Bulletin de la

Commission Géologique

de Finlande

N:o 248

Seismotectonics of the Kuopio region, Finland

by Jouko Talvitie

Geologinen tutkimuslaitos • Otaniemi 1971

Bulletin de la Commission Géologique de Finlande N:o 248

SEISMOTECTONICS OF THE KUOPIO REGION, FINLAND

BY

JOUKO TALVITIE

WITH 23 FIGURES AND 4 TABLES IN THE TEXT AND ONE APPENDIX

GEOLOGINEN TUTKIMUSLAITOS
OTANIEMI 1971

Helsinki 1971. Valtion painatuskeskus

CONTENTS

Talvitie, Jouko 1971: Seismotectonics of the Kuopio region, Finland. *Bull. Comm. Géol. Finlande N:o 248.* 41 p., 23 figs., 4 tables, one appendix.

The source of seismicity in the Baltic Shield was studied in an area of 10 000 km^2 in the central part of the shield. The area consists of Svecokarelian and Basement schists and gneisses, partly migmatitic and invaded by various plutonic rocks.

Linear trenches and scarps in the bedrock show four preferred orientations (270°—275°, 305°—310°, 325° and 0°—5°), and they are concentrated into zones of the same orientation. Evidence indicates that these zones coincide with deep faults, which have been active since the Precambrian: The distribution of basic and other plutonics, migmatites and brecciated rocks coincides with the zones, in which patterns of foliation, lineation and minor folds result from shearing along the zones and intersect earlier patterns preserved in the blocks. Certain adjoining blocks show different rates of present uplift.

The epicentres are situated in these zones. The focal depths are from 3 to 10 km, magnitudes between 3.2 and 4.3, and maximum intensity $I_0 = 6$ (MM scale). The earthquake frequency at one block suggests that an event of magnitude 4.0—4.3 will occur there every 20th to 30th year. This Precambrian block, with its fractured boundary zone, forms a minor seismogenic unit in a seismic zone.

INTRODUCTION

The connection between earthquakes and faulting was noticed as early as the last century (Richter 1958, p. 189). In Finland, it was assumed, like Sederholm (1913, 1932), until quite recent decades that the faults connected with earthquakes were Late-Precambrian or later in origin. It was thought that any planar fractures that could possibly have existed earlier would have disappeared in the plastic conditions of the deep levels where the deformation and plutonism represented by the rocks of the present surface section had taken place (cf., Eskola 1963, p. 206). Sederholm (1932) strongly opposed the views of Asklund (cited in Ramsay 1931, p. 366), who thought that the oldest linear fractures seen in the relief of the Baltic shield were faults dating from the Archean.

Tuominen (1957, 1961 a, 1961 b, 1966) demonstrated in his detailed investigation, carried out in southwestern Finland, that the linear faults seen in the topography had originated during the Precambrian. Antedating the regional metamorphic facies, these faults, in his view, have markedly affected the regional distribution and structure of the Precambrian rocks. Tuominen's findings have been supported by subsequent studies, in which such fault lines — or clusters of them — have been observed to be as much as hundreds of kilometres long (Härme 1960, 1961, 1966; Paarma and Marmo 1961; Paarma 1963, Mikkola and Niini 1968). Rejuvenation of these faults during later periods, up to the present day, has been assumed and a connection between them and the earthquakes in Finland has been suggested by the researchers cited and certain others (Penttilä 1963, Talvitie 1965, 1966, Teisseyre *et al.* 1968). Considered as the cause of recent earthquakes has been the movement of the blocks at varying rates during the recent uplift of the Baltic shield (see, Honkasalo 1960).

On the other hand, in areas where seismicity has been ascertained to exist no clear connection between any particular tectonic unit and the seismicity has been established. Thus the structural characteristics, magnitude and regional distribution of such units as blocks, faults or fracture zones remain unknown.

In the present paper, the geological history and significance of the fracture systems in the Kuopio region, which shows a relatively high frequency of earthquakes, has been examined from the standpoint of seismogenic units (Gubin 1967).

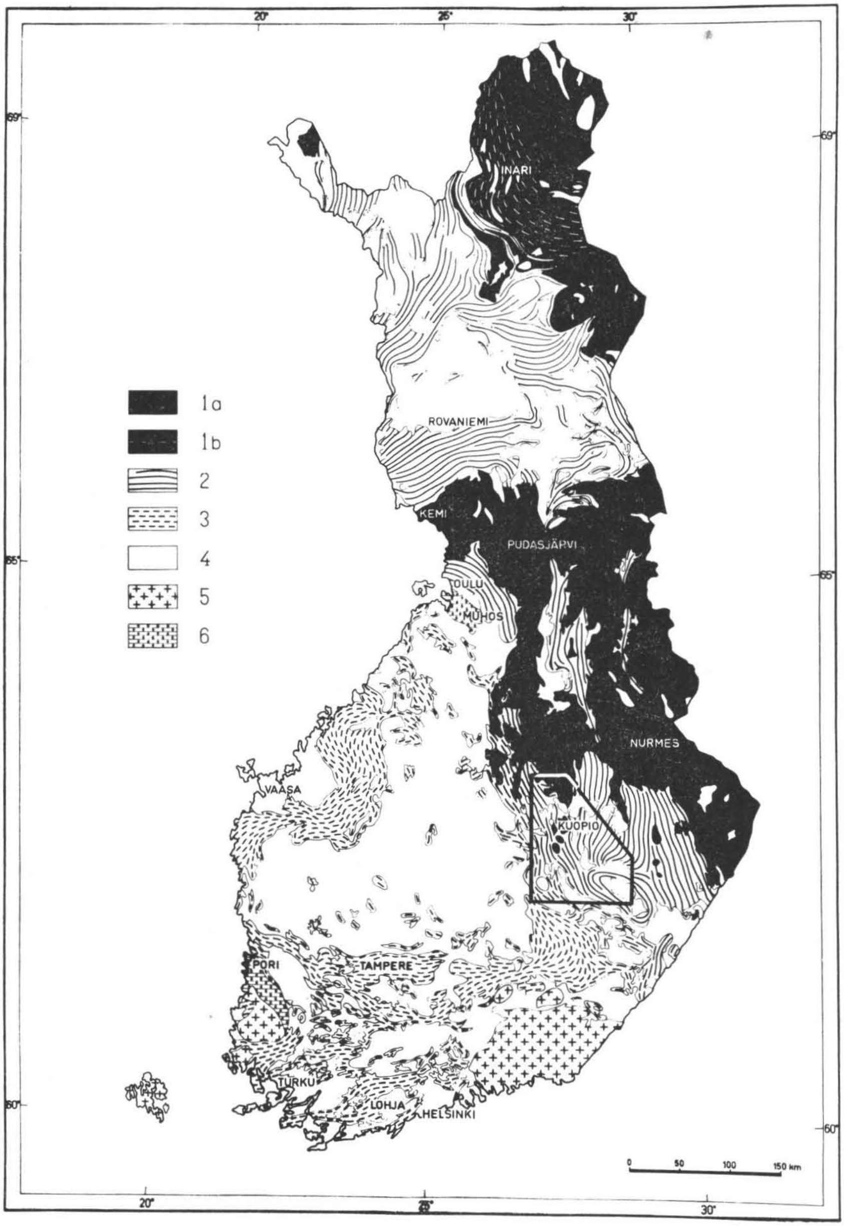


FIG. 1. Location of the Kuopio region, 1 a) pre-Karelian granite gneiss basement, 1 b) granulite, 2) Karelian schist belt, 3) Svecofennian schist belt, 4) Svecokarelian plutonic rocks, 5) anorogenic rapakivi intrusions, 6) Jotnian sediments. From Simonen (1962).

LITHOLOGICAL OUTLINE

The Kuopio region is situated in the border zone between the Karelian and the Svecofennian belts (Fig. 1). The Karelian schists represent transgressive platform sediments upon the pre-Karelian basement complex and are characterized by true quartzites. The Svecofennian schist belt consists of a thick accumulation of graywackes in geosynclinal troughs (Simonen 1960).

The stratigraphic correlation between the Svecofennian and the Karelian sediments is still an open question. T. Mikkola (1953) and Metzger (1959) were the first to suggest that both of these sedimentary groups may actually represent the same cycle of sedimentation. Simonen (1960, pp. 7—9) points out that no valid evidence for an unconformity between the Svecofennian and the Karelian belts has been found in Finland. Besides, radioactive age determinations show ages of between 1800 and 1900 million years for the plutonism and associated metamorphism of both belts (Kahma 1956, Kouvo 1958, Kouvo and Tilton 1966). This suggests that they both belong to a single (Svecokarelian) orogeny.

The geological map of the region investigated (Fig. 2) is based on the General Geological Map of Finland, 1: 400 000, and the explanatory text accompanying the respective sheets of this map (Frosterus 1903, Frosterus and Wilkman 1920, Hackman 1933, Wilkman 1938).

