GEOLOGINEN TUTKIMUSLAITOS

BULLETIN

DE LA

COMMISSION GÉOLOGIQUE

DE FINLANDE

N:o 206

ON THE PEGMATITES IN THE TORRO AREA, SOUTHWESTERN FINLAND

BY

ERKKI AUROLA

WITH 4 FIGURES IN TEXT AND ONE MAP

HELSINKI 1963

GEOLOGINEN TUTKIMUSLAITOS
BULLETIN DE LA COMMISSION GÉOLOGIQUE DE FINLANDE N:o 206

ON THE PEGMATITES IN THE TORRO AREA, SOUTHWESTERN FINLAND

BY
ERKKI AUROLA

WITH 4 FIGURES IN TEXT AND ONE MAP

HELSINKI 1963

Helsinki 1963. Valtioneuvoston kirjapaino

CONTENTS

ABSTRACT

This report deals with the distribution of simple and complex Precambrian pegmatites and their relation to their host rocks in the vicinity of the village of Torro, an area on the boundary between the communes of Somero and Tammela in southwestern Finland. In this area supracrustal crystalline schists of varying composition are penetrated by a series of intrusive igneous rocks, which includes both synorogenic and late-orogenic formations. Typical representatives of the former group are diorites and granodiorites, while the latter group consists mainly of microcline granites.

Simple granite pegmatites occur mostly in association with microcline granites, to which some of them also seem to have a genetic relationship. The complex pegmatites have been observed, on the other hand, to occur in connection with synorogenic rocks. Pegmatite dikes and lumps containing beryl are found mostly within the diorite massif, whereas the most typical Li-pegmatites are situated in the border zone of the massif on the schist area surrounding it. Evidently the beryllium has remained closer to its parent rock, while the lithium has wandered a greater distance. Such observations are likely to prove significant in prospecting for ore deposits containing lithium in commercially valuable amounts.

INTRODUCTION

Among minerals of economic value as industrial raw material, ores containing heavy metals are in a dominant position. However, continuously expanding and growing in diversity that it is, industry needs in addition to the heavy metals many other raw materials occurring in bedrock that are not classified as belonging to the category of ores proper. These materials include, for example, the industrial minerals, among which feldspar and quartz are well-known and commonplace ones. In Finland feldspar and quartz have been quarried from coarse-grained varieties of granite, i.e., pegmatite occurrences.

It was in 1956 that the Geological Survey of Finland undertook to investigate and map out pegmatite occurrences as part of its systematic work program. One objective of this survey has been to obtain detailed data on those pegmatite deposits that could be profitably quarried, whether at present or in the future. In addition, the possibilities of new occurrences being found have been taken into account and prospecting operations carried out in areas regarded as promising. Special attention has been given to minerals containing rare elements and to their occurrence both in individual pegmatite dikes and on a regional scale.

In choosing the areas to be explored, the point of departure was that new pegmatite prospects could very probably be found in places where the mineral had been run across before. Complex pegmatites containing rare elements were known to occur in southwestern Finland in the vicinity of the village of Torro (Fig. 1), situated on the border between the communes of Somero and Tammela. It was decided in 1958 to investigate this area.

The first stage of the field investigation involved a study of individual occurrences that had previously awakened interest. The starting point of survey operations was the pegmatite deposit located in the village of Pajula, which in 1946 had yielded a Li-mineral never before met with in this country, petalite (Toini Mikkola and Wiik 1947). In a comparatively short time the ore geologist Arvo Vesasalo discovered a new, fairly rich petalite-pegmatite deposit at Hirvikallio, in the commune of Tammela, six kilometers to the north-northeast from Luolamäki (Vesasalo 1959). When, upon

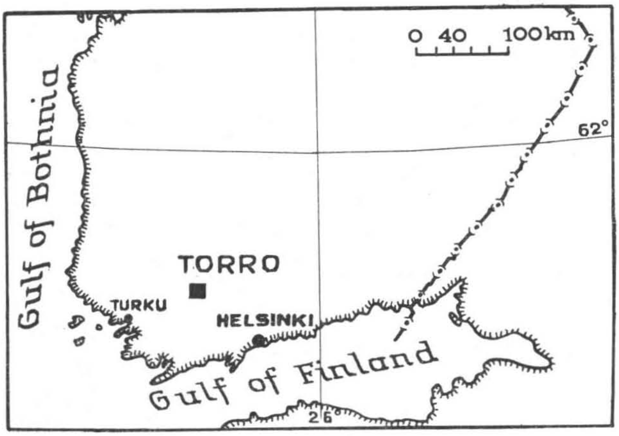

Fig. 1. Location of the Torro area.

re-investigating the occurrence of Luolamäki, Vesasalo observed that the pegmatites contained not only Li-minerals but also the rare Cs-mineral, pollucite (Neuvonen and Vesasalo 1960), I decided it to be necessary to carry out a careful geological mapping of the entire area that from the standpoint of the occurrence of complex pegmatites containing rare minerals appeared critical. The field mapping was performed in 1958—60 by Marjatta Virkkunen. The area mapped comprised c. 140 km^2. The map was drawn on the scale of 1 : 20 000.

I hoped by means of a detailed mapping of the bedrock, to be able to establish, at least for the most part, the limits of the zones in which the complex pegmatites occur and to make observations on the distribution of the different types of pegmatites and their relation to the host rock. It was expressly for this reason that special attention was given to the contact features of pegmatite dikes and their country rocks, alteration phenomena exhibited by the country rocks the structural characteristics of the pegmatites. Diamond drillings have been carried out to ascertain the extent and quality of the pegmatites. Subsequent investigations have concerned the Rb-, Cs- and Li-contents of the mica minerals of different type pegmatites. Mica specimens have been collected for this purpose and spectrographically studied at the Geological Survey.

EARLIER STUDIES

In 1738 the Swedish geologist Daniel Tilas prospected for ores in southwestern Finland, and on the northern side of the village of Torro in the commune of Tammela discovered an ore occurrence containing chalcopyrite, pyrite and magnetic pyrites. Although this ore deposit was a small one, it nevertheless attracted widespread attention. The prospect was investigated first hand by quite a number of geologists, who published scholarly papers on their observations (Mallén 1759, C. Lihr 1780, H. A. Kullhelm 1870—71, F. J. Wiik 1881—1882).

Obviously spurred on by the discovery made by Tilas, investigators began to study the bedrock of Tammela and its neighboring commune more closely. It was then perceived that there were pegmatite occurrences rich in quartz in the surroundings of the village of Torro. Since the quartz was a suitable raw material for the manufacture of glass, J. R. Pont and Jacob Bremer, a couple of business men from Turku, established a glass melting plant in Somero on the Åvik estate. As late as 1824—25 quartz continued apparently to be quarried from the pegmatite occurrences of Somero—Tammela.

