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ARVO VESASALO

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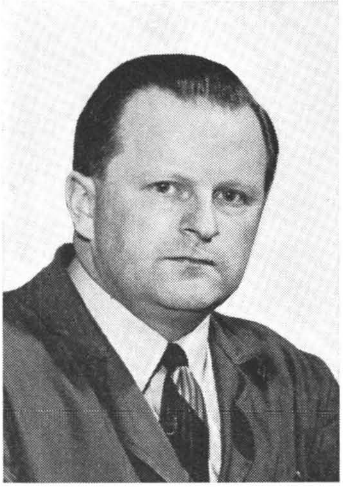

ARVO VESASALO

* 9. 11. 1919 † 17. 5. 1962

ARVO ILMARI VESASALO, *Lic. Phil.*, was born in November 9, 1919, in the commune of Ruokolahti. He passed his matriculation examination in 1941 at the secondary school in Pieksämäki, received his degree of Mag. Phil. at the University of Helsinki in 1941 with geology and mineralogy as his main subject. He passed the examination for the degree of Lic. Phil. in 1961.

Vesasalo was one of those of his age group who during World War II were scarcely out of school when they went to defend their country. Vesasalo did part of his military Service as a schoolboy during the Winter War and the other part in 1941 as soon as he had passed the matriculation examination. The same year he passed through the officers' training school (RUK) and entered the army at the front with the rank of ensign. He served as leader of troop in Sissi P. 3 and 3. D.

With his unit Vesasalo participated in many combats in East Karelia and on the Karelian Isthmus. He reached the rank of first lieutenant and was awarded the following orders: VR 4 m.k. and VR 4 tlk.

As a schoolboy Vesasalo had already shown an interest in natural sciences. He went on rambles, collected and studied butterflies, and observed migrating birds and the nesting of small birds. After the close of the war, when Vesasalo had to choose a career, he felt spontaneously attracted to geology. It was in the peaceful forests, amidst the magnificence and beauty of nature that Arvo Vesasalo wanted to carry out his life's work.

When serving as summer field assistant during his undergraduate years at the Geological Survey of Finland, Arvo Vesasalo had as his first task to clarify the mineralogy and geological location of the anthophyllite-asbestos occurrences of Savo and Karelia. Vesasalo devoted himself to this problem with his entire youthful ardour, wrote his pro gradu thesis (Arvo Vesasalo: Itä-Suomen asbestikivistä, 1951), on the basis of his field observations, and somewhat later, in collaboration with Erkki Aurola, the paper: »Suomen asbestikivistä ja niiden teknillisestä käytöstä (On the asbestos rocks of Finland and their technical use)». At that time it also became clear to Vesasalo which path his scientific career would lead him to. At the Geological Survey he could best serve his country as a geologist. In 1950 he was appointed a temporary geologist at the Survey, and in 1959 he was nominated extraordinary ore geologist at the ore department of the same institute. This work came to an abrupt and when severe illness ended Vesasalo's life on May 17, 1962, in Helsinki.

The largest and scientifically most important research work done by Vesasalo deals with the mineralogical composition of the talc and soapstones of Finland, their geological location and the origin of soapstones. Vesasalo had already considered similar problems in his pro gradu work, and hence the study of soapstones had been closely associated with his earlier sphere of geological interest. As a profound research worker, Vesasalo advanced steadily in this field, made the first collection of samples of the soapstones of Finland and made most precise field and laboratory observations. In 1961 he presented the principal results of this study in the form of a thesis for the degree of Lic. Phil. at the University of Helsinki (Arvo Vesasalo: Suomen talkki- ja vuolukiviesiintymät, 1961) and after having completed his investigations intended to publish his work on talc and soapstone occurrences as an academic dissertation. It is tragic that he was never able to realize this plan. The present paper is the licenciate thesis by Vesasalo as he left it, without any subsequent alterations.

Besides working for this dissertation Vesasalo participated for many years in the pegmatite investigations of the Geological Survey in Häme and Southwestern Finland. Particularly in connection with these studies Vesasalo displayed exceptional discernment and talent in determination rare minerals hard to identify. He was the first to find the mineral pollucite in this country and he also detected a new petalite occurrence in Tammela.

Vesasalo, a skilful research worker and great lover of nature, was a straightforward and true friend to his colleagues. His cheerful, winning smile and his dry sense of humor combined with his serious interest in science made Vesasalo well liked and highly esteemed by us all.

Erkki Aurola

LIST OF THE PUBLISHED WORKS OF ARVO VESASALO

1. Itä-Suomen asbestikivistä. Pro gradu-tutkielma, 1951, Helsingin Yliopisto. Manuscript in the Archives of the Institute of Geology, University of Helsinki.
2. Outokummun malmin löytö. Savonmaa 11. 4. 1953.
3. Suomen asbestiesiintymistä ja niiden teknillisestä käytöstä. English summary: On the asbestos occurrences in Finland and their technical use. Geoteknillisiä julkaisuja 54, pp. 1—53, 1954. Together with Erkki Aurola.
4. Tammelan petaliittiesiintymä. Geologi 1, p. 9, 1958.
5. Uusi suomalainen mineraali. Geologi 8, p. 95, 1959.
6. On the petalite occurrences of Tammela, SW-Finland. Compt. Rend. Soc.Géol. Finlande 31, 5, pp. 59—74, 1959; Bull. Comm. géol. Finlande 184.
7. Kongo-joki. Helsingin Sanomat 30. 6. 1960.
8. The soapstone occurrences of Nunnanlahti. Int. Geol. Congress, XXI Session, Norden 1960. Guide to Excursions nos. A 37, A 38, C 32, C 33; Nonmetallic Mineral Deposits, Finland, pp. 28—30, 1960. Helsinki.
9. The petalite occurrence of Hirvikallio. *Ibid.* pp. 52—53, 1960.
10. The pegmatite occurrence of Luolamäki. *Ibid.* pp. 53—56, 1960.
11. The pegmatite occurrence of Brokärr. *Ibid.* pp. 56—58, 1960.
12. Pollucite from Luolamäki, Somero, Finland. Compt. Rend. Soc. Géol. Finlande 32, 11, pp. 133—148, 1960; Bull. Comm. géol. Finlande 188. Together with K. J. Neuvonen.
13. Suomen talkki- ja vuolukiviesiintymät. Lisensiaattitutkielma, 1961, Helsingin yliopisto. Manuscript in the Archives of the Institute of Geology, University of Helsinki.

ABSTRACT

The geological location and mineralogical composition of the talc and soapstone occurrences of Finland and problems associated with the metamorphism of these rocks are dealt with.

The occurrences investigated are in East Finland, partly in the Karelian schist sequence, partly in the veined gneiss area and partly in the pre-Karelian gneiss-granite zone. On the basis of their main and accessory minerals both the talc schists and soapstones are divided into four groups. In addition to the pure type there are amphibole-bearing, serpentine-bearing and chlorite-rich talc schists and soapstones.

The steatitization of soapstones is considered to be a phenomenon caused by hydrothermal, diluted SiO_2-bearing water solutions. Although laminar gliding can be regarded as the cause of steatitization it may also take place without such movements. The same hydrothermal, diluted and carbon dioxide-bearing silica solutions are held to be responsible of carbonatization. The solutions that caused steatitization may be derivatives of the same magma that produced the ultramafic intrusive rocks.

CONTENTS

PREFACE

As a summer field assistant at the Geological Survey in the summers of 1947—48 I was appointed to study the asbestos occurrences associated with serpentine rocks in Northern Karelia (Aurola and Vesasalo 1954). Subsequently I collected talc and soapstone material for scientific and economic purposes, completing the field work in the summers of 1949—51 and 1954—55. Microscopical studies were carried out during the winters at the Geological Survey.

The results of this research were first presented in the form of a thesis for the degree of Lic. Phil. at the University of Helsinki. Prof. Dr. Martti Saksela followed the work and guided me in its scientific treatment. I wish to express my sincere gratitude to him.

During this study Docent Erkki Aurola, Ph. D., guided and encouraged me in many ways. He also placed the vertical section of Leppälahti and the map of Haarala at my disposal. For all this I am greatly indebted.

Mrs. Toini Mikkola, Mag. Phil., determined the majority of the refractive indices, Dr. Kai Hytönen and Prof. Dr. K. J. Neuvonen assisted me with the X-ray identification of carbonate minerals, Mr. Pentti Ojanperä, Mag. Phil., and Dr. H. B. Wiik made the chemical analyses, Miss Karin Dahl drew the numerous maps and sketches, and Mr. Erkki Halme, research assistant, took the microscopic photographs. To all these colleagues I am greatly obliged.

I owe a debt of gratitude to the managing directors of Suomen Vuolukivi Oy and Suomen Mineraali Oy, who always took a favorable attitude toward my work.

And finally I want to acknowledge my obligation to the former Director of the Geological Survey, Prof. Aarne Laitakari, to the present Director, Prof. Vladi Marmo, and to the Chief of the Exploration Department, Dr. Aarno Kahma, who granted me the opportunity to carry out this study.

Otaniemi, September 8, 1961

Arvo Vesasalo

INTRODUCTION

Talc schist and soapstone occurrences are mentioned in the very earliest works dealing with the geology of Finland. It was not until the turn of the present century that attention began to be drawn to these rocks in earnest by Benj. Frosterus, who produced a series of papers on them (1899, 1901, 1902 a). He recommended the use of soapstone in the construction of facades and ovens and the utilization of talcum powder produced by pulverizing waste rock in the paper, soap and rubber industries as well as in rubber factories. The quarrying of soapstone was started at Nunnanlahti, Juuka, at the end of the last century and, except for a few interruptions, it has been continued up to the present day. At first the quarried rock was transported by ship to Helsinki. Between thirty and forty men, including some Norwegian and German stonecutters, were at one time employed in the stonecutting operations (Sourander 1945). The facades of numerous public buildings in Helsinki, Moscow and Leningrad were at that time covered with soapstone slabs or decorated with soapstone carvings.

Frosterus (1902 b, p. 55) referred to soapstones with talc and magnesite as the principal minerals as talc-magnesite rocks to distinguish them from talc schists and chlorite schists utilized as soapstone that contain no carbonate. Frosterus (pp. 59—60) describes cases in which it is possible to follow step by step the transition from serpentine rock to talc-magnesite rock. He regards talc-magnesite rocks as alteration products of serpentine rocks. Rocks originally rich in olivine and pyroxene first underwent alteration into serpentine rocks and then into talcose and carbonaceous soapstones. Frosterus and Wilkman (1920, p. 33) report the occurrence in the gneiss-granite area of eastern Finland of soapstones that had originated as dikes penetrating the gneiss-granite as rocks of amphibolitic composition turned talcous. Soapstones of this variety differ from ordinary soapstones because of their small carbonate content and the amphibole relicts occurring in them. The majority of these soapstones are considered by Frosterus and Wilkman (p. 38) as dike formations of later origin than the gneiss-granite. It is mentioned in the same article (p. 117) that ultramafic rocks occur in the schists as lumps aligned parallel to the schistosity. Ultramafic rocks are mostly composed of serpentine rock, which in many cases has become altered into talc-magnesite rock. The original olivine rock first altered into serpentine rock and then, as a result of the action of water and silicic acid, into soapstone rich in carbonate (pp. 130—135).

Wilkman (1921, pp. 91—92) describes amphibole schists rich in talc and chlorite as well as serpentine rocks and soapstones found in association with Karelian metabasites. He had often met with rocks that represent clear transitional forms between metabasites and carbonaceous soapstones. The changes are believed by Wilkman to have occurred as a result of the action of CO_2-bearing water on magnesium-silicates, possibly in connection with mountain range folding.

Later on Wilkman (1931, pp. 209—222) writes about ultramafic rocks occurring in the Karelian schist areas and to some extent on the outside which he regards as having erupted during the Karelian folding and, notably during its final phases, in connection with overthrusts. The serpentine rocks occur in most cases in association with altered gabbros. At the contacts of serpentine rocks, amphibole, talc and chlorite schists as well as talc-magnesite rocks are often to be found. Wilkman terms the altered gabbros metagabbros and their schistose types metabasites.

Väyrynen (1928, pp. 67—68) regards the serpentine of the serpentine rocks of the Kainuu region in eastern Finland as an alteration product of tremolite and dolomite. It is his assumption that the serpentine rocks occurring in association with gabbroic amphibolites originated from diabases and gabbros as the mafic components serpentinized and the feldspars disintegrated. In another study Väyrynen (1933, p. 74) writes that basic intrusive varieties of rock invariably occur in strongly folded places, where they form lenticular or fish-shaped schlieren characteristic of ophiolites. In the region of Karelia, serpentine rocks regularly follow particular horizons of schist formations, whereas in the Kainuu region this is not so clearly observable.

In a later paper Väyrynen (1935, pp. 8—9) remarks that it is probable that olivine of the serpentine rocks of Outokumpu and Polvijärvi is not primary but secondary. In many places, he points out, the serpentine rock has metasomatically altered to soapstone or asbestos rock. Väyrynen (1939, pp. 76—77) subsequently presents arguments against the primary character of olivine.

Further, Väyrynen (1954, p. 178) observes that the serpentine rock lenses are laid out one after another in rows. Zones of this kind comprise slip planes or overthrust zones, along which tectonic movements or the dislocation of schist masses took place.

Haapala (1936, p. 79) takes the view that the composition of the ultramafic rock was originally dunitic and that only in a few cases had the original rock been enstatite-bearing peridote. The ultramafic rock has undergone several successive alterations — into amphibolite, serpentine-, carbonate- and talc-rocks. The serpentinization is supposed by him to have been an autometamorphic event. The carbonatization and steatitization were caused by hydrothermic solutions.

Also Vähätalo (1953, p. 93) concurs in the view that in the Outokumpu region the serpentine rocks are the products of autometasomatosis. It is his belief that the arrival in their present positions of the serpentine rocks (peridotites) at Outokumpu occurred during the folding of the schist formation. At that time the necessary openings could be most easily formed in the pressure minima of the quartzite and black schist horizons.

Wiik's study (1953) elucidates the composition and origin of soapstones. He defines as soapstone »rock consisting mainly of talc» (p. 8).

In their article on the asbestos deposits in Finland, Aurola and Vesasalo (1954, pp. 39—40) have briefly touched upon the steatitization of different minerals. Nieminen (1950, pp. 34—37) has looked into the opportunities for the talc industry in Finland, and Aurola and Nieminen (1954, pp. 102—104) have published a report on the Finnich talc industry.

Matisto (1958, p. 15) mentions the talc-magnesite rocks of Suomussalmi, which he includes among Karelian ultramafic plutonic rocks, as occurring in the form of ophiolitic lumps in or near Karelian rock formations. He has run across serpentine rocks with a magnesite content of as much as 25 per cent. In addition, they contain talc, chlorite and tremolite, indicating a stage of alteration from serpentine rock into soapstone.

Talc schists and soapstones contain a large abundance of talc, by virtue of which they are easy to saw and carve. That is why both kinds of rock are often called »vuolukivi» in Finnish, meaning soapstone, or more literally »carving stone». However, they do constitute two distinctive categories of rock, the one representing rocks which contain talc in the main and the other rocks which contain carbonate as well as talc. Accordingly, I have divided the rocks dealt with in this paper into two principal classes:

1. Talc schists, which consist mainly of talc.
2. Soapstones, which consist mainly of carbonate and talc.

Frosterus referred to talc- and magnesite-bearing soapstones as talc-magnesite rock (p. 10). But as soapstones may also contain dolomite or calcite, Wilkman (1921, p. 97) used the designation carbonate soapstone. It is simplest, however, to call these rocks soapstones.

With the exception of a few deposits in northern Finland, the talc-schist and soapstone occurrences are to be found in eastern Finland (Fig. 1, p. 13). In Plate 1 there is a map showing the same area, on which the Karelian schist localities and post-Karelian granites and veined gneisses have been drawn, slightly generalizing the geological maps of Finland. The pre-Karelian

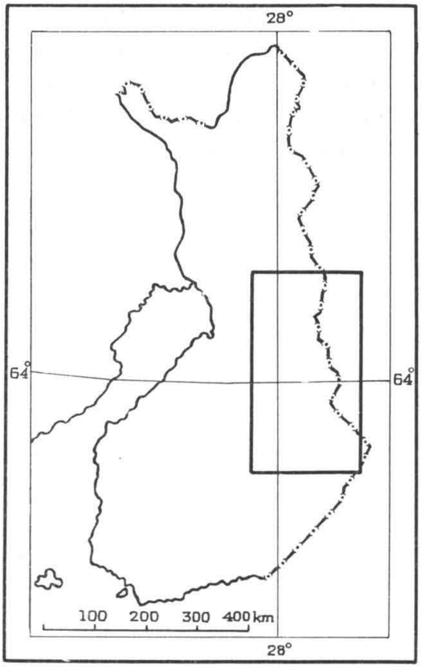

Fig. 1. The area of occurrence proper of the talc schists and soapstones in Finland.

gneiss-granite area has been left white. The talc schist and soapstone occurrences have been marked on the map on an exaggerated scale and numbered according to the list of occurrences at the end of the paper. The same ordinal number has been used in parantheses in connection with the names of the occurrences mentioned in the text.

The majority of the more than a hundred talc schist and soapstone occurrences investigated are situated in the Karelian schist area of eastern Finland, but occurrences can also be found outside the schist sequences in gneiss-granite and in the veined gneiss area. The talc schist and soapstone occurrences situated in these three different types of geological environment constitute, viewed broadly, large categories of their own, which differ among themselves mainly with respect to their mineralogical composition and mode of occurrence.

In the following presentation, the talc schists and the soapstones will be dealt with separately. In both cases, subtypes will be mentioned and examples of each given. The geological mode of occurrence and mineralogy of each type will be described, the chemical analysis of certain examples will be gone into, with mention of the possible origin of the rock and elucidation of the metamorphic phenomena attending their genesis. In certain instances, reference will be made to corresponding occurrences and studies abroad. A vertical section perpendicular to the strike of the schistosity has been drawn in a few cases. The points at which the vertical sections have been made are shown on the map reproduced in Plate 1.

TALC SCHISTS

The chief mineral component of talc schists is talc. In most cases the talc schist is distinctly schistose. The talc schist deposits are ordinarily small and insignificant. They occur in zones a few meters broad in the marginal portions of serpentine, asbestos and soapstone occurrences, as dikelike formations in the tectonic zones of ultramafic rocks and along the borders of amphibole-bearing rocks.

Talc schists have often been observed to contain amphibole and serpentine or abundant chlorite. On this basis I have divided the talc schists into four subtypes:

a) Pure talc schists, consisting in most cases only of talc.

b) Amphibole-bearing talc schists, which contain, in addition to the talc, amphibole minerals.

c) Serpentine-bearing talc schists, which contain, besides the talc, also serpentine.

d) Chlorite-rich talc schists; nearly all talc schists contain a little chlorite, but in this variety the content is likely to be as great as that of talc.

In addition to the subtypes listed above, there are various mixed types. In Table I (p. 16) the geological situation of the talc schist occurrences of different types is presented. The occurrence of various mixed types is also recorded. The table shows that talc schists occur both in gneiss-granite and in schist areas and veined gneiss.

PURE TALC SCHISTS

Table I reveals that pure talc schists occur in the schist areas. In most cases they are situated with soapstones at the margins of serpentine rock massifs and only rarely exclusively in association with serpentine rocks or skarns.

In the Pohjavaara (84) occurrence, in addition to pure talc schist, one will find also serpentine-bearing talc schist and soapstone. The occurrence is

Table I. Classification of talc schist occurrences by type and their geological situation.

Talc schist types	Gneiss-granite	Schist areas	Veined gneiss	Total
Occurrences investigated	11	19	6	36
Pure talc schists	1	13	2	16
Amphibole-bearing talc schists	7	7	5	19
Serpentine-bearing talc schists	2	4	—	6
Chlorite-rich talc schists	4	3	1	8
Mixed type, amphibole and serpentine	1	2	—	3
Mixed type, amphibole, serpentine and chlorite	—	—	—	—
Mixed type, amphibole and chlorite	2	2	1	5
Mixed type, serpentine and chlorite	—	—	—	—

situated at Pohjavaara, Sotkamo commune, less than 1 km SW of the Ahola farmhouse. Fig. 2 has a geological map of the occurrence.

The Pohjavaara occurrence is fine-grained mica schist, the dip of the schistosity of which is most commonly vertical. In addition to quartz, plagioclase (oligoclase) and biotite, the mica schist contains a small amount of chlorite as an alteration product of biotite as well as a little epidote and a very small quantity of small opaque grains. The biotite's $\gamma' - \alpha' = 0.06$.

Inside the mica schist deposit there are two ultramafic lumps. Between the mica schist and the ultramafic rock at the western margin of the larger lump are the chlorite blackwalls. A few centimeters from the blackwalls in the mica schist there occur, in addition to the quartz, plagioclase and biotite, quite an abundance of chlorite altered from biotite as well as little epidote granules and, situated particularly in the chlorite, small opaque grains. The plagioclase is albite, An_5, $2V\gamma \sim 70°$ and $\gamma' - \alpha' = 0.01$. The biotite's $2V\alpha = 0°$ and $\gamma' - \alpha' = 0.06$, the chlorite's $\gamma' - \alpha' = 0.005$, and the monoclinic epidote's $\gamma' - \alpha' = 0.004$.