The age data show that rocks in the pre-Karelian basement complex crystallized 2 600—2 800 m.y. ago (Kouvo and Tilton 1966, p. 421). The basement complex is exposed in a number of mantled domes in the northwestern parts of the region (Fig. 2). The Karelian metasediments are separated from this complex by first order unconformity, i.e., an interval of deep erosion and peneplanation. These metasediments in the Kuopio region consist of basal conglomerate, quartzite, marble, amphibolite, black schist and thick deposits of schists varying from pelitic to psammitic. In Fig. 2, all these rocks are indicated as a single unit of the Svecokarelian schists. In many cases, both the pre-Karelian basement and the Svecokarelian schists are conspicuously sheared or migmatized. In such cases, it is difficult or impossible to differentiate between the basement and the metasediments. In Fig. 2, the migmatites and the intensely sheared rocks have been included among Svecokarelian schists. The strike of the foliation or the streaky or gneissic structure of these two rock groups is indicated by forks or dashes, as it appears in the General Geological Map of Finland, 1: 400 000.

The Svecokarelian metasediments as well as the basement are intersected by various plutonic rocks. In Fig. 2, these are separated into four groups, basic plutonic rocks, a pyroxene-bearing plutonic complex, syenites and granitoid rocks. The basic plutonic rocks are ultrabasics, gabbros and diorites, while the granitoids are granodiorites and granites. According to Simonen (1960), the granodiorites and the basic plutonic rocks represent synkinematic types while the granites are late-kinematic in relation to the Svecokarelian orogenic movements. As a distinction between the

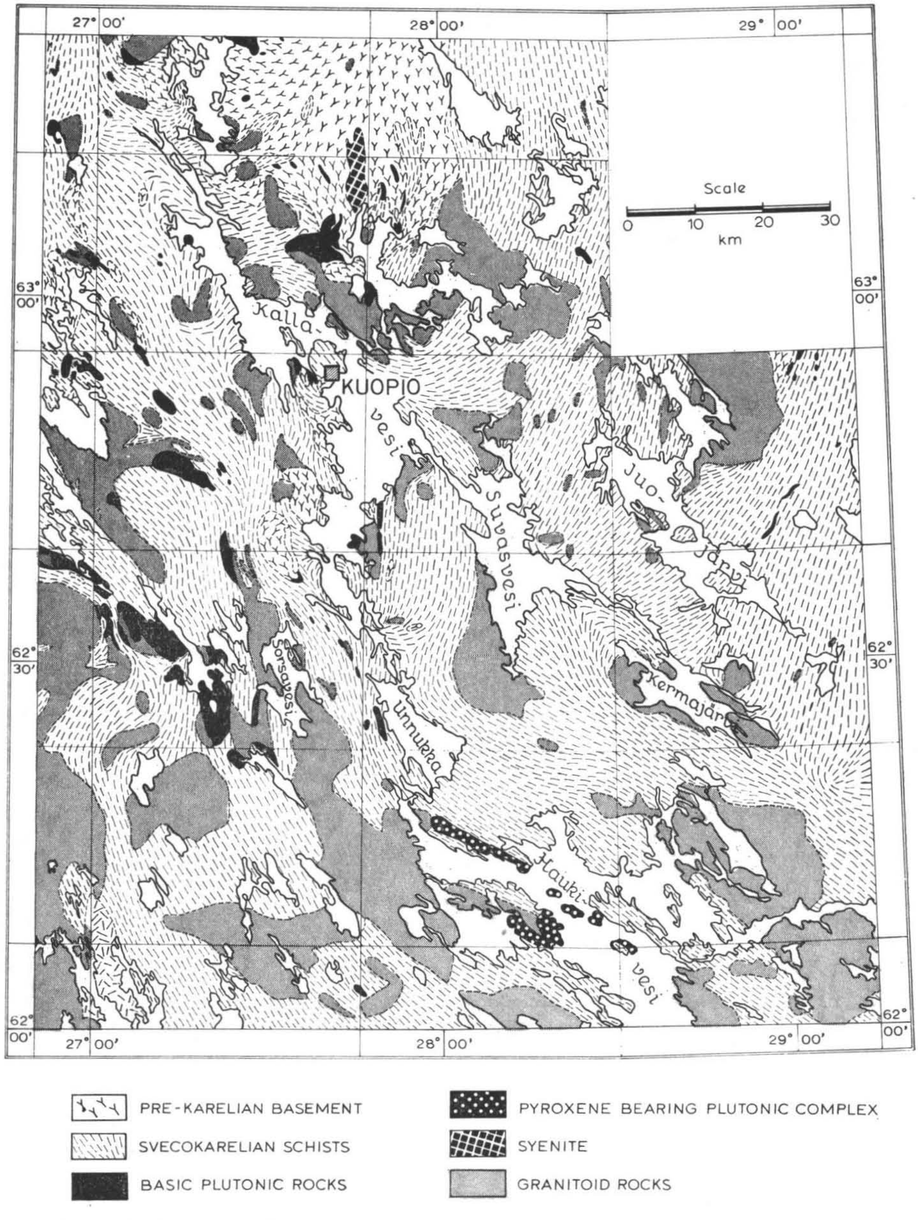


FIG. 2. Geological map of the Kuopio region. Compiled from the general geological map of Finland, 1: 400 000, sheets: C2, C3, D2, D3.

granites and granodiorites is not made in the available geological maps they have been combined under the designation of granitoids in Fig. 2.

The pyroxene-bearing plutonic complex in the area of Lake Haukivesi, between the Svecofennian and Karelian belts (Figs. 1 and 2), consists of rocks ranging from pyroxene granites to gabbros (Hackman 1933, pp. 124—127). These are shown as a single unit in Fig. 2.

A syenite pluton north of Kuopio is also indicated. The pluton, which is elongated in a north-south direction, is intersected by a carbonatite sheet of the same orientation and a probable age of 2 500 m.y. (Puustinen 1968, 1971).

BLOCKS AND FAULTS

Method of study

The recognition of the faults and fault patterns in the area investigated was primarily based on a study of lineaments and lineament distribution in aerial photographs. Hobbs (1911) defined lineaments as significant lines on the earth's face. Since then the term has been used variously as described by Lattman (1958). Billings (1960, p. 160) calls any topographically controlled line on an aerial photograph a lineament. It may be produced by faults, joints, bedding, foliation or even lineation. A lineament that represents a fault is usually a sharp line, and there may be a scarp on one side.

As the main concern of the photolineament study in the Kuopio region was to find the possible faults, the linear scarps and narrow linear topographic trenches occurring in the bedrock were used as the basic criterion for the lineaments. The linear patterns of vegetation or soil tones or texture were added only where they were clear extensions of the lineaments seen in the bedrock. To avoid lineaments caused by bedrock joints and other small features, those shorter than three kilometres were discarded.

The Kuopio region is suitable for observing the linear scarps and topographic trenches of the bedrock for the following reasons. The thickness of the overburden (Quaternary deposits) is relatively thin, usually not exceeding a few metres. These deposits consist mostly of till and there are no large bogs to hamper observation of the lineaments. Because of the large number of islands, the lineaments can easily be traced through the lakes, too. In addition, there are no strongly developed drumlin and fluting landscapes, which form glaciogenic lineaments in certain other areas in Finland. The relief of the bedrock is prominent enough to become visible through the till cover, and the outcropping density is relatively high as appears, for instance, from Fig. 11. In many cases, the trends of the gneissose structures can be readily traced in aerial photographs, a circumtance that contributes to the interpretation of the lineaments (see, Hepworth 1967).

Panchromatic diapositive films on a scale of 1: 60 000 and a photomosaic on a scale of 1: 100 000 were used simultaneously to find and interpret the lineaments.

2 12855—71

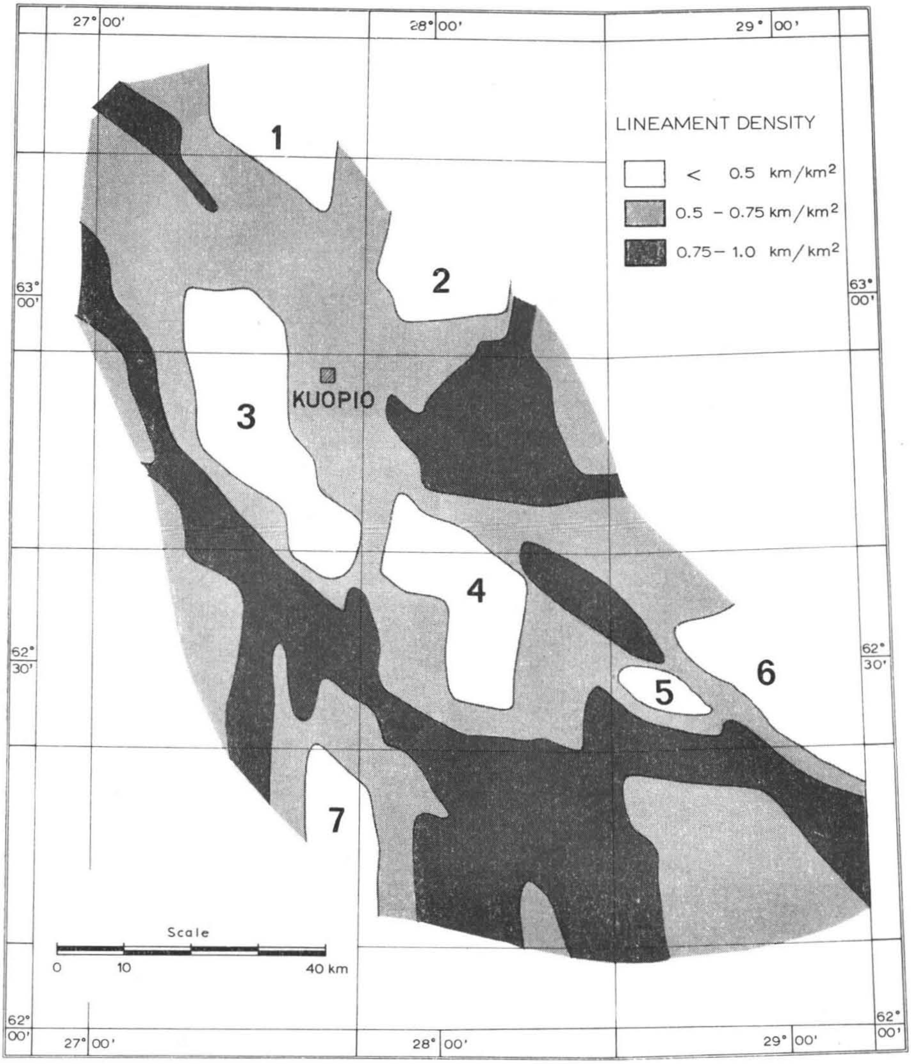


FIG. 3. Lineament density in the Kuopio region. The blocks of low lineament density are indicated by 1—7.