Around the quarries there collected large quantities of waste rock. These accumulations afforded mineralogists and chemists interested in rare minerals an excellent opportunity to make studies. The noted mineralogist N. Nordenskiöld, chief intendant of the Finnish Mining Bureau, collected a large number of mineral specimens in the middle of the last century from the communes of Tammela and Somero. It was he who first found the majority of the rare minerals occurring in the area of the present study and published scientific reports on them. A. E. Nordenskiöld and many other researchers followed in the footsteps of N. Nordenskiöld (see Mäkinen 1913, pp. 3—4).

Geological maps of the bedrock of Finland began to be made toward the end of the 19th century. It was in the years 1887—1889 that mapping operations were carried out in the commune of Tammela. The explanatory text accompanying the map sheet of Tammela, which appeared in print in 1890, was written by the director of the Geological Board (now known as the Geological Survey), J. J. Sederholm.

2 9366—62

The infracrustal rocks of the Tammela area were divided by Sederholm into two classes: gray granites and red granites. As described by Sederholm, the gray granites are »amphibole bearing and in most cases somehow mixed with biotite» while »the feldspar is very extensively plagioclase». These gray granites are compared by Sederholm to the »urgranites» described in Sweden. The granites of the other variety are to be recognized, according to Sederholm, by the abundance of pale red potassium feldspar, which consists solely of microcline. The color of this granite is red.

From the standpoint of pegmatite research, Sederholm's conception of the genetic relationship between the pegmatites and granites of Tammela is of interest. According to Sederholm (1890, pp. 34—35), the red microcline granites of the Tammela area occur in association with a coarse-grained variety of granite, pegmatite-granite. The grading over from one variety of rock to the other occurs by degrees. Proceeding from this basis, Sederholm concludes that the pegmatites (complex pegmatites) of the Torro area containing rare minerals derive from pegmatite-granites related to muscovite-granites.

The pegmatite minerals of Tammela were the subject of an extensive and esteemed study published by Mäkinen in 1913. In it the author devotes very little space to the origin of the pegmatites, and he has little essentially new to add to what Sederholm had previously brought to light. On the other hand, Mäkinen presents a new general map of the Somero—Tammela pegmatite area (Mäkinen 1913, p. 5), which quite clearly reveals the observations that had been made of the geological position of the pegmatites and the bases on which Sederholm had built up his conception of the origin of the complex pegmatites. According to Mäkinen's map, the host rock of the pegmatites situated in the commune of Tammela on the southwestern side of Pyhäjärvi consists either of schist or of microcline granite, whereas the »amphibole granites» are either sparsely penetrated by pegmatite veins or are totally lacking in pegmatitic material. The general map does not make detailed distinctions between simple and complex pegmatites, nor does it show the relation of the different pegmatite types to intrusions of igneous rock. Mäkinen evidently did not wish to risk making any far-reaching conclusions concerning the origin of the Tammela pegmatites on the basis of petrographic maps of a general character.

The commune of Somero and part of the commune ot Tammela were remapped geologically after World War II. The geological map (1 : 100 000) and the accompanying explanatory text were the work of Simonen (1956). In this new map sheet of Somero, which includes the area of Torro the main structural features of the bedrock agree very closely with Sederholm's description of an earlier day. Among igneous rocks penetrating the rock sequence of supracrustal series, red microcline granites dominate. »Gray granites», as Sederholm termed them, occur in the area surveyed on the northern side of the church of Somero as an extensive massif running west-east, the rocks of which vary in composition from gabbros to granodiorites and quartz diorites.

According to the map sheet of Somero drawn up by Simonen, pegmatites associated with microcline granites appear to occur by and large only in the surroundings of two lakes, Talpiajärvi and Kalliojärvi, situated on the northern side of the village of Torro. In addition, pegmatite has been marked on the geological map of the area as present in a few scattered occurrences in association with both supracrustal rocks and basic igneous rocks. At the time of the mapping operations, the pegmatite occurrences had not been subjected to any detailed study.

THE MAIN FEATURES OF THE BEDROCK

In respect to its bedrock, the area of Torro belongs to the deeply eroded root zone of the Svecofennian mountain range. Its crystalline schists, with their west—east orientation, cut across the extensive massifs of igneous rock. The contact relations indicate that the basic igneous rocks of the area, the gabbros and diorites, are older than the acid granodiorite and quartz diorite varieties of rock associated with them. The transitions in this rock sequence are gradual and without clear lines of demarcation; it is therefore evident that what we are confronted with is a uniform series of rocks that originated by differentiation. Unmistakably younger than the foregoing are the red microcline granites discussed previously (cf. Simonen 1956, Härme 1960).

Among supracrustal rocks the most extensively distributed are the amphibolites, which vary in both structure and composition. Along the northern edge of the area surveyed, amphibolite is met with as a broad intercalation in the mica schist.

BASIC VARIETIES OF IGNEOUS ROCKS

For the present investigation the pegmatite area situated on the boundary between Somero and Tammela was mapped in detail on the scale of 1 : 20 000 (App. I). According to the field observations of the cartographer (Marjatta Virkkunen), it is not possible to set apart the basic igneous rocks, including the granodiorites and quartz diorites, diorites and gabbros, for no clearly demarcated areas containing any of these members of the basic series are to be detected. All the varieties of rock mentioned grade over into each other by degrees without any determinable contacts. Some sort of division can, however, be noted in that the granodiorite and quartz diorite exposures occur in the marginal parts of the massif while the middle of the areas is »darkest».

The predominant variety of rock (see map) is diorite, which is composed of plagioclase, biotite and hornblende as well as the accessory constituents sphene, apatite, zircon, ore grains, chlorite and epidote. The plagioclase mostly consists of andesine, which has undergone only slight alteration. The dark constituents reveal a weak orientation only under the microscope. A slight tendency to conform to the contacts of the intrusive can be detected in the portions of the massif's margin containing granodiorite and quartz diorite.

In this area of basic rocks, especially its middle portions, there are sections of the bedrock that are quite dark and have the appearance of gabbro and peridotite. The composition of the feldspar in these rocks, too, represents andesine. Under microscopic examination these rocks also generally prove to be diorites.

MICROCLINE GRANITES

Microcline granites are to be found in the southern part of the area mapped in detail. On the northeastern and eastern side of the basic massif, microcline granite, however, is the prevailing variety of rock (see Sheet 2024 —Somero). In mineral composition the microcline granites deviate quite essentially from the ingneous rocks described in the foregoing. Their principal mineral components are microcline, quartz and albitic plagioclase (An_{15-20}). The mafic minerals are biotite and, on occasion, small amounts of muscovite. In places the microcline granites contain garnet. The mafic minerals account for less than 10 % of the total constituents (cf. Neuvonen 1956). On the southern side of Talpiajärvi and Kalliojärvi Mäkinen (1913) ran across microcline granite that contained both muscovite and biotite. The mineral composition of the rock, according to Mäkinen, was: microcline 49.0 %, quartz 26.1 %, albite (An_5) 20.8 %, muscovite 2.6 % and biotite 1.5 %.