At the edge of the larger ultramafic lump, next to the partially chloritized mica schist, there is an unoriented mica blackwall 2 cm thick, which has been composed of scales 2—3 mm in diameter. The chlorite is brownish green, colorless in thin section and contains inclusions of sphene, apatite and biotite. Around the majority of inclusions are small dark rings, which are visible when the length of the flake is in the direction of oscillation but vanish upon the microscope table's being turned 90 °. The interference color of the chlorite is dark gray, $2V\gamma = 14°$, $\alpha \sim 1.599$, $\gamma \sim 1.608$ and $\gamma - \alpha \sim 0.009$. The properties fit prochlorite. Between this coarse-grained blackwall and the soapstone proper is a fine-flaked (0.2—0.3 mm), oriented chlorite blackwall 10—20 cm thick. The chlorite of this blackwall is dark green but colorless in thin section and it contains an abundance of sphene grains as well as some apatite inclusions. Around certain of the inclusions are pleochroic haloes. The

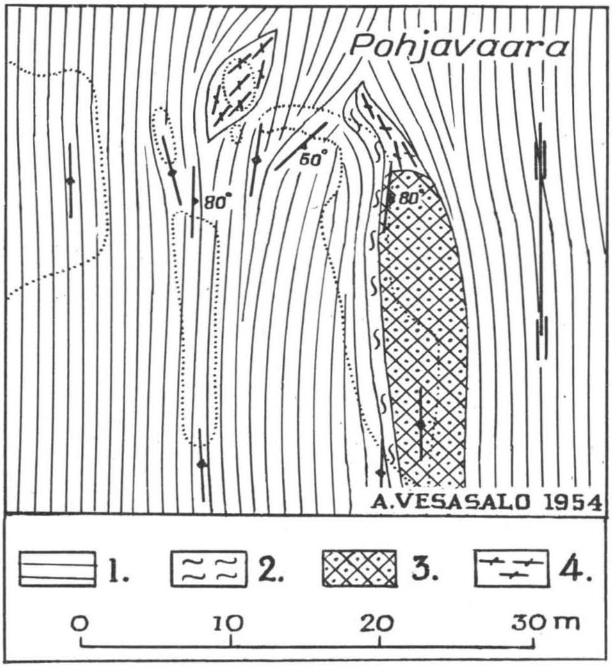

Fig. 2. Map of the Pohjavaara (84) talc schist and soapstone occurrence in Sotkamo. 1. Mica schist, 2. Chlorite blackwall, 3. Soapstone, 4. Talc schist.

chlorite's $2V\gamma \sim 10°$, $\alpha = 1.597$, $\gamma = 1.607$, $\gamma - \alpha = 0.010$. These properties also correspond to prochlorite.

Next to the chlorite blackwall is situated indistinctly oriented, greenish gray soapstone. In addition to talc, the rock contains magnesite, dolomite and a little antigorite. In association with the carbonate there are opaque grains. The opaque minerals comprise pyrrhotite, magnetite, chalcopyrite, pentlandite, nickelite and pyrite. The pentlandite and nickelite occur in association with the pyrrhotite.

At the end of the soapstone lump there is pure talc schist. Besides talc, the rock contains some small chlorite flakes and a small number of opaque grains 0.1—0.2 mm in diameter.

The talc is colorless in thin section, its longitudinal direction is positive and its optical character negative. The cleavage along the basal plane is exceedingly good. The axial angle is generally small, so that the mineral appears nearly uniaxial. Usually in the talc schists the talc's $2V\alpha \sim 2°$. With respect to the pure talc schist of Pohjavaara, the talc's $\alpha = 1.542$, $\beta = 1.587$, $\gamma = 1.590$ and $\gamma — \alpha = 0.048$.

Table II. Pure talc dike in soapstone. Solansaari (59), Polvijärvi. (Wiik, 1953, p. 49, Anal. 16).

% by weight		Molecule ratio x 1 000
SiO_2	62.30	1037
TiO_2	0.00	
Al_2O_3	0.19	2
FeO	1.46	20
MnO	0.00	
MgO	31.66	785
H_2O +	4.75	264
H_2O —	0.00	
Total	100.36	

In the larger lump at Pohjavaara, there also occurs a pale green, partly talcose tremolite rock. The tremolite needles in it are thin, 2 to 7 mm long, radially crystallized and colorless in thin section. The tremolite's $c \wedge \gamma = 14°$ and $2V\alpha = 70°$; $\alpha = 1.611$, $\gamma = 1.635$ and $\gamma—\alpha = 0.024$.

The small lump is only talc schist. In addition to fine-flaked talc, it contains small antigorite flakes, a few partly steatitized chlorite flakes and — particularly mixed in with the antigorite — a small number of tiny opaque grains.

Evidently, both the ultramafic lumps of Pohjavaara once belonged to the same massif, which broke up during later movements.

No polished section of the pure talc schist of Pohjavaara is available, but it may be assumed to contain the same opaque minerals as the soapstone occurring in association with the rock. A few of the other pure talc schists have been found to contain pyrite and, with the exception of nickelite, the same opaque minerals as at Pohjavaara. The most common of these minerals are pyrrhotite, pentlandite and chalcopyrite. The magnetite mostly occurs as small idiomorphic crystals and the pyrrhotite invariably as accumulations of indefinite form, particularly in between chlorite flakes and as narrow veins filling the cracks of the chlorite and talc flakes. The pyrrhotite grains have often been found to contain pentlandite and sometimes chalcopyrite. Pyrite is uncommon, occurring as idiomorphic crystals.

The chemical composition of pure talc schists may approximate the theoretical composition of talc (SiO_2 = 63.35 %, MgO = 31.90 % and H_2O = 4.75 %), as shown in Table II.

The pure talc schists occurring in both gneiss-granite and schist sequences and veined gneisses in association with serpentine rocks and soapstones all apparently belong among originally ultramafic intrusive rocks, in the contact zones of which pure talc schist has evolved as a product of steatitization.

These talc schist occurrences correspond to the type of talc described by Hess (1933, p. 639). According to him, in these rocks the steatitization, of a hydrothermic nature, caused by diluted water solutions, has in most cases been limited to the marginal portions of ultramafic rocks and fracture zones intersecting them. This has brought about a zoned structure. The country rock has chloritized next to the contact (cf. Pohjavaara, p. 17), and in the contact there has developed a chlorite blackwall and a talc zone, followed by serpentine rock.

The contacts between the ultramafic rock and the country rock are suitable channels for hydrothermic solutions. Since the chemical composition of these rocks is highly different, the hydrothermic solutions in the immediate vicinity of the contact cause metasomatic changes. At a higher temperature a biotite zone evolves along the edge of the country rock and a tremolite zone along the edge of the ultramafic rock. As the temperature drops, the part of the biotite zone on the side of the ultramafic rock alters into chlorite and the tremolite and serpentine turn wholly or partly into talc under the influence of the SiO_2-bearing hydrothermic solution.

Biotite-chlorite blackwalls of this kind are characteristic of talc schist and soapstone ocurrences. A biotite blackwall generally grades over into a chlorite blackwall. Near the contact the country rock often has a biotite-rich zone, especially when the country rock consists of veined gneiss or gneiss-granite. On the other hand, in cases where the country rock is granite, the contact is usually sharp. The thickness of the biotite and chlorite blackwalls varies from a few centimeters to several decimeters. In certain cases (Paakkila, 103) the blackwalls have been observed to be much thicker next to the granite than in the same lump up against veined gneiss, and in such instances biotite blackwalls in particular are thick. The biotite is often seen to be quite fine-flaked at a contact and usually arranged in conformity with the trend of the contact, but farther from the contact the biotite flakes are commonly larger and lacking in orientation.

Both biotite- and chlorite-bearing blackwalls are most common in the western part of the Joensuu schist belt and in the veined gneiss area still farther west, where the influence of the pegmatitic post-Karelian granite has extended in many places. Also in the gneiss-granite area there are such blackwalls in numerous occurrences, but in the central parts of the schist areas they seem to be less common than elsewhere. In many occurrences in the schist area, only chlorite or tremolite is to be found in the contacts of ultramafic rocks.

The same hydrothermal solutions that account for the genesis of the biotite-chlorite blackwall are also responsible for the steatitization process to be observed along the edges of ultramafic lumps. In the western parts of the Joensuu schist area and, particularly, in the veined gneiss area, these solu-

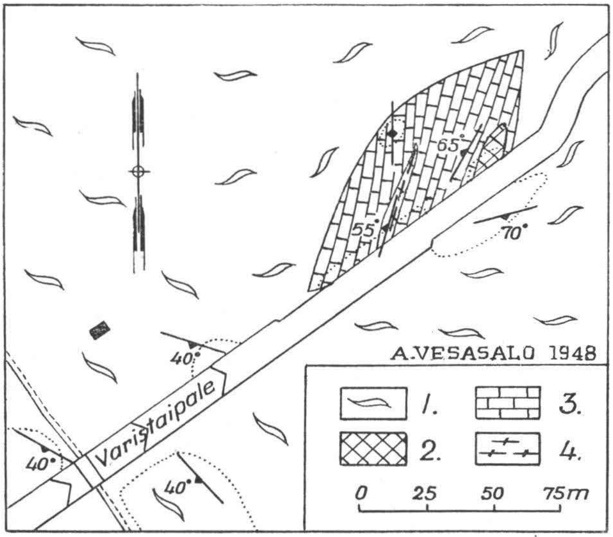

Fig. 3. Sketch of the Varistaipale (101) talc schist occurrence at Heinävesi. 1. Veined gneiss, 2. Serpentine rock, 3. Tremolite-diopside skarn, 4. Talc schist.

tions may have derived, at least in part, from post-Karelian granite, but in general steatitization is an autometamorphic process, one that occurs when conditions favor it. What is required is a temperature so low that the rock's own pore solutions are activated. This does not take place until the conditions of a green schist facies have been established.

The conditions producing talc have been experimentally determined by Bowen and Tuttle (1949). They have observed talc to originate in the $MgO—SiO_2—H_2O$ system when the temperature has been below about 800° C and over 350° C and the steam pressure has varied from 422 kg/cm^2 to 2 110 kg/cm^2 (p. 443).

The temperature under the conditions cited is in many cases so very low already that steatitization does not always follow. Total movements are needed before the process can begin. To the genesis of talc has often been connected stress movement (Heim 1918, p. 10) as well as stress- and shear-movement (Kulp and Brobst 1954, p. 215). It has been explained that a large quantity of solutions might have run through the ultramafic mass. The solutions could have increased the amount of SiO_2 and raised the temperature to induce the creation of talc occurrences. Hess (1933, p. 643), however, does not regard stress movement as a factor contributing to the origin of talc.

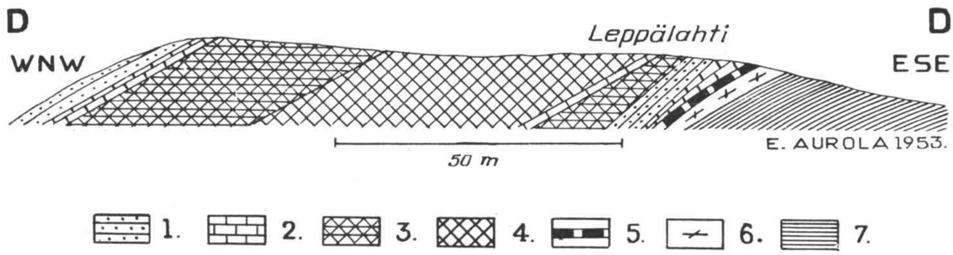

Fig. 4. Vertical section of the Leppälahti (54) serpentine rock horizon at Liperi, according to a map drawn by E. Aurola. 1. Quartzite, 2. Skarn, 3. Carbonate-bearing serpentine rock, 4. Serpentine rock, 5. Dolomite, 6. Talc schist, 7. Mica schist.

Certain pure talc schists are very schistose and have slickensides in abundance (e.g., Solansaari, 59). But many pure talc schists (e.g., Pohjavaara, 84, and Kivikallio, 79) are indistinctly oriented or altogether unoriented, and evidences of movements are not always detectable even in associated blackwalls. It would therefore appear that steatitization could also occur without movements completely affecting deposits.

According to Du Rietz (1935, p. 256), the degree of metamorphism of country rocks could have significance in the genesis of talc. He says that the alteration of peridotites in northern Sweden into talcose rocks generally occurred in areas where the rocks have undergone greater metamorphism than their surroundings, as in mica schist, amphibolite and gneiss belts.

Pure talc schist is likely to form in some instances also with the partial steatitization of skarn formations. Examples of this are the pure talc schists of Varistaipale (101) and Leppälahti (54).

The Varistaipale occurrence is situated at Yläkanava, Varistaipale, in the commune of Heinävesi. At the northeastern end of the canal a section has been quarried out of the veined gneiss, which contains tremolite-diopside skarn and chrysotile-bearing serpentine rock (Fig. 3). The skarn has narrow pockets of serpentine penetrated by quartz and pegmatite veins as well as four bodies of talc schist.

Near the eastern margin of skarn there is an occurrence of talc schist to a breadth of 50 cm and ten meters from there toward the southwest another corresponding occurrence. On the western side of the last-mentioned spot, the skarn contains quartz veins and a pegmatite dike one meter in breadth. The pegmatite dike is separated by a thin blackwall of biotite from a talc schist body five meters broad (to be seen in the figure). On the other side of it there is serpentine rock with a strip of talc schist 5 cm wide. The serpentine rock is followed by an occurrence of skarn penetrated by pegmatite veins and granite, the latter of which contains a fragment of amphibole rock 50 cm in diameter and penetrated by a quartz dike starting out of the granite. The contact between the skarn and the veined gneiss is overlain by soil.

The talc schist of Varistaipale contains amphibole pseudomorphs 5—10 cm in length. A fine opaque pigment in many cases runs along the edges of the pseudomorphs. The axial angle of the talc is under 5°, $\alpha = 1.538$, $\beta = 1.581$, $\gamma = 1.590$ and $\gamma - \alpha = 0.052$. No amphibole relicts have been found in the talc schist. On the other hand, fine-grained calcite and chlorite occur to a small extent at least in the easternmost, 50-cm-broad talc schist body. The small opaque minerals are pyrrhotite and pentlandite.

The talc deposit of Leppälahti is situated in Liperi (Fig. 4, p. 21). The bedrock consists of mica schist, which contains a narrow, tremolite-bearing quartzite sequence. Between the quartzite and the mica schist there occur dolomite- and tremolite-bearing serpentine rock, dolomite, skarn sequences and talc schist. The talc schist is completely steatitized tremolite skarn, the appearance of which is still pseudomorphous.

AMPHIBOLE-BEARING TALC SCHISTS

Table I (p. 16) shows that amphibole-bearing talc schists occur in both gneiss-granite and schist and veined gneiss areas. Half the occurrences are at the margins of serpentine rocks and soapstones, where they form the same kinds of narrow, steatitized zones as the pure talc schists. These are likewise intrusive lumps, mostly ultramafic by origin, the marginal parts of which have steatitized through the action of hydrothermal solutions. The process of steatitization has not been complete, for amphibole relicts remain in them. The majority of these occurrences, which are associated with serpentine rocks and soapstones, are to be found in the veined gneiss area, but they are present also in gneiss-granite and schist areas.

The talc schist deposit of Tervaniemi (51) is situated at Konttimäki, in the commune of Säyneinen, about 200 meters from the southern shore of Lake Suuri Säyneinen, on the western side of the Tervaniemi farm. There is a rock outcrop about 30 m long on the site. I consists mainly of black chrysotile-bearing serpentine rock. At the southern end of the outcrop there used to be a vertical talc schist zone 2 m broad and some 10 m long, which has been quarried out to the level of the ground. At one point along the margin of the talc schist there occurs nearly white, schistose and partly steatitized anthophyllitic schist. Here and there the talc schist contains smooth slickensides produced by movements. The contact between the ultramafic rock and the mica schist occurring around it cannot be seen.

The talc schist of Tervaniemi is for the greatest part unoriented and either light or dark gray. Besides the talc the rock contains thin relicts, 0.5 to 1 cm long, of radially crystallized anthophyllite crystals as well as a scattering of chrysotile laths a couple of centimeters long, a little chlorite and, embedded especially within the chrysotile, a small quantity of opaque grains. The anthophyllite's $2V\alpha = 80°$, $\alpha = 1.550$, $\gamma = 1.605$ and $\gamma - \alpha = 0.055$. The indices of refraction are below normal and the double refraction is greater than normal, which is apparently due to the partial alteration of the mineral.

Anthophyllite is to be found also in certain other talc schist occurrences associated with serpentine rocks and soapstones, and a few of the deposits contain anthophyllite-asbestos or tremolite.

Amphibole-bearing talc schists occur not only along the edges of serpentine rocks and soapstones but also in association with hornblende schists and amphibolites. These deposits are to be found in the gneiss-granite area.

Kissakallio (22) is situated in the village of Reittiö, Nilsiä commune, in the locality known as Lapinsalo, about 2 km northwest of the northern end of Eitikkajärvi. The occurrence consists of a solitary hill ten meters long and three wide in the middle of a bog.

According to Wilkman (1933, Map p. 92), the bedrock of Reittiö consists of gneiss-granite containing a syenite massif approximately ten kilometers long. Present in the syenite is metamorphosed gabbro running in a longitudinal direction as well as lumps with a diorite content. Kissakallio represents such a lump.

At one end of the outcrop is dark green, indistinctly schistose hornblende schist, in which hornblende is present as partially steatitized laths 2—3 mm long, which appear weakly pleochroic in thin section. The hornblende's $2V\alpha = 72° - 86°$, $c \wedge \gamma = 17°$, $\alpha = 1.625$, $\gamma = 1.645$ and $\gamma - \alpha = 0.020$.

It abounds in fine-flaked talc. The steatitization of the hornblende has started in places by the formation of a roundish area of talc within the laths. Most commonly the steatitization process in this rock has had the result that of the large hornblende laths all that remains is long, narrow, colorless laths with a simultaneous extinction in thin section (Fig. 5). Between the laths are fine-flaked talc and small opaque grains. Also in the cracks in the chlorite flakes there is fine talc present as an alteration product.

The other end of the outcrop consists of greenish gray talc schist containing hornblende relicts. The rock is indistinctly schistose and fine-grained. More than half of it is fine-flaked (0.1—0.2 mm) talc, the remainder chiefly consisting of hornblende. In thin section the hornblende occurs in the form of an occasional very weakly pleochroic laths 0.1—0.6 mm long, within and in the cracks of which one can observe fine-flaked talc or chlorite. The hornblende's $2V\alpha = 85°$, $c \wedge \gamma = 16°$, $\alpha = 1.629$, $\gamma = 1.650$ and $\gamma - \alpha = 0.021$. For the most part the hornblende consists of small laths without color in thin section. In addition to the talc and the hornblende, the talc schist contains

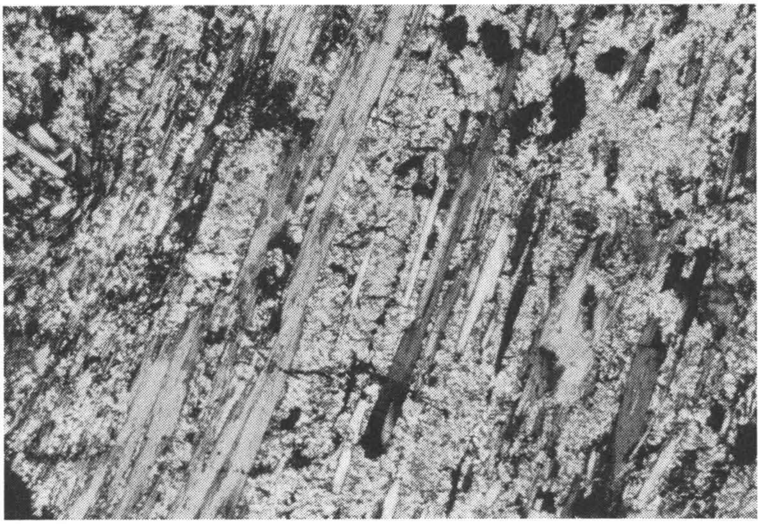

Fig. 5. Relicts of hornblende crystal in talc. Partially steatitized hornblende schist. Kissakallio (22), Nilsiä. Nic. +, 48 x.

a fair abundance of small chlorite flakes, which occur as stripes running parallel to the schistosity, as well as pyrite crystals 1—5 mm in diameter and small magnetite grains. Besides the magnetite and the pyrite, also pyrrhotite has been met with in certain other amphibole-bearing talc schists.

The hornblende of amphibole-bearing talc schist may undergo alteration in other ways as well. Fig. 6 shows a large hornblende lath in the middle of which is a chloritized area. The chlorite has steatitized both parallel to the basal plane and at right angles to it. The hornblende has color on both sides of the chlorite, whereas both ends of the crystal are colorless. As an extension of the colorless portions, talc occurs as a pseudomorph after amphibole.