The advantages of small-scale aerial photographs in stereoscopic interpretation has been described by Hemphill (1958). The mosaic was prepared according to the geographical coordinate system. Lineaments observed stereoscopically in the films were drawn on this mosaic. In this way the locations, directions, continuities and lengths of the lineaments were properly recorded.

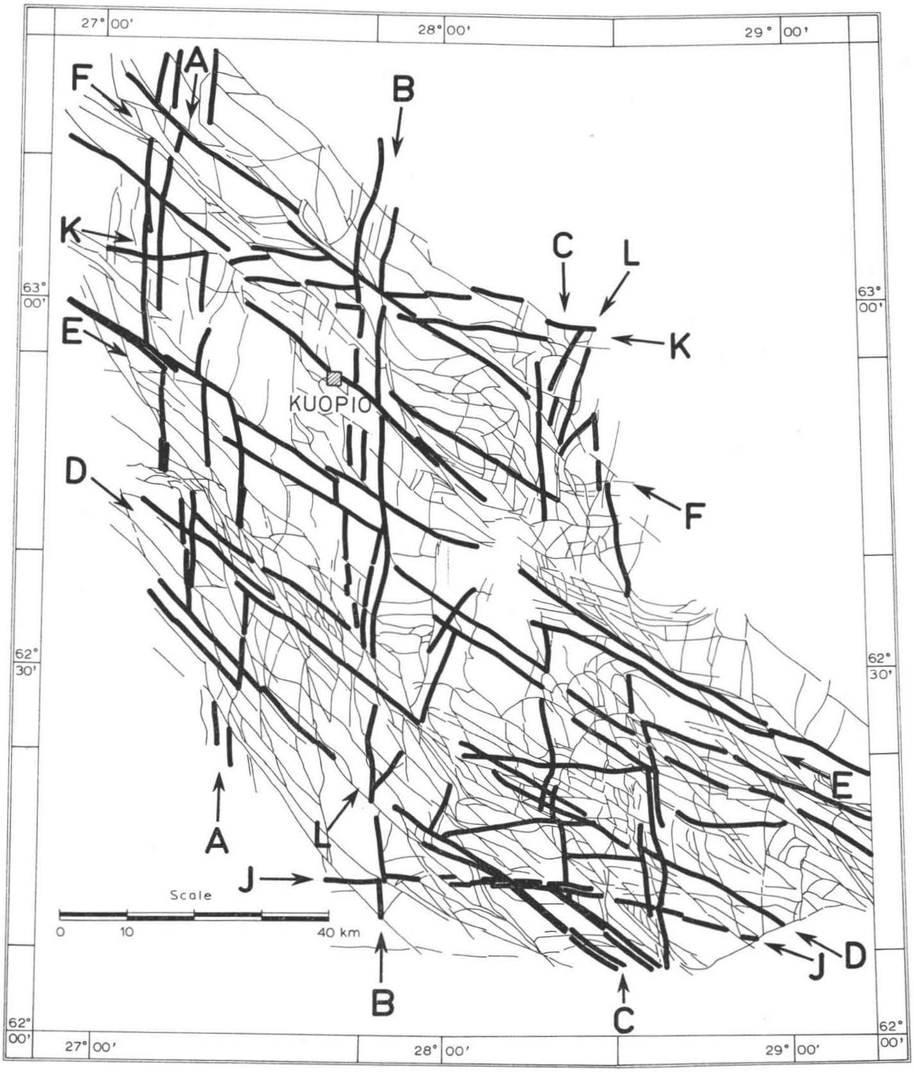


FIG. 4. Position of lineament sets A—A, B—B etc. Some of the most pronounced lineaments in each set are indicated by heavy lines.

In order to analyze the structural significance of the lineaments, the lineament map was compared with geological and aeromagnetic maps of the region. These were reproduced as transparent overlays to fit the mosaic (Paarma and Talvitie 1968, Paarma et al. 1968). The preliminary lineament map was revised on the basis of later field checking. Plate 1 is the revised map.

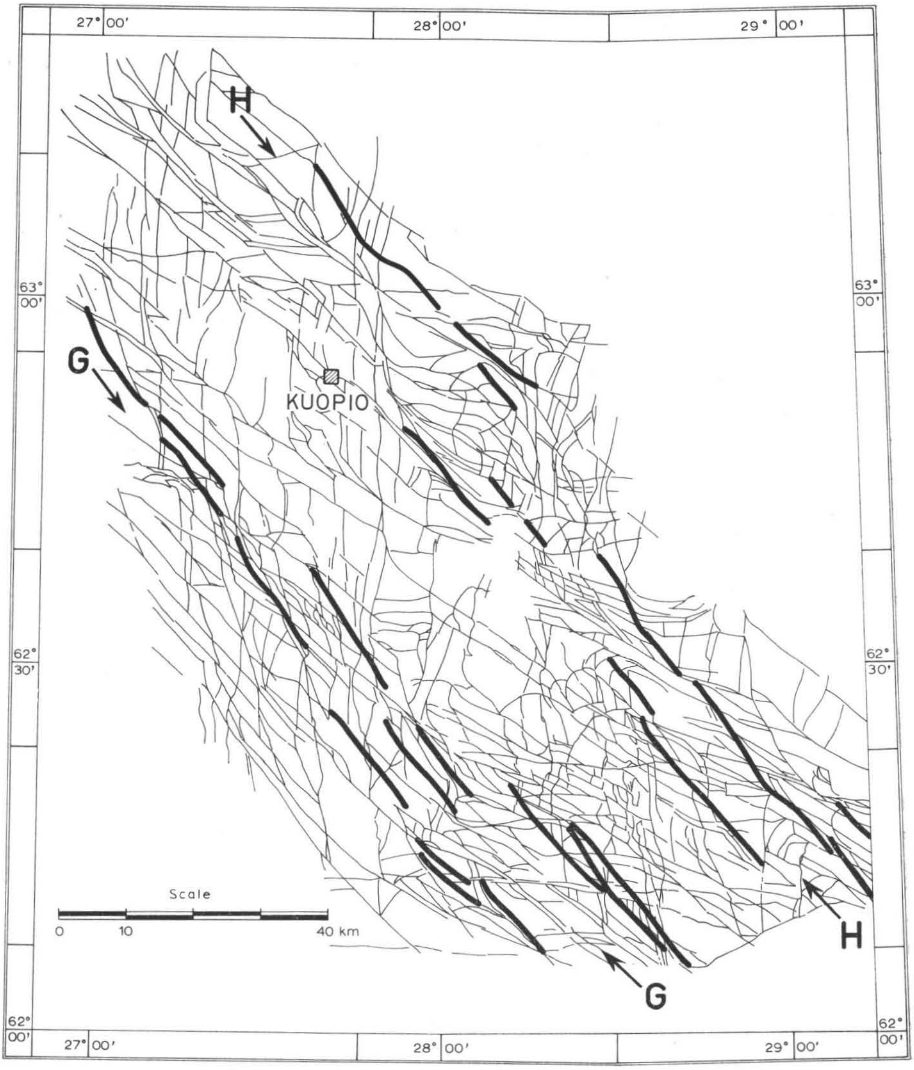


FIG. 5. 325° lineament sets indicated by G—G and H—H.

