in the salic portion.

Thin section:

Garnet (5-10 mm) forms a large cluster in a matrix of quartz and feldspar (0.1-0.3 mm). Calcite (0.1-0.3 mm) and pyroxene (0.08 - 0.1 mm) form intergranular spacefillings. The grains of quartz and feldspar are mostly rounded and sometimes have irregular shapes. Garnet is poikiloblastic when it is present in the ground mass. It has inclusions of quartz and calcite. These are zonally arranged so that needles of calcite concentrate in the centre, while quartz inclusions are found along the edges of the garnet. In an area 1.5 x 0.5 cm large within the garnet patch, there is quartz and calcite with diffuse grain boundaries. Randomly orientated needles of wollastonite are frequent in this area.

The grain boundaries of garnet are irregular and fractured. The fractures are usually filled with quartz or calcite.

Sample number: 3

Location: Drillhole no. 4, 37.00 - 37.05 m.

Rock type: Wollastonite skarn

Estimated mineral mode (%):

Hand specimen:		Thin section:	
Wollastonite	40	Wollastonite	30
Garnet	20	k-feldspar	45
Quartz and feldspar	30	Quartz	5
Calcic pyroxene	10	Garnet	10
Allanite	<1	Diopside	10

Handspecimen:

The sample consists mainly of white fine grained wollastonite. Potassium feldspar forms irregular, aphanitic, greyish pink patches. Brown garnet is found as up to 1 cm large crystals. Scattered minute crystals of pyroxene are green in colour. Allanite forms 2-3 mm large particles.

Thin section:

The section is divided up in patches dominated by wollastonite (0.1-0.5 mm) and by potassium feldspar (0.05 - 0.1 mm) with minor quartz (0.1 - 0.5 mm). Diopside (0.2-1.0 mm) is evenly distributed throughout the sample. The wollastonite crystals have a columnar or needle-like shape with random orientation. Quartz and feldspar form rounded grains with curved grain boundaries. Garnet is poikiloblastic with inclusions of quartz and feldspar. It has extensive overgrowths of needleshaped wollastonite.

Sample number: 4

Location: Drillhole number 4, 43.15 - 43.20 m.

Rock type: Metaleptite.

Estimated mineral mode (%):

Quartz	37
K-feldspar	46
Plagioclase	5
Garnet	8
Calcic pyroxene	3
Zircon	1

Hand specimen:

Very fine grained to aphanitic pinkish grey quartz-feldspar groundmass, with pinkish brown speckles of garnet.

Thin section:

Quartz and feldspar (0.08 - 0.1 mm) form an equigranular groundmass. Anhedral pyroxene (0.1 - 0.2 mm) and garnet (0.1 - 0.5 mm) are scattered throughout the sample. The pyroxene forms minute grains and is evenly distributed, while garnet constitutes a diffuse banding. Zircon occurs as rodshaped (0.02 - 0.04 mm) crystals evenly distributed throughout the sample.

Some of the feldspar grains have sericitic alteration.

Sample number: 5

Location: Drillhole number 4, 45.60 - 45.75 m.

Rock type: Wollastonite skarn.

Estimated mineral mode (%):

Wollastonite	35
K-feldspar	28
Plagioclase	15
Quartz	12
Diopside	7
Garnet	3
Sphene	<1
Allanite	<1
Opaques	<1

Hand specimen:

White wollastonite forms a web-like structure in pale grey groundmass of quartz and feldspar. Calcic pyroxene forms green aggregates with fuzzy outlines in a preferential linear orientation. Garnet forms pinkish brown irregular patches.

Thin section:

The ground mass consists of granular feldspar and quartz (0.5-1.0 mm) with wollastonite (0.1 mm) in the intergranular spaces. Anhedral pyroxene (0.1-0.5 mm) is mostly found in elongated clusters with preferred orientation. Garnet (4÷5 mm) has extensive over-growths of minute wollastonite crystals, so that its surface appears cloudy, garnets crystal outlines are poorly defined.

Grain boundaries between feldspars are mostly straight, but often there is a thin layer of wollastonite separating two crystals. Secondary crystal growths along edges are also commonly observed. Wollastonite shows a great variety of crystal shapes and twinning is common. Needles of wollastonite commonly protrude into the other mineral phases.

Sample number: 6

Location: Drillhole no. 4, 33.95-34.10 m

Rock type: Wollastonite skarn

Estimated mineral mode (%):

Hand specimen:		Thin section:	
K-feldspar	30	Vesuvianite	92-93
Wolastonite	30	Wollastonite	5
Garnet	15	Muscovite	1-2
Vesuvianite	10	Quartz	<1
Pyroxene	15	Calcite	<1

Hand specimen:

The sample shows compositional layering, with alternating layers of pale green vesuvianite, white wollastonite and pink potassium feldspar. Brown garnet megacysts are found in the wollastonite sections and green calcic pyroxene is found as green speckles in the feldspathic sections. The texture is fine grained.

Thin section:

An aggregate of vesuvianite (1-5 mm) constitutes the main part of the section. Quartz (0.05-0.1 mm) and wollastonite (0.2 mm) fill in spaces between grains. The wollastonite is also found as inclusions that protrude into vesuvianite grains. Vesuvianite mostly forms rhombohedral crystals, but elongated particles in radial structures are also fairly common. The wollastonite inclusions within the elongated crystals conform with the crystal shape of the vesuvianite. In the rhombohedral particles they are concentrated towards the centre of the crystal, leaving the edges clear and free from inclusions. The vesuvianite crystals often have yellow to brown cloudy overgrowths.

The shape of wollastonite is fibrous or needle-like, more rarely tabular. Muscovite forms thread-like inclusions in the vesuvianite. A few fractures filled with quartz or calcite have been observed.

Sample number: 7

Location: Drillhole no. 2, 26.90-27.10 m.

Rock type: Wollastonite skarn

Estimated mineral mode (%):

Hand specimen:

Quartz and feldspar	30
Wollastonite	40
Calcic pyroxene	10
Garnet	15
Vesuvianite	5

Thin section:

Quartz	25
K-feldspar	35
Wollastonite	35
Garnet	3
Vesuvianite	2
Sphene	<1

Hand specimen:

Pale grey, fine grained ground mass of wollastonite, quartz and feldspar, with pink poikiloblasts of garnet (2 cm). Irregular patches of vesuvianite have an olive green colour and calcic pyroxene forms green speckles.

Thin section:

Equigranular quartz and feldspar (0.1-0.5mm),with wollastonite (0.1 mm) and pyroxene (0.1-0.3 mm) in intergranular spaces, constitute the bulk of the section. Garnet forms isotropic patches.

The wollastonite crystals have needle shapes, and are often embedded in crystals of quartz and feldspar.

Quartz shows patchy extinction. Feldspars have frequent perthitic intergrowths.

Vesuvianite crystals (2-3 mm) with cuspate grain boundaries frequently have inclusions of wollastonite.

Sample number: 8

Location: Drillhole number 2, 33.00 - 33.07 m.

Rock type: Metaleptite

Estimated mineral mode (%):

Hand specimen

Quartz and feldspar	20
Garnet	40
Vesuvianite	20
Fluorspar	10
Pyroxene	10

Thin section:

Quartz	40
K-feldspar	30
Garnet	17
Fluorspar	11
Calcic Pyroxene	<1
Calcite	<1

Hand specimen:

0.5 cm thick, white fine-grained quartz-feldspar layers with purple staining alternating with 0.5 - 1 cm thick garnet-vesuvianite layers. The garnet is pinkish brown and appears as flattened poikiloblasts with olive green vesuvianite and green diopside inclusions. Fine grained colourless fluorspar is also found within the garnet sections. The apparent dip of the layering is 80° against the core axis.

Thin section:

The ground mass consists of equigranular rounded particles of quartz (0.2-2mm) and potassium feldspar (0.5-1 mm). Fluorspar occurs in intergranular spaces in the ground mass.

Clusters of anhedral garnet (0.05 - 1mm) form a saccharoidal texture. In these parts irregular patches of fluorspar make up the bulk of the ground mass with subordinate amounts of quartz.

Calcite is found as scattered minute intergranular space fillings throughout the sample.

Garnet is found as inclusions in both feldspar and quartz, and quartz is in turn found as inclusions in the feldspar. This shows that the garnet recrystallisation was followed by that of quartz, and potassium feldspar was last phase to recrystallise.

Sample number: 9

Location: Drillhole no. 2, 33.07-33.15 m

Rock type: Wollastonite skarn

Estimated mineral mode(%):

Quartz	25
K-feldspar	10
Albite	10
Wollastonite	30
Vesuvianite	8
Garnet	10
Fluorspar	5
Calcic pyroxene	1
Calcite	<1
Opaques	<1

Hand specimen:

The rock is fine grained and has a greyish green colour with white small featherlike wollastonite across the lower half of the sample. The green colour is caused by vesuvianite together with transparent quartz. Garnet forms an oval shaped 3cm large pinkish brown, zoned poikiloblast.