At the universal stage I have ascertained that with respect to the colored center of the hornblende $2V\alpha = 76°$ and $c \wedge \gamma = 20°$, but at the colorless end of the crystal, which is usually set off by a sharp border, $2V\alpha$ increases, in part gradually, in part in spots, so that in advancing toward the end of the crystal the following values have been obtained: $2V\alpha = 104°$, $108°$ and $110°$, or $2V\gamma = 76°$, $72°$ and $70°$. The angle of extinction diminishes simultaneously, the colorless portion having yielded the values: $c \wedge \gamma = 18°$ and $12°$. It will be seen in stereographic projection (Fig. 7, p. 25) that the axial plane is nearly the same both as regards the hornblende and the colorless portion occurring at the end of it, though α and γ have shifted at the same time as $2V\alpha$ enlarges in moving from the middle of the crystal to its end. Accordingly, at the ends of optically negative bornblende, there occurs colorless,

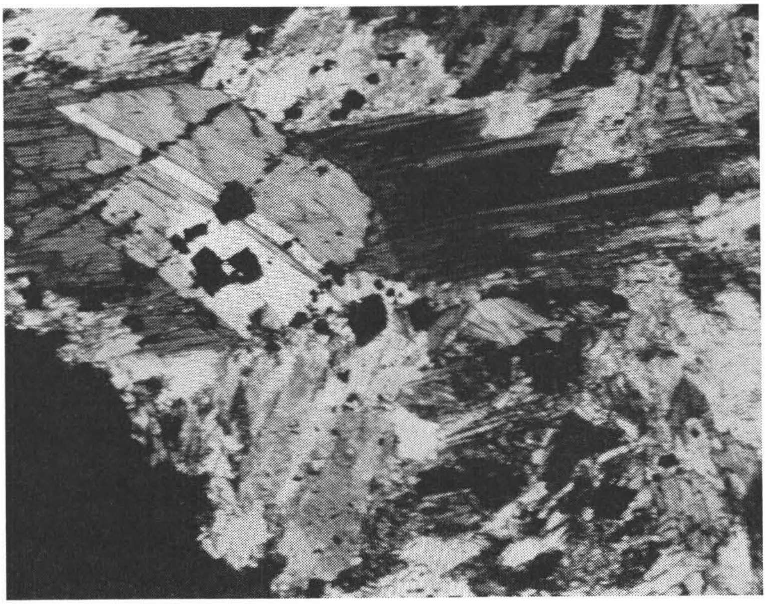

Fig. 6. Steatitized chlorite embedded in hornblende lamina. Amphibole-bearing talc schist. Ahola (29), Sonkajärvi. Nic +, 81 x.

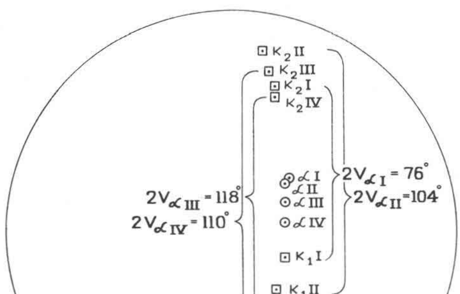

Fig. 7. Axial angles hornblende and cummingtonite occurring at its ends, in stereographic projection. Talc schist. Ahola (29), Sonkajärvi. K = optic axis.

Table III. Amphibole-bearing talc schist. Kylmänkallio (7), Kuhmo. (Wiik, 1953, p. 52, Anal. 35).

	% by weight	Molecule ratio x 1 000
SiO_2	56.29	937
TiO_2	0.11	1
Al_2O_3	2.34	23
Fe_2O_3	1.13	7
FeO	4.24	59
MnO	0.07	1
MgO	26.69	662
CaO	3.52	63
Na_2O	0.14	2
K_2O	0.08	1
P_2O_5	0.00	
CO_2	0.00	
H_2O +	4.93	274
H_2O —	0.11	
Total	99.65	

monoclinic and optically positive amphibole, the properties of which correspond to cummingtonite.

Some occurrences containing amphibole-bearing talc schist are not associated with serpentine rocks or soapstones or hornblende schists. Keinälänkallio (105) represents a partly steatitized tremolite rock occurring in veined gneiss. In addition to talc and tremolite, the rock contains amphibole-asbestos and a slight amount of magnetite. The Kylmänkallio (7) and Kelvänsaari (13) occurrences are situated in gneiss-granite.

The Kylmänkallio occurrence is situated in the village of Lentiira, Kuhmo commune, on the southern shore and near the western end of Kylmänjärvi, which drains into Änättijärvi.

Kylmänkallio consists of hornblende-bearing gneiss-granite with a content of talc schist as irregular, dike-like formations. In the country rock, near the contact, biotite is present as striped accumulations. Between the talc schist and the gneiss-granite, there are everywhere the blackwalls of biotite-chlorite. Elsewhere, too, in the occurrence there are blackwalls and fault surfaces. Between the blackwall and the talc schist at certain points there occurs a tremolite zone, in which the tremolite crystals lie alongside the blackwall at right angles to the contact but then at a distance of a couple of centimeters as unoriented tremolite rock. The tremolite is bright, a light green in color, and its refractive indices have yielded the values: $\alpha = 1.610$, $\gamma = 1.636$ and $\gamma - \alpha = 0.026$.

The talc schist of Kylmänkallio contains, in addition to the fine-flaked talc, thin, bright green tremolite crystals as much as 3—4 cm long. Some of

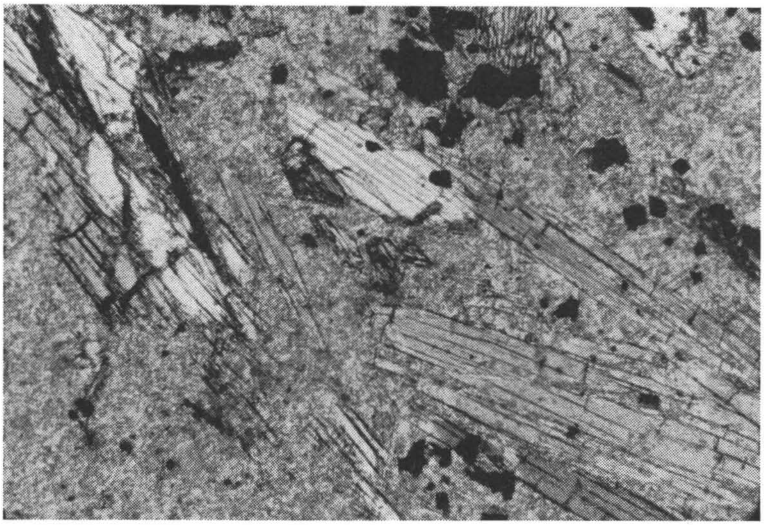

Fig. 8. Partially steatitized tremolite. Amphibole-bearing talc schist. Kelvänsaari (13), Pielisjärvi. Nic. +, 49 x.

the tremolite needles have begun to undergo steatitization, and a certain proportion of them have already turned half or wholly into talc. Under the microscope real pseudomorphs may be seen at the sites of completely steatitized tremolite crystals. The tremolite crystals are generally unoriented in a matrix of fine-flaked talc. The tremolite appears colorless in thin section, $c \wedge \gamma = 16°$ and $2V\alpha = 76—89°$. Wiik (1953, p. 22) has reported the following values for the indices of refraction of tremolite: $\alpha = 1.620$, $\beta = 1.628$ and $\gamma = 1.640$; $\gamma—\alpha = 0.020$. He has reported in the same connection also the molecule ratio of tremolite, calculated according to analysis: $(Fe^{+3} + Fe^{+2} = Mn) : Mg = 15.4 : 84.6$. The talc schist contains small magnetite grains as well as a scattering of chlorite flakes measuring 0.5—3 mm in length. In thin section, with the exception of colorless variety, the chlorite has the appearance of pale olive-brown pleochroic flecks. The interference color is ultramarine blue with dark olive-brown stripes, which may be due to twinning. The longitudinal direction in the blue portion is positive, in the olive-brown negative, $2V\gamma \sim 15°$, $\alpha \sim 1.582$, $\gamma \sim 1.588$ and $\gamma—\alpha \sim 0.006$. The properties apply to clinochlore.

The chemical composition of the Kylmänkallio talc schist containing tremolite is presented in Table III, p. 26.

The water content of this talc schist is seen to be slightly greater than that of pure talc, but the SiO_2 and MgO contents are considerably smaller. The contents of calcium and iron are due to the tremolite.

The talc schist of Kelvänsaari contains the same kind of partly steatitized tremolite crystals as does that of Kylmänkallio (Fig. 8, p. 27). Wiik (1953, p. 22) has reported the following optical properties for the tremolite of Kelvänsaari: $2V\alpha = 72°—87°$, $\alpha = 1.616—1.625$, $\beta = 1.628—1.635$ and $\gamma = 1.643$; $\gamma—\alpha = 0.027—0.018$.

The optical properties of the partially altered tremolite vary even in the same thin section, as evidenced by the values of the tremolite of the amphibole-bearing talc schist of Leppälahti (54): $c \wedge \gamma = 13°—17°$ and $2V\alpha = 76°—82°$. The optical properties of the tremolite, again, may be nearly the same in different talc schists. Thus, with respect to the Keima (70) tremolite, $c \wedge \gamma = 14°$, $2V\alpha = 78°$, $\alpha \sim 1.613$, $\gamma \sim 1.639$, $\gamma—\alpha \sim 0.026$ and the Portinkallio (69) tremolite, $c \wedge \gamma = 15°$, $2V\alpha = 80°$, $\alpha = 1.615$, $\gamma = 1.640$ and $\gamma—\alpha = 0.025$.

In certain cases the amphibole relicts of the talc schists are very small. For example, at Siikaniemi (17) the talc contains a number of tremolite relicts 0.2—0.4 mm long, of which the ones situated close together have a simultaneous extinction in thin section, thus indicating their having previously belonged to the same individual crystal. This tremolite's $c \wedge \gamma = 16°$, $\alpha = 1.622$, $\gamma \sim 1.645$ and $\gamma—\alpha \sim 0.023$.

At the margin of the amphibole-bearing talc schist occurring in conjunction with a certain lump of asbestos rock at Paakkila (103), there is unsteatitized tremolite that registers: $c \wedge \gamma = 15°$, $2V\alpha = 80°$, $\alpha = 1.610$, $\gamma = 1.635$ and $\gamma—\alpha = 0.025$.

The chlorite occurring in certain amphibole-bearing talc schists has been found to be rumpfite. Thus, the chlorite of Ahola (29) and Portinkallio (69) is weakly pleochroic: $\alpha = \beta =$ light blue-green, $\gamma =$ very pale yellowish green. The longitudinal direction is negative. The interference color is almost black, which means that the double refraction is very small. The optical character is positive. The $2V\gamma$ is in one case about 2°, in the other approximately 10°. The indices of refraction are over 1.590. These properties apply to rumpfite. With respect to their chemical composition, clinochlore and rumpfite are very close to each other. Rumpfite contains more ferroantigorite than clinochlore (Winchell 1956, p. 381).

Like certain pure talc schists, certain amphibole-bearing talc schists appear to be skarn formations in origin. In such cases the steatitization process has not been completed, but amphibole relicts remained in the talc schist. This has happened at Kupinpuro (62), where there occurs, between dolomite and quartzite, talc schist containing partially steatitized tremolite relicts (Fig. 9. p. 29).

In the schist area of Kajaani, the occurrences containing amphibole-bearing talc schist at Portinkallio (69) and Keima (70) are found within quartzite. They likewise appear to be steatitized skarn formations and thus

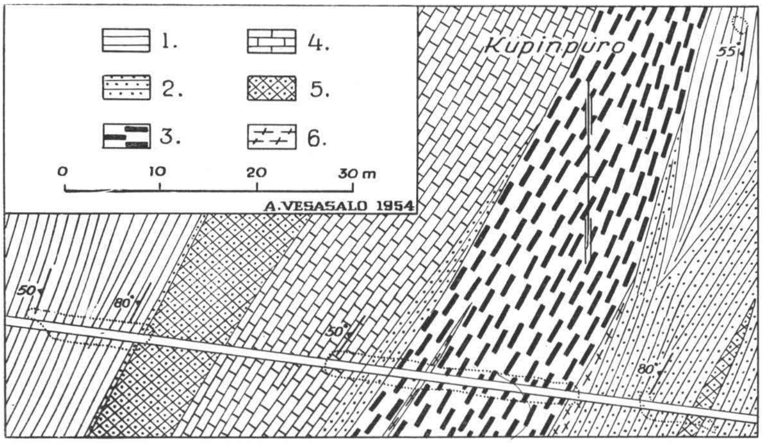

Fig. 9. Sketch of Kupinpuro (62) talc schist and soapstone occurrence at Polvijärvi, 1. Mica schist, 2. Quartzite, 3. Dolomite, 4. Skarn, 5. Soapstone, 6. Talc schist.

of sedimentogeneous origin. Such talc occurrences are to be found, for example, in North Carolina. They were produced in limestone through the action of originally magmatic solutions (Stuckey 1937, p. 1016). In southern Norway, pegmatitic SiO_2-bearing solutions have acted on dolomite to cause its alteration into serpentine, tremolite and talc. The serpentine and tremolite have undergone further steatitization (Mortensen 1945, p. 283). Similar occurrences have been reported from Uruguay (Walther 1914, pp. 424—425).

SERPENTINE-BEARING TALC SCHISTS

Serpentine-bearing talc schist is present in a few occurrences of schist sequences as well as in the gneiss-granite area (Table I, p. 16). All the deposits are associated with serpentine rocks and soapstones and are originally ultramafic intrusive rocks. In their contact and tectonic zones, steatitization has occurred, except that a portion of the serpentine has remained unaffected or that antigorite has been produced in the rock following steatitization. Half the serpentine-bearing talc schist contains chrysotile in addition to talc, the other half antigorite.

In the amphibole-bearing talc schist of Tervaniemi (51), described in the foregoing (p. 22), the chrysotile occurs as laths measuring a couple of centimeters in length. Accordingly, it represents an amphibole- and serpentine-bearing mixed type. Similar chrysotile flecks are to be observed also in the talc schist of Kivikallio (79), in the commune of Sotkamo, where they appear at the margin of the serpentine rock. Besides chrysotile, the serpentine rock contains abundant talc and carbonate as well as small amounts of chromite, pyrrhotite and pentlandite grains. The talc schist is dense and indistinctly oriented. It has some idiomorphic magnetite crystals and grains of pyrrhotite 1—10 mm in diameter. Certain of the grains contain pentlandite. In places the talc schist contains veins of talc varying in width from a few millimeters to 1 or 2 centimeters. Large talc flakes are also to be found in unoriented accumulations. Here and there in the talc schist are thin, sharp-edged chrysotile flecks 1—2 cm long, which have remained inside the talc while the greatest part of the chrysotile has steatitized.

In thin section the chrysotile is colorless and its interference color is gray. The location of the cleavage cracks of the original olivine can be seen plainly. Coinciding with the cleavage cracks are chrysotile bands, in which the fiber-thin chrysotile lies transversely. Its longitudinal direction is negative. In the middle of each band there is nearly always a fragmentary chain formed by small opaque grains. In gaps in the chain there is serpentine with an orientation different from the two ends of the opaque chain. In some cases there may be on both sides of the midmost opaque chain other zones with the same orientation composed of very fine-grained opaque pigment. The center of the network of opaque chains situated amid these zones and the chrysotile bands also consists of chrysotile, but there the flakes are often arranged radially or not at all.

In the small lump embedded in the Pohjavaara (84) occurrence, described in the foregoing (p. 15), antigorite-bearing talc schist is present. The antigorite occurs in it as accumulations of small, partly steatitized flakes. Talc schist with an antigorite content likewise occurs in the Niskasuo (20) rock.

The occurrence is in the village of Ruunaa, Pielisjärvi commune, 0.5 km south of the Niskavaara farmhouse, in the middle of the bog known as Niskasuo, at the boundary between the lands owned by the commune and the State.

The western end of the roughly 20-meter-long outcrop is serpentine rock, which, in addition to the antigotite, contains carbonate and small flakes of talc. Small opaque grains form a thin network in the rock. The middle portion of the exposure also consists of hard serpentine rock, which, however, in addition to large antigorite flakes, contains chrysotile with a mesh structure. Carbonate is found both in the meshes of the chrysotile network and outside them. Mixed up with the antigorite is an abundance of fine-flaked talc. At the eastern end of the outcrop, talc schist covers an area of some 20 sq. m—as it does in a small exposure situated ten meters east of this larger one. Fifty meters farther on to the east there occurs hornblende-bearing gneiss-granite.

The talc schist of Niskasuo is dark gray, fine-grained and largely lacking in orientation. Over half the rock is talc, in addition to which it contains

Table IV. Serpentine-bearing talc schist. Pohjavaara (84), Sotkamo. Anal. H. B. Wiik.

% by weight		Molecule ratio x 1 000
SiO_2	55.14	918
TiO_2	0.03	
Al_2O_3	1.22	2
Fe_2O_3	1.20	8
FeO	3.89	54
MnO	0.05	1
MgO	31.46	780
CaO	0.00	
CO_2	0.00	
H_2O +	6.56	364
H_2O —	0.03	
Total	99.58	

antigorite and a little chlorite as well as, in contrast to other talc schists, apatite. The opaque minerals occur as grains of as much as 4 mm in diameter and as a network of very small grains. The talc is fine-flaked. The antigorite replaces the chlorite and penetrates the opaque grains. The edges of the antigorite flakes are not sharp, for the antigorite is undergoing alteration into talc. The antigorite's $2V\alpha = 59° — 63°$. The chlorite has both antigoritized and steatitized. The chlorite is pleochroic: $\alpha = \beta =$ very pale bluish green, $\gamma =$ very light brown. The interference color is olive brown, longitudinal direction negative and $2V\gamma \sim 15°$. There are some apatite grains 0.4—0.8 mm in diameter into which narrow chlorite flakes have penetrated. It is from the powder photograph taken with a Debye-Scherrer camera that the mineral has been identified as apatite.

The talc schist of Havukkavaara (4) also contains antigorite, but in this rock the process of antigoritization followed the steatitization. The long (0.5—1.5 mm), thin and needle-shaped antigorite flakes penetrate the tremolite and chlorite as well as talc.

The antigorite, which belongs to the chlorite category, generally occurs in the form of thin greenish flakes. The flakes have in many cases crystallized radially and twinned on 001; this is also a prominent cleavage direction. In certain instances the antigorite reveals a 100 cleavage running transversely to the trend of the flakes. In thin section the antigorite is colorless, in some cases slightly greenish. The interference color is dark gray, nearly black. The Havukkavaara antigorite's $2V\alpha = 53°$.

The chemical composition of the serpentine-bearing talc schist is presented in Table IV. The analysis was made from the serpentine-bearing talc schist of the afore-described (p. 15) Pohjavaara deposit. In conformity with the serpentine content, that of SiO_2 is smaller than in pure talc schist and the water content correspondingly larger.

Table V. Chlorite-rich talc schist. Kinttumäki (52), Kuusjärvi. (Wiik 1953, p. 48, Anal.3).

	% by weight	Molecule ratio x 1 000
SiO_2	54.52	908
Al_2O_3	2.49	24
Fe_2O_3	0.48	3
FeO	3.53	49
MgO	30.68	761
CaO	0.00	
CO_2	2.05	47
H_2O +	5.62	312
H_2O —	0.00	
Cr_2O_3	0.36	2
Total	99.73	

CHLORITE-RICH TALC SCHIST

According to Table I (p. 16), the chlorite-rich talc schists occur for the most part in gneiss-granite and schist areas. The same table shows that the talc schists are mostly amphibole- and chlorite-bearing mixed types.

Only two of these occurrences may be regarded as intrusive rocks of clearly ultramafic origin. One involves the amphibole- and chlorite-rich marginal zones of the lumps of asbestos rock at Paakkila (103) and the other the chlorite-rich talc schist dikes connected with the chrysotile-bearing serpentine rock lump at Kinttumäki (52).

When the large lump of serpentine rock at Kinttumäki was quarried, two talc schist dikes were met with. The one, nearly two meters thick, formed a slab narrowed at the edges and embedded in the contact zone between the serpentine rock and mica schist. The other talc schist dike ran across the lump, and it exhibited shear planes worn by movements of the rock. These talc schist dikes consist mostly of pure talc. In addition to the talc, they contained an abundance of large-flaked chlorite in spots. Moreover, there are sporadic occurrences of magnesite as well as large grains of pyrrhotite and small ones of pentlandite and chalcopyrite. The chlorite flakes are as much as 5 mm long and appear twisted and colorless in thin section. The longitudinal direction of the flakes is negative. The interference color is bluish gray. The optical character is positive, $2V\gamma = 45°$, $\alpha = 1.574$, $\gamma = 1.585$ and $\gamma - \alpha = 0.011$. The properties would apply to clinochlore.

A chemical analysis of the chlorite-rich talc schist of Kinttumäki is available, Table V. The CO_2 content is due to the presence of a few magnesite grains.

Most of the chlorite-rich talc schists occur in association with amphibolites and hornblende schists. Two such occurrences are in the schist area, the rest in the gneiss-granite area.

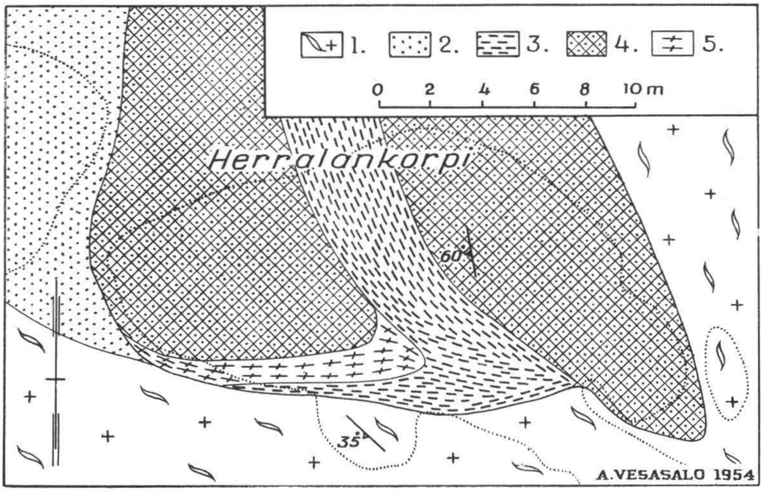

Fig. 10. Sketch of Herralankorpi (18) talc schist and soapstone occurrence in commune of Nurmes. 1. Gneiss-granite, 2. Amphibolite, 3. Hornblende schist, 4. Soapstone, 5. Talc schist.