Distribution of blocks and faults

The total length of the lineaments measured from the lineament map (Plate 1) gives an average lineament density of 0.6 km per km^2 for the whole area. For determining the areal variations in the lineament density, the lineament map was scanned with a circle representing a unit area of 80 km^2. The density variations

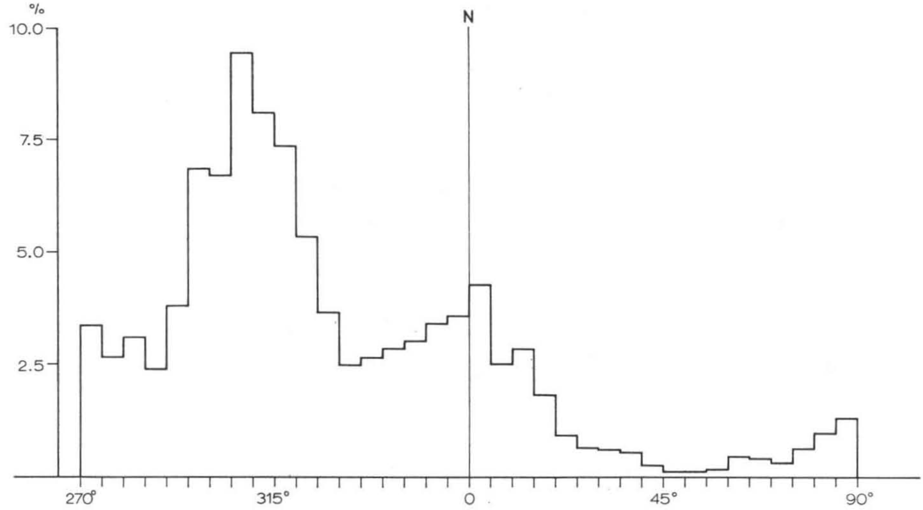


FIG. 6. The strike distribution of the lineaments in Plate 1.

are presented in Fig. 3. The areas of low lineament density (≥ 0.5 km/km²) are numbered 1—7. These low-density areas form islands or blocks surrounded by areas or zones of higher density. The most pronounced high-density (0.75—1.0 km/km²) zone is southwest of blocks 3 and 4, and it trends NW. The zones of high and intermediate lineament density are fracture zones, and the areas of low lineament density less fractured blocks, as will be shown in the following.

Some of the individual lineaments or parallel sets of shorter lineaments extend continuously through the Kuopio region (Plate 1). Such long lineaments and sets of lineaments determine the trend of the fracture zones. The thicker lines in Figs. 4 and 5 are intended to emphasize some of the lineaments forming sets of this kind. The sets have been marked with letters, to wit, A—A, B—B, etc. Thus, in the western part of the region, the most prominent fracture zone adheres alternately to the set marked D—D (305°, Fig. 4) and the one marked G—G (325°, Fig. 5). In the southern part of the Kuopio region, this zone expands into a fracture area where several lineament sets running in different directions intersect.

Fig. 6 represents the relative azimuthal distribution of the lineaments shown in Plate 1. The diagram is based on the sum of the lengths of the lineaments at each interval of five degrees. Three major peaks are revealed.

The highest peak is situated at 305°—310°. It is the peak of a broad maximum occurring between 290° and 330°. It is due mainly to lineament sets D—D, E—E and F—F (Fig. 4), which have an average strike of 305°, and to sets G—G and H—H, with their strike of 325° (Fig. 5). These sets form the NE and SW boundaries of the blocks in Fig. 3.

The second peak in the diagram is situated at 0°—5°. It is composed mainly of the N—S-striking lineament sets A—A, B—B and C—C indicated in Fig. 4, which define the western and eastern boundaries of the blocks in Fig. 3.

The third peak in the diagram lies at 270°—275°. It is composed mainly of the sets indicated by J—J and K—K in Fig. 4. Set J—J contributes strongly to the fracture zone south of blocks 4 and 5.

Figure 4 indicates one more individual and slightly developed lineament set L—L, which strikes NNE and intersects block 4 (Fig. 3).

DISTRIBUTION OF THE PLUTONIC ROCKS AND MIGMATITES

When Plate 1 is superimposed on the geologic map (Fig. 2) the distribution of the basic and pyroxene-bearing plutons appears to coincide with the lineament sets (Fig. 4 and 5). These plutons are frequent in sets D—D (305°—310°), B—B (0°—5°) and G—G (325°). In certain cases, the elongation of the individual bodies coincides with set A—A (0°—5°). When the distribution of these plutons is compared with the fracture zones and blocks in Fig. 3, the plutons appear to be situated in the fracture zones only. For instance, they are numerous around block 3.

The basic plutons met with in the most prominent fracture zone SW of blocks 3 and 4 (Fig. 3), usually show a brecciated (agmatitic) structure. In this fracture zone, there are also many minor bodies of basic and ultrabasic rocks not indicated in Fig. 2. Such small bodies are found also in the fracture zone between blocks 3 and 4. Savolahti and Kurki (1964, p. 190) considered these bodies to be tectonic and metamorphic in origin connected with migmatization.

The syenite pluton with the related carbonatite sheet is situated in the fracture zone between blocks 1 and 2 (Fig. 3).

The long and deep fractures and fracture zones are the places where the basic and pyroxene-bearing plutons occur. The same correlation is suggested by Mikkola and Niini (1968) for Finnish basic plutons in general. In their view, the deep faults have served not only as locations but also as passageways for the basic magmas to rise from greater depths. The presence of the carbonatite sheet indicates an age of 2 500 m.y. and the pyroxene-bearing and basic plutons an age of 1 800—1 900 m.y. for the igneous activity and movements in the fracture zones.

The distribution of the granitoid rocks seems to be partly connected with the lineament sets as does that of the basic plutonic rocks. Their further correlation with the lineament sets is premature because a proper division of the granitoids is lacking. Besides, some of the granitoid rocks may belong to the pre-Karelian basement.

In the Kuopio region, there are migmatites with both a streaky and an agmatitic structure. Generally, they are white-grey in colour and trondhjemitic in composition (Figs. 7, 8). Migmatites are markedly developed along the fracture zones and poorly

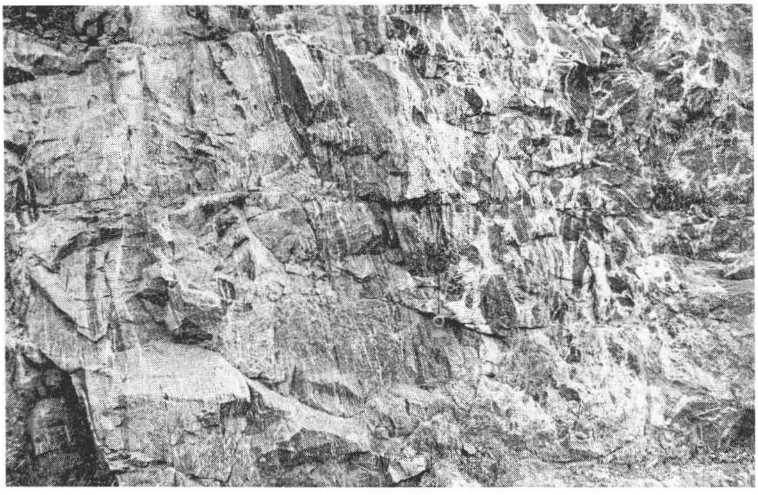


FIG. 7. Agmatite in sheared gneiss in a zone of high lineament density (area B of Fig. 9).

in the blocks. Closely spaced agmatitic »dikes» parallel to the prevailing lineaments are common in the fracture zones. This has been observed also by Preston (1954, pp. 65, 85—91), who notes that white-grey migmatites predominate in the fracture zone that coincides with the lineament set designated F—F in Fig. 4. In his view, the migmatites have derived from the pre-Karelian basement rocks and the overlying metasediments under shearing along the fault zone. Preston points out that the migmatization took place after the plutonic activity and doming had waned.

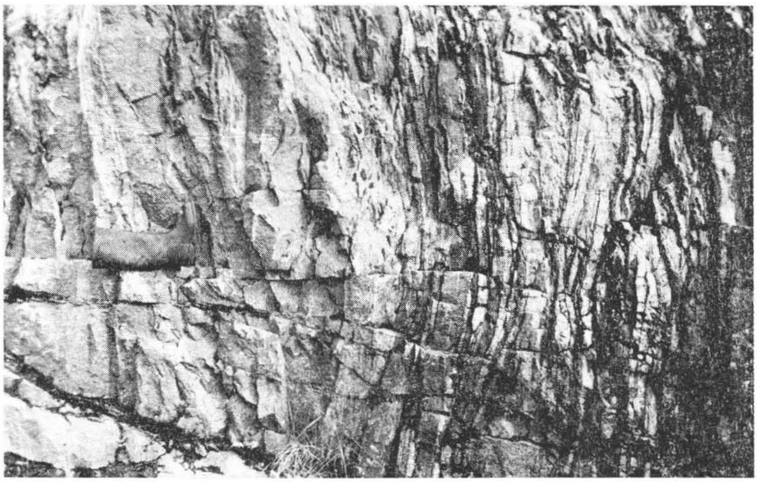


FIG. 8. Agmatite »dike» in quartz-dioritic rock in a zone of high lineament density (area C of Fig. 9.).