Thin section:

Needle shaped randomly orientated wollastonite (0.05 - 0.1 mm), with quartz, feldspar (0.2 - 0.4 mm) and pyroxene (0.08 - 0.1 mm) in intergranular spaces, make up the bulk of the section. In this ground mass, large crystals of vesuvianite (0.5 - 1 cm) and garnet (1 cm) are present. In one of the corners a quarter of the oval garnet is found. The zoning observed in hand specimen is due to the amounts of inclusions. In the centre the garnet is clear and only contains a few larger inclusions of quartz. Going outwards it becomes more cloudy and contains inclusions of calcite and microcrystalline quartz. Along the edge the garnet is frequently fracture and exhibits a saccharoidal texture. At a distance within at least 2 mm from the garnet there is no wollastonite, the concentration of wollastonite increasing away from the garnet. This tendency is directly opposite to that

Sample no. 9 continued

in most other slides, see for example number 17, where the wollastonite is actually nucleating on the garnet. However, wollastonite forms frequent inclusions in vesuvianite, completely masking the outline of the latter.

Fluorite is found as myrmecitic intergrowths in quartz, occurring in a few mm large patches.

Sample number: 10

Location: Drillhole no. 2, 34.35 -34.45 m.

Rock type: Wollastonite skarn

Estimated mineral mode (%):

Wollastonite	35
Quartz	35
K-feldspar	13
Plagioclase	2
Calcic Pyroxene	6
Garnet	5
Calcite	4

Hand specimen:

The sample has compositional layering with 2-3 cm thick alternating layers. White wollastonite layers have green elongated aggregates of pyroxene. Quartz and feldspar constitute greyish pink layers with brownish pink garnet in a saccharoidal texture. Both layer types are fine grained. A quartz filled 1 mm thick vein cuts across the sample at 30° against the core axis.

Thin section:

The section is divided into two different units. One is made up of quartz (0.01-0.1 mm) and feldspar (0.08 - 0.1 mm) in a granular texture. The other is mainly composed of wollastonite (0.05 - 0.3 mm). The wollastonite grains have needle- or columnar shapes and are randomly orientated. Pyroxene (0.05 - 2mm) is present in both types of ground mass. It forms very small intersticial particles within patches of wollastonite. It is more frequent, and forms larger and anhedral cyrstals, in the quartz-feldspar sections but it is extensively overgrown in the wollastonite portion.

A 2-3 mm thick fracture cuts across the section. This is filled with 0.1-1 mm large crystals of quartz. Along the edges of the fracture calcite is found, only where it intersects wollastonite. Microfaulting with displacements of 2-3 mm have occurred along the fracture.

Sample number: 11

Location: Drillhole number 8, 40.75 - 40.85 m.

Rock type: Crystalline limestone with wollastonite rich layer.

Estimated mineral mode:

Hand specimen:		Thin section:	
Wollastonite	55	Wollastonite	10
Calcite	25	Calcite	65
Garnet	15	Garnet	20
Calcic pyroxene	5	Calcic pyroxene	5

Hand specimen:

The rock is composed of white, fine-grained wollastonite ground mass with scattered green spots of pyroxene and dark green to dark brown idioblasts of garnet. Grey medium-grained calcite is found along the upper and lower end of the sample.

Thin section:

Calcite (0.5 - 4 mm) forms an idiotopic texture with intergranular calcic pyroxene (0.1 - 0.5 mm) and idioblasts of garnet (3-16 mm). Needleshaped wollastonite (0.05 - 2mm) is found randomly orientated in small irregular aggregates in spaces between calcite grains. These needles are terminated by the boundaries of calcite. Wollastonite occurs preferentially along edges of garnet on which it forms a rim. Minerals forming inclusions within garnet are calcite, pyroxene and more rarely wollastonite.

Sample number: 12

Location: Drillhole number 14, 15.70 - 15.75 m.

Rock type: Wollastonite skarn

Estimated mineral mode (%):

Hand specimen		Thin section:	
Wollastonite	70	Wollastonite	45
Garnet	15	Garnet	20-25
Calcite	8	Vesuvianite	15-20
Pyroxene	5	Diopside	10-12
Vesuvianite	2	Calcite	2-3

Hand specimen:

White, very fine grained wollastonite with idioblastic to poikiloblastic brown patches of garnet. Green speckles of pyroxene are distributed evenly throughout the sample. A blackish brown irregularly shaped patch of vesuvianite is found in close association with garnet. The garnets appear to be arranged in a subplanar fashion.

Thin section:

The texture consists of a fine grained ground mass of wollastonite (0.05 - 3mm) and pyroxene (0.05 - 0.5 mm) with larger crystals of garnet and vesuvianite (2-10 mm). Some of the wollastonite occurs as very fine fibres in radiating sheafs or clusters of parallel fibres. Wollastonite particles can also have needle- or columnar shapes, and some are tabular and occurring in very fine grained masses. Pyroxene is pale green to colourless and is found in close association with the wollastonite. Since wollastonite too is colourless, the two mineral species are difficult to tell apart. However, in most cases pyroxene has a higher birefringence than wollastonite. Examples of fibrous pyroxene are found, forming pseudomorphs after wollastonite. More commonly, the pyroxene is anhedral and the wollastonite is often found partially embedded in the pyroxene, causing the latter to appear as small blebs.

Sample number: 12 continued

Garnet forms euhedral to subhedral, and vesuvianite subhedral, crystals with irregularly fractured surfaces and calcite filling in the fractures. They occur closely together in larger masses, and have the same relief and pale green to neutral colour in parallel light. Therefore the grain boundaries are almost impossible to discover unless the nicols are crossed. Then the garnet becomes black (isotropic) and vesuvianite shows grey interference colours, revealing that the vesuvianite follows the form of the garnet. In well defined areas on larger vesuvianites there is a brown to yellow colouration in two sets of zones.at right angles to each other. Those brownish zones have been determined to be more iron rich parts of the vesuvianite crystals, from microprobe analyses.

Diopside, wollastonite and calcite are found as inclusions in garnet and vesuvianite. In one case wollastonite is found as an inclusion in a calcite inclusion in a garnet.

Fibrous clusters of wollastonite are partially embedded within garnet and vesuvianite.

Sample number: 13

Location: Drillhole number 14, 21.85 - 22.00 m.

Rock type: Crystalline Limestone

Estimated mineral mode:

Calcite	70
K-feldspar	8
Plagioclase	2
Wollastonite	10
Calcic pyroxene	10
Allanite	<1
Sphene	<1

Hand specimen:

Pale grey fine to medium grained calcite with white, misty blotches of wollastonite and green speckles of calcic pyroxene.

Thin section:

Ground mass of calcite (0.5 - 2mm) in a granular texture, with scattered intergranular k-feldspar (0.1 - 0.7 mm) and calcic pyroxene (0.1 - 1mm). In larger spaces between calcite particles there are a few areas with randomly orientated needles of wollastonite. (0.05 - 1mm).

Sample Number: 14

Location: Drillhole no. 10, 65.15 - 65.20 m.

Rock type: Wollastonite skarn

Estimated mineral mode (%):

Hand specimen		Thin section	
Quartz and feldspar	40	Quartz	50
Wollastonite	50	K-feldspar	5
Garnet	8	Wollastonite	35
Diopside	2	Diopside	10
		Calcite	<1
		Opaques	<1

Hand specimen:

A diffusely defined layer of wollastonite cut across a fine grained grey matrix of quartz and feldspar. Embedded in the Wollastonite there is a 2-3 cm large, brown garnet poikiloblast. Diopside occurs as green, fine grained impregnations.

Thin section:

The section is divided into two areas. One consists of lath shaped wollastonite (0.05 - 1mm) together with some diopside (0.05 - 0.5 mm) in an arrangement described in sample 12. The other part consists of quartz (0.05 - 2mm) and feldspar (0.05 - 0.2 mm) in a granular texture. This part has unequal grain size so that veils of fine grained material wrap around aggregates of coarser quartz. Diopside is randomly distributed in this part.

Sample number: 15

Location: Drillhole number 10, 65.10 - 65.15 m.

Rock type: Metaleptite

Estimated mineral mode (%):

Quartz	41-43
K-feldspar	50
Calcic pyroxene	5-7
Garnet	1
Calcite	<1
Sphene	<1

Hand specimen:

The quartz-feldspathic ground mass is aphanitic and pale grey translucent in colour. Green elongated 1-3 mm long particles of pyroxene form a lineation at 80° against the core axis. Very fine grained pinkish brown garnet occurs in irregular 1-2 mm thick aggregates roughly conforming with the lineation of the pyroxene.

Thin section:

Quartz and potassium feldspar (0.05 - 0.4 mm) form a granular texture. The grain size varies in patches, each patch being equigranular within itself. Diopside (0.05 - 0.1 mm) occurs as very fine individual particles in intergranular spaces, or in up to 4 mm long thin aggregates in parallel orientation with each other. It is also found in close association with garnet. The colour is pale green or neutral. Garnet (0.05 - 0.1 mm) occurs in irregularly shaped aggregates, together with pyroxene, and its colour is neutral.