The occurrences of the schist area are the already mentioned amphibole-bearing ones at Portinkallio (69) and Keima (70), which appear to be skarn formations by origin. The occurrences of the gneiss-granite area are apparently originally hornblende-rich gabbroid rocks, in which talc schist evolved as the result of steatitization. Most of them also contain amphibole relicts.

An example of such an occurrence is Herralankorpi (18). It is situated in the village of Höljäkkä, in the commune of Nurmes, some three kilometers to the southwest from the Mätäsvaara depot, on the south side of Konnanvaara, near the east end of the Herralankorpi meadows, in the southeastern part of the approximately 300-meter-long NW-SE hill.

On the southern side of the occurrence there is hornblende-bearing gneiss-granite (Fig. 10). Between the gently sloping gneiss-granite and the ultramafic formation, there occurs a thin hornblende- and epidote-bearing biotite blackwall. Beside this blackwall is a narrow pocket of hornblende schist, which grades over into talc schist. The talc schist is present only in a narrow zone at the edge of the soapstone comprising the central portion of the occurrence. In addition to the talc, the talc schist contains some opaque grains as well as considerable chlorite and partly steatitized amphibole relicts. The middle of many of the amphibole laths is light green and weakly pleochroic, but the optical properties ($2V\alpha = 85°$ and $c \wedge \gamma = 16°—18°$) correspond to tremolite. The occurrence further contains magnesite- and dolomite-bearing, chlorite-rich soapstone, which is divided into two parts by hornblende schist. On the western side of the soapstone is a dense amphibolite, which farther on turns coarse in grain.

Found in the chlorite-rich talc schists associated with the hornblende-bearing rocks have been magnetite, pyrrhotite and pyrite. The soapstone occurring in association with the talc schist of Herralankorpi also contains pentlandite.

SOAPSTONES

The chief minerals of the soapstones are carbonate and talc. Carbonate is a distinguishing mineral of these rocks, its share of the total most commonly varying between 40 and 60 per cent by weight. In certain instances the proportion of carbonate may be higher and in other instances lower but seldom under 10 per cent by weight.

With respect to their mode of occurrence, soapstones deviate from talc schists in that they form in many instances long sequences running parallel to the schistosity of the country rocks either as independent deposits or, more usually, in association with serpentine rocks.

Such long sequences of ultramafic rocks occur particularly in mica schist areas. Sequences of this kind can often be followed in the same horizon for several kilometers, as witness the Kalliola—Haaralanniemi (64)—Viitaniemi occurrence at Polvijärvi (Fig. 11, p. 36). According to the same map, next to the main horizon there are ultramafic rocks also in other horizons. The formation of Haaralanniemi—Viitaniemi contains, in addition to the serpentine rock, soapstone and talc schist as well as hornblende peridotite, which are separated from each other by pockets of phyllite, quartzite and tremolite.

Soapstone has often been seen to occur in horizons composed of similar ultramafic rocks also in the schist area of Kajaani. Fig. 12 (p. 37) presents a map of the ultramafic sequences of the Talvivaara area in Sotkamo commune. In this area ultramafic rocks are to be found in at least five parallel sequences. The horizon situated on the northeastern side of Hyllävä contains nothing but serpentine rock, whereas the other ones contain soapstone, some of them with talc schist in addition. Fig. 13 (p. 37) shows a cross section of the locality marked in the preceding picture. At the margins of the Uutela horizon there is rusty phyllite; also the Kivikallio and Pirttimäki sequence contains phyllite as well as quartzite and basal schist. A comparison of these sequences with the Kalliola—Haaralanniemi—Viitaniemi sequence (Fig. 11) reveals a clear uniformity between them. Ultramafic rocks have penetrated into horizons where within a unified schist area there are zones of weakness composed of pockets of several different rocks.

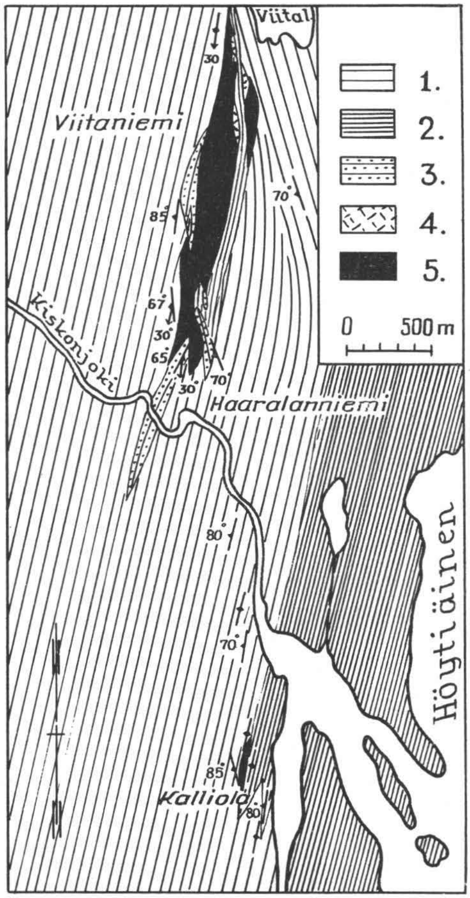

Fig. 11. Map of ultramafic rock sequences at Viitaniemi, on the Kalliola—Haaralanniemi (64) site, in the commune of Polvijärvi, partly after a map drawn by E. Aurola. 1. Mica schist, 2. Phyllite, 3. Quartzite, 4. Hornblende peridotite, 5. Serpentine rock, soapstone and talc schist.

In addition to carbonate and talc, the soapstones are likely to contain appreciable amounts of certain other minerals. On the basis of their mineralogical composition, I have divided the soapstones into four subtypes:

a) Pure soapstones, which consist mainly of carbonate and talc.

b) Amphibole-bearing soapstones, which, in addition to carbonate and talc, contain amphibole minerals.

c) Serpentine-bearing soapstones, which, in addition to carbonate and talc, contain serpentine.

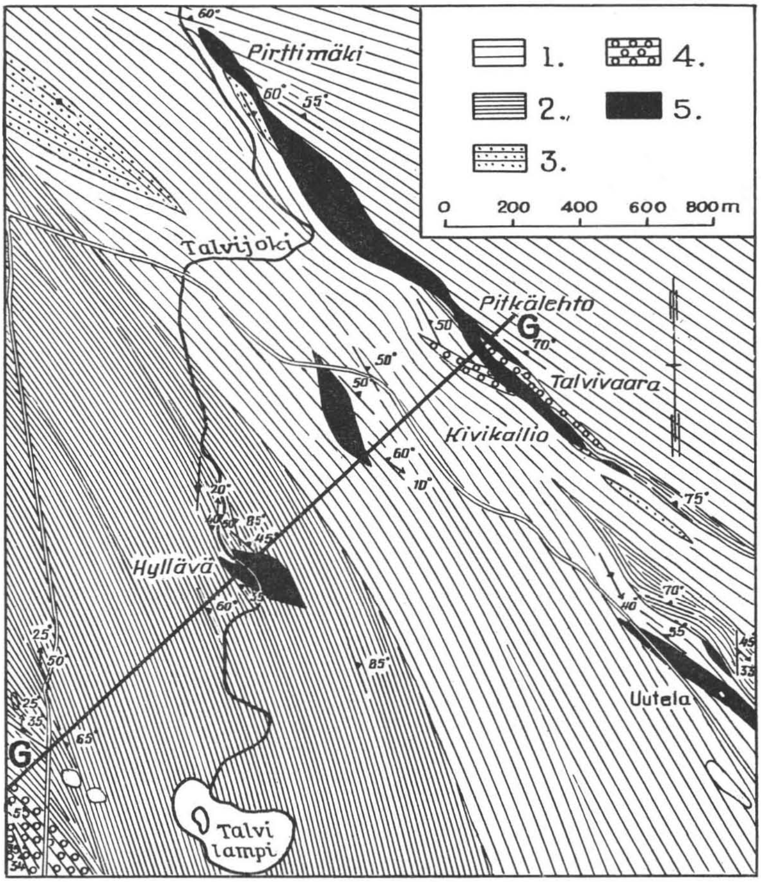

Fig. 12. Map of the ultramafic rock sequences in the Talvivaara area (77—81) of the commune of Sotkamo. 1. Mica schist, 2. Phyllite, 3. Quartzite, 4. Basal schist, 5. Ultramafic rock.

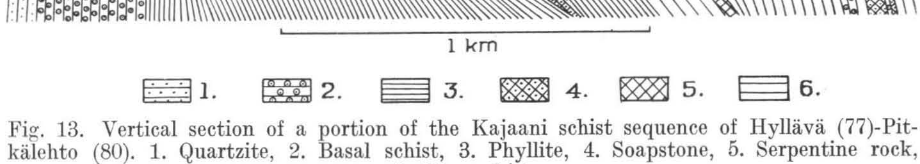

Fig. 13. Vertical section of a portion of the Kajaani schist sequence of Hyllävä (77)-Pitkälehto (80). 1. Quartzite, 2. Basal schist, 3. Phyllite, 4. Soapstone, 5. Serpentine rock, 6. Mica schist.

Table VI. Classification of soapstone occurrences by type and their geological situation.

Soapstone types	Gneiss-granite area	Schist areas	Total
Occurrences investigated	22	68	90
Pure soapstones	3	39	42
Amphibole-bearing soapstones	8	13	21
Serpentine-bearing soapstones	5	12	17
Chlorite-rich soapstones	15	22	37
Mixed type, amphibole and serpentine	1	—	1
Mixed type, amphibole, serpentine and chlorite	—	—	—
Mixed type, amphibole and chlorite	5	10	15
Mixed type, serpentine and chlorite	2	3	5

d) Chlorite-rich soapstones, which, in addition to carbonate and talc, contain an abundance of chlorite.

Table VI presents the division of the soaptone deposits into different types and their geological situation. Soapstones occur only in gneiss-granite and schist areas. Among mixed types, those containing amphibole and chlorite are the most common.

PURE SOAPSTONES

It will be seen from Table VI that nearly half the soapstone deposits contain pure soapstone. It will further be seen that the pure soapstone deposits are nearly all situated in schist areas. Accordingly, both pure talc schists and pure soapstones are characteristic of schist areas.

In the pure soapstones of the gneiss-granite area, magnesite, dolomite and calcite have been met with, as shown in Table VII. In corresponding occurrences of the schist sequences, there have been only magnesite and dolomite, the former, in particular, being a carbonate characteristic of the pure soapstones of the schist sequences.

Table VII. Occurrence of carbonate minerals in the pure soapstones of the gneiss-granite area and the schist sequences.

Sample	Magnesite	Dolomite	Calcite
Pure soapstones of the gneiss-granite area	2	2	1
Main portion of carbonate	1	1	1
Pure carbonate	—	—	1
Pure soapstones of schist sequences	35	20	—
Main portion of carbonate	30	9	—
Pure carbonate	19	4	—

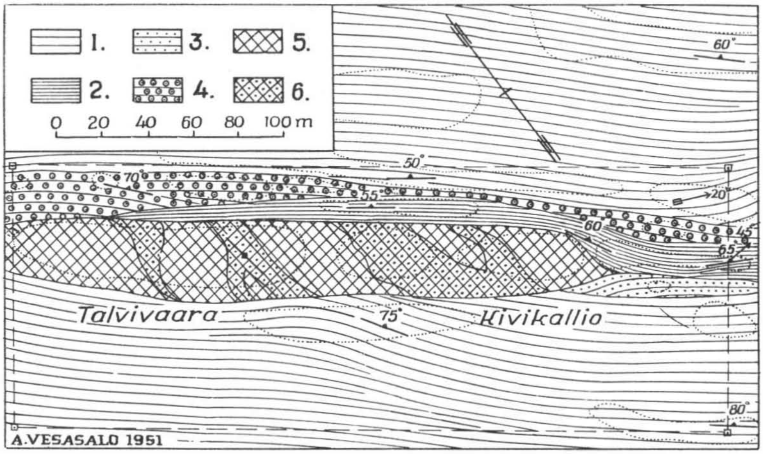

Fig. 14. Map of the soapstone and talc schist occurrence of Kivikallio—Talvivaara (79) in Sotkamo commune. 1. Mica schist, 2. Phyllite, 3. Quartzite, 4. Basal schist, 5. Serpentine rock, 6. Soapstone and talc schist.

GNEISS-GRANITE AREA

In the gneiss-granite area pure soapstone is to be found in only three deposits. In two instances the deposits are associated with hornblende-rich mafic rocks and in one instance (Koivula, 26) the soapstone occurs within the gneiss-granite as a solitary lump. Between the gneiss-granite and the soapstone is a blackwall of fine-flaked chlorite a few centimeters wide. Besides chlorite, the blackwall contains a little talc and small sphene and apatite crystals. At the edge of the blackwall, on the side of the gneiss-granite, there is hornblende.

SCHIST SEQUENCES

By the greatest part of the pure soapstones of the schist areas are associated with serpentine rocks. The soapstones generally occur in the marginal parts of the serpentine rock massifs between the serpentine rock and the schist.

Wherever the serpentine rock sequence is narrow, as, for example, at Talvivaara (79), Sotkamo commune, the soapstone might have evolved in tectonic zones cutting across the sequence (Fig. 14).

At Paltamo, in the schist area of Kajaani, there is an abundance of ultramafic rocks, but they do not form such long sequences parallel to the schistosity as at Sotkamo. At Paltamo there are large, more or less roundish

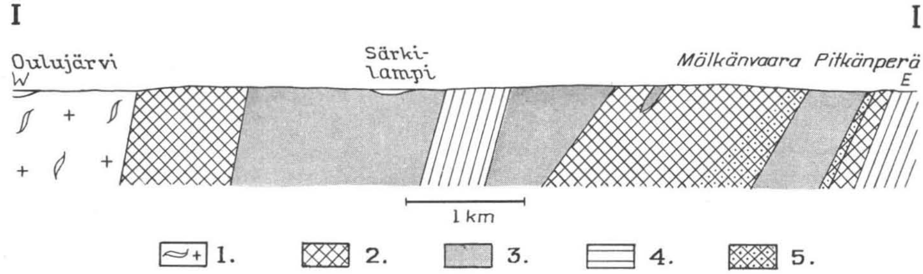

Fig. 15. Vertical section of Kajaani schist sequence in locality of Särkilampi—Pitkänperä (91). 1. Gneiss-granite, 2. Serpentine rock, 3. Metabasite, 4. Mica schist, 5. Soapstone.

metabasite and metagabbro massifs, which in many cases are associated with serpentine rock. Along the borders of the serpentine rock massifs, pure soapstone occurs in many places. Metabasites are schistose, fine-grained, mafic rocks, which may be of magmatic or sedimentogeneous origin. The metagabbros are generally coarse-grained and weakly oriented, metamorphosed gabbros. Fig. 15 presents a vertical section, I—I, from the area of ultramafic rocks at Paltamo. At the margins of the serpentine rock massifs of Mölkänvaara (92) and Pitkänperä (91), it contains soapstone.

Mölkänvaara consists of a serpentine rock massif about 2 km in diameter, which rises above the elevation of the surrounding country. The serpentine rock is surrounded completely by metabasite. At the northeastern edge of the massif there is soapstone. There are many outcrops, which makes it easy to draw the boundaries of the soapstone deposit, the length of which is some 450 m and the breadth 100—150 m (Fig. 16, p. 41).

The dip of the schistosity of the metabasite occurring next to the soapstone varies from 50° to 70° SW. The grain size of the rock is 1—2 mm and the color dark greenish gray or light gray, depending on the color of the hornblende. The hornblende is partly chloritized. Alongside the highway occurs very light-colored and fine-grained metabasite, which in places abounds in chlorite. The contact between the metabasite and the ultramafic rocks is not visible.

The serpentine rock of Mölkänvaara is mostly unoriented, and only at certain points can one notice a schistose appearance. There is quite an abundance of fissures. Near the soapstone the serpentine rock usually contains carbonate grains. Carbonate is also often to be found in fault cracks. The contact between the soapstone and the serpentine rock may be seen at many points. For example, at the southern end of the occurrence there is a sharp contact, in which in places between the rocks on the surface there is a cleft 2—3 m wide. Up to the contact the soapstone is coarse-grained and

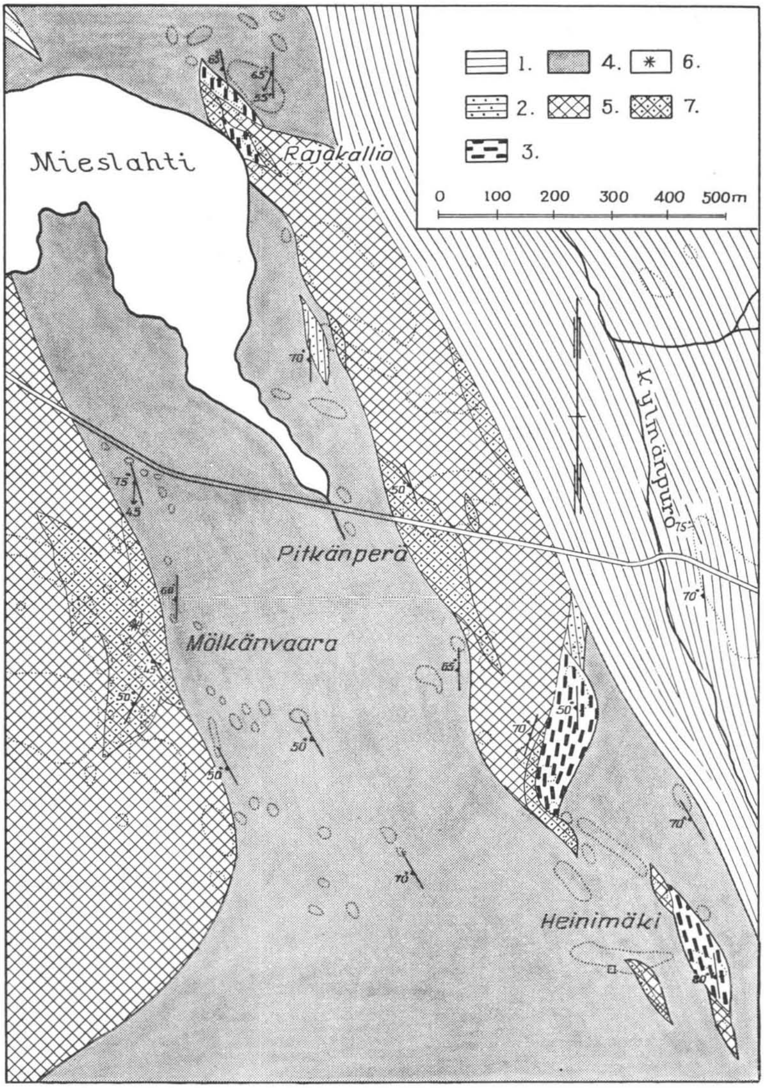

Fig. 16. Map of bedrock in the surroundings of Pitkänperä (90—92) in the commune of Paltamo. 1. Mica schist, 2. Quartzite, 3. Dolomite, 4. Metabasite, 5. Serpentine rock, 6. Amphibole schist, 7. Soapstone.

unoriented. Near the contact the serpentine rock contains magnesite in abundance and a little talc. Magnesite can be found in the serpentine rock as much as 5 m away from the contact, but very little talc. At a distance of a few dozen meters from the contact, there is only a small grain or so of carbonate, and no talc whatsoever any more.

The soapstone works itself underneath the serpentine rock, the dip of the schistosity being 45°—50°. Near the eastern border of the occurrence there is a slight exposure, one side of which consists of soapstone and the other of chlorite-bearing amphibole schist. In another exposure situated nearby the soapstone contains folded pockets of chlorite schist. Diamond drillings carried out on the site have revealed that the soapstone contains such chlorite-schist and pockets of amphibole rock in abundance.

The soapstone of Mölkänvaara is for the most part schistose. In fine-grained spots the carbonate grains are small, whereas in coarse-grained spots they may measure 1—2 cm in diameter. About half the soapstone consists of carbonate, the other half being fine-flaked talc. The talc's $\alpha = 1.542$, $\beta = 1.587$, $\gamma = 1.590$ and $\gamma - \alpha = 0.048$. The chlorite occurs mainly in strongly schistose spots. The carbonate of the soapstones as well as of the adjacent serpentine rock is magnesite.

Magnesite has not been found in the soapstones of Finland in altogether pure form. According to Wiik (1953), the magnesite's ω varies between 1.708—1.738, which corresponds (Winchell 1956, p. 108) to $FeCO_3$ = 5—22 mol-%. According to Wiik's analysis (p. 15), again, in the magnesite of Solansaari (59) $FeCO_3$ = 14.0 mol-%, $MnCO_3$ = 2.1 mol-% and $MgCO_3$ = 85.8 mol-%. The Leskisensuo (21) magnesite's $\omega = 1.707$.

Wiik reports the ω of the dolomite found in three soapstone deposits as varying from 1.685 to 1.695. This corresponds (Winchell 1956, p. 115) to $CaFe(CO_3)_2$ = 6—17 mol-%. The Leskisensuo (21) dolomite's $\omega = 1.681$.