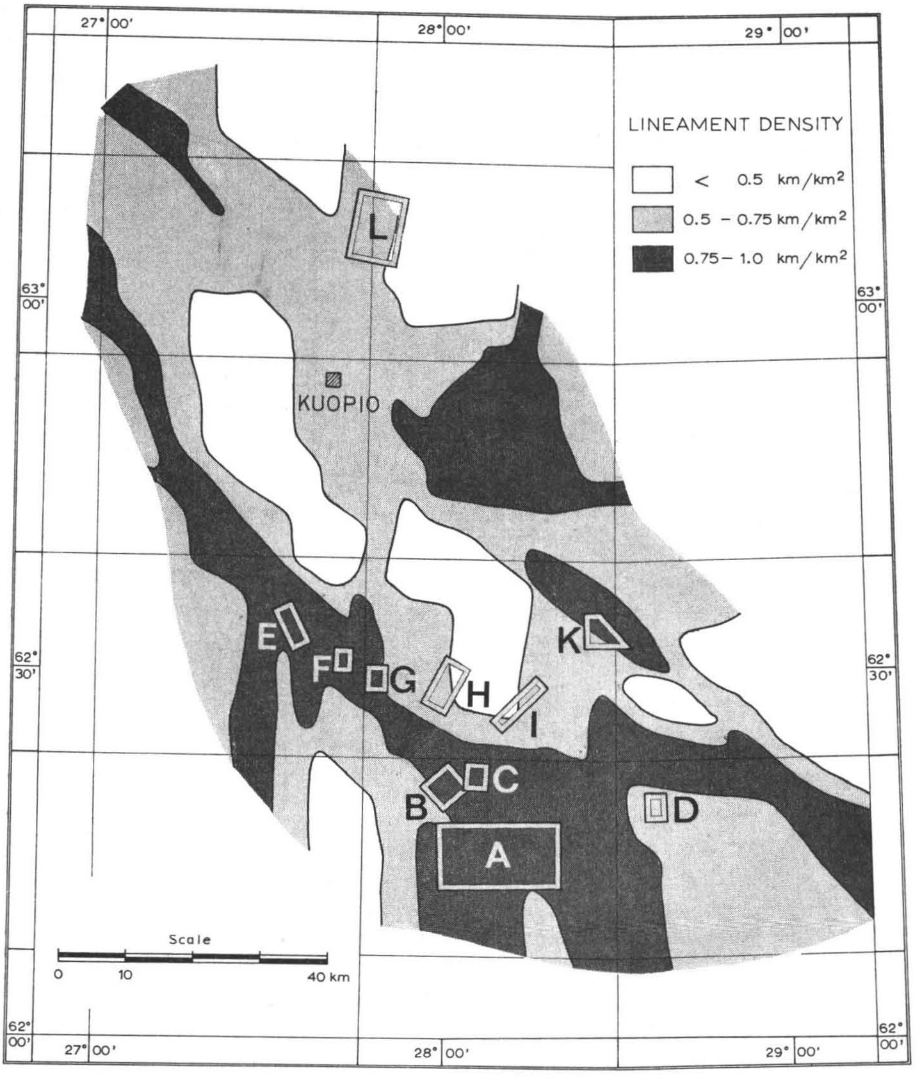


FIG. 9. Location of areas (A, B. . .L) studied in detail. Observations for area A made by Rauhamäki (1965), D, E and K by U. Vihreäpuu and the author, L by K. Mäkelä and the rest by the author.

FOLIATION, LINEATION AND SMALL FOLDS

To study the possible relationship between the lineaments and certain undoubtedly Precambrian structures, such as foliation, lineation and small folds, the areas A, B. . .L indicated in Fig. 9 were studied in more detail. In this connection, foliation and lineation refer to the parallel planar and parallel linear orientation of minerals and mineral aggregates, respectively. The fold axes were measured from small folds ($\lambda/2$ to two metres) visible in single outcrops.

When the lineament density map (Fig. 3) is compared with the geological map (Fig. 2), the strike of the foliation in the fracture zones trending 305° and 325° and bordering blocks 3 and 4 appears to be remarkably parallel to these zones. The fracture zone north of blocks 3 and 4 trends through lakes Kallavesi, Suvasvesi and Kermajärvi. It coincides with a rather narrow zone of foliation parallel to it and intersects a broad belt of almost perpendicular foliation. Väyrynen (1939, pp. 16—18) considered this zone as a fault zone and designated its rocks »tectonic gneisses». Preston (1954) mentions that the foliation in this fracture zone developed under penetrative shearing parallel to the fracture. He considers this foliation to be later than the foliation of the normal rocks of the basement complex and Svecokarelian schists prevailing outside the zone. When Plate 1 is superimposed on Figs. 2 and 3, the zone actually seems to zig-zag in accordance with variously oriented lineament sets, chiefly 305° and 325°.

Area K in Fig. 9 represents the part of this zone controlled by the 305°-striking lineament set E—E (Fig. 4). This set seems to have contributed strongly to the orientation of the foliations, fold axes and lineations seen in Figs. 10 K_{1-2}. The linear elements plunge steeply and are in the plane of foliation that strikes 300° and dips on the average 80° SSW. Two slight maxima of foliation, one parallel to the 325° lineaments and another parallel to the NNE foliation, which prevails in the neighbouring blocks, can be seen in this figure.

Slightly migmatized Svecokarelian gneisses prevail in block 4 (Fig. 3). The foliation of the gneisses is steep and strikes on an average NNE, which produces the highest maximum in Fig. 10 H—I_1 (areas H and I in Fig. 9). Slight maxima for the foliations striking 305°, 325°, 0° and 80° are also present. They correspond to the general directions of the lineaments. Some of the linear elements in areas H and I (Fig. 10 H—I_2) are in the plane of the 305°-striking foliation, as in area K of Fig. 9, which represents a fracture zone (Fig. 10 K). In the main, however, these elements are largely in the plane of the NNE foliation and have a comparatively steep SSW plunge. The latter pattern of foliation and linear elements seems to prevail in the areas situated north-east of the Kallavesi—Kermajärvi fracture zone (Fig. 2, Väyrynen 1939, Huhma 1970).

Areas A, B, C, E, F and G in Fig. 9 are situated in the most prominent fracture zone southwest of blocks 3 and 4. This zone is described in the following examples.

Diagrams B—C in Fig. 10 show the orientations of the foliation, fold axes and lineations in areas B and C of Fig. 9. The rocks of the areas are strongly agmatitic and sheared or foliated along vertical shear zones striking parallel to the prevailing lineaments (305° and 325°). Blastomylonitic and cataclastic zones containing gouge are also met with parallel to the shear zones (Figs. 7, 8, 14, 15). The linear elements (Fig. 10 B—C_2) are in the same shear planes.

3 12855—71

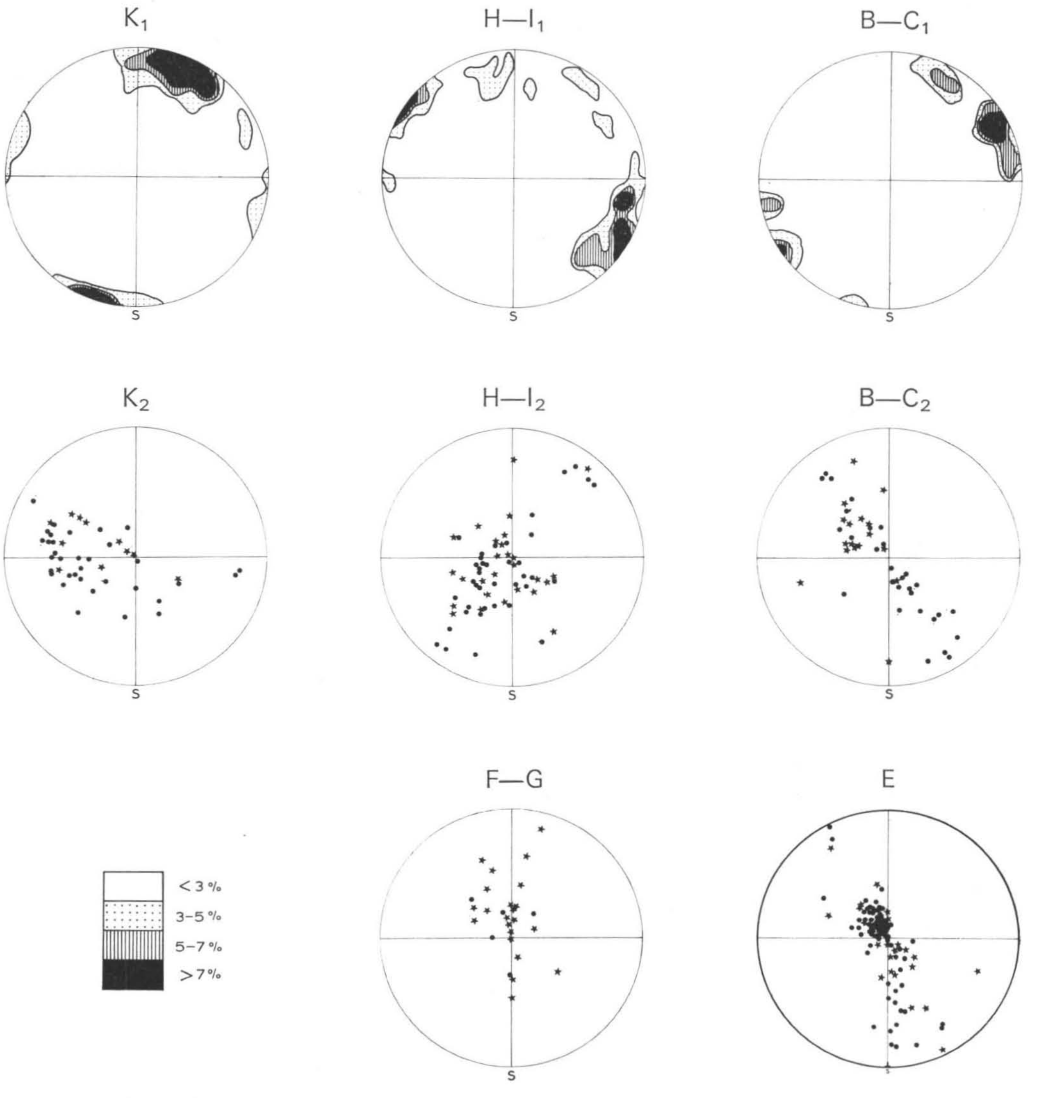


FIG. 10. Axes of small folds (asterisks), lineations (solid dots) and poles of foliation (contours) on Schmidt net, lower hemisphere. Letters refer to areas indicated in Fig. 9.