In the area north of Torro covered by the map sheet of Forssa, Neuvonen (1956) has studied the feldspar components of the granitic, granodioritic and dioritic igneous rock. According to his observations, the change in composition is even and gapless in passing from diorites to granodiorites. On the other hand, there are no transitional forms between the granodiorites and microcline granites. Simonen (1956) and Neuvonen (1956) have been in full accord in their judgment that the microcline granites do not belong with the diorites and granodiorites in the same series of rocks, but represent a separate stage of their own in the evolution of igneous rocks. The unoriented structure of the microcline granites indicates that they crystallized at a time when the folding movements had already weakened. In regard to age, the microcline granites are younger than the rocks of the diorite-granodiorite series.

SCHISTS

Typical representatives of the supracrustal rocks in the Torro area are the amphibolites and mica schists.

In composition, the amphibolites are plagioclase—hornblende rocks, in which both minerals are present just about equally, each accounting for approximately 50 %. In addition to the principal minerals, the amphibolites contain ore grains, apatite, zircon and sphene, but their combined share is only about 1 %. The plagioclase is An_{35}. The amphibolite in both the northern and southern zones of the basic pluton contains porphyritic components here and there as well as intercalations of mica schist and quartz-feldspar schist. In Simonen's view, the amphibolites of the area are predominantly of volcanic origin (Simonen 1956).

The mica schist contains principally quartz, feldspars, biotite and muscovite. On the northern side of the village of Torro, mica schist with rather large andalusite porphyroblasts is to be met with. In the amphibolite zone of the village of Kultela (App. I), mica schist occurs as an intercalation with inclusions stretched out parallel to the schistosity, some 10 cm long, dense, slightly lighter than the surrounding rock on the surface and also somewhat protuberant. In the same area of bedrock in the village of Kultela there occur dense layers parallel to the schistosity composed of material that has the same appearance as the stretched-out inclusions. In the mica schist marked in the northern part of the map, there are also tuffaceous intercalations resembling those mentioned in the foregoing.

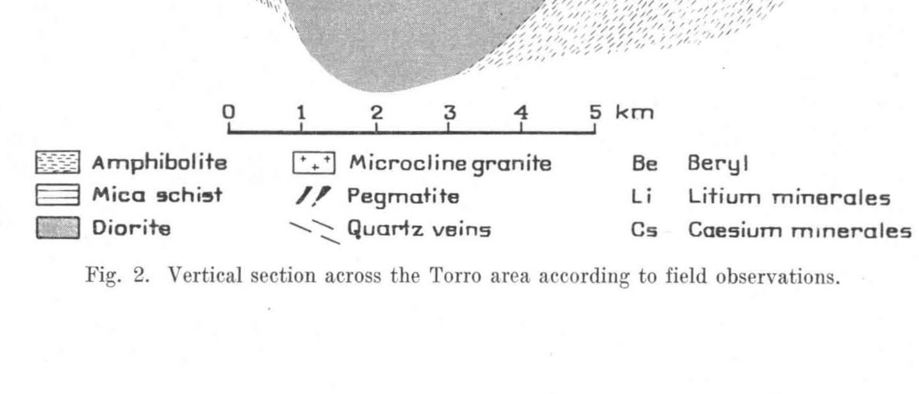

Fig. 2. Vertical section across the Torro area according to field observations.

In the schist zone the schistosity conforms to the trend of the contacts of the igneous rock massif to be seen in the middle of the map sheet. The dips are steep, usually 80—85 %, and they are inclined toward this massif, with a couple of exceptions, which may be only local disturbances. The schists form a syncline trending almost east—west (Fig. 2), in the middle of which is situated a massif of basic intrusive rocks conforming to the tectonics of its surroundings.

PEGMATITE OCCURRENCES

The mineral composition of microcline granites has already been discussed in the foregoing. These widely distributed varieties of igneous rock are in places quite coarse of structure and pegmatitic in outward appearance, as Härme, for inctance, has noted in the map sheet area of Turku (Härme 1960). On account of the coarse appearance of the microcline granites, they have also been called pegmatite granites (Metzger 1947, Simonen 1949, Salli 1953, Härme 1954, 1958).

In studying the technical utilization of pegmatite occurrences and the origin of pegmatitic solutions, one should distinguish between pegmatite granites and intrusive igneous rocks in which pegmatite is met with as formations penetrating the host rock. In the former case, the coarsely crystallized portions of the granite seldom contain enough feldspar and quartz to justify quarrying operations; even more seldom does one find in them minerals containing rare elements of the kind characteristic of complex pegamatites. The zoned structure characteristic of pegmatites proper is either totally missing from the coarse-grained portions or only faintly noticeable.

Interesting from the standpoint of the present study are Härme's observations of pegmatite granites in the area covered by the map sheet of Turku. According to Härme (1960, p. 32), it can be clearly demonstrated that the coarse-grained microcline granite is not pegmatite but true granite, which only because of its primary composition and the conditions prevailing during its crystallization took on its coarse, pegmatitic appearance. The previously presented view that the pegmatites in the Turku area are associated mainly with microcline granites derives apparently from the fact that the coarse-grained varieties of red microcline granite have been described by researchers as pegmatite formations penetrating their host rock.

The pegmatite occurrences of Torro may be classified on the basis of their geological position into three groups:

Pegmatites occurring in diorite or its contact zone;
Pegmatites of the schist series;

Pegmatite dikes and lenses occurring in association with microcline granite.

Regarded as not belonging among pegmatite occurrences proper are pure quartz veins, which are met with principally in the schist zone, but also occasionally along the margins of the diorite massif and even in the microcline granites.

PEGMATITES ASSOCIATED WITH DIORITE

The observations made in the area of Torro (App. I) reveal that the diorite massif embraces two distinctly separate pegmatite »provinces». The pegmatites are for the most part situated in the middle of the diorite massif, in a semicircular zone in the vicinity of a pond named Ahvenisto. These pegmatites form the Pajula area. Another concentrated occurrence of pegmatite is located near the southern contact of the diorite massif, southwest of the Pajula area. This pegmatite province has been named, after its best known occurrence, the Penikoja area.