The carbonate determinations dealt with in the present paper have in most cases been made from a single specimen. Accordingly, it is possible that in other parts of the occurrence there may be another carbonate. In the light of a number of determinations made from the same deposits, this probably is not, however, very usual. On the other hand, carbonate dikes occurring in soapstone have often been seen to contain a different kind of carbonate from that in the soapstone itself. The carbonate minerals have been determined from powder patterns obtained with a Philips X-ray diffractometer by applying Cu-radiation with a nickel filter. Judging by the highest peaks of the curves of three carbonate minerals (2 Θ-angles: calcite 29.35°, dolomite 31.0° and magnesite 32.6°), these minerals are quite easy to distinguish from each other. Certain refraction indices determinations made of the carbonates by the immersion method have tallied with the powder pattern determinations.

Talc is the other of the chief minerals, along with carbonate, found in soapstones. In pure, carbonate-poor soapstones the talc content may be as high as 80 per cent, but usually the figure is between 40 and 60 per cent. The talc is an alteration product of other minerals, and in many cases it forms pseudomorphs after earlier minerals. With the exception of the talc dikes, the talc of the soapstones is quite fine-flaked; the length of the flakes generally varies between 0.1 and 1 mm.

The axial angle of the talc of the soapstones is also in most cases so small that the mineral appears uniaxial. Nevertheless, it may be said that $2V = 0°—5°$. Also the refractive indices vary very little. According to Wiik (1953, pp. 15 and 21), in the talc of the soapstone of Solansaari (59) Mg:Fe = 97.5 : 2.5, and in the large talc flakes of Viitala (32) Mg:Fe = 96.2 : 3.8.

In pure soapstones there is mostly very little or no chlorite. In the pure soapstone of Kallioinen (43) there is little fine-flaked chlorite. The mineral is pleochroic: $\alpha = \beta$ = light green, γ = very pale yellowish green, $2V\gamma \sim 2°$, $\alpha \sim 1.588$, $\gamma = 1.592$ and $\gamma—\alpha$ 0.004. The properties apply to + penninite. Dense lumps of chlorite occur in Kylän kivipalsta (58). The chlorite's $2V\gamma \sim 30°$, $\alpha = 1.577$, $\gamma = 1.582$ and $\gamma—\alpha = 0.005$. These properties correspond to those of clinochlore.

Biotite is a common mineral in the contact zones of soapstones, but within the soapstone itself it is rare. Only once have I found biotite in pure soapstone. In the soapstone of Katajalahti (85), there are pleochroic biotite flakes in abundance, being 1—3 mm in diameter and partly steatitized and chloritized. The biotite contains pleochroic rings and small opaque inclusions. The biotite's $2V\alpha = 0°$, $\alpha = 1.594$, $\beta = \gamma = 1.619$ and $\gamma—\alpha = 0.025$.

A lump of grossularite about 1 m in diameter has been met with in the soapstone of Jormua (88). The grossularite occurs in very pure form, being light brownish red in color and with a greasy lustre. The cracks in the mineral contain a little carbonate and chlorite. A little epidote has been brought to light from a chlorite- and carbonate-rich pocket in the same occurrence.

In pure soapstones there are always small amounts of opaque minerals — in exceptional cases over 5 per cent. The grain size is usually 0.5—1 mm, but especially the magnetite grains are in many instances smaller and the pyrrhotite grains larger.

The commonest opaque minerals of pure soapstones are magnetite, pyrrhotite and pentlandite. Magnetite has often been observed to occur as the sole opaque mineral. Pentlandite nearly always is present in association with pyrrhotite, and both minerals are commonly in the same grains. In most cases under such circumstances there is a greater amount of pyrrhotite, but in certain soapstones there is more pentlandite. Pyrite is also rather common, and it ordinarily occurs as large idiomorphic crystals. In certain soapstones small amounts of chalcopyrite are usually found, along with other sulfides, in association with pyrrhotite. In addition to pyrrhotite and pentlandite, the soapstone of Lahnaslampi (83) contains a little melnikovite and abundant bravoite. Starting from its cracks, the pentlandite has altered into bravoite. The soapstone of Jormua (88) has yielded a clump of galena 3—4 cm in diameter. In addition to pyrrhotite, pentlandite, magnetite,

Table VIII. Powder diffraction data of gersdorffite.

1		2	
d	I	d	I
2.82	medium	2.83	4.0
2.52	strong	2.53	6.0
2.31	strong	2.31	5.0
2.00	weak	2.01	1.0
—		1.90	0.5
1.71	strong	1.715	6.0
1.63	weak	—	
1.58	medium	1.55	1.0
1.52	medium	1.518	2.0

1. Gersdorffite. Soapstone. Haaralanniemi (64), Polvijärvi
2. Gersdorffite. Cream Hill, Sudbury, Ontario, Canada

chalcopyrite and pyrite, the soapstone of Juttusuo (63) contains gersdorffite and a trifle nickelite. The nickelite is embedded within the pyrrhotites. Gersdorffite has also been met with in the soapstones of Haaralanniemi (64) and Kohverinsaari (86). It occurs in grains of indefinite shape 1—2 mm long in conjunction with pyrrhotites and pentlandite. The gersdorffite has been identified from powder patterns. The d-values obtained are presented in Table VIII. The same table includes the d-values of the gersdorffite of Cream Hill (Hercourt 1942, p. 83).

According to the analyses, the several constituents of magnesite- and dolomite-bearing soapstones represent the following proportions: SiO_2 = 28—44 % by weight, MgO = 26—35 %, CO_2 = 4—23 %, CaO = 0—5 % and H_2O = 1—6 % by weight. The Fe_2O_3 content is usually under 1 % by weight, but in soapstones with an abundance of magnetite it may be 8 % by weight. The FeO content generally varies between 3 and 9 % by weight.

Table IX (p. 45) presents the chemical composition of typical, pure soapstone.

Whereas in most instances in the genesis of the talc schists the steatitization has been limited to the marginal parts of ultramafic rocks, practically the entire ultramafic rock mass, or at least a large portion of it, underwent alteration with the formation of soapstone. According to Hess (1933, p. 637), the original olivine and pyroxene have first been replaced by amphibole. Usually it is actinolite, but if the original rock contains sufficient aluminum, hornblende is produced. As the temperature drops, the amphibole alters toward tremolite and is replaced by chlorite, with the result that the entire rock is apt to chloritize. However, before this stage is reached, carbonatization and steatitization generally occur. The end product is a carbonate-bearing soapstone in which there may be slight chlorite relicts. If very little

Table IX. Pure soapstone. Horsmanaho (57), Polvijärvi. (Wiik, 1953, p. 48, Anal. 8).

% by weight		Molecule ratio x 1 000
SiO_2	33.61	560
TiO_2	0.04	1
Al_2O_3	0.50	5
Fe_2O_3	0.72	5
FeO	5.33	74
MnO	0.08	1
MgO	33.40	828
CaO	2.28	41
Na_2O } K_2O }	0.16	
CO_2	21.44	487
H_2O +	2.00	111
H_2O —	0.00	
Cr_2O_3	0.13	1
NiO	0.19	3
S	0.62	
	100.50	
— O = S	0.31	10
	Total 100.19	

aluminum is present in the rock, talc and carbonate directly replace the amphibole. Also according to Du Rietz (1935, p. 244), completely altered peridotite represents a talc-carbonate-bearing soapstone with only a few per cent chlorite.

Carbonatization and steatitization are regarded as caused by diluted hydrothermal solutions, and these alterations are interconnected in the genesis of soapstones. Much has been written about the origin of these solutions. Haapala (1936, p. 76) takes the view that the solutions responsible for the carbonatization had absorbed CO_2 from rocks with they had come into contact. In many instances the solutions causing the steatitization process are regarded as deriving from nearby SiO_2-rich intrusive magmas. For example, Čech (1951, p. 88) attributes steatitization to SiO_2-bearing solutions deriving from young, SiO_2-rich, intrusive granite magmas. However, Finnish soapstones are for the most part — especially those situated in schist areas — to be found far from all granites. Apparently, the carbonatization and steatitization of these rocks have been induced by diluted hydrothermal solutions charged with carbon dioxide which originated from the same magma as the ultramafic intrusive rocks.

In the genesis of soapstones carbonatization is a key process. Carbonatization may begin in an ultramafic rock at the fissures. The carbonate replaced olivine and tremolite. The latter phenomenon occurs according to the reaction equation propounded by Eskola (1939, p. 266),

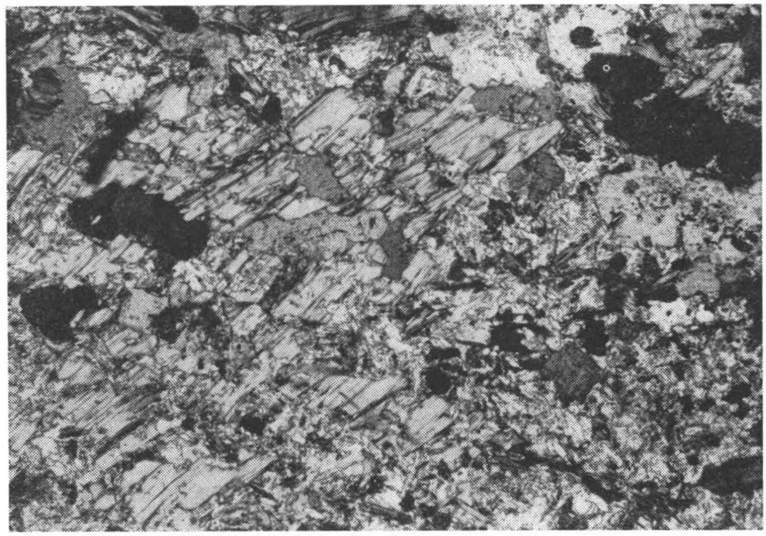

Fig. 17. Chlorite replaced by carbonate. Soapstone. Puravaara (9), Ilomantsi. Nic. +, 50 x.

$$8\ SiO_2 + 5\ \underset{\text{dolomite}}{CaMg(CO_3)_2} \leftrightarrows \underset{\text{tremolite}}{H_2Ca_2Mg_5Si_8O_{24}} + CaCO_3 + 8\ CO_2$$

where the reaction proceeds under the conditions of the green schist facies from right to left.

The released SiO_2 then binds itself to the talc. In the accompanying figure one can see a few talc flakes. The carbonate determined from the soapstone is dolomite.

Fig. 17 presents an interesting event. In this soapstone, chloritization has proceeded rather far, as proved by the large number of chlorite flakes. But carbonate has begun to replace the chlorite, and at the same time the silica released has become bound to the talc. The soapstone contains both dolomite and magnesite.

Pure soapstones are present in the schist areas not only in association with occurrences involving serpentine rocks but also with metabasites, hornblende-schists, tuffites and skarns.

The soapstone of Kallioniemi (96) is embedded in metabasite (Fig. 18, p. 47). The deposit is situated in the commune of Paltamo, on the eastern side of the tip of Kallioniemi, on the southern shore of Mieslahti. Kallioniemi consists of metabasite penetrated by quartz dikes. Along the southeastern border of the rock there occurs folded metabasite, which grades over into talc-bearing amphibole schist. On the other side of the amphibole

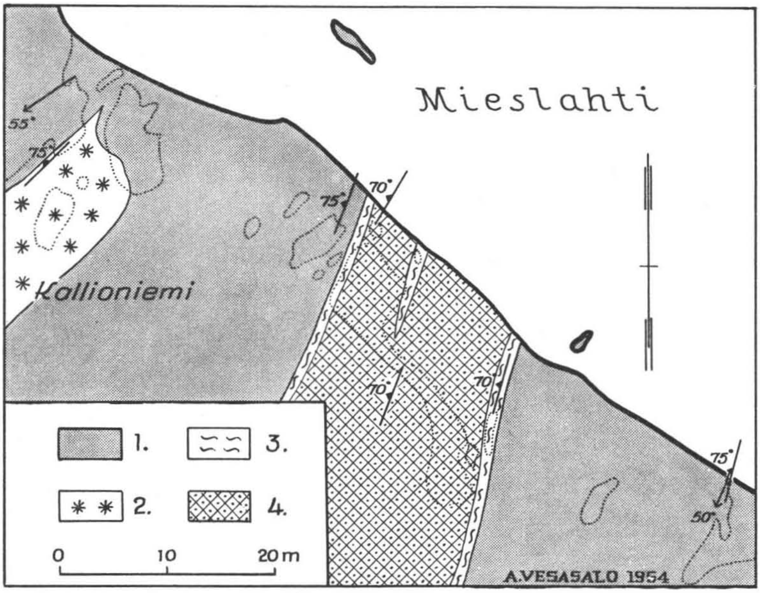

Fig. 18. Map of Kallioniemi (96) soapstone occurrence at Paltamo. 1. Metabasite, 2. Amphibole schist, 4. Soapstone.

schist one again meets with metabasite, in the more schistose portions of which chlorite and tremolite are present. At the contact of the metabasite and the soapstone there is chlorite schist to a breadth of 1 m. On the metabasite side it is quite hard and weakly oriented, but next to the soapstone highly schistose. The chlorite schist contains carbonate stripes. The soapstone forms a mass 20 m broad running parallel to the schistosity, the length of which cannot be determined because of its situation on the shore and its overburden. On the eastern side of the soapstone dense chlorite schist also occurs before the metabasite.

The metabasite is in places quite fine-grained, and frequently it appears to be folded. The folds are likely to contain soapstone. Thus, a short distance toward the southeast from the Kallioniemi occurrence, right on the shore there occurs folded, dense, epidote-bearing metabasite, in which there is a vertical lump of twisted and folded magnesite- and dolomite-bearing soapstone about 10 m long and 1—2 m thick. The soapstone contains chlorite-bearing pockets, and at the edge of the soapstone is tremolite.

The soapstone of Kallioniemi is schistose and coarse-grained. Besides talc, the rock contains considerable magnesite and dolomite. The soapstone contains dolomite lumps 10—20 cm in diameter, many of which are elongated in conformity with the schistosity.

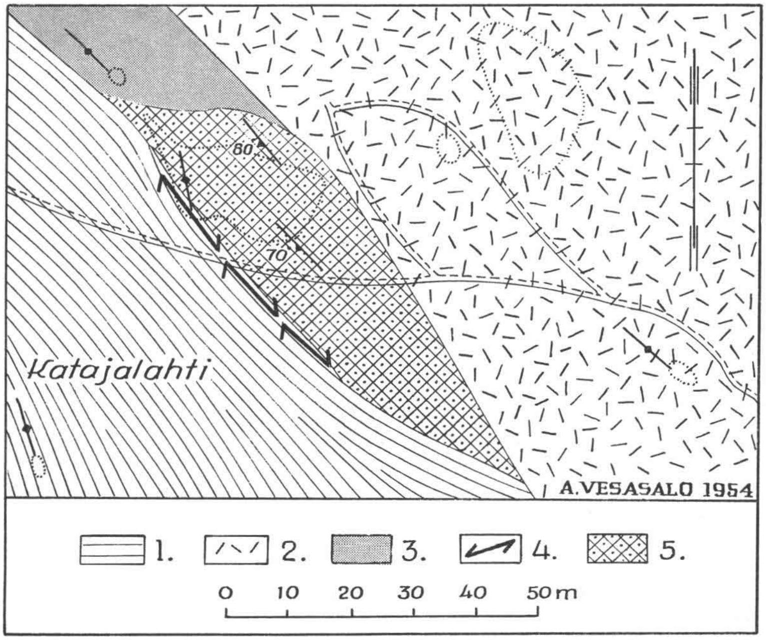

Fig. 19. Map of Katajalahti (31) occurrence at Kuhmo. 1. Mica schist, 2. Hornblende schist, 3. Metabasite, 4. Mica blackwall, 5. Soapstone.

The soapstone of Katajalahti (31), in the village of Katerma, Kuhmo commune, is associated with hornblende schist and metabasite (Fig. 19). The deposit is situated approximately 200 m to the northeast from the farmhouse of Katajalahti, which stands on the shore of Ontojärvi.

The schist area of Kuhmo consists mainly of hornblende schist and metabasites, but in addition there are also occurrences of leptite, mica schist and serpentine rock. At a number of places the serpentine rock is associated with soapstone. The soapstone of Katajalahti deviates from other pure soapstones with respect to its mineralogical composition and habit.

The mica schist occurring on the southwestern side of the Katajalahti soapstone contains abundant quartz in fine- and coarse-grained layers as well as fine-flaked biotite and quantities of small epidote grains. The biotite's $\gamma'—\alpha' = 0.031$. The epidote is rhombic, $2V\gamma \sim 30°$ and $\gamma'—\alpha' = 0.006$. The properties correspond to those of zoisite. Along the southwestern margin of the soapstone at the edge of the quarry, there is a dense blackwall of chlorite, which contains 3—5 cm broad dolomite-bearing intercalations running parallel to the schistosity. The chlorite's $2V\gamma \sim 10°$, $\gamma = 1.605$, $\gamma = 1.607$ and $\gamma—\alpha = 0.002$. These properties apply to rumpfite. Between the chlorite occurrence and the soapstone there is a dense, sulfide-bearing blackwall of biotite 10—20 cm broad. These blackwalls are thus situated in unusual sequence. The biotite flakes are only 0.3—0.6 mm long and the biotite's $2V\alpha = 0°$. On the northwest side of the soapstone deposit there is fine-grained carbonate-bearing metabasite. In addition to pleochroic hornblende and zonal plagioclase, the rock contains biotite and chlorite flakes and small epidote grains. On the eastern side of the soapstone there is hornblende schist. In addition to weakly pleochroic hornblende, the rock contains a little carbonate and, as an alteration product of horblende, chlorite. Opaque pigment is present at the margins of the altered hornblende laths.

The soapstone of Katajalahti is dark green, distinctly schistose and coarse-grained. The rock contains considerable dolomite as large grains and as dikes running in different directions. Talc ($2V\alpha \sim 4°$) is also present in abundance as large flakes and as a fine mass. Deviating from other Finnish soapstones, the Katajalahti occurrence contains considerable amounts of partly both chloritized and steatitized pleochroic biotite flakes measuring between 1 and 3 mm in length. The flakes also contain pleochroic rings and small opaque inclusions. The biotite's $2V\alpha = 0°$, $\alpha = 1.594$, $\beta = \gamma = 1.619$ and $\gamma—\alpha = 0.025$. The chlorite is fine-flaked, $2V\gamma \sim 20°$. Here and there the soapstone contains pyrite crystals a few mm in diameter as well as small grains of magnetite, pyrrhotite and pentlandite.

Many of the rocks of the Suomussalmi schist sequence, which is an extension of the Kuhmo schist sequence, are characterized by a volcanic origin. Of the mafic vulcanites, the tuffites occur most extensively. Serpentine rocks and soapstones are for the most part associated with tuffites. Of the soapstones occurring in tuffites, the country rocks of the Portti occurrence (44) can be seen most clearly (Fig. 20, p. 50).

The Portti occurrence is situated at Ruhtinaansalmi, Suomussalmi commune, alongside the Hallasenaho-Juntusranta highway, 12 km from Juntusranta. The soapstone deposit is approximately 160 m long and 60 m wide.

At the site of the soapstone deposit there is an outcrop on the southern side of the road, at the eastern margin of which there is fine-grained biotite- and quartz-bearing tuffite containing quartz phenocrysts. Toward the other side of the outcrop there occurs a rusty area containing pyrite bands and grains of pyrrhotite as well as quartz and dolomite. Next to it is a black, dense, carbonaceous phyllite. Following the rusty intercalation one again meets with fine-grained tuffite. This soon grades over into carbonate-bearing tuffite, in which the biotite of the fine-flaked mafic mass has for the most part chloritized and thereafter steatitized. Outwardly this rock looks quite the same as the soapstone of Portti. The same rock occurs at the end of the soapstone on the northern side of the highway.

On the western side of the soapstone occurrence, the tuffite is slightly

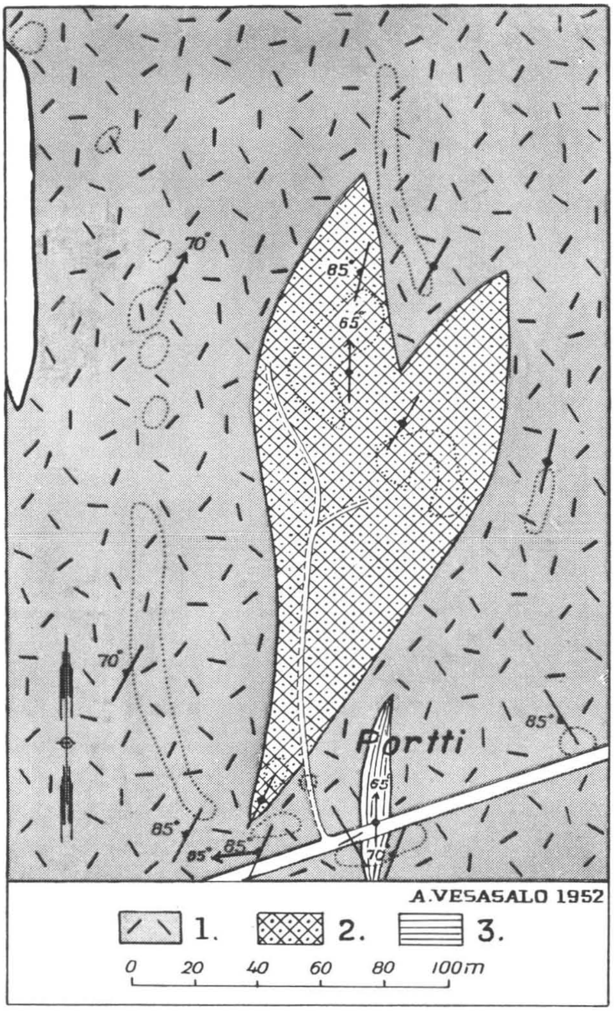

Fig. 20. Sketch of Portti (44) soapstone deposit, Suomussalmi commune. 1. Tuffite, 2. Soapstone, 3. Phyllite.

harder than that just mentioned, for only a small part of its biotite has chloritized and the talc content is low. However, this rock also contains carbonate. In the other outcrop the rock contains abundant chlorite; only a few scattered biotite flakes remain unaltered. In places there are talc flakes in abundance. On the northern side of the soapstone deposit there is a large tuffite outcrop. The tuffite contains narrow fuchsite-bearing dolomite bands. The fuchsite's $\alpha \sim 1.575$, $\gamma \sim 1.608$ and $\gamma—\alpha \sim 0.033$.