Calcite (0.05 - 0.01 mm) is present in intergranular spaces in the ground mass. Sphene (0.01 - 0.05 mm) forms euhedral, colourless crystals.

Sample number: 16

Location: Akatjvare, Tjåmotis

Rock type: Wollastonite skarn

Estimated mineral mode:

Wollastonite	60
Diopside	30
Calcite	9
Garnet	1

Hand specimen:

White to pale grey columnar diopside and wollastonite, 3-4 mm across, with a silky lustre, are arranged loosely parallel to one another or in sheafs. Reddish brown garnet crystals, approx. 0.5 mm across occur individually or in irregularly shaped aggregates. Yellowish green epidote occurs either with garnet or separately, and makes up less than 1% of the sample.

Thin section:

The section is cut parallel to the elongation of the columns of wollastonite (0.5 - 1.5 mm across, 1-6 mm long) and diopside (0.5 - 1 mm across, 1 - 10 mm long). Calcite (0.5 - 4mm) is found in intergranular spaces, the outlines following the forms of diopside and wollastonite. Garnet (0.1 - 0.5 mm) forms brown, rounded particles that occur as partially embedded inclusions within wollastonite. It should be noted that diopside was not distinguishable from wollastonite in the hand specimen. Its presence was discovered in thin section by its higher birefringence, oblique extinction and the pyroxene cleavage. The white colour of the diopside indicates that it is iron free, but it also makes it difficult to distinguish from wollastonite macroscopically. Therefore the estimated wollastonite percentage may be lower than first thought.

Sample number: 17a

Location: In a trench at coordinates 40N/130E in the drillhole grid.

Rock type: Layered wollastonite skarn.

Estimated mineral modes (%):

Hand specimen		Thin section	
Wollastonite	45	Wollastonite	55-60
K-feldspar	20	K-feldspar	20-25
Garnet	15-20	Garnet	15
Pyroxene	10-15	Pyroxene	5-10

Hand specimen:

The sample is divided into two mineralogically different sections. The lower part, 2 cm thick, consists of pink aphanitic potassium feldspar containing white radiating clusters of wollastonite. The upper 5 cm of the sample is composed of fine grained, white wollastonite with large brown garnets and green speckles of pyroxene. Along the boundary between the two sections there is an olive green 1 mm thick band of vesuvianite. Another vesuvianite band is found within the upper section conforming with a flattened brown garnet megacryst.

Thin section:

The matrix consists of randomly orientated, needle-like wollastonite (0.01 - 0.05 mm) in which scattered pyroxene (0.05 - 0.2 mm) is found, as shown in fig. 13. In this matrix there are large crystals of garnet (5-10 mm) and scattered grains of potassium feldspar (0.1 - 0.5 mm). The feldspar is particularly frequent around the garnet, in which it also occurs as inclusions. It is anhedral and commonly has wollastonite needles growing into it.

The shape of the garnet is very irregular, partly because of the frequent nucleation of wollastonite along its edges. It also contains very small inclusions of pyroxene. In one area of the section, the

Sample number 17a continued

rock consists of granular potassium feldspar with pyroxene in the intergranular spaces. The boundary between the two rock types is sharp. Feldspar shows sericitic alteration, pyroxene has a grey coating, probably formed by some alteration.

Sample Number: 17b

Location: In a trench at coordinates 40N/130E in the drillhole grid.

Rock type: Wollastonite skarn.

Estiamted mineral modes (%):

Hand specimen		Thin section	
Wollastonite	45	K-feldspar	80
K-feldspar	20	Wollastonite	12
Garnet	15-20	Diopside	5
Pyroxene	10-15	Garnet	3
		Quartz	<1

Hand specimen:

The sample is divided into two mineralogically different sections. The lower 2 cm, consists of pink aphanitic potassium feldspar with white star shaped clusters of wollastonite. The upper 5 cm of the sample is composed of fine grained, white wollastonite with large, brown garnets and green speckles of pyroxene.

Along the boundary between the two sections, there is an olive green milimeter thick band of vesuvianite. Another similar band is found within the upper section, conforming with a flattened garnet crystal.

Thin section:

The sample has a granular ground mass of potassium feldspar (0.1 - 0.2 mm) with poikiloblasts of garnet (4-5 mm) and a few millimetre large starshaped clusters of wollastonite (0.1 mm).

On the garnet extensive nucleation of wollastonite has taken place, leading to total replacement along the edges, so that the inclusion rich garnet forms a core in a wollastonite rich patch.

Diopside (0.02 - 0.05 mm) forms minute individual particles or aggregates in the same way as in sample 15.

Sample number: 20

Location: Drillhole no. 1, 39.40 - 39.50 m.

Rock type: Wollastonite skarn.

Estimated mineral mode (%):

Hand specimen		Thin section	
Quartz	40	K-feldspar	58-60
Feldspar	25	Quartz	20
Wollastonite	17-18	Wollastonite	5
Garnet	12	Garnet	10-12
Pyroxene	5	Pyroxene	3
Allanite	<1	Allanite	1
		Sphene	1
		Calcite	<1

Hand specimen:

The sample is fine grained and is pinkish grey with ½-2 cm veil-like layers of wollastonite. The whole sample has pink and green speckles fairly evenly distributed throughout the sample. A few pinkish brown poikiloblasts are also present.

Thin section:

The quartz (0.1 - 0.6 mm) and feldspar (0.1 - 0.5 mm) make up a granular texture with curved or cuspate grain boundaries.

Wollastonite (0.01 - 0.2 mm) forms randomly orientated needles or columns, occurring in clusters that form poorly defined bands.

In these areas feldspar occurs as subidioblastic crystals. Garnet (10-12 mm) forms poikiloblastic particles or small anhedra filling in intergranular spaces.

Pyroxene (0.05 - 0.5 mm) also forms small anhedra and is often found together with garnet.

Allanite (0.05 - 0.1 mm) and sphene (0.05 - 0.2 mm) form rod shaped scattered crystals.

Sample Number: 21

Location: Drillhole no. 2, 29.00 - 29.10 m.

Rock type: Wollastonite skarn

Estimated mineral mode:

Hand specimen		Thin section	
Quartz + feldspar	75-78	Quartz	40-55
Wollastonite	10-12	K-Feldspar	20-30
Garnet	10	Wollastonite	15-20
Pyroxene	2-3	Garnet	5
Allanite	<1	Calcic pyroxene	5
		Allanite	<1

Hand specimen:

Finegrained, pale greyish green ground mass of quartz and feldspar, with poorly defined areas of white wollastonite, alternating with areas of scattered pinkish brown garnet.

Thin section:

The quartz (0.1 - 1.7 mm) and feldspar (0.1 - 0.5 mm) constitute a granular texture with curved or cuspate grain boundaries. Garnet (0.1 - 4mm) form poikiloblasts rich in wollastonite inclusions. Wollastonite (0.05 - 0.2 mm) occurs in the same way as in sample 20. Diopside (0.01 - 0.2 mm) forms anhedral or subhedral particles, often occurring in aggregates.

Sericite alteration on the feldspar is common.

Sample number: 22

Location: Drillhole number 2, 31.00 - 31.15 m.

Rock type: Wollastonite skarn

Estimated mineral mode (%):

Hand specimen		Thin section	
Quartz + feldspar	57-70	Wollastonite	52-60
Wollastonite	10-15	Quartz	25-30
Garnet	15-20	K-feldspar	10
Pyroxene	5-7	Garnet	2
Allanite	<1	Pyroxene	3-6
		Allanite	<1
		Sphene	<1

Hand specimen:

The appearance is the same as in sample 21, except that the wollastonite dominated areas are richer in wollastonite, and garnet is incorporated in these rather than separated from them.

Thin section:

Similar to that of sample 21.

Sample number: 23

Location: Drillhole number 5, 71.80 - 71.90 m.

Rock type: Biotite rock with magnetite

Estimated mineral mode:

Biotite	55-70
Magnetite	20-30
Aegirin-Augite	10-15

Hand specimen:

The sample has a fine- to medium-grained dark green matrix of biotite. Fine-to medium-grained magnetite with dark grey colour and metallic lustre, form irregular patches. Tabular pyroxene crystals of medium-grained size are found alternating with the magnetite aggregates. All mineral species show preferred orientation.

Thin section:

The rock consists mainly of elongated grains of green biotite (0.2 - 4 mm) showing preferred orientation. The pyroxene porphyroblasts (0.5 - 5mm) are tabular in shape and are mostly orientated parallel to the biotite. Grain boundaries are straight or slightly curved. Magnetite grains (0.2 - 2mm) have rectangular or polygonal outlines and occur randomly scattered or in elongated aggregates with their orientation parallel to that of biotite.

Biotite contains inclusions of zircon (0.2 mm) with pleocroic haloes.

Kinking is found in some of the biotite grains.

Some magnetite grains have been oxidized to hematite.