The dimensions of the pegmatite occurrences have been marked down on the appended map according to the indications of surface sections without the removal of soil on any extensive scale. In the western part of the Pajula area as well as in the Penikoja area, the longitudinal trend of the pegmatite occurrences is NW — SE. This same trend quite obviously corresponds to the principal tectonic fracture trend of the bedrock, as also shown by the local riverbeds and the form of the lake basins.

The greatest length of the pegmatites along the eastern margin of the Pajula area runs in a NE — SW direction. These pegmatite occurrences appear to be situated in the same way as the foregoing in tectonic zones of weakness in the bedrock, the general orientation of which conforms to the schistosity of the schists surrounding the igneous rock massif.

On the basis of the occurrence or absence of minerals containing rare elements, the pegmatites are generally divided into two main categories: complex pegmatites and simple pegmatites. The Torro area has long been known as a place where rare pegmatite minerals can be found. The present investigation has given special attention to the occurrence of the economically important Be- and Li- minerals. Up to now, beryl ($3BeO \cdot Al_2O_3 \cdot 6SiO_2$) has been met with in altogether ten pegmatite occurrences and petalite ($LiAlSi_4O_{10}$), or Li-bearing mineral, in six. In addition to the foregoing rare minerals, pollucite ($CsAlSi_2O_6 \cdot 1/2H_2O$) has been found in one occurrence along with petalite and beryl.

3 9366—62

In respect to geological situation, all the Be-bearing pegmatites in the Torro area are connected with the extensive diorite massif, as is the sole Cs-Li-pegmatite (Luolamäki). On the other hand, three of the Li-pegmatites are in the diorite area and three beyond it in the schist area. Tourmaline occurs in varying amounts in the pegmatite deposits throughout the entire area, either as the sole rare mineral or as one among other rare minerals. According to the field observations, it is not possible on the basis of tourmaline to divide the pegmatites into simple and complex pegmatites.

Certain of the pegmatites associated with the diorite massif are thus typical complex pegmatites whereas the other ones contain chiefly plagioclase, microcline, quartz and biotite as well as, in some occasional instances, other ordinary pegmatite minerals. No clear structural differences between the simple and complex pegmatites of the Pajula and Penikoja areas could be detected: nor has it been possible to determine from the contact relations between the diorite and the pegmatite whether any significant age difference exists between the various pegmatite types. The making of observations in the latter case is rendered difficult by the unoriented structure of the Torro diorite.

CONTACTS

The contacts of the pegmatites against the wall rock in the Pajula and Penikoja areas are generally very sharp. On the contact belt the diorite fairly regularly exhibits a zone running parallel to the contact as well as, in places, a crushed schistosity. On the hanging-wall side of the Luolamäki pegmatite (Fig. 3) that had been probed with a diamond drill, the diorite becomes richer in chlorite near the contact. At the contact of the pegmatite at the footwall end, there is a narrow alteration zone in the diorite containing, besides the principal minerals, biotite and chlorite, plagioclase, muscovite, epidote, tourmaline, sillimanite and apatite. The thickness of the tectonized contact zone in the Luolamäki occurrence averages 10 centimeters.

Moving farther from the contact in the direction of the country rock, the changes in the mineral composition of the country rock lessen. One can detect the transformation of hornblende into biotite and the chloritization of the biotite — which is also likely to result from regional metamorphmis and not exclusively from the influence of the pegmatites. The enrichment of the contact zone from chlorite is closely connected with tectonic activity. The diorite on the hanging-wall side of the Luolamäki pegmatite occurrence, in the proximity of the contact, contains thin tourmaline veins and solitary tourmaline crystals. It is quite probable that the boron of the tourmaline derives from the pegmatites. This idea was previously presented by Mäkinen (1913).

On account of the lack of pegmatite quarries now being worked, it has been possible to make relatively few observations regarding the structure of the zones of the simple and complex pegmatites in the Torro area. The making of observations has further been hampered by the fact that many of the pegmatite outcrops are situated on the vertical walls of precipitous hills, along which tectonic movements and faults occurred even after the crystallization of the pegmatites. The exposures thus reveal only a very limited section of the pegmatite.

In order to gain a more detailed picture of the inner structure of the pegmatites of the diorite area, we shall undertake in the following to examine the pegmatite occurrence of Luolamäki (App. I), of which also the results of the diamond drilling investigations are at our disposal. The Luolamäki outcrop has been mineralogically mapped and described by Neuvonen and Vesasalo (1960).

THE PEGMATITE OCCURRENCE OF LUOLAMÄKI

The pegmatite occurrence of Luolamäki comprises within the massive, dark-gray diorite a slab-like formation about eight meters thick (Fig. 3). The principal minerals of the diorite are andesine-plagioclase (An_{80-50}) and hornblende. Andesine is also met with as porphyric, idiomorphic grains, which in places are slightly sericitized and kaolinized. The hornblende has partly changed to biotite and the latter, again, into chlorite. Accessory minerals in the diorite are apatite, epidote, carbonate and opaque minerals.

It has been possible on the basis of diamond drillings, rock exposures and the walls of a quarried cave to make observations that clarify to a high degree of accuracy the contact relations and structure of the pegmatite of Luolamäki. In proceeding from the country rock toward the center of the pegmatite, the following boundary zones can be mineralogically distinguished.

B o r d e r z o n e. In places between the diorite and the pegmatite there is a thin mica seam. In other places it is missing and the outermost portion of the pegmatite consists of an aplite zone 2—3 cm thick.

W a l l z o n e. The aplite is followed by a zone 30—50 cm thick containing tourmaline, microcline and quartz grains measuring 2—10 cm in diameter.

I n t e r m e d i a t e z o n e. The preceding zone is now followed by a coarse-grained zone 1.5 m thick in which the grain size of the quartz and, to some extent, that of the microcline with a graphic feldspar structure

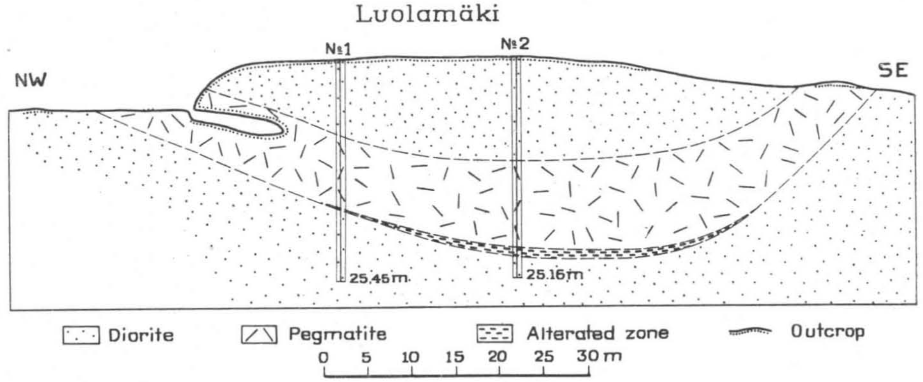

Fig. 3. Cross-profile of the pegmatite occurrence of Luolamäki in the Pajula district.

and of the tourmaline varies between twenty and thirty centimeters. In addition, this zone contains muscovite as well as albite and, in association with it, sometimes tourmaline. In the albite there have also occurred a few laminar columbite crystals, which measure between 1 and 2 centimeters in length. Moreover, blocks of waste rock that had evidently been quarried out of this zone have been found to contain crystals of beryl 0.5—3 cm in diameter.