The soapstone of Portti is greenish gray, coarse-grained and schistose.

The magnesite content of the soapstone is throughout considerable, making the rock rather hard. The talc is a fine-flaked mass. Fine-flaked chlorite occurs as thin stripes running parallel to the schistosity. For the most part the magnesite occurs as light brown layers likewise situated parallel to the schistosity. There is a small amount of magnetite grains. Here and there in shear surfaces a few centimeters broad the soapstone contains pure, green talc schist and large, brown carbonate crystals. Matisto (1958, p. 80) has found spherical quartz lumps 5—25 cm in diameter in the soapstone.

A few of the other pure soapstone deposits of the Suomussalmi schist area occur in tuffite without being accompanied by serpentine rock. Since in between the soapstone and the unaltered tuffite at Portti there occurs partly carbonatized and steatitized tuffite, one might consider it possible that these soapstones evolved out the tuffite as it underwent carbonatization and steatitization. The surplus quartz was then left in the soapstone as spherical lumps.

Among the occurrences associated with skarn that contain pure soapstone, mention has already been made of Kupinpuro (62), of which a map has been drawn (Fig. 9, p. 29). The deposit is situated at Kupinpuro, in the commune of Polvijärvi, about 150 m to the east from the Joensuu highway. Exposures can be seen along the edges of the ditch. Proceeding along the ditch eastward, one will observe at the margin of the fine-grained, black mica schist a thin layer of tremolite- and carbonate-bearing quartzite, which before the soapstone is reached turns into a fine-grained and folded rock. Between the quartzite and the soapstone there is a bright green tremolite without any mica blackwalls. After the soapstone horizon there follow tremolite skarn and tremolite-bearing quartzite as well as a dolomite layer with talc schist intercalations. The dolomite contains large tremolite crystals, a small amount of talc as an alteration product of tremolite and an abundance of opaque pigment. On the other side of the dolomite is quartzite, inside which there is a narrow soapstone layer.

The soapstone of Kupinpuro is gray, indistinctly schistose and coarse-grained. In addition to talc, it contains both dolomite and magnesite as well as a small amount of chlorite. Dolomite dikes a few cm wide are to be observed in it. This soapstone deposit is so closely bound up with a skarn formation that it may be regarded as steatitized skarn. Accordingly, it represents pure soapstone of sedimentogeneous origin.

AMPHIBOLE-BEARING SOAPSTONES

According to Table VI (p. 38) amphibole-bearing soapstones occur in both gneiss-granite and schist areas. The majority of the deposits are situated, however, in schist areas.

Table X. Occurrence of carbonate minerals in the amphibole-bearing soapstones of the gneiss-granite area and schist sequences.

Sample	Magnesite	Dolomite	Calcite
Amphibole-bearing soapstones of the gneiss-granite area	1	5	2
Main portion of carbonate	1	5	2
Pure carbonate	1	5	2
Amphibole-bearing soapstones of schist sequences	3	13	—
Main portion of carbonate	2	11	—
Pure carbonate	—	10	—

In contrast to pure soapstones, dolomite is more commonly present than is magnesite in amphibole-bearing soapstones (Table X). This is to be clearly seen especially in the occurrence of schist sequences. Calcite alone has been met with in two of the occurrences in the gneiss-granite area.

GNEISS-GRANITE AREA

Of the amphibole-bearing soapstones of the gneiss-granite area, only one occurrence (Haukkavaara, 4) is associated with serpentine rock, all the others being bound up with hornblende schists. In many cases the hornblende schist can be observed to grade over into soapstone, which, in addition to carbonate and talc, then contains hornblende relicts. Soapstone of this kind occurs at, for example, Saunaniemi (11).

The Saunaniemi soapstone deposit is situated on the shore of Savilahti at Ahmovaara, Juuka. The gneiss-granite with its amphibolite bands grades over in this locality into hornblende schist and this, in turn, into soapstone-bearing hornblende relicts.

In addition to the hornblende, the hornblende schist contains chlorite, epidote and opaque pigment. Alongside the soapstone, a substantial portion of the hornblende has undergone chloritization; but also the processes of carbonatization and steatitization have made headway in it. The hornblende's $c \wedge \gamma = 18°$ and $2V\alpha = 72°$. This rock turns into soapstone as the contents of talc and carbonate increase and that of hornblende decreases.

The soapstone of Saunaniemi is greenish gray, unoriented and dense. It contains numerous talc dikes. Also present in it are fine-grained dolomite and fine-flaked chlorite and talc as well as, here and there, hornblende relicts 0.2—0.5 mm long. The hornblende's $c \wedge \gamma = 16°$, $2V\alpha = 75°—80°$, $\alpha = 1.615$, $\gamma = 1.639$ and $\gamma—\alpha = 0.024$. The soapstone has an abundance of small-grained magnetite as well as a scattering of pyrite and chalcopyrite.

Tremolite-bearing soapstone has also been found in the gneiss-granite area. Such an occurrence is at Leskisensuo (21), situated in the village of Kotila, Puolanka, roughly one kilometer to the northwest from Rakennusjärvi.

About 50 m to the north from Lehtojoki, on the western side of the sporadically oriented granite situated in the gneiss-granite, near the border of the Kajaani schist area, there is a soapstone exposure approximately 10 m long. Immediately alongside the granite on the southern side of the soapstone, there is an occurrence of hard, green hornblende schist, which in addition to the hornblende contains a considerable amount of chlorite, some talc flakes and a trifle carbonate and opaque grains.

The greatest portion of the soapstone outcrop contains a gray, coarse-grained and indistinctly oriented variety of the rock. Over half of this soapstone consists of talc, the flakes are 0.2—0.5 mm long, $2V\alpha \sim 2°$. Dolomite is present in abundance, and the grains are as much as 5 mm in diameter. Opaque grains, chlorite, talc and tremolite relicts with a simultaneous extinction occur in it as inclusions. Chlorite is present abundantly in the soapstone, also mixed in with the talc. The chlorite is weakly pleochroic, $2V\gamma \sim 15°$, $\alpha = \beta =$ light green, $\gamma =$ colorless. Here and there in the soapstone there are thin tremolite crystals 1—2 cm long. The tremolite crystals are bright, and many of them have twinned on 100. The tremolite is only slightly steatitized, mainly starting from its transverse fissures. Opaque grains are contained in the tremolite as inclusions. The tremolite's $c \wedge \gamma = 14°$, $2V\alpha = 80°$, $\alpha = 1.609$, $\gamma = 1.634$ and $\gamma - \alpha = 0.025$.

Right next to the granite, the soapstone is distinctly schistose and darker than the rock described in the foregoing. The talc flakes are slightly longer than in the gray soapstone. The talc's $\alpha = 1.542$, $\beta = 1.585$, $\gamma = 1.590$ and $\gamma - \alpha = 0.048$. The dolomite grains are 0.5 to 1.5 mm in diameter. This soapstone likewise contains tremolite. Some of the tremolite laths are partially steatitized. The chlorite content is higher than in the gray type. The chlorite is pleochroic: $\alpha = \beta =$ light green, $\gamma =$ very faintly yellowish green, $2V\gamma \sim 0°$. These properties as well as the indices of refraction with respect to the talc apply to +penninite. The chlorite is partially steatitized. The soapstone contains a small amount of opaque grains.

Pure soapstone occurs at Leskisensuo, too, having been met with between granite outcrops some 100 m NNE of the occurrence just described as well as at the bottom of a nearby ditch.

Tremolite occurs in a few of the other soapstone deposits in the gneiss-granite area as well. In the soapstone of Kainula (27), the tremolite relict's $c \wedge \gamma = 13°$, $2V\alpha = 78°$, $\alpha \sim 1.609$, $\gamma = 1.635$ and $\gamma - \alpha \sim 0.026$, while in the occurrence at Havukkavaara (4), the tremolite's $c \wedge \gamma = 14°$, $2V\alpha = 80°$, $\alpha \sim 1.617$, $\gamma = 1.643$ and $\gamma - \alpha \sim 0.026$.

Table XI. Amphibole-bearing soapstone. Kainula (27), commune of Iisalmi. Anal. P. Ojanperä.

% by weight		Molecule ratio x 1 000
SiO_2	39.15	652
TiO_2	0.28	4
Al_2O_3	5.09	50
Fe_2O_3	4.69	29
FeO	5.32	74
MnO	0.21	3
MgO	24.70	213
CaO	6.06	108
Na_2O	0.23	4
K_2O	0.00	
P_2O_5	0.02	
CO_2	7.09	161
H_2O +	6.94	385
H_2O —	0.06	
Cr_2O_3	0.18	1
NiO	0.22	3
Total	100.24	

Almost all the amphibole-bearing soapstones of the gneiss-granite area contain considerable amounts of chlorite, most commonly occurring in fine flakes. The soapstone of Kainula (27) contains both small and large chlorite flakes. The large flakes contain pleochroic rings. This chlorite's $2V\gamma \sim 10°$, $\alpha > 1.590$ and $\gamma > 1.590$. These properties apply to rumpfite.

The amphibole-bearing soapstones associated with gneiss-granite have been observed to contain not only the aforementioned magnetite, pyrite and chalcopyrite but also pyrrhotite and pentlandite.

The chemical composition of the amphibole-bearing soapstone present in the gneiss-granite of Kainula (27) is presented in Table XI. The rock also contains an abundance of chlorite, which accounts for the high Al_2O_3 content.

SCHIST SEQUENCES

The amphibole-bearing soapstones occurring in the schist sequences can also be classified according to origin.

Some of the soapstones situated in the Kuhmo schist sequence are associated with hornblende-rich metabasites. The metabasite has carbonatized and steatitized in places, causing soapstone to evolve. Such an occurrence is to be found at Riihijoki (41), in the vicinity of Tapanivaara, Hyrynsalmi commune. Embedded in fine-grained and schistose metabasite are two shallow soapstone outcrops. Near the soapstone contact in the metabasite are small carbonate grains. The soapstone of Riihijoki is greenish gray, coarse-grained and schistose. It contains fine-flaked talc and chlorite in bands running parallel to the schistosity. There is an abundant content of dolomite as narrow stripes or individual grains. The soapstone includes magnetite grains as well as a scattering of tremolite laths. The tremolite's $\alpha = 1.615$, $\gamma \sim 1.638$ and $\gamma - \alpha \sim 0.023$.

Amphibole-bearing soapstone deposits associated with metabasite also occur at Nunnanlahti, in the schist area of Joensuu (Vesasalo 1960, map on p. 29). These should be distinguished from the pure soapstone associated with the serpentine rocks at Nunnanlahti. Amphibole-bearing soapstones are situated in the metabasite area to the southwest of the serpentine sequence. From among these deposits, Pilkkavaara (67) has been taken here as an example for discussion.

On the northern edge of the great metabasite outcrops at the bend in the river at Pilkkavaara, there are two soapstone quarries. Near the soapstone is fine-grained metabasite, which within a span of a single meter grades over into carbonate-bearing anthophyllite schist. Besides anthophyllite the rock contains abundant dolomite, present principally as stripes running parallel to the schistosity, as well as fine-flaked chlorite as thin, twisted veins and some small talc flakes. Quite at the margin of the soapstone deposit the anthophyllite schist is highly schistose and has convex slickensides. The anthophyllite schist passes very abruptly into soapstone.

The soapstone of Pilkkavaara is greenish gray and distinctly schistose. The carbonate is dolomite. Fine-flaked talc and chlorite occur in approximately equal amounts. Fine-flaked talc and chlorite-rich bands alternate. The chlorite bands contain opaque grains in abundance. Both anthophyllite and tremolite are present in this soapstone. The anthophyllite's $2V\alpha = 76°$, $\alpha = 1.616$ and $\gamma > 1.645$; the tremolite's $c \wedge \gamma = 12—14°$.

The majority of the amphibole-bearing soapstone met with in the schist areas are associated with the hornblende schist occurring within the quartzite. The hornblende schist forms a narrow sill in the quartzite, one parallel to the schistosity of the latter. Certain similar occurrences have already been mentioned in connection with the talc schists, and they may be regarded as skarn formations. Deposits of this kind have been found particularly in the quartzites of the Kajaani schist area. The contact between the quartzite and the soapstone is visible in only one place, namely, Portinkallio (69), where there is an occurrence of amphibole schist containing a small amount of biotite and a considerable amount of chlorite. The schist is featured by numerous chlorite-bearing slickensides.

At Jormaskylä, in the commune of Sotkamo, about 1 km to the SEE from the Väyryvaara farmhouse, there is, embedded in quartzite, a deposit of soapstone, which grades over into chlorite-bearing hornblende schist. The Väyryvaara (72) soapstone is gray, fairly hard, unoriented and coarse-

Table XII. Amphibole-bearing soapstone. Väyryvaara (72), Sotkamo. Anal. P. Ojanperä

	% by weight	Molecule ratio x 1 000
SiO_2	43.21	720
TiO_2	1.01	13
Al_2O_3	5.42	53
Fe_2O_3	0.90	6
FeO	8.82	123
MnO	0.29	4
MgO	22.17	550
CaO	6.70	120
Na_2O	0.22	4
K_2O	0.00	
P_2O_5	0.16	1
CO_2	4.81	109
H_2O +	6.04	335
H_2O —	0.07	
Cr_2O_3	0.11	1
NiO	0.17	2
	Total 100.10	

grained. The rock contains dolomite, talc, chlorite and partially steatitized tremolite and anthophyllite. The tremolite's $c \wedge \gamma = 15°$, $2V\alpha = 82°$, $\alpha = 1.620$, $\gamma = 1.647$ and $\gamma - \alpha = 0.027$. The anthophyllite's $2V\alpha = 92°$. The soapstone contains grains of magnetite, pyrrhotite, pentlandite and chalcopyrite. A chemical analysis of the amphibole-bearing soapstone of Väyryvaara is given in Table XII.

SERPENTINE-BEARING SOAPSTONES

In the marginal portions of certain of the serpentine rock occurrences one will see a variety of rock containing small amounts of talc and carbonate; but since it contains more serpentine than talc, it is regarded as belonging among serpentine rocks. It represents a certain cross between serpentine rock and serpentine-bearing soapstone. The latter contains considerably more talc than serpentine.

Just like serpentine-bearing talc schists, serpentine-bearing soapstones may also contain chrysotile or antigorite. To be sure, chrysotile has been found in only one occurrence, namely, the soapstone of Kuikkavaara (61), which also contains antigorite.

The soapstone of Kuikkavaara occurs at the edge of a large outcrop of serpentine rock. Present in the chrysotile of the serpentine rock are olivine relicts, but the antigorite visible in the same thin section contains no olivine. I have not met with antigoritic olivine elsewhere, either, but on the other

Fig. 21. Carbonate-bearing serpentine rock. Horsmanaho (57), Polvijärvi. Nic. +, 48 x.

hand the pigment (usually magnetite) of fine opaque minerals in the antigorite indicates in many cases the situation of the cleavage cracks of an ancient olivine crystal. In this instance, too, it may be considered obvious that the original rock had been an olivine-bearing dunite. Apparently, the olivine had first altered into chrysotile and this, in turn, into antigorite. The chrysotile found in the Kuikkavaara soapstone as well as in certain talc schists exhibits sharp-edged laths a few cm long in which all the olivine has altered into chrysotile.

The antigorite is a far commoner mineral than the chrysotile, and it is to be found in all the serpentine-bearing soapstones. Antigorite replaces soapstone, as it does other minerals present in talc schists, too. Alteration into antigorite is thus a very late process in the metamorphism of ultramafic rocks. In certain cases it has occurred prior to steatitization and in other cases after steatitization. In the former cases the rock may have undergone total antigoritization, with the result that serpentine rock containing antigorite almost exclusively was produced. When such a rock carbonatizes and steatitizes, there is produced serpentine-bearing soapstone or, with the complete replacement of the antigorite, pure soapstone. An example of this kind of metamorphism is to be seen at Horsmanaho (57), where there is an

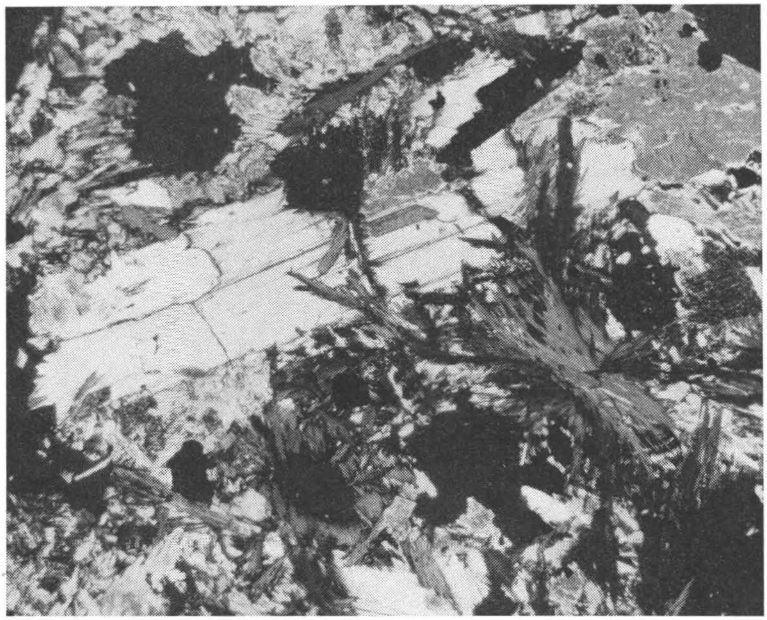

Fig. 22. Antigorite penetrates tremolite. Amphibole- and serpentine-bearing soapstone. Havukkavaara (4), Kuhmo. Nic. +, 50 x.

abundance of magnesite- and dolomite-bearing serpentine rock, in which the antigorite replaces the carbonate (Fig. 21, p. 57). Between the antigorite flakes there are small pentlandite and pyrrhotite grains. Closer to the soapstone the antigorite content diminishes, while a fair quantity of fine-flaked talc is seen to be present instead. An examination of the thin section reveals that antigorite continues to replace carbonate, but, on the other hand, part of the antigorite has steatitized in such a way that one end of the large antigorite flakes is likely to form a partially steatitized pseudomorph. In general, the antigorite flakes in this rock are not so sharp-edged or so broad as in the former case. The optical properties, however, are the same: $2V\alpha = 53^\circ$, $\alpha \sim 1.569$, $\gamma \sim 1.573$ and $\gamma—\alpha \sim 0.004$.

An example of the antigoritization that followed steatitization is to be seen in Fig. 22 where antigorite also replaces tremolite and penetrates opaque minerals. The antigorite flakes in these cases are usually long, thin and needle-like.

Table VI (p. 38) shows that serpentine-bearing soapstones occur in both gneiss-granite and in the schist areas, although the majority of the occurrences are situated in the latter localities.

Magnesite and dolomite have been met with in serpentine-bearing

Table XIII. Occurrence of carbonate minerals in the serpentine-bearing soapstones of the gneiss-granite area and the schist sequences.

Sample	Magnesite	Dolomite
Serpentine-bearing soapstones of the gneiss-granite area	2	4
Main portion of carbonate	1	4
Pure carbonate	1	3
Serpentine-bearing soapstones of schist sequences	10	5
Main portion of carbonate	10	2
Pure carbonate	7	2

soapstones. According to Table XIII dolomite occurs most commonly in the gneiss-granite area, but in the occurrences of the schist sequences magnesite is more prevalent than dolomite, quite as in pure soapstones.

GNEISS-GRANITE AREA

The serpentine-bearing soapstones occurring in the gneiss-granite area are associated with serpentine rocks or hornblende schists and metabasites. The soapstones occurring in association with serpentine rocks are alteration products of serpentine rocks and were apparently dunites by origin. As an example of such a soapstone there is the Valkeiskylä (28) occurrence, in which antigorite penetrates carbonate but has subsequently partially steatitized. The soapstone contains grains of magnetite, pentlandite, pyrrhotite and chalcopyrite.

The serpentine-bearing soapstones associated with hornblende schists and metabasites are probably by origin either altered inclusions of mafic rocks older than the gneiss-granite or then alteration products of gabbroic rocks cutting across it. The Lautalampi (25) occurrence is presented as an example of this.

The Lautalampi soapstone deposit is situated in the village of Ollikkala, Lapinlahti commune, about 2.5 km from Nerkoo depot to the east and near the farmhouse about 300 m to the east from the northern end of Lautalampi.

A sketch of the occurrence is reproduced in Fig. 23 (p. 60). The gneiss-granite surrounding the soapstone abounds in hornblende-bearing strips and small mafic lumps. The hornblende in them is in many instances partially chloritized.