Sample Number: 24

Location: Drillhole number 9, 8.45 - 8.50 m.

Rock type: Pyroxene-amphibole skarn

Estimated mineral mode:

Riebeckite	35-40
Diopside	60-65

Hand Specimen:

Dark green medium-grained amphibole and greyish green coarse-grained pyroxene form monomineralic clusters in random distribution. Pyroxene forms continuous patches in the amphibole matrix.

Thin Section:

Diopside (0.2 - 5 mm) makes up the bulk of the sample. The pyroxene is poikiloblastic with anhedral inclusions of riebeckite. The amphibole (0.1 - 1.5 mm) is also found in aggregates approx. 5 mm across with irregular outline. In these, the texture is idiotopic. When in contact with diopside, the grain boundaries of riebeckite are embayed. The riebeckite was identified by its strong pleocroism, in green and blue colours.

Sample number: 26

Location: 430 m west of the Hulta mines.

Rock type: Dolerite

Estimated mineral mode:

Augite	5-10
Serpentine	59-64
Plagioclase	25
Opaques	6

Hand specimen:

The sample is fine-grained and is greenish black with small white speckles.

Thin section:

The texture is subophitic. Augite (0.5 - 2mm) is pale brown and is partly or wholly replaced by pale green serpentine, which has a yellow tint, especially along grain boundaries. Laths of plagioclase (0.3 - 0.7mm) are partly enclosed within the augite or the serpentine. They show extensive twinning parallel to the elongation, and have in some places been altered to sericite.

Sample number: 27

Location: Southern part of the Hulta mines, see sample location map.

Rock type: Crystalline limestone

Estimated mineral mode:

Calcite	80-84
Hornblende	8-10
Garnet	5-6
Microcline	2-3
Quartz	1

Hand specimen:

The sample is medium-to fine-grained, and has a grey colour with dark green blebs.

Thin section:

The ground mass consists of calcite (0.5 - 2.5 mm) with straight, slightly wavey or embayed grain boundaries. Hornblende (0.2 - 1.2 mm) occurs in the intergranular spaces, and is also found as inclusions in calcite. It is anhedral or subidiomorphic, and is most commonly found as individual particles. Large grains of garnet (0.1 - 1.2 mm) are poikiloblastic and the smaller ones are almost perfectly rounded. Anhedral quartz and feldspar occur as inclusions or embayments in calcite.

Sample Number: 30

Location: Outcrop in the northern part of the Hulta mines, see sample location map.

Rock type: Leptite

Estimated mineral mode (%):

Potassium feldspar	50
Quartz	34-41
Albite	5-10
Calcite	2-3
Chlorite	1-2
Opaques	1

Hand specimen:

The rock has a pinkish grey colour and is medium to fine grained. Very thin parallel fractures, filled with chlorite cut across the sample.

Thin section:

Quartz (0.1 - 1.5 mm) and feldspare (0.1 - 1mm) form an allotriomorphic inequigranular texture. Quartz has wavey extinction, and lobate grain boundaries.

Feldspars are subhedral with straight or curved grain boundaries.

Some of the feldspar grains have thin rims of microcrystalline calcite or quartz along the edges.

Feldspars are frequently altered to sericite.

Microcrystalline calcite and chlorite is found in thin randomly orientated fractures and in intergranular spaces. In some areas they form a web-like pattern enclosing quartz and feldspar. these areas grade into irregular patches composed solely of microcrystalline clacite and chlorite. When they occur together in veins, chlorite forms the centre and calcite is found along the rims. Opaques (0.05 - 0.3 mm) occur as scattered anhedra, often in association with chlorite and calcite.

Sample number: 31

Location: The northern part of the Hulta mines, see sample location map.

Rock type: Garnet skarn

Estimated mineral mode (%):

Hand Specimen:

Garnet	86-89
Pyroxene	8-10
Quartz	3-4

Thin section:

Garnet	65-72
Pyroxene	5-6
Quartz	8-10
Hornblende	8-10
Muscovite	3-4
Epidote	3-4
Allanite	<1
Vesuvianite	<1
Calcite	<1

Hand specimen:

Garnet forms a large aggregate of brown poikiloblasts. Green pyroxene and transparent quartz form inclusions in the garnet.

Thin section:

Garnet forms a continuous poikiloblastic mass with inclusions of the other mineral species.

Quartz (0.05 - 1.5 mm) has wavey extinction and lobate grain boundaries.

Pyroxene (0.1 - 0.5 mm) is anhedral and has a saccharoidal texture.

Hornblende (0.05 - 0.2 mm) form fibrous or irregular masses, and is often found together with pyroxene.

Sericitic muscovite form feltic masses in pseudomorphs after feldspar.

Epidote and allanite (0.1 - 0.2 mm) form rounded particles. Allanite is also found as rims on epidote.

Calcite (0.1 - 0.2 mm) forms polygonal crystals with straight grain boundaries. Vesuvianite is found only in one grain with polygonal outline.

Sample number: 32

Location: 220m northwest of the Hulta mines.

Rock type: Red leptite.

Estimated mineral mode (%):

Potassium feldspar	72-74
Plagioclase	5
Quartz	15
Biotite	5-7
Opaques	1

Hand specimen:

The sample is fine grained and greyish pink. It has a foliation due to parallel orientation of biotite.

Thin section:

Potassium feldspar (0.2 - 0.5 mm), plagioclase (0:2 - 0.3 mm) and quartz (0.1 - 0.7 mm) form an allotriomorphic inequigranular texture. The grains have curved or cuspate grain boundaries. Flakes of biotite (0.1 - 0.7 mm) are pleocroic green to brown. They have preferred orientation, and are evenly distributed throughout the section.

Sample number: 34

Location: Drillhole no. 16, 72.40 - 72.50 m.

Rock type: Leptite gneiss

Estimated mineral mode (%):

Potassium feldspar	65-76
Quartz	10-15
Chlorite	3 -4
Hematite	10-15
Opaques	1

Hand specimen:

The sample is fine grained and dark grey with pink and yellow speckles. Pink potassium feldspar forms elongated phenocrysts with preferred orientation.

Thin section:

The texture is allotriomorphic inequigranular. Grain boundaries of quartz (0.1 - 0.7 mm) and feldspar (0.1 - 0.5 mm) are cuspate, and thin rims of microcrystalline material are often found along the edges. Quartz grains generally have wavey extinction, but larger crystals have patchy extinction. The feldspar grains often have sericitic alteration. Thin fractures, that cross over grain boundaries, cut through the sample. Along these; microfaulting is often observed. Hematite is brown or reddish brown and is mostly translucent. It is often found as scaley overgrowths on feldspars. Hematite can also form intergranular space fillings, giving a web-like texture. When occurring in veins, hematite is partly opaque. Chlorite occurs as pseudomorphs after biotite, and often in intergranular spaces. It also occurs together with hematite in veins, where chlorite is found along the edges and hematite in the centres.

Sample number: 35

Location: 390 m. west of the Hulta mines.

Rock type: Grey leptite

Estimated mineral mode (%):

Quartz	84-88
Potassium feldspar	5-7
Diopside	5-7
Wollastonite	1
Garnet	<1

Hand specimen:

The rock is fine grained, and pale grey with green crystals of diopside.

Thin section:

Quartz (0.1 - 0.2 mm) and feldspar (0.1 - 0.3 mm) make up an equigranular ground mass. Subhedral diopside (0.1 - 0.3 mm) occurs in small irregular aggregates, in which quartz sometimes is embedded. Garnet (1 - 2 mm) is poikiloblastic with inclusions of pyroxene. Wollastonite (0.1 - 0.2 mm) occurs as prismatic or needle-shaped particles that are randomly orientated, and form aggregates.

APPENDIX 3

Instrumental conditions for XRF. Settings on the Philips PW1212 X-ray vacuum spectrometer

Element	collimator	analysing crystal	counting time (secs.)	KV	MA	amplifier/ analyser	counter
Si	coarse	PE 2-1	40	60	32	EXT	flow
Ti	fine	LIF 3-1	10	40	24	EXT	flow
Al	coarse	PE 2-1	40	60	32	EXT	flow
Fe	fine	LIF 3-1	10	40	24	EXT	flow
Mn	fine	LIF 3-1	100	60	32	EXT	scint.
Mg	coarse	TAP 1-1	100	60	32	LL 1.3 window 1.4	flow
Ca	fine	LIF 3-1	10	40	16	EXT	flow
K	fine	PE 2-1	10	60	24	EXT	flow
P	coarse	Ge 1-1	100	60	32	LL 3.8 window 3.0	flow
S	coarse	Ge 1-1	100	60	32	LL 3.8 window 3.0	flow

Other common conditions:

Spinner On

Vacuum delay 120 sec.

Attenuation 2

Setting on manual control panel: automatic

Goniometer 216° 2θ/min

Printer A + B

PE = Pentaerythritol

LIF = Lithium fluoride

TAP = Thallium acid phthalate

Ge = Germanium

APPENDIX 4

Instrumental conditions for X-ray diffraction. Settings on the Philips PW 1050 diffractometer:

Tube: 40 kV, 40 mA

Radiation = CuKα = 1.542 Å

Window:	100
Lower level:	280

Time constant = 4 sec.