At F and G in Fig. 9, where this zone is intersected by another one striking 0°, the foliation is mainly parallel to the latter. A corresponding tendency and steep plunge can also be observed in the linear elements (Fig. 10 F—G_2). At G, the Svecokarelian gneisses are intersected by a younger steep foliation with a strike of 0°.

In area E of Fig. 9 two lineaments striking 305° and 325° cross. Fig. 10 E is the corresponding diagram for the linear elements. The steep lineations and fold axes

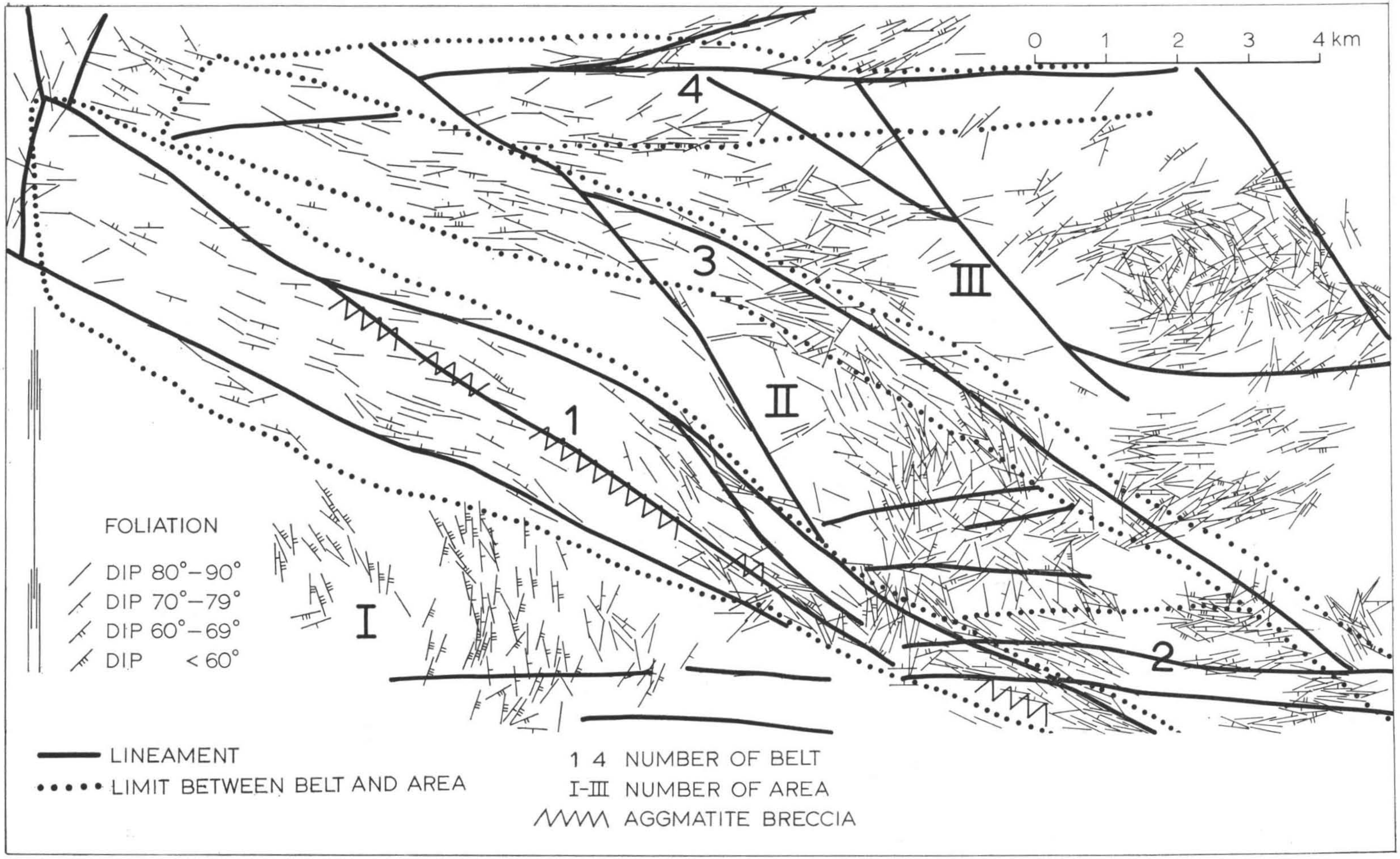


FIG. 11. Lineaments and foliation in area A of Fig. 9. Data for foliation from Rauhamäki (1965).

are from the agmatitic crossing site and the gentler ones from the southern peripheral area, where the 350° strike of non-agmatitic gneisses prevails.

Area A in Fig. 9 is one of high lineament density. It has been mapped by Rauhamäki (1965) independently of the present study. Thanks to the abundance of observations on the planar and linear elements, the area is suitable for testing the foregoing results. Fig. 11 is a map of this area, compiled by the author from these observations, and it shows the strikes and dips of the foliation as measured by Rauhamäki. The map also shows the lineaments as they appear in Plate I.

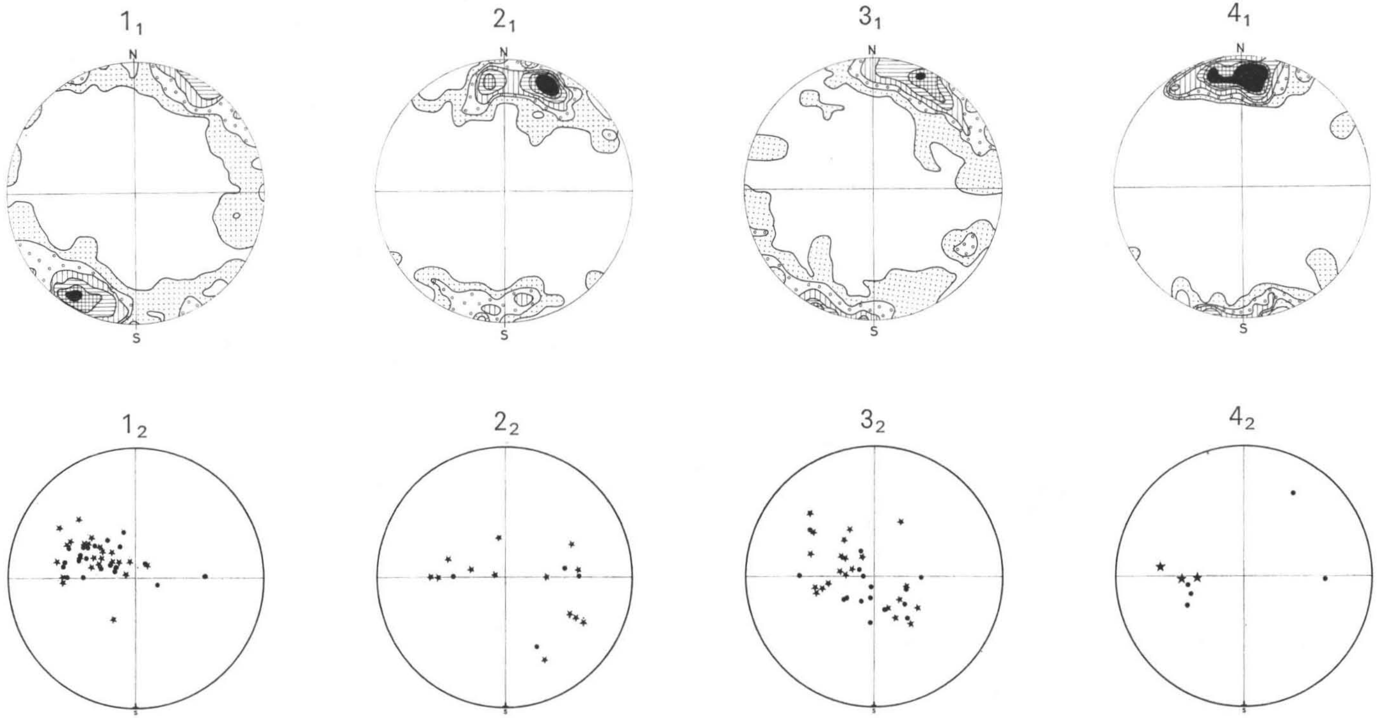
The lineaments striking 305° and 270° appear to coincide with narrowish belts where the dominant strike of foliation runs parallel to these lineaments. These belts are indicated by numbers 1—4. This parallelism is not dominant in the areas between, indicated by I—III. The lineaments striking 325° do not clearly coincide with the belts of parallel foliation. White-grey agmatites occur throughout the area. A continuous zone of these rocks, called intrusive breccia by Hackman (1933), coincides with belt 1.

In Figs. 12 and 13, the poles of foliation as well as the lineations and fold axes of each belt (1—4) and area (I—III) of Fig. 11 are plotted separately on a Schmidt net. The following main features appear.

In belts 1—4 (Fig. 12), the dominant foliations are vertical or nearly vertical and strike parallel to the respective lineaments (270° and 300°). In each belt, the linear elements are in the plane of foliation and plunge steeply, 40°—90°.

The orientation of the foliation and linear structures seen in the belts are also visible in the areas between (I—III, Fig. 13), but they are not dominant. Common features in each area are the two patterns of steep foliation striking 325° and 65°. Area I shows an additional strong foliation striking 0° and dipping 40°—90° E. Of these three patterns, only the first (325°) has a parallel lineament system in the area of Fig. 11.