Between the soapstone mass and the gneiss-granite, along the south-western edge of the deposit, there is a black, coarse-grained blackwall of biotite, which contains, in addition to the biotite, a few apatite grains and

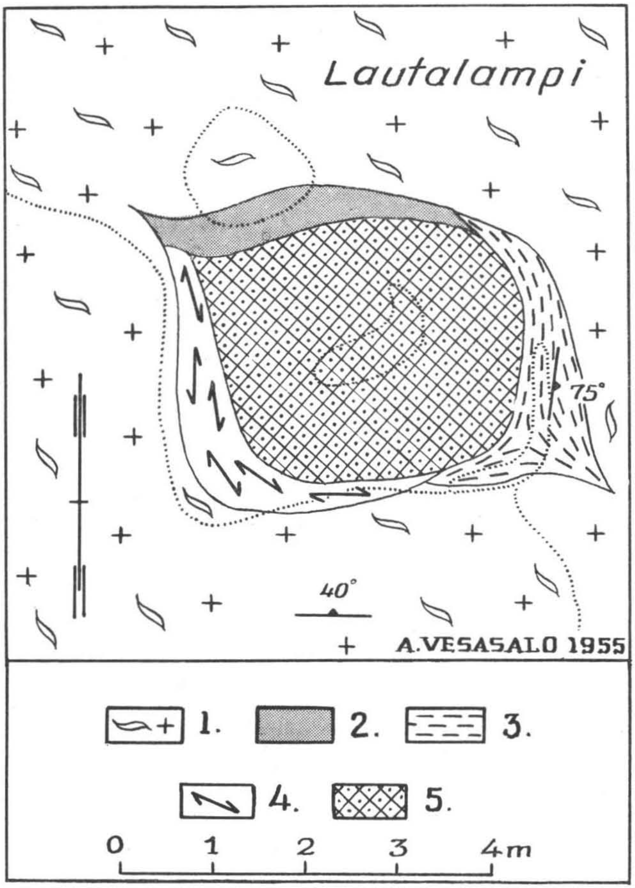

Fig. 23. Sketch of Lautalampi (25) soapstone deposit at Lapinlahti. 1. Gneiss-granite, 2. Metagabbro, 3. Amphibole schist, 4. Biotite blackwall, 5. Soapstone.

a considerable amount of epidote. The biotite's $2V\alpha \sim 5°$. At the northern edge of the soapstone, before the gneiss-granite, there is some metagabbro. In addition to partially sericitized plagioclase and partially biotitized hornblende, the rock contains some apatite and epidote grains. At the southeastern margin of the soapstone there is amphibole schist.

The soapstone of Lautalampi is dark gray and unoriented. It contains fine-flaked talc, chlorite and antigorite. Some of the chlorite flakes have begun to turn to antigorite at their ends. The chlorite's $2V\gamma \sim 20°$. The antigorite also replaces talc. The large-grained carbonate is dolomite. Here and there in the soapstone one will see a large opaque grain, whereas small opaque grains abound, especially in a mixture with chlorite.

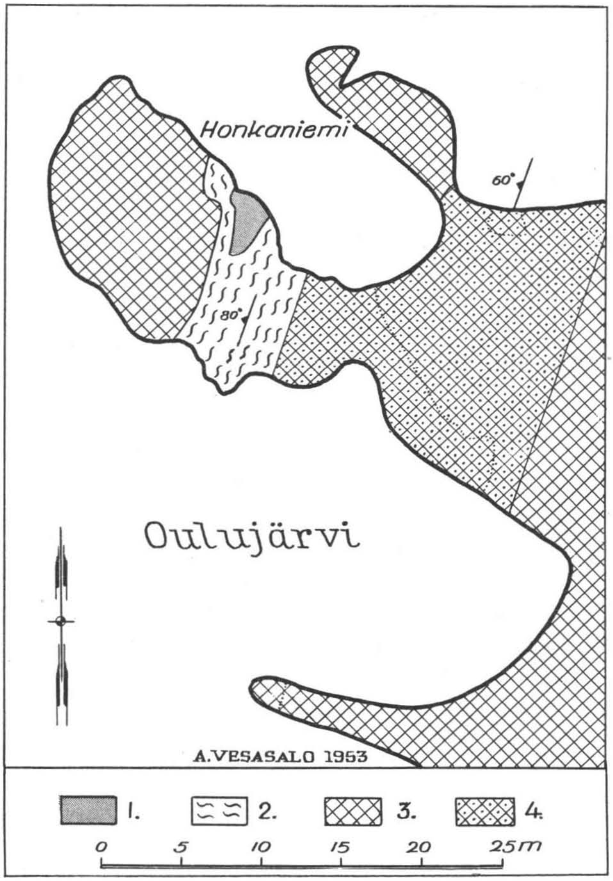

Fig. 24. Sketch of Honkaniemi (93) soapstone deposit at Paltamo. 1. Metabasite, Chlorite schist, 3. Serpentine rock, 4. Soapstone.

SCHIST SEQUENCES

For the greatest part the serpentine-bearing soapstone occurrences are in the schist areas and nearly all of them are associated with serpentine rocks. The occurrences are at the margins of serpentine rock massifs. They are steatitized and carbonatized serpentine rocks and mostly, to all appearances, dunites by origin. In certain occurrences antigoritization has followed the steatitization, with the result that antigorite has replaced all the other minerals, including the talc.

The soapstone deposit of Honkaniemi (93), in the Mieslahti region of Paltamo, is discussed in the following as an example of serpentine-bearing soapstone associated with a serpentine massif in a schist sequence. The deposit is situated in a headland of great Lake Oulujärvi (Fig. 24, p. 61).

The outermost tip of the headland consists of dark green, dense serpentine rock. The bulk of the serpentine is chrysotile, which forms a typical mesh structure. The chrysotile has partially steatitized. The serpentine rock has narrow antigorite dikes. Closer to the base of the headland, some brown carbonate flecks 1—5 mm in diameter and more talc begin to appear in the serpentine rock. The steatitization has begun from the chrysotile network, the meshes still in many cases being serpentine. In the serpentine rock are many faults running N 60° W and at right angles to them.

On the eastern side of the serpentine rock is a dense chlorite schist. Next to the contact it contains considerable amounts of carbonate and talc but grades over at a greater distance from it into a hard and amphibole-bearing rock. Inside the chlorite schist is a small metagabbro lump. On the eastern side of the chlorite schist one can see a soapstone area some 15 m in breadth. On the north, east and south sides of the soapstone there are small talc flakes and a substantial occurrence of serpentine rock containing carbonate. The serpentine is antigorite pure and simple.

The soapstone of Honkaniemi is gray, schistose and coarse-grained. The magnesite grains are 1—2 mm in diameter. In the marginal portions of the grains are opaque grains. The fine-flaked talc's $2V\gamma = 0°$. Mixed up in the talc are partially steatitized antigorite specks 1—2 mm in diameter.

In the schist sequence of Kuhmo there are two occurrences containing serpentine-bearing soapstone situated in association with metabasite and one in quartzite. Apparently these soapstones likewise belong among intrusive rocks of ultramafic origin.

Pyrrhotite and pentlandite have been met with in most of the serpentine-bearing soapstones of the schist areas. In addition, the presence of magnetite, pyrite, nickelite and chromite has been noted. Nickelite has been found in the afore-described Pohjavaara (p. 16) occurrence and chromite in the soapstone of Paljakanmäki (55). Chromite occurs as idiomorphic grains.

CHLORITE-RICH SOAPSTONES

Chlorite-rich soapstones are greener in color, by virtue of their high chlorite content, than pure soapstones and on the whole contain less carbonate. Occurrences are to be found in both gneiss-granite and schist areas (Table VI, p. 38). According to Table XIV (p. 63) dolomite is the prevailing carbonate in these soapstones, but magnesite as well has been found in many occurrences, especially in the schist areas. Two of the deposits have contained calcite exclusively.

Table XIV. Occurrence of carbonate minerals in the chlorite-rich soapstones of the gneiss-granite area and the schist sequences.

Sample	Magnesite	Dolomite	Calcite
Chlorite-rich soapstones of the gneiss-granite area	4	13	1
Main portion of carbonate	2	12	1
Pure carbonate	1	10	1
Chlorite-rich soapstones of the schist sequences	9	15	1
Main portion of carbonate	8	13	1
Pure carbonate	6	12	1

GNEISS-GRANITE AREA

All the chlorite-rich soapstones met with in the gneiss-granite area are associated with metabasites, amphibolites and hornblende schists. It appears probable that these soapstones are alteration products of these rocks. Also, according to Du Rietz (1935, p. 244), the soapstones with a high chlorite content situated in northern Sweden are alteration products of a rock, usually amphibolite, that occurs along the margin of peridotite.

Most of the chlorite-rich soapstones of the gneiss-granite area contain magnetite and a few of them pyrite and chalcopyrite. Present in many of the deposits has also been pyrrhotite and invariably in association with this mineral pentlandite.

An example of a typical chlorite-rich soapstone-bearing occurrence can be pointed to at Haaposuo (10), in the village of Mönni, Kontiolahti commune. The occurrence is situated approximately 0.5 km east of the Selkie-Mönni highway. A vertical section of the occurrence is given in Fig. 25, together with a geological map (p. 64).

In the western part of the region shown in the map, there occur Karelian schists. The soapstone of Haaposuo is situated in the amphibolite lying to the east of the schists. The amphibolite has been regarded as pre-Karelian, just as has been the red, even-grained granite penetrating the gneiss-granite occurring east of it (Frosterus and Wilkman 1920, pp. 48 and 53).

At Haaposuo the margin of the amphibolite contains amphibole schist, within which occurs chlorite-rich soapstone. The amphibolite is very fine of grain and dark greenish gray in color, with hornblende occurring as thin needles 3—4 mm long. It is distinctly pleochroic: α = light yellowish green, β = light olive green, γ = light bluish green, $c \wedge \gamma = 16°$ and $2V\alpha = 76°$. The amphibolite contains a large amount of fine-grained plagioclase (oligoclase).

In the rock (lower part of map) situated on the eastern side of the soapstone deposit, the amphibole schist is very dense and nearly black. Mixed

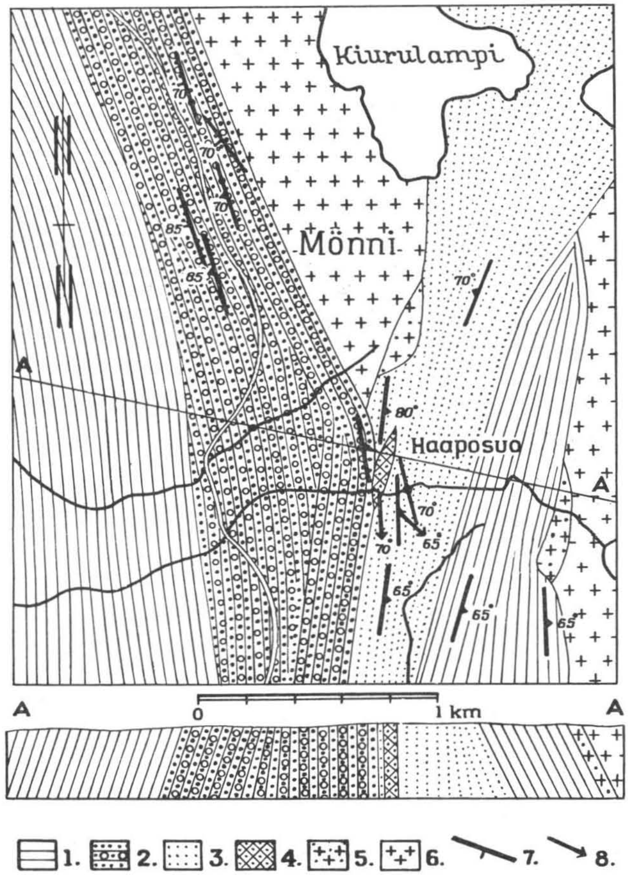

Fig. 25. Map of Mönni village and vertical section of Haaposuo (10) occurrence in the commune of Kontiolahti. 1. Mica schist, 2. Conglomerate and quartzite, 3. Amphibolite, 4. Soapstone, 5. Pegmatite, 6. Granite, 7. Bedding, 8. Lineation.

in with distinctly pleochroic hornblende needles 0.1—0.3 mm long, it contains a fine-grained quartz and scattered small biotite flakes. The hornblende's $c \wedge \gamma = 16°$ and $2V\alpha = 74°$. Quartz is also present in the schist as small accumulations and thin veins. The amphibole schist contained in the massive rock situated on the northern side of this occurrence contains mostly hornblende composed of fine laths (0.5—2 mm). Amid the laths are some small plagioclase grains. The amphibole schist is penetrated by quartz veins, which also contain carbonate and plagioclase as well as a trifle chlorite. The quartz contains inclusions of amphibole, epidote and muscovite. The muscovite's $\gamma'—\alpha' = 0.05$; the epidote's $\gamma'—\alpha' = 0.007$, which is applicable to zoisite.

The opaque grains are very small. Also on the western side of the soapstone there occurs amphibole schist. The hornblende here is almost colorless and only in spots weakly pleochroic, $c \wedge \gamma = 18°$ and $2V\alpha = 78°$.

At the western edge of the rock situated on the eastern side (lower margin of the map) of the soapstone, the dark amphibole schist turns very fine of grain and pale green in color. Here the amphibole needles are about 3 mm long and nearly colorless in thin section; $c \wedge \gamma = 12°$. In addition, there are some chlorite accumulations.

Between this light-colored amphibole schist and the soapstone there is a dense, dark green chlorite schist. The schist consists for the greatest part of fine-flaked (0.1—0.3 mm) chlorite, whose $2V\gamma \sim 10°$, $\alpha = 1.606$, $\gamma = 1.615$ and $\gamma—\alpha = 0.009$. These properties are applicable to prochlorite. Besides chlorite, the thin section reveals the presence of colorless, partially chloritized hornblende, $c \wedge \gamma = 17°$ and $2V\alpha = 78°$.

On the west side of the soapstone, moreover, there occurs a narrow zone of chlorite schist. Especially in the upper part of the map, however, the rock contains so much amphibole that it has been marked as amphibole-chlorite schist. In thin section the nearly colorless amphibole laths are twisted, $2V\alpha = 78°$. In certain spots quite at the margin of the soapstone, the fine-flaked chlorite schist contains a large number of small talc flakes as well as 1—2 mm idiomorphic magnetite crystals. Soapstone shows up in numerous exposures in an area 120 m long and 20—40 m wide.

The Haaposuo soapstone is greenish gray, highly schistose and fine-grained. It abounds in fine-flaked (approx. 0.5 mm) chlorite and fine (0.1—0.6 mm) talc as well as dolomite which forms stripes running parallel to the schistosity. In spots there are large amounts of small magnetite grains. The chlorite's $2V\gamma \sim 40°$, $\alpha = 1.585$, $\gamma = 1.592$ and $\gamma—\alpha = 0.007$. The properties apply to clinoclore.

A shemical analysis of the chlorite-rich soapstone of Haapoauo appears in Table XV. It shows that such soapstone contains appreciably less carbonate than does pure soapstone.

SCHIST SEQUENCES

The majority of the occurrences in the schist sequences that contain chlorite-bearing soapstone likewise are associated with metabasites, amphibolites and hornblende schists. In most cases these soapstones, too, may be considered alteration products of these rocks. Only those chlorite- and tremolite-bearing soapstones that occur in association with the mafic rocks embedded in the quartzite situated in the schist area of Kajaani seem to represent altered skarn formations.

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Table XV. Chlorite-rich soapstone. Haaposuo (10), Kontiolahti. Anal. P. Ojanperä.

	% by weight	Molecule ratio x 1 000
SiO_2	37.38	622
TiO_2	0.34	4
Al_2O_3	5.80	57
Fe_2O_3	7.27	46
FeO	7.25	101
MnO	0.12	2
MgO	24.41	605
CaO	3.94	70
Na_2O	0.17	3
K_2O	0.00	
P_2O_5	0.03	
CO_2	5.96	136
H_2O +	7.06	392
H_2O —	0.07	
Cr_2O_3	0.26	2
NiO	0.18	3
Total	100.24	

The majority of the chlorite-rich soapstones associated with metabasites, amphibolites and hornblende schists contain magnetite. Present in some of them are grains of chalcopyrite, furthermore, and one occurrence has been found to have pyrrhotite and pentlandite, too. The chlorite is most commonly clinochlore. The following optical properties have been established for the clinochlore of Keima (70): $2V\gamma \sim 5°$, $\alpha = 1.588$, $\gamma = 1.597$ and $\gamma—\alpha = 0.009$.

Chlorite-rich soapstone also occur in the schist sequences in association with serpentine rocks. In most cases they constitute the same ultramafic intrusive type of rock as the serpentine massif. But in certain instances carbonatization and steatitization have occurred also in the chloritized country rock of the ultramafic rock, resulting in the genesis of soapstone. Soapstone of this kind occurs also in Vermont. Gillson (1927, p. 255) reports that in a few cases observed in that state a narrow zone of country rock situated at the contact of strongly chloritized ultramafic rock had altered into soapstone through replacement with talc and still betrayed the structure of chlorite schist quite unmistakably as a pseudomorph.

The Rytys (49) occurrence in the village of Ruhtinaansalmi, Suomussalmi commune, has been taken here as an example of a chlorite-rich soapstone associated with the serpentine rocks of schist sequences. The occurrence is situated about 300 m NNW from the Rytys farmhouse, which stands at the north end of Saarijärvi. Fig. 26 shows a vertical section of the occurrence.

On the northwestern side of the soapstone there stands a high cliff of tuffite. Toward the southeast the tuffite grades over into partly oriented

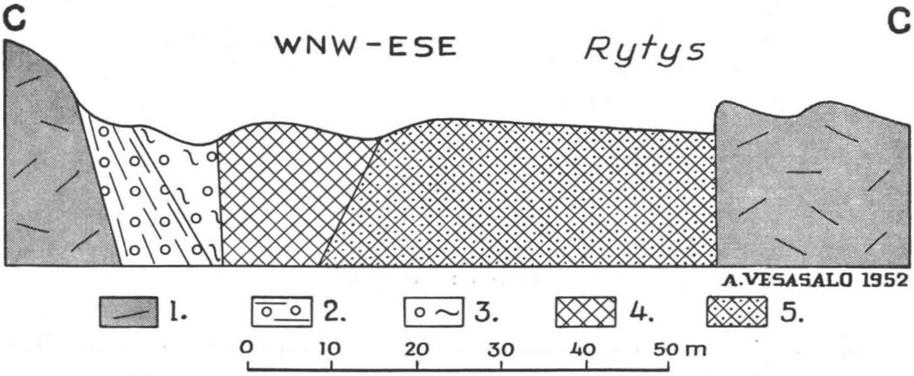

Fig. 26. Vertical section of Rytys (49) soapstone occurrence in the commune of Suomussalmi. 1. Tuffite, 2. Leptite, 3. Quartz-chlorite schist, 4. Serpentine rock, 5. Soapstone.

leptite, which is followed by highly schistose quartz-chlorite schist marked by drag folding. On the other side of it occurs serpentine rock, which in turn borders on soapstone. On the southeast side of the soapstone there is conspicuously schistose, dark green tuffite. The leptite contains accumulations of quartz grains, surrounded by fine-grained plagioclase and sericite. The tuffite contains a large amount of hornblende ($c \wedge \gamma = 30°$ and $2 V\alpha \sim 75°$) and plagioclase (An_{10-20}) as a mass of small crystals and as large, irregularly formed crystals. Additional components are chlorite and epidote.

Alongside the serpentine rock the soapstone is greenish gray and schistose. A couple of meters from the serpentine rock the soapstone is gray, coarse-grained and in general unoriented. Soapstone is to be seen in exposures over an area 100 m long and 40 m wide. The soapstone contains talc both as a fine-flaked mass and as large flakes, in addition to carbonate and large amounts of fine-flaked chlorite. For the greatest part the carbonate consists of magnesite, besides which there also occurs dolomite. The carbonate mostly occurs as small, brown grains, but the soapstone also contains white lumps and dikes of carbonate measuring as much as 5 to 10 cm across. The carbonate grains are porous and full of little, elongated, to some extent parallel cavities. The carbonate also contains chlorite inclusions. Magnetite grains occur in profusion, especially in association with the carbonate. Magnetite has further been found in other chlorite-rich soapstones associated with the serpentine rocks situated in the schist areas.

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CONCLUSIONS

Finland's talc schist and soapstone occurrences are to be found in the eastern part of the country. They are situated in surroundings of three different kinds, geologically speaking: a gneiss-granite area, Karelian schist sequences and a veined gneiss area. The deposits situated in these areas form separate major categories, which, considered by and large, differ from each other with respect to their mode of occurrence and mineralogical composition.

On the basis of their mineralogical composition, the talc schists, the main mineral constituent of which is talc, are divided into four subtypes: pure, amphibole-bearing, serpentine-bearing and chlorite-rich talc schists. Pure talc schist does not contain amphibole, serpentine or much chlorite. The soapstones, the main mineral constituents of which are carbonate and talc, have been similarly divided into four subtypes: pure, amphibole-bearing, serpentine-bearing and chlorite-rich soapstones. Pure soapstone does not contain amphibole, serpentine or much chlorite. Of the 90 known soapstone occurrences, 42 contain pure soapstone, and of the 36 known talc schist occurrences, only 16 contain pure talc schist.