Scanning speed: 0.5° 2θ/min.

Count rate = 400 cps (sample 4, 11, 17, 19) and 2000 cps (sample 16 and standard).

Scanned range: 4-60° 2θ.

Chart speed = 10 mm/min.

APPENDIX 5

Recipe for preparation of froth flotation reagent.

The Jafaflots AA 106, AA 107 and AA 117 are modified amines based on alkyl groups mainly between $C_{14} - C_{22}$.
These can be used from aqueous solution by making the hydrochloride or acetate.

JAFAFLOT AA 106	average mol. weight	280
JAFAFLOT AA 107	" " "	310
JAFAFLOT AA 117	" " "	330

Example: 1% RNH_2 + - Cl. aqueous of AA 106

Reaction: $RNH_2 + HCl = RNH_3 + - Cl$

Average mol. weight	280	(AA 106)
	316,5	(RNH_3 +- Cl)

$$\frac{10\ \text{g (amine)}}{280\ \text{g/m}} = \frac{X\ \text{g}\ (RNH_3 +- Cl)}{316{,}5\ \text{g/m}}$$

$$\underline{\underline{X = 11{,}3\ \text{g}\ (RNH_3 +- Cl)}}$$

This means 1,3 g 100% HCl equals 3,5 ml 37% HCl.

PROCEDURE: 500 ml 1% RNH_3 +- Cl.

1. Heat 485 ml H_2O with 3,5 ml of 37% HCl to approx. 50° C.
2. Add 10g of liquid AA 106 slowly while stirring.
3. When all AA 106 is added stir for 20 min.

Care sould be taken that the dissolution temperature does not exceed 55° C to avoid decomposition.

Application: Add in acid or basic pulp at a level of 50-200 g/ton of ore.

Solutions were prepared from AA107 and AA117 in the same way, using 10g of the material.

APPENDIX 6

List of Microprobe Analyses

Explanation to codes:

A = Fluorspar

ALN = Allanite

B = Mica

CAC = Calcite

FAC = Feldspar Albite Core

FAM = Feldspar Albite Margin

FKC = Feldspar potassium Core.

FKM = Feldspar potassium Margin

FPC = Feldspar Plagioclase Margin

GNC = Garnet Core

GNM = Garnet Margin

IC = Idocrase (vesuvianite) Core

IM = Idocrase (vesuvianite) Margin

PCC = Pyroxene Calcic Core

PCM = Pyroxene Calcic Margin

TI = Sphene

WC = Wollastonite Core

WM = Wollastonite Margin

WOLLASTONITE ANALYSES

Sample	9	9	9	9	9	9	9	9	12
Code	WC	WM	WC	WM	WC	WM	WC	WM	WC
Spot	7	8	9	10	11	12	21	22	3
SIO2	52.08	52.05	51.13	50.80	51.98	50.57	51.56	51.17	51.09
TIO2	- -	- -	- -	- -	- -	- -	- -	- -	- -
AL2O3	- -	- -	- -	- -	- -	- -	- -	- -	- -
FEO	0.36	- -	- -	- -	- -	- -	- -	- -	0.37
MNO	0.67	0.83	0.78	0.67	0.83	0.95	0.75	0.70	0.51
MGO	- -	- -	- -	- -	- -	- -	- -	- -	- -
CAO	48.11	48.21	48.20	48.03	48.35	48.01	47.68	48.01	47.88
NA2O	- -	- -	- -	- -	- -	0.31	- -	- -	- -
K2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	101.22	101.09	100.11	99.50	101.16	99.84	100.00	99.87	99.85

FORMULAE CALCULATED FOR 6 OXYGENS AND 4 CATIONS

SI	1.993	1.994	1.977	1.976	1.990	1.956	1.997	1.983	1.981
AL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE3	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012
FE2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MN	0.022	0.027	0.025	0.022	0.027	0.031	0.025	0.023	0.017
MG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CA	1.973	1.979	1.997	2.002	1.983	1.990	1.978	1.994	1.990
NA	0.000	0.000	0.000	0.000	0.000	0.023	0.000	0.000	0.000

WOLLASTONITE ANALYSES

Sample	12	12	12	12	5	5	5	17	17
Code	WC	WC	WC	WM	WC	WC	WC	WC	WC
Spot	14	15	19	20	9	16	17	2	6
SIO2	51.57	50.88	51.35	51.16	51.34	50.48	51.78	51.90	51.47
TIO2	- -	- -	- -	- -	- -	- -	- -	- -	- -
AL2O3	- -	- -	- -	- -	- -	- -	- -	- -	- -
FEO	0.36	- -	- -	- -	- -	- -	- -	- -	- -
MNO	0.56	0.48	0.56	0.65	0.38	0.48	0.38	- -	0.37
MGO	- -	- -	- -	- -	- -	- -	- -	- -	- -
CAO	48.32	48.01	47.71	48.22	47.97	47.92	48.48	48.36	48.92
NA2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
K2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	100.81	99.36	99.62	100.03	99.69	98.88	100.63	100.26	100.77

FORMULAE CALCULATED FOR 6 OXYGENS AND 4 CATIONS

SI	1.981	1.981	1.995	1.980	1.993	1.975	1.991	2.002	1.976
AL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE3	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MN	0.018	0.016	0.018	0.021	0.012	0.016	0.012	0.000	0.012
MG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CA	1.987	2.003	1.986	1.999	1.995	2.009	1.997	1.998	2.012
NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

WOLLASTONITE ANALYSES

Sample	17	17	16	16	16	16	16
Code	WC	WC	WC	WM	WC	WC	WC
Spot	7	8	1	2	5	8	13
SIO2	51.42	51.50	51.33	51.28	51.74	51.69	51.35
TIO2	- -	- -	- -	- -	- -	- -	- -
AL2O3	- -	- -	- -	- -	- -	- -	- -
FEO	- -	- -	- -	- -	- -	- -	- -
MNO	- -	- -	0.72	0.83	0.88	0.78	0.70
MGO	- -	- -	- -	- -	- -	- -	- -
CAO	48.27	48.35	48.85	47.80	48.38	48.39	49.17
NA2O	- -	- -	- -	- -	- -	- -	- -
K2O	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -
TOTAL	99.69	99.85	100.90	99.91	101.00	100.86	101.21

FORMULAE CALCULATED FOR 6 OXYGENS AND 4 CATIONS

SI	1.994	1.994	1.969	1.988	1.984	1.984	1.963
AL	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TI	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE3	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MN	0.000	0.000	0.023	0.027	0.029	0.025	0.023
MG	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CA	2.006	2.006	2.008	1.985	1.988	1.990	2.014
NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000

PYROXENE ANALYSES

Sample	9	9	12	12	12	12	12	12	5
Code	PCC	PCM	PCC	PCM	PCC	PCM	PCC	PCC	PCC
Spot	18	19	10	11	12	13	21	22	5
SIO2	54.31	54.56	51.09	51.16	51.05	51.58	51.39	51.45	52.04
TIO2	- -	- -	- -	- -	- -	- -	- -	- -	- -
AL2O3	- -	- -	- -	- -	- -	- -	- -	- -	- -
FEO	5.31	5.62	15.46	16.15	16.75	14.47	14.09	14.15	11.90
MNO	2.18	0.85	1.38	1.02	1.06	1.11	1.16	1.26	1.03
MGO	13.89	14.06	7.72	7.21	6.95	8.06	8.58	8.68	10.02
CAO	25.54	25.54	24.06	24.23	24.05	24.29	24.10	24.02	23.96
NA2O	- -	- -	- -	- -	- -	- -	- -	- -	0.42
K2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	101.23	100.62	99.71	99.76	99.85	99.52	99.33	99.56	99.38

FORMULAE CALCULATED FOR 6 OXYGENS AND 4 CATIONS

SI	1.999	2.015	1.994	2.002	2.000	2.010	2.000	1.998	1.996
AL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE3	0.002	0.000	0.011	0.000	0.000	0.000	0.000	0.004	0.040
FE2	0.162	0.174	0.493	0.529	0.549	0.472	0.459	0.455	0.342
MN	0.068	0.027	0.045	0.034	0.035	0.037	0.038	0.041	0.034
MG	0.762	0.774	0.449	0.420	0.406	0.468	0.498	0.502	0.573
CA	1.007	1.011	1.006	1.016	1.010	1.014	1.005	0.999	0.985
NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031