The area mapped out in detail (Fig. 11) forms as a whole an area of high lineament density (Fig. 9), where lineament sets D—D (305°), G—G (325°) and J—J (275°) intersect (Figs. 4, 5). In Figs. 11, 12 and 13, all the patterns of the linear and planar elements characterizing these sets emerge, the 325° pattern least prominently. Examining the individual lineaments, we will notice that they generally occur in narrow belts, in which the strike of the foliation runs parallel to the lineament and is vertical. Besides their characteristic foliation, these belts also possess typical patterns of linear elements that deviate from the patterns of the areas situated between the belts. Wherever there occur several parallel lineaments close together, as in belt 1 (Fig. 11), they form a broader continuous belt. In such cases, the belt resembles in character a set of parallel lineaments. The situation is similar to the more general picture drawn in the foregoing, according to which the lineament sets and the coinciding fracture zones are characterized by their own typical patterns of foliation, lineation and minor folding — patterns that deviate from the corresponding ones in the blocks. These typical patterns make it apparent that the lineaments,



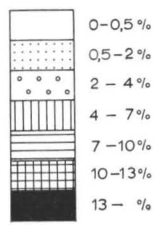


FIG. 12. Poles of foliation (1_1—4_1) and linear elements (1_2—4_2) of belts 1—4 of Fig. 11. Schmidt net, lower hemisphere. Symbols same as in Fig. 10.

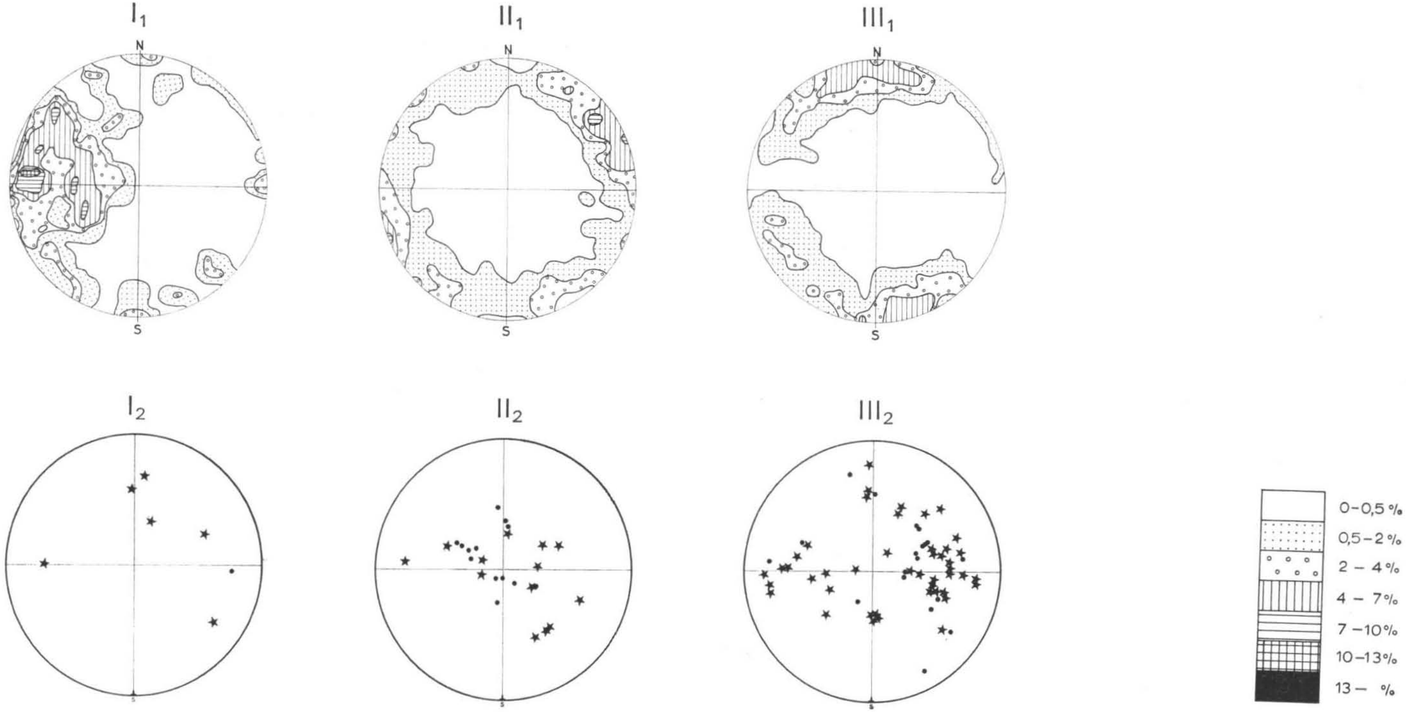


FIG. 13. Poles of foliation (I_1—III_1), linear elements (I_2—III_2) of areas I—III between the belts in Fig. 11. Symbols same as in Fig. 10.

sets of lineaments and the zones of high lineament density are surface expressions of Precambrian faults and shear zones. The 305° lineaments and patterns of linear elements are commonest in the Kuopio region.

TECTONIC PATTERNS

In the linear valleys, rock exposures are normally found on the flanks only. These outcrops are generally steeply foliated parallel to the valleys. In a number of cases, such foliation is seen to intersect (e.g. areas B, C and G of Fig. 9) an earlier foliation of the Svecokarelian gneisses. In the fracture zones, the later shearing and recrystallization have, in many cases, completely destroyed the older foliation and other structures of the Svecokarelian metasediments and their basement (Fig. 14; Preston 1954).

In the foliated or sheared zones coinciding with the lineament sets, the linear elements seem to be in the plane of foliation and plunge steeply. In this way, the fracture zones have their own characteristic patterns of minor structural elements, different from the blocks. Also some basic bodies up to two metres in diameter have been observed to be elongated parallel to the lineations in the fracture zones.

Diagrams A and B in Fig. 16 comprise all the axes and lineations observed in areas B—L of Fig. 9, while C gives the strike distribution of the lineaments throughout the region. All three diagrams show a clear maximum at approximately 305°. This broad maximum also includes the 325° lineament sets and the related linear elements.

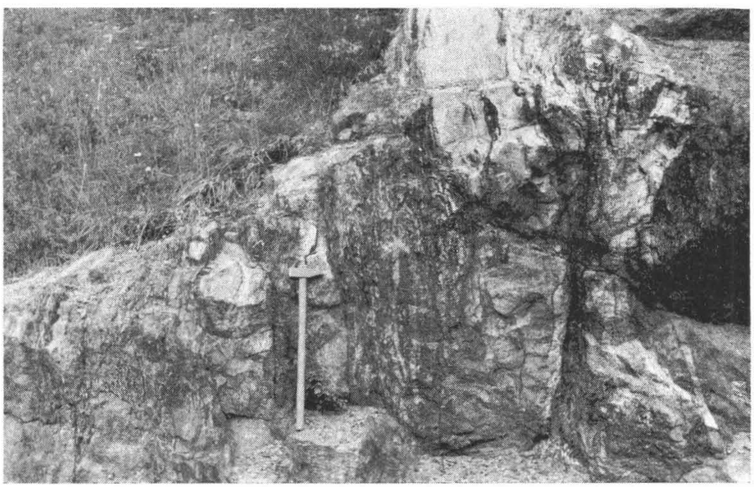


FIG. 14. Blastomylonitic gneiss in a highway cut, area C of Fig. 9.

FIG. 15. Cataclastic zones with gouge in trondjhemitic rock, area C of Fig. 9.

A maximum at 0°—5° is also evident in each diagram. Axes and lineations related to the 270°—275° lineaments do not form clearly discernable groups in diagrams A and B. However, the existence of such a group is evidenced by, for instance, diagrams 2_{1-2} and 4_{1-2} of Fig. 12, which represent the lineament set J—J of Fig. 4. The observations represented in these diagrams are not included in diagrams A and B of Fig. 16.

The gneisses prevailing in the blocks are strongly lineated parallel to a general foliation striking N to NE, the plunge of the lineations being 0°—90° S to SW (Fig. 16 B). Readily observable folds related to this lineation are scarce, a circumstance revealed by Fig. 16 A. Most of the small folds found in the blocks are apparently genetically related to the fracturing, while some of the lineations come from the antedating gneisses (see, Tuominen 1957, p. 30). This explains the greater dispersion and occurrence of lineations in the southwestern quadrant of the diagram, Fig. 16 B.

The small folds have been generated by buckling of the foliation of the Svecokarelian gneisses along the axes in the plane of the shear zones. The steep plunge of the axes suggests a wrench fault system. On the basis of the linear elements and lineaments, the 305°-striking lineaments may be interpreted as a wrench direction of the first order, in the sense suggested by Moody and Hill (1956). In this connection, it is noteworthy that Asklund (in Ramsay 1931, p. 366) suggested that a part of the Precambrian (»Algonkian») faults were strike slip faults.