Core zone. This part of the pegmatite consists of large microcline and petalite crystals, in addition to which one is likely to run across quartz, accumulations of albite, mica, pollucite and spodumene as well as various alteration products. The largest microcline crystals measure one meter in length, while the largest petalite crystals are 1.5 m long. In most cases the petalite crystals are surrounded by an alteration zone 3—5 cm broad. Pollucite has been met with both at the mouth of the cave (Fig. 3) as a crystal 0.5 m in diameter as well as on the northern wall of the quarry as a lump about one meter in diameter (Neuvonen and Vesasalo 1960).

In comparing the various pegmatite occurrences one with another, the observation will be made that the mineral zones are not in all cases clearly developed or to be seen in the same way as has been described in the foregoing. This is mainly because the tectonic movements had continued after the crystallization of the pegmatites, causing new crushed zones and the penetration of new solutions into old pegmatites. The pegmatites of Luolamäki also exhibit numerous nearly horizontal cracks representing fractures caused by movements taking place subsequent to crystallization.

PEGMATITE OCCURRENCES OF THE SCHIST BELT

The pegmatites of the schist belt have been investigated in considerable detail in the vicinity of Torro bog (Torronsuo) in the northeastern part of the Torro area. On the northern side of the diorite massif shown in the map, there occurs mica schist containing in places granite veins running parallel to the schistosity as well as pegmatite veins intersecting the mica schist. The mica schist grades over in the northern part of the map into amphibolite, in which intercalations of uralite plagioclase porphyrite occur. The transition from mica schist into porphyrite is gradual. The strike of the schistosity is W — E and the dip 60—90°S.

Pegmatites occur in this area as lenticular veins, which cut across or run parallel to the bedding of the porphyrites. The pegmatite vein of Varessaari (Vesasalo 1959, p. 61) contains principally microcline, quartz, biotite, muscovite and tourmaline. At Härksaari (App. I, the northeastern corner), the prevailing minerals comprising the pegmatite are pretty nearly the same, except that the mica is muscovite. This occurrence also contains, according to Mäkinen, gigantolite, chrysoberyl, andalusite, tapiolite and apatite (Mäkinen 1913, pp. 37—96).

From the economic standpoint, the most attention has been attracted by the petalite pegmatite deposit of Hirvikallio, situated at the southern margin of Torro bog. The quality and extent of this deposit have also been investigated by means of diamond drillings. The occurrence has been subjected to detailed mineralogical analysis (Vesasalo 1959). The vertical pegmatite dike at Hirvikallio is some 170 m long and from 5 to 25 meters broad, being situated partly in the contact zone between the mica schist and the uraliteplagioclase porphyrite, and partly in the porphyrite. The contact between the pegmatite and its country rock is invariably sharp, and in the southern part of Hirvikallio the pegmatite cuts across the bedding of the porphyrite. The contact between the pegmatite and the mica schist generally conforms to the schistosity of the mica schist.

The structure of the Hirvikallio pegmatite has been described in detail by Vesasalo (*o. c.*). In this connection, it should be mentioned, perhaps, that no distinct zoned structure has been observed in the Hirvikallio occurrence, although petalite is met with most abundantly around the coarse-grained microcline and quartz accumulations at the broadest point of the pegmatite dike. Evidently, this coarse portion represents the core of the deposit. Lithium is met with in both the petalite and the spodumene. Tourmaline is a mineral of common occurrence, but beryl and biotite appear to be lacking.

Among pegmatite deposits situated exclusively in amphibolite, Havulinnanmäki, at the southern edge of the mapped area (App. I), may be cited as an example. The principal minerals of this pegmatite are microcline, quartz and muscovite; but its finer-grained portion also contains some biotite, tourmaline and apatite. The pegmatite dike runs parallel to the schistosity of the amphibolite (N 30° E). In the contact zone of the pegmatite, the host rock has been compressed and altered into biotite-rich mylonite.

It is quite rare for the pegmatites of the schist belt to contain simultaneously both muscovite and biotite. Such an occurrence is Kivisoja (east of Havulinnanmäki), from which feldspar used to be quarried. The mineral composition of the pegmatite is quartz, microcline, plagioclase, muscovite, biotite and tourmaline. The plagioclase occurs as thin, sheetlike crystals. Muscovite is present as flakes measuring between 1 and 7 cm in diameter, but mostly 2 or 3 cm. The biotite accumulations may measure as much as 20 cm in diameter, though individual biotite scales are smaller. The wall of the quarry has rusty splotches, which cause a Geiger-counter to react. At the contact between the pegmatite and the amphibolite on one side of the pegmatite quarry, there is some dark rock containing round quartz grains and, between them, large biotite flakes that had turned lighter of color as well as a fine-scaled chlorite mass. The tectonization of the contact zone is not quite as clearly observable as in the Havulinnanmäki occurrence described in the foregoing.

As the observations just discussed show, both simple and complex pegmatites are to be met with in the schist belt. In the course of the investigation now reported on, beryl was not found in a single pegmatite occurrence in the schist belt, whereas lithium minerals came to light in numerous instances.

The pegmatite occurrences in the schist belt generally seem to adhere to the strike and the dip of the schistosity, but we can meet also there pegmatite veins that cut across the schistosity. The petalite pegmatite of Hirvikallio evolved in the zone of weakness that had opened up along the contact between the mica schist and the amphibolite.

THE PEGMATITES OF THE MICROCLINE GRANITES

In addition to the pegmatites described in the foregoing, the Torro area has feldspar-quartz veins whose connection with the microcline granites appears certain despite the fact that their host rock is now diorite or schist. Numerous veins of this description occur in the marginal zone of the diorite massif on the eastern side of the pegmatite area of Pajula. The contacts of these pegmatite veins against the side rock may be sharp, but all traces of compression and movement are usually lacking in the contact zone. In many cases, it will be noticed that the line of demarcation between the pegmatite vein and the country rock twists and turns in accordance with individual mineral grains. No rare minerals have been found in these pegmatites. In certain cases they have been quarried to a small extent for the quartz.