In addition to talc and carbonate (magnesite, dolomite and calcite), these rocks always contain opaque minerals, of which the most prevalent are magnetite, pyrrhotite and pentlandite. Quite a common additional mineral is chlorite. Less common than the minerals mentioned are hornblende, tremolite, anthophyllite, chrysotile, antigorite, biotite, quartz and apatite.

Less than one-third of all the occurrences are situated in the gneiss-granite area. A third of them consist of talc schist. The talc schists and soapstones generally occur as isolated deposits in the gneiss-granite. In only a few instances can certain closely situated occurrences be observed to belong to the same sequence. Some of the occurrences represent separate masses in the gneiss-granite, but the bulk of the deposits are associated with the hornblende schists or amphibolites embedded in the gneiss-granite.

The soapstones of the gneiss-granite area deviate from the soapstones of the schist areas in that their carbonate content is slight, and they contain in many cases a considerable quantity of chlorite as well as amphibole relicts. Of the talc schist occurrences of the gneiss-granite area, only one contains pure talc schist. In neither these talc schists nor soapstones have I run across olivine, any more than in their country rocks; and, with but a single exception, the serpentine discovered in a very few of the occurrences is antigorite. It seems as if these occurrences have metamorphosed from the gabbroic amphibolites with which they are associated. Possibly many of them had been dikes penetrating the gneiss-granite, as Frosterus and Wilkman have surmised (p. 10). In some instances, what might be involved is an inclusion of a rock older than the gneiss-granite. Certain of the occurrences could conceivably represent not only gabbroic amphibolites but also skarn formations by origin.

The bulk of the talc schist and soapstone occurrences are to be found in Karelian schist areas. They consist predominantly of soapstone, and they are mostly associated with serpentine rocks. They represent ultramafic intrusive rocks typical of the root portions of mountain ranges. Many of these synorogenic rocks occur in schists as concordant, layered masses and when present in the same horizon form intrusive zones. Some instances have been observed of several parallel horizons situated close together (Figs. 11 and 12). An examination of such horizons has revealed that they ordinarily contain several different kinds of rock. These horizons have been zones of weakness, into which ultramafic bodies have forced entry.

The talc schist and soapstone deposits in the schist sequences are mostly situated at the edges of lumps of serpentine rock — in their contact zones. Also in localities where serpentine rocks do not form long sequences but occur as extensive massifs (Fig. 16), talc schists and soapstones are to be found in the marginal portions of these massifs.

The metamorphic changes in the talc schists and soapstones of the schist areas are usually so far gone that relicts of earlier minerals seldom appear. In only a few occurrences have I found the relicts of amphibole minerals, but I have failed to find any olivine relicts in these rocks. In most cases, however, the original rock should be regarded as dunite, which, after undergoing the metamorphic process, has altered into talc schist or soapstone. In many plases one will see transitional forms between serpentine rock and soapstone, and the gradual passage from serpentine rock to soapstone may be noted. In certain instances, again, the contact between these rocks is a sharp one. In other instances, particularly in the western part of the Joensuu schist area, the original rock may also be pyroxenite, for in the locality mentioned partially serpentinized and steatitized pyroxene rock has been found.

Certain soapstones deviate from the other ones in the schist areas: namely, the deposits of Hallapelto and Pilkkavaara (67) in the Joensuu area as well as of Väyryvaara (72), Porttivaara (68), Portinkallio (69), Keima (70) and Roninrinne (71) in the Kajaani schist area. No serpentine rock occurs in association with these soapstones. Hallapelto is situated in mica schist embedded in metabasite, Pilkkavaara in metabasite and the other deposits in quartzite. All these soapstones abound in amphibole relicts, and their carbonate content is correspondingly below what might be considered average. In only one occurrence has a little magnesite been met with in addition to dolomite, whereas in all the other the carbonate is exclusively dolomite. Accordingly, it is possible that at least some of these soapstones, especially the ones associated with quartzite, are steatitized skarn formations and thus of sedimentogeneous origin.

In the veined gneiss area lumps of talc schists only have been met with. The majority of them are associated with chrysotile-bearing serpentine or asbestos rock and have a magmatic origin. Even closely situated lumps are no longer in mutual contact, and around each lump one usually finds zones of talc schist and tremolite as well as blackwall of chlorite and biotite (Aurola 1960, Fig. 11, p. 35). The granite-pegmatite penetrating the veined gneiss also cuts through the ultramafic lumps.

The talc schists and soapstones have gained their present habit after undergoing a multiple series of alterations as the temperature declined in the root portions of mountain ranges. The most important alteration processes are serpentinization, carbonatization and steatitization. All these stages involve in the main only ultramafic rocks, but the same final result could be arrived at also where gabbroic amphibolites or skarn formations were exposed to corresponding conditions.

Serpentinization is quite a common phenomenon in the ultramafic rocks of eastern and northern Finland. In the western parts of the Joensuu schist area and in the veined gneiss area west of it, one mostly meets with chrysotile, mixed in many spots with olivine. The most common serpentine, however, is antigorite, which occurs principally in the gneiss-granite area and in the ultramafic rocks situated in the central parts of the schist areas.

Väyrynen (1939, p. 75) mentions the occurrence of olivine in both chrysotile and antigorite. I have not observed olivine to be present in plain antigorite, but on the other hand in chrysotile flecks (Kuikkavaara, 61) occurring in partially carbonatized and subsequently antigoritized serpentine rock. The olivine is completely surrounded by chrysotile, which, again, appears to be replaced by antigorite. Similar observations have been reported by Frosterus (1902 b, p. 40), Haapala (1936, p. 20) and Väyrynen (1939, p. 75). Thus, I have no evidence of olivine's directly undergoing alteration to antigorite. On the other hand, amphibolites do alter directly to antigorite, too. Accordingly, it appears possible that chrysotile-bearing serpentine rocks are principally olivine rocks — dunites — that have turned into chrysotile. Of these some subsequently underwent carbonatization and steatitization, forming talc schist and soapstone. In another case the dunites would have first turned into amphibolite and then into antigorite, resulting in the genesis of antigorite-bearing serpentine rock. Approximately at the same time carbonatization and steatitization occurred in the contact zones of these rocks, producing talc schists and soapstones. Since chrysotile- and antigorite-bearing serpentine rocks occur in different horizons, the factor determining when dunite changes into chrysotile-bearing serpentine rock or first amphibolitizes and then antigoritizes would seem to be its situation in the geosyncline. If, again, the dunite first alters into chrysotile and this subsequently into antigorite, its situation in the geosyncline might be the cause. Serpentinization does not appear to be connected with the occurrence of granites, for serpentinization may be regarded as an autometamorphic process.

Carbonatization begins already during serpentinization, as a result of which, as the amphibole is altered, free silica remains. This is bound to the talc. Thus, steatitization represents a direct continuation of carbonatization. Carbonate may also replace chlorite, whereat the surplus SiO_2 also forms talc.

Steatitization has often been attributed to solutions deriving from granites. For the greatest part, however, the soapstones of Finland, especially those situated in schist areas, occur far from granites, and the proximity or remoteness of granites does not appear to bear any relation to the degree of steatitization. Evidently both the carbonatization and steatitization of these rocks have been caused by diluted carbonate- and silicate-bearing hydrothermal solutions. Volcanic gases contain at the very beginning the carbon-dioxide required for the formation of carbonate, but more of it may come during the process of intrusion from the surrounding sediments. The hydrothermal solutions presumably derived from the same magma as the ultramafic intrusive rocks did.

On the other hand, in the veined gneiss area and in the western part of the Joensuu schist area, post-Karelian Maarianvaara granite occurs with its extensive pegmatite dikes. The hydrothermal solutions deriving from this granite could conceivably have initiated the genesis of the biotite-chlorite blackwalls as well as tremolite and talc schist zones situated in the ultramafic rocks of this region.

Steatitization in the majority of cases represents the final stage in the complex series of alterations of which the final products are talc schists and soapstones. Talc has been observed to replace many previously formed minerals, but in a number of instances the talc has yet been penetrated by antigorite. This signifies that antigoritization occurred subsequent to the steatitization. On the other hand, antigorite flakes are to be seen that are partially or totally steatitized, signifying that steatitization has been the last stage of metamorphism.

An examination of the areal distribution of carbonates occurring in soapstone deposits will reveal that in the soapstones of the gneiss-granite area dolomite is more common than magnesite, whereas in schist sequences magnesite is met with more often. This can be seen particularly clearly in pure soapstones, which are the variety typical of schist sequences. Also the serpentine-bearing soapstones of schist sequences in most cases contain magnesite. Calcite is an exceedingly rare mineral in soapstones. The enrichment of magnesium in soapstones of schist areas indicates that the ultramafic intrusions were submarine and the magnesium derived from sea water. According to Rittman (1960, pp. 247—248), under the high pressure prevailing at the bottom of the geosynclinal sea, sea water enters the residual liquid and, together with the residual liquid and volcanic gases, forms pneumatolytic and hydrothermal contact solutions.

Areal differences can also be noted in the quantitative occurrence of amphibole minerals in talc schists and soapstones as well as in other ultramafic rocks closely associated with them. Amphiboles are common in the gneiss-granite area. In many cases what is involved is a primary amphibole. In occurrences of schist sequences, amphiboles are rare. They are met with in the main only in talc schists and soapstones situated in quartzites, concerning the sedimentogeneous origin of which surmises have been made in the foregoing. In the western parts of the Joensuu schist area and in the area of veined gneiss, there occur, in addition to tremolite, also anthophyllite and anthophyllite asbestos, the occurrence of which appears to be bound up with post-Karelian Maarianvaara granite (Vesasalo 1951, p. 50).

The State Geologist, Erkki Aurola, Ph. D., and Mrs. Marjatta Virkkunen, Mag. Phil., geologist, colleagues of Arvo Vesasalo prepared this paper for printing. Mr. Paul Sjöblom, M.A., translated it into English.

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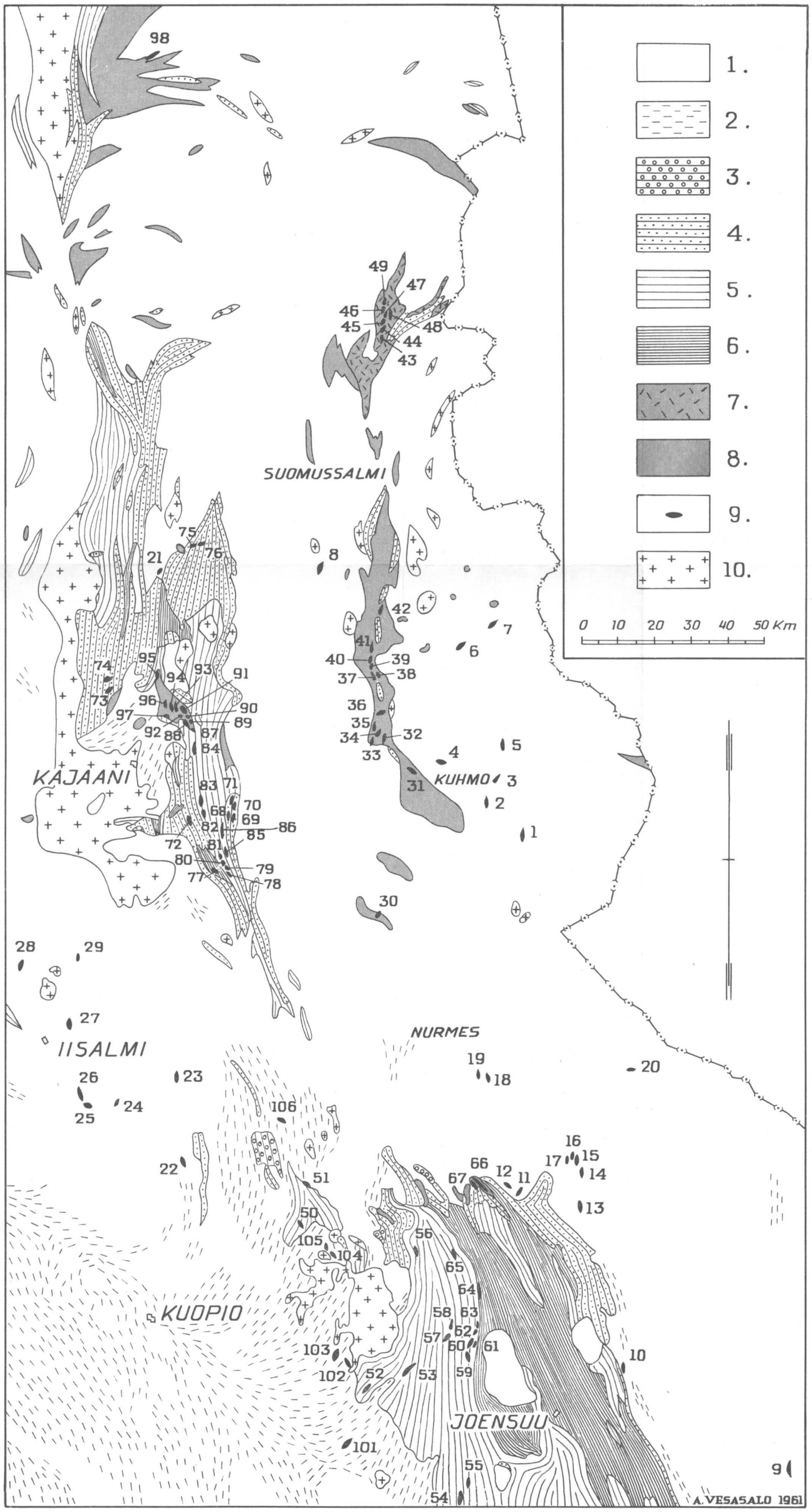
GEOLOGICAL MAPS USED

General geological map of Finland, 1 : 400 000

C 3, Kuopio; W. W. Wilkman (1935).
C 4, Kajaani; W. W. Wilkman (1929).
C 5 and B 5, Oulu and Tornio; A. Enkovaara, M. Härme, H. Väyrynen (1952).
D 3, Joensuu; Benj. Frosterus, W. W. Wilkman (1924).
D 4, Nurmes; W. W. Wilkman (1924).
D 5, Suomussalmi; A. Matisto (1954).

Atlas of Finland **1960**

Sheet 3, Pre-Quaternary rocks; Ahti Simonen.



THE KARELIAN SCHIST AREAS AND TALC SCHIST AND SOAPSTONE OCCURRENCES OF EASTERN FINLAND.

1. Gneiss-granite, 2. Veined gneiss, 3. Blebbed gneiss, 4. Quartzite and leptite, 5. Mica schist, 6. Phyllite, 7. Basic vulcanite, 8. Metabasite, metagabbro and serpentine rock, 9. Talc schist or soapstone deposit, 10. Post-Karelian granite.

LIST OF TALC SCHIST AND SOAPSTONE OCCURRENCES

THE NUMBERS REFER TO THOSE IN PLATE 1.

I. OCCURRENCES IN GNEISS-GRANITE AREA

THE KUHMO AREA

1. Louhivaara. Korpisalmi, Kuhmo
2. Salminen. Korpisalmi, Kuhmo
3. Kupsusenvaara. Korpisalmi, Kuhmo
4. Havukkavaara. Korpisalmi, Kuhmo
5. Koivuvaara. Lentua, Kuhmo
6. Takkusenaho. Iivantiira, Kuhmo
7. Kylmänkallio. Lentiira, Kuhmo
8. Hukkakallio. Luvankylä, Kuhmo

THE JOENSUU AREA

9. Puravaara. Luutalahti, Ilomantsi
10. Haaposuo. Mönni, Kontiolahti
11. Saunaniemi. Ahmovaara, Juuka
12. Majalahti. Larinsaari, Juuka
13. Kelvänsaari. Vuonislahti, Pielisjärvi
14. Kujoskallio. Vuonislahti, Pielisjärvi
15. Siikalahti. Vuonislahti, Pielisjärvi
16. Siikalahden ranta. Vuonislahti, Pielisjärvi
17. Siikaniemi. Vuonislahti, Pielisjärvi
18. Herralan korpi. Höljäkkä, Nurmeksen mlk.
19. Laukkasen kallio. Höljäkkä, Nurmeksen mlk.
20. Niskasuo. Ruunaa, Pielisjärvi

THE KAJAANI AREA

21. Leskisensuo. Kotila, Puolanka

THE IISALMI AREA

22. Kissakallio. Reittiö, Nilsiä
23. Kotimaa. Juminen, Varpaisjärvi
24. Kiukonmäki. Ollikkala, Lapinlahti
25. Lautalampi. Ollikkala, Lapinlahti
26. Koivula. Nerkoo, Lapinlahti
27. Kainula. Viitaa, Iisalmen mlk.
28. Valkeiskylä. Valkeiskylä, Vieremä
29. Ahola. Ryhälänmäki, Sonkajärvi

II. OCCURRENCES IN SCHIST SEQUENCES

THE KUHMO AREA

30. Autiojärvi. Sivakkavaara, Valtimo
31. Katajalahti. Katerma, Kuhmo
32. Viitala. Vieksi, Kuhmo
33. Näätäniemi. Vieksi, Kuhmo
34. Niikkulan louhos. Vieksi, Kuhmo
35. Verikallio. Vieksi, Kuhmo
36. Pitkälahti. Vieksi, Kuhmo
37. Aittojärvi. Vieksi, Kuhmo
38. Aittoranta. Vieksi, Kuhmo
39. Kiimasaari. Vieksi, Kuhmo
40. Hyyrylä. Vieksi, Kuhmo
41. Riihijoki. Tapanivaara, Hyrynsalmi
42. Liitukallio. Tapanivaara, Hyrynsalmi

THE SUOMUSSALMI AREA

43. Kallioinen. Ruhtinaansalmi, Suomussalmi
44. Portti. Ruhtinaansalmi, Suomussalmi
45. Kurikkalampi. Ruhtinaansalmi, Suomussalmi
46. Ala-Luomajärvi. Ruhtinaansalmi, Suomussalmi
47. Luomajoki. Ruhtinaansalmi, Suomussalmi
48. Ruunakallio. Ruhtinaansalmi, Suomussalmi
49. Rytys. Ruhtinaansalmi, Suomussalmi

THE JOENSUU AREA

50. Rautavuori. Hirvisaari, Kaavi
51. Tervaniemi. Konttimäki, Säyneinen
52. Kinttumäki. Maljasalmi, Kuusjärvi
53. Outokumpu. Outokumpu, Kuusjärvi
54. Leppälahti. Leppälahti, Liperi
55. Paljakanmäki. Kolehmala, Liperi
56. Mihkala. Halivaara, Juuka
57. Horsmanaho. Horsmanaho, Polvijärvi
58. Kylän kivipalsta. Horsmanaho, Polvijärvi
59. Solansaari. Sola, Polvijärvi
60. Sola. Sola, Polvijärvi
61. Kuikkavaara. Sola, Polvijärvi
62. Kupinpuro. Kupinpuro, Polvijärvi
63. Juttusuo. Kupinpuro, Polvijärvi
64. Haaralanniemi. Haaralanniemi, Polvijärvi
65. Repokangas. Nenäsenvaara, Polvijärvi
66. Nunnanlahti. Nunnanlahti, Juuka
67. Hallapelto-Pilkkavaara. Nunnanlahti, Juuka

THE KAJAANI AREA

68. Porttivaara. Vaarankylä, Sotkamo
69. Portinkallio. Jormaskylä, Sotkamo
70. Keima. Jormaskylä, Sotkamo
71. Roninrinne. Jormaskylä, Sotkamo
72. Väyryvaara. Jormaskylä, Sotkamo
73. Ruokosuo. Melalahti, Paltamo
74. Matalansuo. Melalahti, Paltamo
75. Rutjansuo. Paljakka, Hyrynsalmi
76. Letuspuro. Paljakka, Hyrynsalmi
77. Hyllävä. Jormaskylä, Sotkamo
78. Uutela. Jormaskylä, Sotkamo
79. Kivikallio-Talvivaara. Jormaskylä, Sotkamo
80. Pitkälehto. Jormaskylä, Sotkamo
81. Pirttimäki. Jormaskylä, Sotkamo
82. Koivukorpi. Korholanmäki, Sotkamo
83. Lahnaslampi. Korholanmäki, Sotkamo
84. Pohjavaara. Pohjavaara,Sotkamo
85. Mustinlehto. Jormaskylä, Sotkamo
86. Kohverinsaari. Jormaskylä, Sotkamo
87. Papinkallio. Jormua, Kajaanin mlk.
88. Jormua. Jormua, Kajaanin mlk.
89. Heinälän kallio. Mieslahti, Paltamo
90. Heinimäki. Mieslahti, Paltamo
91. Pitkänperä. Mieslahti, Paltamo
92. Mölkänvaara. Mieslahti, Paltamo
93. Honkaniemi. Mieslahti, Paltamo
94. Säynäniemi. Mieslahti, Paltamo
95. Kiehimänjoki. Kiehimä, Paltamo
96. Kallioniemi. Mieslahti, Paltamo
97. Lehminiitty. Jormua, Kajaanin mlk.

OCCURRENCES IN LAPLAND

98. Hoppula. Kynsperä. Posio
99. Matarakoski. Petkula, Sodankylä
100. Tarpomapää. Kiistala, Kittilä

III. OCCURRENCES IN VEINED GNEISS AREA

101. Varistaipale. Koskijärvi, Heinävesi
102. Usinmäki. Varislahti, Kuusjärvi
103. Paakkila. Kiukoonniemi, Tuusniemi
104. Ruunapuro. Kortteinen, Kaavi
105. Keinälän kallio. Kortteinen, Kaavi
106. Hankamäki. Hankamäki, Rautavaara