PYROXENE ANALYSES

Sample	5	5	5	5	5	5	5	5	11
Code	PCM	PCC	PCM	PCC	PCM	PCC	PCM	PCC	PCC
Spot	6	7	8	10	11	14	15	20	1
SIO2	53.62	52.89	52.18	52.33	52.27	52.40	52.95	52.15	49.83
TIO2	- -	- -	- -	- -	- -	- -	- -	- -	- -
AL2O3	- -	- -	- -	- -	- -	0.49	- -	- -	- -
FEO	5.60	10.64	11.12	10.37	11.46	11.99	11.87	12.84	20.42
MNO	0.81	1.30	1.10	1.04	0.91	1.12	1.24	0.90	2.86
MGO	14.08	10.68	10.36	10.80	10.47	9.86	10.00	9.68	3.43
CAO	25.21	24.58	24.70	24.34	24.55	24.25	24.84	24.33	23.11
NA2O	- -	- -	0.44	- -	- -	- -	- -	- -	0.60
K2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	0.73	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	99.31	100.09	99.91	98.90	100.39	100.10	100.89	99.89	100.26

FORMULAE CALCULATED FOR 6 OXYGENS AND 4 CATIONS

SI	2.005	2.012	1.984	2.011	2.000	2.003	2.009	2.003	1.986
AL	0.000	0.000	0.000	0.000	0.000	0.022	0.000	0.000	0.000
TI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE3	0.000	0.000	0.063	0.000	0.000	0.000	0.000	0.000	0.075
FE2	0.175	0.339	0.290	0.333	0.367	0.383	0.376	0.412	0.606
MN	0.026	0.042	0.036	0.034	0.029	0.036	0.040	0.029	0.097
MG	0.785	0.606	0.588	0.619	0.597	0.562	0.566	0.554	0.204
CA	1.010	1.002	1.007	1.002	1.007	0.993	1.010	1.001	0.987
NA	0.000	0.000	0.032	0.000	0.000	0.000	0.000	0.000	0.046

PYROXENE ANALYSES

Sample Code Spot	11 PCM 2	11 PCC 3	11 PCM 4	8 PCC 1	8 PCM 2	16 TPCC 3	16 TPCM 4	16 TPCC 6	16 TPCM 7
SIO2	50.18	51.61	52.14	50.93	50.89	54.57	54.44	54.21	54.92
TIO2	- -	- -	- -	- -	- -	- -	- -	- -	- -
AL2O3	- -	- -	- -	0.40	- -	- -	- -	- -	0.39
FEO	16.05	10.54	10.20	13.57	13.31	0.51	0.68	0.36	0.55
MNO	3.53	2.33	2.42	1.95	2.67	1.56	1.61	1.45	1.48
MGO	5.32	10.05	10.14	8.12	8.00	15.89	15.93	16.24	16.38
CAO	23.65	24.01	24.62	23.71	24.35	25.77	25.52	25.99	26.16
NA2O	0.63	0.43	0.40	0.62	- -	1.21	0.93	1.01	1.30
K2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	99.36	98.97	99.92	99.31	99.23	99.51	99.11	99.25	101.19

FORMULAE CALCULATED FOR 6 OXYGENS AND 4 CATIONS

SI	1.986	1.986	1.987	1.976	1.990	1.985	1.993	1.976	1.960
AL	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.016
TI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE3	0.077	0.060	0.056	0.076	0.021	0.016	0.021	0.011	0.017
FE2	0.454	0.280	0.269	0.364	0.415	0.000	0.000	0.000	0.000
MN	0.118	0.076	0.078	0.064	0.088	0.048	0.050	0.045	0.045
MG	0.314	0.577	0.576	0.469	0.466	0.862	0.869	0.882	0.871
CA	1.003	0.990	1.005	0.986	1.020	1.004	1.001	1.015	1.001
NA	0.048	0.032	0.029	0.046	0.000	0.085	0.066	0.071	0.090

PYROXENE ANALYSES

Sample	16	16	16	16
Code	TPCC	TPCM	TPCC	TPCM
Spot	17	18	19	20
SIO2	54.43	53.92	54.43	53.97
TIO2	- -	- -	- -	- -
AL2O3	0.36	0.41	- -	- -
FEO	1.74	1.59	0.89	0.75
MNO	0.99	1.29	1.29	1.33
MGO	15.98	15.71	16.10	15.76
CAO	25.57	25.61	25.61	26.00
NA2O	1.51	1.17	1.01	0.90
K2O	- -	- -	- -	- -
ZNO	- -	- -	- -	- -
NIO	- -	- -	- -	- -
TOTAL	100.58	99.72	99.33	98.71

FORMULAE CALCULATED FOR 6 OXYGENS AND 4 CATIONS

SI	1.957	1.961	1.985	1.984
AL	0.015	0.018	0.000	0.000
TI	0.000	0.000	0.000	0.000
FE3	0.052	0.048	0.027	0.023
FE2	0.000	0.000	0.000	0.000
MN	0.030	0.040	0.040	0.041
MG	0.856	0.852	0.875	0.864
CA	0.985	0.998	1.001	1.024
NA	0.105	0.083	0.071	0.064

GARNET ANALYSES

Sample	12	12	12	17	17	17	17	17	2
Code	GNC	GNC	GNC	GNC	GNC	GNM	GNC	GNM	GNC
Spot	16	17	18	3	4	5	9	10	7
SIO2	38.19	37.50	37.07	37.01	36.59	37.26	37.29	37.45	38.06
TIO2	- -	- -	- -	1.36	1.40	- -	1.48	- -	- -
AL2O3	14.39	13.63	13.34	13.77	13.45	11.95	13.09	12.92	16.94
FEO	10.32	10.35	11.14	10.37	10.48	12.86	10.83	12.05	7.77
MNO	0.52	0.61	0.67	- -	0.28	0.45	0.37	0.60	1.01
MGO	- -	- -	- -	- -	- -	- -	- -	- -	- -
CAO	35.28	35.02	35.62	35.33	35.55	35.35	34.93	35.94	35.39
NA2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
K2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
CR2O3	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	98.71	97.11	97.84	97.83	97.76	97.87	97.99	98.96	99.16

FORMULAE CALCULATED FOR 24 OXYGENS AND 16 CATIONS

SI	5.989	5.985	5.881	5.876	5.820	5.940	5.929	5.888	5.896
AL	2.660	2.563	2.495	2.576	2.522	2.245	2.453	2.394	3.092
TI	0.000	0.000	0.000	0.162	0.168	0.000	0.177	0.000	0.000
CR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE3	1.353	1.381	1.479	1.348	1.394	1.715	1.334	1.585	1.006
FE2	0.000	0.000	0.000	0.029	0.000	0.000	0.106	0.000	0.000
MN	0.069	0.083	0.090	0.000	0.038	0.061	0.050	0.079	0.132
MG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CA	5.928	5.988	6.056	6.009	6.058	6.039	5.951	6.053	5.873

END MEMBERS

PYROPE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALMANDINE	0.00	0.00	0.00	0.48	0.00	0.00	1.76	0.00	0.00
SPESSTN	1.16	1.38	1.50	0.00	0.64	1.01	0.83	1.32	2.20
UVAROVITE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANDRADITE	33.83	34.53	36.97	37.75	39.04	42.88	37.79	39.62	25.16
GROSS	65.02	64.09	61.54	61.76	60.32	56.11	59.62	59.05	72.64

GARNET ANALYSES

Sample	11	11	11	11	11	11	8	8	16
Code	GNC	GNM	GNC	GNM	GNC	GNC	GNC	GNM	TGNC
Spot	5	6	7	8	9	10	10	11	9
SIO2	37.18	36.70	37.93	37.69	37.12	37.47	37.61	37.33	35.93
TIO2	- -	- -	- -	- -	- -	- -	- -	- -	0.40
AL2O3	11.03	9.55	14.88	10.86	9.30	9.65	14.23	14.10	3.28
FEO	14.58	16.15	9.45	14.98	17.11	16.15	10.38	10.52	23.26
MNO	0.79	0.95	0.69	0.78	0.62	0.79	0.85	1.04	0.55
MGO	- -	- -	- -	- -	- -	- -	- -	- -	- -
CAO	34.34	34.27	35.25	35.32	33.84	33.51	35.91	35.69	34.11
NA2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
K2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
CR2O3	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	97.92	97.61	98.21	99.63	97.99	97.57	98.98	98.68	97.53

FORMULAE CALCULATED FOR 24 OXYGENS AND 16 CATIONS

SI	5.958	5.933	5.966	5.940	5.989	6.061	5.884	5.863	5.954
AL	2.084	1.820	2.758	2.018	1.769	1.840	2.625	2.610	0.640
TI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050
CR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE3	1.954	2.183	1.243	1.974	2.253	2.039	1.359	1.382	3.223
FE2	0.000	0.000	0.000	0.000	0.056	0.145	0.000	0.000	0.000
MN	0.108	0.129	0.092	0.104	0.084	0.109	0.113	0.139	0.078
MG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CA	5.897	5.935	5.941	5.964	5.849	5.807	6.020	6.006	6.055

END MEMBERS

PYROPE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALMANDINE	0.00	0.00	0.00	0.00	0.93	2.42	0.00	0.00	0.00
SPESSTN	1.79	2.16	1.54	1.73	1.40	1.81	1.88	2.31	1.30
UVAROVITE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANDRADITE	48.84	54.57	31.08	49.35	56.32	50.97	33.97	34.55	81.83
GROSS	49.36	43.27	67.38	48.92	41.34	44.80	64.16	63.14	16.87