THE ORIGIN OF THE COMPLEX AND SIMPLE PEGMATITES

In determining the origin of the pegmatite occurrences, it would be necessary to carry out absolute age determinations. Lacking them, efforts have been made to gain the desired objective by observing the regional distribution and geological situation of the pegmatites of various types occurring in the area of the investigation together with contact phenomena and, above all, the relation of the pegmatites to the structural features of the host rock. Traces of strong compression have in many cases been perceived on the country rock side of contacts of pegmatite veins in the schist belt. Corresponding observations have been made in the pegmatites of the diorite area, too, as witnesses, for example, the description of the pegmatite occurrence at Luolamäki. Signs of tectonization are to be detected in the pegmatite itself as well. However, tectonic activity has not affected equally all the pegmatites in the area. Many pegmatites — above all, simple ones — in both the diorite and the schist belt appear to be connected to their country rock by quite unbroken contacts and in a way that indicates the mildness of the tectonic activity. Certain of the pegmatites adhere plastically to the geological orientation of their country rock, while other ones cut across the schistosity and bedding of the host rock sharply. Judging by all evidence, the pegmatites evolved in the Torro area in several different stages. The pegmatites obviously differ considerably in respect to age.

Many investigators have previously taken note of the varying age of the pegmatites. Studying the pegmatite occurrences of Pusu island (on the north shore of Lake Ladoga), in the commune of Impilahti, Gadolin (1858) made the observation that in the area there were two pegmatite groups marked by differences in mineral composition. The ore field of Pitkäranta belongs in the same geological milieu. In his report on this area, Trüstedt (1907) clearly brings out the difference in the ages of the pegmatite occurrences. According to Saksela (1932, 1935), the region covered by the map sheets of Kokkola and Vaasa embraces pegmatites belonging to series of both younger and older igneous rocks.

From the standpoint of the present study, it is interesting to note that, in addition to Trüstedt, also Ramsay & Zilliacus (1897), Törnebom (1891) and Gadolin (*o. c.*) remarked on the existence of two kinds of pegmatites in the Pitkäranta area — part of them, at least, being in their view of juvenile origin. This group would include the so-called complex pegmatites (cf. Saksela 1952). Eskola has likewise distinguished two kinds of pegmatites in the area of Pitkäranta, one kind being in his opinion juvenile and the other palingenetic.

The classification of pegmatites into different age groups solely on mineralogical grounds has not received general acceptance in geological circles. In his study of the mineral composition and origin of the Pitkäranta ore, Saksela (1951, p. 186) remarks that it is possible to classify pegmatites only on a tectonic basis. American geologists have likewise rejected petrographic features in classifying pegmatites and used as the basis of their classification the inner structure of pegmatites. An American publication appearing in 1949 on the structure of pegmatites recognized only two pegmatite types: zoned and unzoned (Cameron, Jahns, McNair and Page 1949).

According to Sederholm (1890, 1897) and Mäkinen (1913), the pegmatites of the Torro area should be regarded as younger than the microcline granites. This same conception is held by Eskola, too, in his Orijärvi study. He justifies his view on the following grounds (Eskola 1914, p. 36):

The pegmatites occur most abundantly near the borders of the leptite area at no great distance from the great microcline granite masses.

Where pegmatites occur in the microcline granites they do so either as dikes with sharp boundaries, or as masses of irregular outline which show a gradual transition from pegmatite into normal granites.

At the junction of the microcline granites and the crystalline schist pegmatite dikes cut the boundary line. Hence they can not be older than the microcline granites.

In large dikes within the leptite area pegmatites grade into even-grained microcline granites.

All the foregoing arguments concerning the pegmatites met with in the boundary zones of the microcline granites still hold water and shed light on the origin of the simple pegmatites and their relation to the microcline granites. On the other hand, the observation is inescapable in the area of Torro and also in the leptite zone of Kisko—Kemiö (Fig. 4) mapped by Eskola that the pegmatites genetically associated with the microcline granites are generally rich in biotite and consistently lack accessory minerals. The coarse-grained »pegmatite-granites» cannot, after all, probably be regarded as pegmatites, as has been pointed out in the foregoing (p. 10).

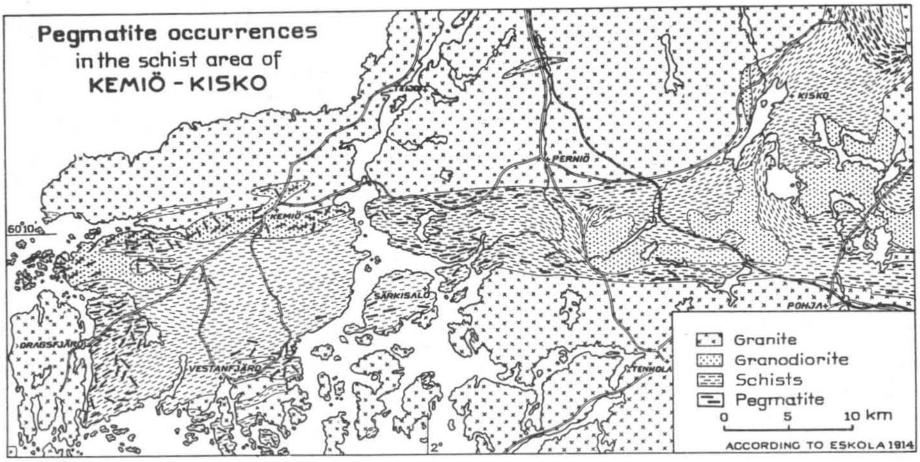

Fig. 4. Geological map of southwestern Finland according to Eskola (1914).

The number of true pegmatite occurrences in the area of microcline granites appears to be very small if we leave out of the count the coarse-grained varieties of microcline granite originating under different crystallization conditions. This phenomenon is not restricted to the pegmatite occurence in the Torro area now being referred to. Corresponding observations have been made elsewhere in the zone of the Svecofennian mountain range. In petrographic maps of the Kisko—Kemiö schist series (Eskola 1914), there are abundant markings of pegmatites whose host rock consists of synkinematic gabbros, diorites and oligoclase granites, but not a single indication of pegmatite occurring in the area of microcline granites (Fig. 4). On the other hand, there are pegmatites in the supracrustal schist sequence just as there are in the area covered by the present study.

In seeking to explain the origin of the magma producing pegmatites, attention has been drawn to the presence or absence of rare elements in pegmatite occurrences. Reference has been made in the foregoing (p. 25) to, for example, the view presented by Eskola regarding the origin of the pegmatites of Pitkäranta. According to him, the complex pegmatites had evolved out of juvenile magma whereas the simple pegmatites had derived from magmas produced palingenetically. If we were to follow the path blazed by Eskola into our own area of investigation, it would mean that the pegmatites in the Pajula and Penikoja districts containing beryl and associated with diorites must be considered juvenile, together with the lithium pegmatites skirting the diorite massif. Whether the all the simple pegmatites are of palingenetic origin is a question extremely hard to answer. This is because not all the solutions deriving from the same magma source invariably produce pegmatites having the same mineral composition. Pegmatitic magmas travel long distances in the bedrock and pegmatites crystallize from them under varying conditions. The distance from the parent magma and the geological surroundings play a prominent role in the origin pegmatites.

In the earliest studies (Sederholm 1890, Mäkinen 1913, Eskola 1914), microcline granites were regarded as the last member of the series of igneous rocks to which the basic igneous rocks of the area of the present survey belong. According to this theory, the microcline granites evolved out of a primary magma — thus, the occurrence of rare elements in the portion of the microcline granites to solidify last would have a natural explanation. Between the theory and the field observations, however, there prevails an obvious discrepancy. In the part of the area investigated up to now, the rare minerals have been missing from the pegmatites cutting across the microcline granites. The explanation offered has been that the rare elements wandered with the solutions (and gases) producing pegmatites farther from the parent rock and beyond the microcline granite area. Although this might have happened in numerous cases, it is nevertheless hard to understand the lack of rare minerals in extensive microcline granite massifs containing scattered portions of pegmatite and pegmatite veins in amounts causing petrographic cartographers to speak even of »pegmatite-granite». To mention an example, there is the area covered by the map sheet of Hämeenlinna, which is geographically located fairly near the Torro area. The investigator, Simonen (1949, p. 24) writes that pegmatitic microcline granite occurs extensively in the SW-part of the map sheet area... The pegmatites of the map sheet are of a so-called simple character. They do not contain minerals composed of rare elements. In my view, the observations concerning pegmatite-granites made in both the Torro and Hämeenlinna areas lend support to the concept that the pegmatites associated with red microcline granites evolved of solutions that from the very beginning lacked the rare elements typical of so-called juvenile magma. It is very difficult, at least, to explain the regional distribution of complex and simple pegmatites solely in the light of the transportation for long distances of rare elements.

The study of igneous rocks and their genetic relations in southwestern Finland has it more evident than ever that homogeneous, coarse-grained granites may have derived metasomatically from rocks representing an extreme variety (cf. Eskola 1952, p. 133). Many geologists have, indeed, reached conclusion in their investigations that the microcline granites are of palingenetic origin and late-kinematic in respect to age, as has frequently been stated on earlier occasions (Sederholm 1912, Wahl 1936, 1944, Metzger 1947, Simonen 1948, Eskola 1955, 1956, Neuvonen 1956, cf. Härme 1960,

p. 33). In his explanatory text accompanying the map sheet of Somero, Simonen (1956, p. 15) specifically points out that the microcline granites do not seem to be directly associated with the magmatic series as the most acid member. When these points of view are taken into account, it is justified on genetic grounds to consider the microcline granites and the simple pegmatites associated with them as a group apart, the mineral and chemical composition of which has been determined by a magma of palingenetic origin. After the crystallization of the microcline granites, the solutions left over from this magma contained rare elements in only very slight amounts, at best, or not at all. For this reason, the pegmatites of »pegmatite-granites» have very seldom yielded minerals containing rare elements. Field observations seem to support this body of evidence.

In pegmatite investigations aiming at practical objectives, it is of prime importance to know the relation of complex and simple pegmatites to their probable parent rocks. As is well known, the crystallization of pegmatite minerals takes place in several different stages (see Pehrman 1945, Volborth 1953, Cameron et al. 1949). The oldest generation includes, *inter alia*, tourmaline and beryl. These minerals crystallize closer to their parent rock than do the lithium minerals, for, compared to boron and beryllium, lithium is a long-distance wanderer. The petrographic map of Torro reveals that beryl has been met with primarily in the middle of the diorite massif, whereas the places where lithium has been mostly found are situated in the schist belt along the borders of the diorite massif. Assuming that the solutions producing rare pegmatite minerals derive from the same magma source — as would appear exceedingly likely at the present stage of field research — the areal situation of the beryl- and lithium-pegmatites would further indicate their relative distance from their parent rock. Beryl-pegmatites are situated closer to their parent rock than lithium-pegmatites are. Inasmuch as the pegmatites of the microcline granites in the area of the present survey have proved without exception to be simple pegmatites, it would be necessary for this reason, too, to seek the parent rock of the pegmatites containing beryl and lithium minerals among synorogenic igneous rocks. All the observations so far made in the Torro area seem to indicate that the complex pegmatites could have evolved only out of the residual solutions of magma producing synorogenic igneous rocks. The mineral composition of the pegmatites may, however, have changed subsequently as younger solutions used as their channels of flow zones of weakness in the bedrock marked out by the older pegmatites. There are numerous examples of this to be seen in the Torro area of investigation. One generally observable phenomenon is the replacement of microcline by albite. The production of pegmatites is a continuous process, during which later solutions are likely to cause partial or total changes in the mineral composition of the original pegmatite.

Very little research has been done on the regional distribution of pegmatite types and pegmatite minerals and the geological factors responsible. The present study is the first one in this sphere of research here in Finland. Although the pegmatite investigation carried out in the area of Torro must be regarded as having only an orientating character, it will probably at least give readers interested in economic geology some hints as to the geological situation and local distribution in the bedrock area of pegmatites containing rare minerals.

ACKNOWLEDGMENTS

To my co-workers, the late Mr. Arvo Vesasalo, Lic. Phil., and Mrs. Marjatta Virkkunen, Mag. Phil., who participated in both the field and the laboratory research, I whish to extend my warm thanks. They helped me in many ways. I also want to thank the geologists who served as my summer assistants as well as all the other persons who in one way or another have taken part in the pegmatite investigations reported in this paper. Mr. Paul Sjöblom, M. A., translated the manuscript into English.

REFERENCES

CAMERON, E. N., JANS, R. H., MCNAIR, A. H. and PAGE, L. R. (1949) Internal structure of granitic pegmatites. Econ. Geol., Monograph 2.

ESKOLA, PENTTI (1914) On the petrology of the Orijärvi Region in southwestern Finland. Fennia 37, N:o 3.

—»— (1952) A discussion of domes and granites and ores. Compt. Rend. Soc. Géol. Finlande XXV, pp. 125—144. Bull. Comm. géol. Finlande 157, 13.

—»— (1955) About the granite problem and some masters of the study of granite. Compt. Rend. Soc. Géol. Finlande XXVIII, pp. 117—130. Bull. Comm. géol. Finlande 168, 11.

—»— (1956) Postmagmatic potash metasomatism of granite. Compt. Rend. Soc. Géol. Finlande XXIX, pp. 85—100. Bull. Comm. géol. Finlande 172, 9.