GARNET ANALYSES

Sample Code Spot	16 TGNM 10	16 TGNC 11	16 TGNM 12	16 TGNC 14	16 TGNM 15
SIO2	36.03	36.00	36.26	36.26	35.56
TIO2	0.32	0.60	0.51	0.43	0.46
AL2O3	3.87	3.33	4.07	3.98	3.63
FEO	22.78	22.28	21.95	22.22	22.00
MNO	0.59	0.62	0.43	0.45	0.80
MGO	- -	- -	- -	- -	- -
CAO	34.05	33.76	34.82	33.98	34.61
NA2O	- -	- -	- -	- -	- -
K2O	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -
CR2O3	- -	- -	- -	- -	- -
TOTAL	97.63	96.59	98.04	97.32	97.07

FORMULAE CALCULATED FOR 24 OXYGENS AND 16 CATIONS

SI	5.951	6.019	5.953	6.003	5.906
AL	0.754	0.656	0.787	0.777	0.711
TI	0.039	0.075	0.063	0.054	0.057
CR	0.000	0.000	0.000	0.000	0.000
FE3	3.147	3.115	3.014	3.076	3.055
FE2	0.000	0.000	0.000	0.000	0.000
MN	0.082	0.087	0.060	0.063	0.113
MG	0.000	0.000	0.000	0.000	0.000
CA	6.027	6.047	6.124	6.027	6.158

END MEMBERS

PYROPE	0.00	0.00	0.00	0.00	0.00
ALMANDINE	0.00	0.00	0.00	0.00	0.00
SPESSTN	1.37	1.46	0.99	1.06	1.88
UVAROVITE	0.00	0.00	0.00	0.00	0.00
ANDRADITE	79.66	79.77	76.92	78.24	77.80
GROSS	18.97	18.77	22.09	20.71	20.31

VESUVIANITE ANALYSES

Sample	9	9	12	12	12	12	12	12	12
Code	IC	IM	IC	IM	IM	IC	IM	IC	IC
Spot	13	14	1	2	4	5	6	7	8
SIO2	36.79	37.23	36.75	38.15	37.76	35.21	35.36	36.39	35.39
TIO2	- -	- -	- -	- -	- -	- -	- -	0.31	- -
AL2O3	16.87	18.07	12.86	13.72	13.83	12.64	13.54	15.64	14.43
FEO	3.88	3.61	12.70	11.24	10.74	6.57	5.99	5.68	5.32
MNO	0.42	0.65	0.59	0.49	0.69	0.40	0.64	- -	0.66
MGO	1.75	0.77	- -	- -	- -	1.04	1.06	1.02	1.11
CAO	35.80	36.46	35.01	35.47	35.19	31.87	32.56	35.52	32.84
NA2O	- -	0.33	- -	- -	- -	- -	- -	- -	- -
K2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	95.50	97.12	97.91	99.07	98.20	87.72	89.15	94.57	89.75

FORMULAE CALCULATED FOR 72 OXYGENS AND 50 CATIONS

SI	18.172	18.079	18.274	18.676	18.633	19.212	18.941	18.307	18.774
AL	9.822	10.343	7.538	7.916	8.044	8.127	8.546	9.273	9.020
FE2	1.601	1.467	5.282	4.601	4.431	2.998	2.684	2.390	2.360
FE3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MG	1.285	0.560	0.000	0.000	0.000	0.847	0.850	0.768	0.879
TI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.117	0.000
MN	0.174	0.267	0.251	0.205	0.288	0.184	0.290	0.000	0.297
CA	18.946	18.972	18.655	18.602	18.604	18.632	18.688	19.146	18.670
NA	0.000	0.313	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
X	18.946	19.284	18.655	18.602	18.604	18.632	18.688	19.146	18.670
Y	12.882	12.637	13.071	12.722	12.763	12.156	12.371	12.548	12.557

VESUVIANITE ANALYSES

Sample	12	2	2	2	2	2	2	8	8
Code	IM	IC	IC	IC	IC	IC	IC	IC	IM
Spot	9	1	2	3	4	5	6	3	4
SIO2	35.60	36.64	36.22	37.67	35.13	36.27	36.15	35.99	35.64
TIO2	0.26	0.69	0.89	0.66	0.86	0.58	0.45	0.43	0.41
AL2O3	13.98	16.50	16.14	16.29	12.54	16.27	16.22	16.06	15.99
FEO	5.09	5.03	4.98	7.45	5.95	4.71	4.75	5.25	4.74
MNO	1.18	- -	- -	0.83	2.05	0.31	0.71	0.50	- -
MGO	1.11	1.00	0.82	- -	0.65	0.89	1.10	0.98	0.92
CAO	32.66	36.28	35.52	34.92	31.56	35.71	34.66	34.57	34.40
NA2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
K2O	- -	- -	- -	- -	- -	- -	- -	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	89.88	96.15	94.57	97.83	88.74	94.73	94.03	93.78	92.10

FORMULAE CALCULATED FOR 72 OXYGENS AND 50 CATIONS

SI	18.900	18.106	18.226	18.516	19.084	18.195	18.266	18.260	18.373
AL	8.750	9.609	9.571	9.439	8.025	9.618	9.663	9.603	9.717
FE2	2.260	2.080	2.095	3.060	2.701	1.977	2.006	2.227	2.044
FE3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MG	0.876	0.740	0.619	0.000	0.528	0.666	0.826	0.743	0.707
TI	0.105	0.256	0.338	0.245	0.350	0.217	0.171	0.164	0.159
MN	0.530	0.000	0.000	0.346	0.945	0.130	0.305	0.213	0.000
CA	18.578	19.208	19.150	18.393	18.367	19.196	18.764	18.790	19.001
NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
X	18.578	19.208	19.150	18.393	18.367	19.196	18.764	18.790	19.001
Y	12.522	12.686	12.623	13.091	12.549	12.608	12.970	12.951	12.626

VESUVIANITE ANALYSES

Sample	8	8	8
Code	IC	IM	IC
Spot	5	6	9
SIO2	36.39	36.76	37.27
TIO2	- -	- -	0.26
AL2O3	16.35	16.14	16.42
FEO	4.19	4.17	5.01
MNO	0.43	0.57	0.32
MGO	1.23	1.83	1.19
CAO	36.04	35.92	36.30
NA2O	- -	- -	- -
K2O	- -	- -	- -
ZNO	-	- -	- -
NIO	- -	- -	- -
TOTAL	94.62	95.37	96.77

FORMULAE CALCULATED FOR 72 OXYGENS AND 50 CATIONS

SI	18.199	18.206	18.279
AL	9.636	9.421	9.490
FE2	1.751	1.726	2.054
FE3	0.000	0.000	0.000
MG	0.917	1.350	0.869
TI	0.000	0.000	0.097
MN	0.182	0.238	0.135
CA	19.315	19.060	19.077
NA	0.000	0.000	0.000
K	0.000	0.000	0.000
X	19.315	19.060	19.077
Y	12.486	12.734	12.644

FELDSPAR ANALYSES

Sample	5	5	8	8
Code	FPC	FPM	FKC	FKM
Spot	3	4	7	8
SIO2	65.32	68.62	65.57	66.09
TIO2	- -	- -	- -	- -
AL2O3	21.78	19.80	17.71	18.05
FEO	- -	- -	- -	0.31
MNO	- -	- -	- -	- -
MGO	- -	- -	- -	- -
CAO	3.09	0.35	- -	0.27
NA2O	10.50	12.45	- -	0.39
K2O	0.14	- -	16.00	15.99
ZNO	- -	- -	- -	- -
NIO	- -	- -	- -	- -
TOTAL	100.81	101.23	99.28	101.10

FORMULAE

SI	2.860	2.972	3.038	3.017
AL	1.124	1.011	0.967	0.971
FE3	0.000	0.000	0.000	0.000
FE2	0.000	0.000	0.000	0.012
MG	0.000	0.000	0.000	0.000
CA	0.145	0.016	0.000	0.013
NA	0.891	1.046	0.000	0.035
K	0.008	0.000	0.946	0.931

END MEMBERS

OR	0.73	0.00	100.00	95.13
AB	85.40	98.47	0.00	3.53
AN	13.87	1.53	0.00	1.34

FELDSPAR ANALYSES

Sample	9	9	9	9	9	9	9	5	5
Code	FKC	FKM	FKC	FKM	FAC	FAM	FKC	FPC	FPM
Spot	1	2	3	4	5	6	15	1	2
SIO2	64.68	66.62	65.54	66.25	69.22	68.86	65.76	66.27	67.41
TIO2	- -	- -	- -	- -	- -	- -	- -	- -	- -
AL2O3	18.06	18.47	18.03	18.02	18.34	19.45	18.13	21.34	19.08
FEO	- -	- -	- -	- -	- -	- -	- -	- -	- -
MNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
MGO	- -	- -	- -	- -	- -	- -	- -	- -	- -
CAO	- -	0.22	- -	- -	1.15	0.54	- -	2.55	0.75
NA2O	0.51	5.13	- -	- -	10.92	11.70	- -	10.59	11.90
K2O	15.75	8.99	15.94	16.16	- -	- -	15.80	- -	- -
ZNO	- -	- -	- -	- -	- -	- -	- -	- -	- -
NIO	- -	- -	- -	- -	- -	- -	- -	- -	- -
TOTAL	99.00	99.43	99.52	100.44	99.63	100.56	99.70	100.75	99.14