GADOLIN, A. (1858) Geognostische Beschreibung der Insel Pusu (Pusunsaari) im Ladoga-See. Verh. d. russ. min. Ges. St. Petersburg.

HÄRME, MAUNU (1954) Kallioperäkartan selitys. Lehti — Sheet — 2024, Karkkila. Explanation to the map of rocks. Geological map of Finland, 1 : 100 000.

—»— (1958) Examples of the granitization of plutonic rocks. Compt. Rend. Soc. Géol. Finlande XXX, pp. 45—64. Bull. Comm. géol. Finlande 180, 3.

—»— (1960) Kivilajikartan selitys. Lehti — Sheet — B 1, Turku. Explanation to the map of rocks. General geological map of Finland, 1 : 400 000.

KULLHEM, H. A. (1870—1871) Mineralogiska bidrag. Öfversikt af Finska Vet. Soc. Förh. XIII, p. 43.

LIHR, C. (1780) Tilasvuori grufvor i Tammela. Manuskr. im Archiv des finnl. Bergamts.

MALLEN, JACOB (1759) De monte cuprifero Tilasvuori. Acad. afh. Åbo.

METZGER, ADOLF A. T. (1947) Zum tektonischen Stil von Palingengranit und Marmor in den Svekofenniden in Finnland. Compt. Rend. Soc. Géol. Finlande XX, pp. 183—192. Bull. Comm. géol. Finlande 140, 16.

MIKKOLA, TOINI and WIIK, H. B. (1947) Petalite, a mineral new to Finland. Compt. Rend. Soc. Géol. Finlande XX, pp. 281—286. Bull Comm. géol. Finlande 140, 23.

MÄKINEN, EERO (1913) Die Granitpegmatite von Tammela in Finnland und ihre Minerale. Bull Comm. géol. Finlande 35.

NEUVONEN, K. J. (1956) Kallioperäkartan selitys. Lehti — Sheet — 2113, Forssa. Explanation to the map of rocks. Geological map of Finland, 1 : 100 000.

NEUVONEN, K. J. and VESASALO, ARVO (1960) Pollucite from Luolamäki, Somero, Finland. Compt. Rend. Soc. Géol. Finlande XXXII, pp. 133—146. Bull. Comm. géol. Finlande 188, 11.

PEHRMAN, GUNNAR (1945) Die Granitpegmatite von Kimito (SW-Finnland) und ihre Minerale. Medd. f. Åbo Akad. geol. -min. inst. 26.

RAMSAY, WILHELM und ZILLIACUS, ALLAN (1897) Monatzit von Impilaks. Öfversikt af Finska Vet. Soc. Förh. XXXIX.

SAKSELA, MARTTI (1932) Tektonische und stratigraphische Studien im mittleren Ostbothnien, mit einigen Vergleichspunkten aus anderen Gebieten. Compt. Rend. Soc. Géol. Finlande V, pp. 16—39. Bull. Comm. géol. Finlande 97, 1.

—»— (1935) Über den geologischen Bau Süd-Ostbothnies. Bull. Comm. géol. Finlande 110.

—»— (1951) Zur Mineralogie und Entstehung der Pitkäranta-Erze. Compt. Rend. Soc. Géol. Finlande XXIV, pp. 181—231. Bull. Comm. géol. Finlande 154, 10.

—»— (1952) Nochmals über die Entstehung der Granitgneiskuppeln und der Erze im Pitkärantagebiet. Compt. Rend. Soc. Géol. Finlande XXV, pp. 115—124. Bull. Comm. géol. Finlande 157, 12.

SALLI, ILMARI (1953) Kallioperäkartan selitys. Lehti — Sheet — 2111, Loimaa. Explanation to the map of rocks. Geological map of Finland, 1 : 100 000.

SEDERHOLM, J. J. (1890) Kertomus karttalehteen N:o 18. Tammela. Helsinki.

—»— (1897) Über eine archäische Sedimentformation im südwestlichen Finland und ihre Bedeutung für die Erklärung der Entstehungsweise des Grundgebirges. Bull. Comm. géol. Finlande 6.

—»— (1912) Om palingenesen i den sydfinska skärgården samt den finska urbergsindelningen. Geol. Fören. i Stockholm Förh. Bd. 34, p. 285.

SIMONEN, AHTI (1948) On the petrochemistry of the infracrustal rocks in the Svecofennidic territory of southwestern Finland. Bull. Comm. géol. Finlande 141.

—»— (1949) Kallioperäkartan selitys. Lehti — Sheet — 2131, Hämeenlinna. Explanation to the map of rocks. Geological map of Finland, 1 : 100 000.

—»— (1956) Kallioperäkartan selitys. Lehti — Sheet — 2024, Somero. Explanation to the map of rocks. Geological map of Finland, 1 : 100 000.

TÖRNEBOHM, A. E. (1891) Om Pitkäranta malmfält och dess omgifningar. Geol. Fören. i Stockholm Förh. Bd. XIII, pp. 313—334.

TRÜSTEDT, OTTO (1907) Die Erzlagerstätten von Pitkäranta am Ladoga-See. Bull. Comm. géol. Finlande 19.

WAHL, W. A. (1936) The granites of the Finnish part of the Svecofennian Archaean mountain chain. Compt. Rend. Soc. Géol. Finlande IX, pp. 489—505. Bull. Comm. géol. Finlande 115, 27.

—»— (1944) Altersvergleich der Orogenesen und Versuch einer Korrelation des Grundgebirges in verschieden Teilen der Erde. Geol. Rundschau 34. Heft. 2—6. S. 209.

VESASALO, ARVO (1959) On the petalite occurrences of Tammela, SW-Finland. Compt. Rend. Soc. Géol. Finlande XXXI, pp. 59—74. Bull. Comm. géol. Finlande 184, 5.

WIIK, F. J. (1881—1882) Mineralogiska meddelanden VII; Om mikroklin och andesin från Pargas samt andesin från Tammela. Öfversikt af Finska Vet. Soc. Förh. XXIV, p. 24.

v. VOLBORTH, A. (1954) Phosphatminerale aus dem Lithiumpegmatit von Viitaniemi, Eräjärvi, Zentral-Finland. Ann. Acad. Sci. Fennicae, Ser. A, 39.

GEOLOGICAL MAP OF THE TORRO AREA SHOWING THE DISTRIBUTION OF THE BE-, CS-, AND LI-BEARING PEGMATITE OCCURRENCES

LEGEND

- Microcline granite
- Pegmatite
- Amphibolite
- Mica schist
- Basic intrusive
- Quartz-feldspar schist
- 30 Schistosity
- 5 Lineation
- Fold axis
- Striae direction
- Quarry