FORMULAE

SI	3.011	3.014	3.028	3.035	3.031	2.993	3.029	2.893	2.981
AL	0.991	0.985	0.982	0.973	0.946	0.997	0.985	1.098	0.994
FE3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CA	0.000	0.011	0.000	0.000	0.054	0.025	0.000	0.119	0.035
NA	0.046	0.450	0.000	0.000	0.927	0.986	0.000	0.896	1.021
K	0.935	0.519	0.940	0.944	0.000	0.000	0.929	0.000	0.000

END MEMBERS

OR	95.27	52.98	100.00	100.00	0.00	0.00	100.00	0.00	0.00
AB	4.73	45.94	0.00	0.00	94.49	97.49	0.00	88.26	96.64
AN	0.00	1.08	0.00	0.00	5.51	2.51	0.00	11.74	3.36

ALLANITE ANALYSES

Sample	5	5	17
Code	ALN	ALN	ALN
Spot	18	19	1
SIO2	33.07	30.37	31.82
TIO2	- -	- -	- -
AL2O3	3.92	7.09	13.23
FEO	7.04	4.53	12.50
MNO	2.86	0.96	- -
MGO	- -	0.40	- -
CAO	13.83	10.20	15.81
NA2O	- -	- -	- -
K2O	- -	- -	- -
ZNO	- -	- -	- -
NIO	- -	- -	- -
TOTAL	60.72	53.55	73.36

SPHENE ANALYSIS

Sample	5
Code	TI
Spot	12

SIO2	30.41
TIO2	30.37
AL2O3	3.78
FEO	2.87
MNO	- -
MGO	- -
CAO	28.31
NA2O	- -
K2O	- -
ZNO	- -
NIO	- -
TOTAL	95.75

FORMULA CALCULATED FOR 20 OXYGENS AND SI=4

SI	4.000
AL	0.586
TI	3.004
FE3	0.000
FE2	0.316
MN	0.000
MG	0.000
CA	3.990
NA	0.000
K	0.000

MICA ANALYSIS

Sample	5
Code	B
Spot	13

SIO2	46.12
TIO2	- -
AL2O3	5.70
FEO	- -
MNO	0.25
MGO	24.80
CAO	3.08
NA2O	- -
K2O	0.16
ZNO	- -
NIO	- -
TOTAL	80.12

FORMULA CALCULATED FOR 22 OXYGENS

SI	7.639
AL	1.113
TI	0.000
FE2	0.000
MG	6.123
MN	0.035
CA	0.546
NA	0.000
K	0.034

CALCITE AND FLUORSPAR ANALYSES

Sample	16	9	9	9
Code	CAC	A	A	A
Spot	16	16	17	20
SIO2	- -	0.27	0.31	- -
TIO2	- -	- -	- -	- -
AL2O3	- -	- -	- -	- -
FEO	- -	- -	- -	- -
MNO	- -	- -	- -	- -
MGO	- -	- -	- -	- -
CAO	56.66	79.82	82.00	78.61
NA2O	0.32	- -	0.51	- -
K2O	- -	- -	- -	- -
ZNO	0.00	- -	- -	- -
NIO	- -	0.00	0.00	0.00
TOTAL	56.98	80.09	82.82	78.61

REFERENCES

Andrews. R.W. 1970
Wollastonite
Her Majesty's Stationery Office. London. 114 pp.

Arvanitidis, N. and Richard, D., 1981.
"REE geochemistry of an early proterozoic volcanic ore district, Dammberg, central Sweden: A summary of results".
Ann. Rep. Ore Res. Group, Stockholm Univ. 1981, 105-135.

Blomberg, A., 1879
Beskrifning till kartbladet "Hjulsjö"
Sver. Geol. Undersök. Ser. Aa no. 69.

British Standard 1795: 1976 (1985)
Specifications for extenders for paints
British Standard Institution, London 16 pp.

Deer, W.A., Howie, R.A. and Zussman, J., 1975.
Rock forming minerals vol. 1, ortho- and ring silicates
Longman Group, London,333 pp. 8th ed.

Dunham, A.C. and Wilkinson, F.C.F., 1978
"Accuracy, precision and detection limits of energy-dispersive microprobe analyses of silicates".
X-ray Spectrometry, 7, 50-56.

Gumaelius, O., 1875.
Beskrifning till kartbladet "Nora"
Sver. Geol. Undersök. Ser. Aa. No. 56.

Harben, P. 1986.
"Fine particles and fillers - a conference report."
Industrial Minerals no. 222, 153-157.

Hjelmqvist, S., 1942.
Stribergs malmfält, geologisk beskrivning
Sver. Geol. Undersök, Ser. C. no. 449, 158 pp.

Hummel, D., 1873.
Beskrifning till kartbladet "Linde"
Sver. Geol. Undersök, Ser. Aa. No. 46.

Lundqvist, T., 1979.
The Precambrian of Sweden
Sver. Geol. Undersök, Ser. C. No. 768, 87 pp.

Lundstrom, I., 1983
Beskrivning till berggrundskartan Lindesberg SV 1:50000 (Description to the map of solid rocks Lindesberg SV; summary in English)
Sver. Geol. Undersök. Ser. Af. No. 126, 140 pp.

Norrish, K. and Hutton, J.T., 1969.
"An accurate spectrographic method for the analysis of a range of geological samples".
Geochim. Cosmochim. Acta 33, 431-453.

Power, T., 1986.
"Wollastonite, performance filler potential"
Industrial Minerals no. 220, 19-34.

Santesson, H., 1883
Beskrifning till karta öfver berggrunden inom de malmförande trakterna i norra delen af Örebro län I. Allmän geologisk beskrifning.
Sver. Geol. Undersök. Ser Bb No. 3.

Santesson, B., 1889
Beskrifning till karta öfver berggrunden inom de malmförande trakterna i norra delen af Örebro län. II. Geognostiska kartor och beskrifningar öfver de viktigaste gruvfälten
Sver. Geol. Undersök. Ser. Bb No. 4.

Tidigare publicerade arbeten i serien "Examensarbeten i Geologi vid Lunds Universitet':

1. Claeson,D., Nilsson,M.: Beskrivning av och relationer mellan karlshamnsgraniten och leukograniten i Blekinge. 1984.
2. Möller,C.: Eklogitiska bergarter i Roan, Vestranden, Norge. En mineralinventering och texturstudie. 1984.
3. Simeonov,A.: En jämförelse mellan Jorandomens tennanomala graniters och revsundgranitens (Västerbotten) mineralogiska och petrografiska karaktär. 1984.
4. Annertz,K.: En petrografisk karakteristik av en sent postorogen mafisk intrusion i östra Värmland. 1984.
5. Sandström,K.: Kartläggning av grundvattenförhållandena i ett delområde av provinsen Nord Kordofan, Sudan. 1984.
6. Gustafsson,B.-O., Ralfsson,S.: Undersökning av högsta kustlinjen på Rydsbjär vid Margreteberg i södra Halland. 1985.
7. Helldén,J., Nilsson,A.-G.: Undersökning av den baltiska moränleran vid Svalöv, NV-Skåne. 1985.
8. Persson,K.: Kobolt i pyrit från Kiruna Järnmalmsgruva. 1985.
9. Ekström,J.: Stratigrafisk och faunistisk undersökning av Vitabäckslerorna i Skåne. 1985.
10. Säll,E.: Neobeyrichia from the Silurian of Bjärsjölagård, Scania, Sweden. 1986.
11. Markholm,C.-O.: Svagt naturgrus och bergkrossmaterial till bärlager. En laboratoriestudie. 1986.
12. Hellström,C.: Klassifikation av leptiter i malmstråket mellan Ö. Silvberg och Vallberget, Dalarna. 1986.
13. Öhman,E.: En petrografisk och mineralogisk studie av en komplex gång bestående av metadiabas och kvartskeratofyr i Kiirunavaaragruvan. 1986.
14. Holmberg,G., Johansson,L.: Sedimentologisk undersökning av de övre glacifluviala avlagringarna i Vombsänkan, södra Skåne. 1986.
15. Thuning,B., Linderson,H.: Stratigrafi och överplöjning i Bussjösjöområdet, Ystad. 1986.
16. Bergstedt,E., Lööf,A.I.: Naturvärme - teknik och geologi med en översiktlig kartläggning av tillgångarna i Kalmar län och Västerviks kommun. 1986.

12/10-87