The distribution of the pyroxene-bearing and basic plutonic rocks and the carbonatite sheet in the lineament sets A—A, B—B and D—D as well as the great length of the sets (Figs. 2, 4 and 5) indicate that they are surface manifestations of deep

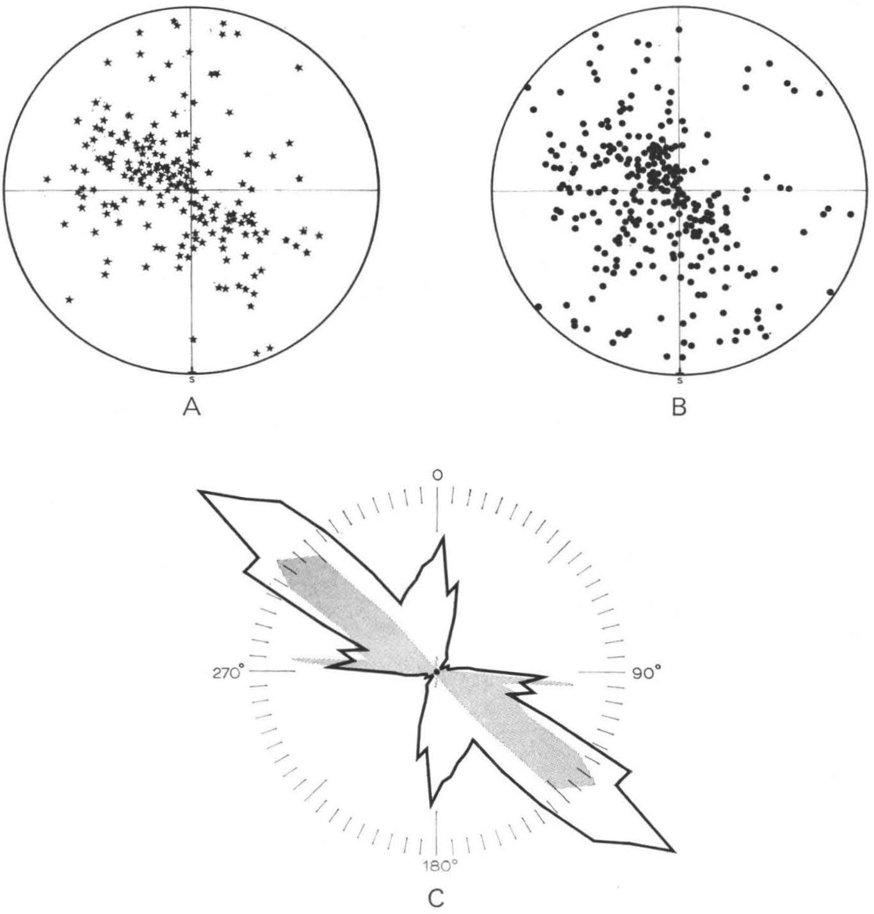


FIG. 16. Diagram A shows small folds, B lineations from areas B—L of Fig. 9, Schmidt net, lower hemisphere. C shows the strike distribution of lineaments from Plate 1. Diagram C illustrates (shaded grey) also the azimuth distribution of a diabase dike set (Laitakari 1969).

faults. Certain of the deep faults in the basement complex seem to have existed as early as 2 500 m.y. ago, in a possible period of taphrogenic movements (carbonatite). The basic and pyroxene-bearing plutons probably intruded along the fracture zones about 1 800—1 900 m.y. ago (pp. 7 and 9). The agmatites, which are also associated with the fracture zones, indicate the last intense Svecokarelian movements in the Kuopio region approximately 1 800 m.y. ago. On the other hand, the parallelism of the lineament sets to both the blastomylonitic (Fig. 14) and the cataclastic gouge (Fig. 15) zones encountered in areas B and C of Fig. 9 indicates that movements during different periods, also postmetamorphic ones, occurred along the same zones of crustal weakness.

4 12855—71

In the Karelian belt up to a hundred kilometres east-northeast of the Kuopio region, most of the youngest faults and shear zones seem to strike 325° (Väyrynen 1939, pp. 16—18, Gaal 1964, pp. 34—39 and Beilage I). This suggests that strong movements affecting large areas had taken place in this system (325°). The system also conforms with the suggested world-wide foliation and fault trend (327°—328°) of Precambrian shields proposed by Badgley (1965, p. 498).

The strike distribution of the diabase dikes situated about 200 km southwest of the Kuopio region is similar to the strike distribution of the lineaments. This is shown in diagram C of Fig. 16. According to Laitakari (1969), the age of the diabase dikes is approximately the same as that of the rapakivi massifs of southwest Finland (1 700 m.y., Neuvonen 1970, p. 106). Since the fracture system is distinctly older in the Kuopio region, it seems reasonable to say that the diabase dikes have intruded in a pre-existing fracture system, i.e., the fracture system is a large-scale phenomenon in the Finnish Precambrian.

The problem of the mantled domes is beyond the scope of this study. Their mode of occurrence, however, suggests that they, too, are connected with the fracture tectonics.

In general, concentrations of various plutonic and metamorphic rocks along the fracture zones, the metamorphic ones ranging from ultrametamorphites to recent gouge, indicate that the fracture zones extend to great depths and have been active from early Precambrian till recent times.

GEOPHYSICAL DATA

Aeromagnetic map

Figure 17 represents the relative intensities of the total magnetic field at a height of 150 metres above the ground. The main field in the region increases northeastwards 100 gammas per 40 km or 250 gammas for the area of the aeromagnetic map (M. Puranen, oral comm.).

The relative regional field varies between 4 000 and 5 000 gammas. In order to improve the distinctness of the regional anomalies, the intensity area of 4 500—5 000 gammas was shaded grey and the anomalies between 5 000 and 8 000 gammas black.

When Plate 1 is superimposed on this map, the distribution of the ridges of magnetic intensity and their accidents appear to correlate to the sets of lineaments and the individual lineaments. Strong local anomalies follow the fracture zones, while the blocks form areas of even intensity (Fig. 3). For instance, the fracture zones around blocks 3 and 4 are zones of local anomalies of varying intensity. This demonstrates that in the fracture zones, in contrast to the blocks, there are smallscale lithologic units with different concentrations of magnetic minerals. Thus the variation of the magnetic field supports the validity of the fault and block structure presented.

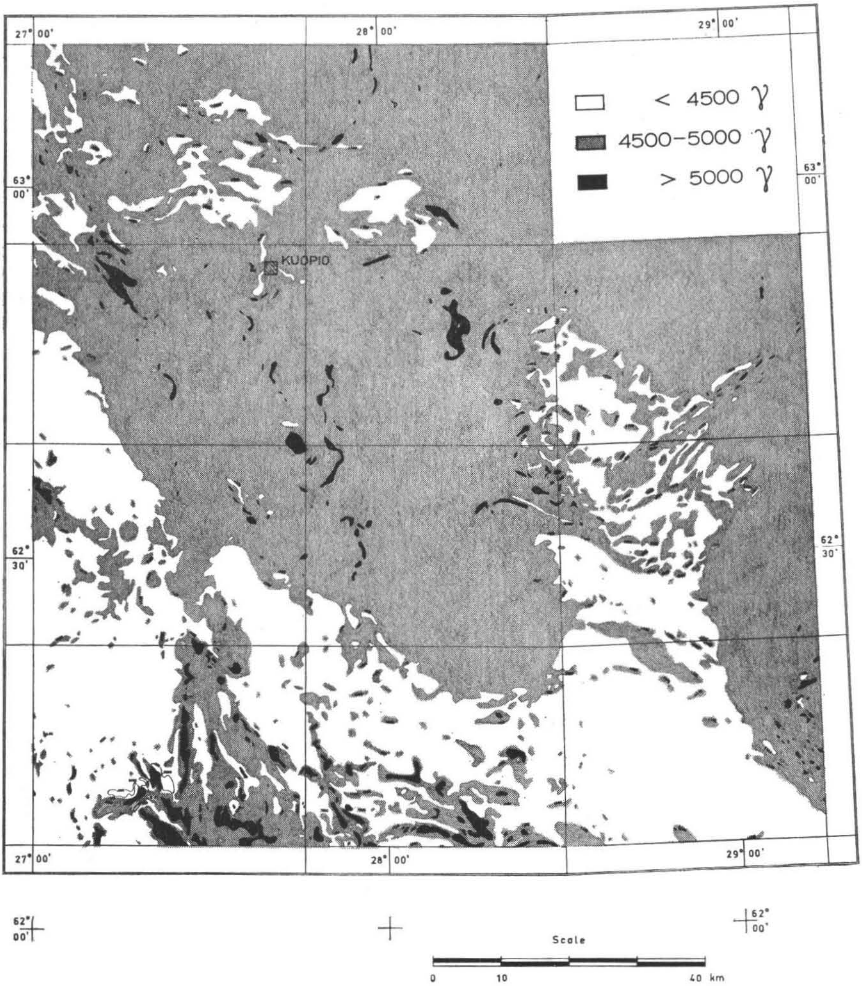


FIG. 17. Aeromagnetic map of the Kuopio region. Total field anomalies, relative values. Geological Survey of Finland.

Gravity map

The fracture zone southwest of blocks 3 and 4 (Fig. 3) coincides with the steep northeastern slope of a deep gravity (Bouguer) trough running roughly 325° through Central Finland (Figs. 3 and 18). The gravity trough evidently represents the boundary of two major blocks. The movements of the major blocks may regenerate the 325° lineament system in particular (Fig. 5). Block 3 (indicated by B in Fig. 18) is characterized by an area of even anomalies with earthquakes along its eastern and northern boundaries. This block is situated at the northeastern side of the gravity trough.

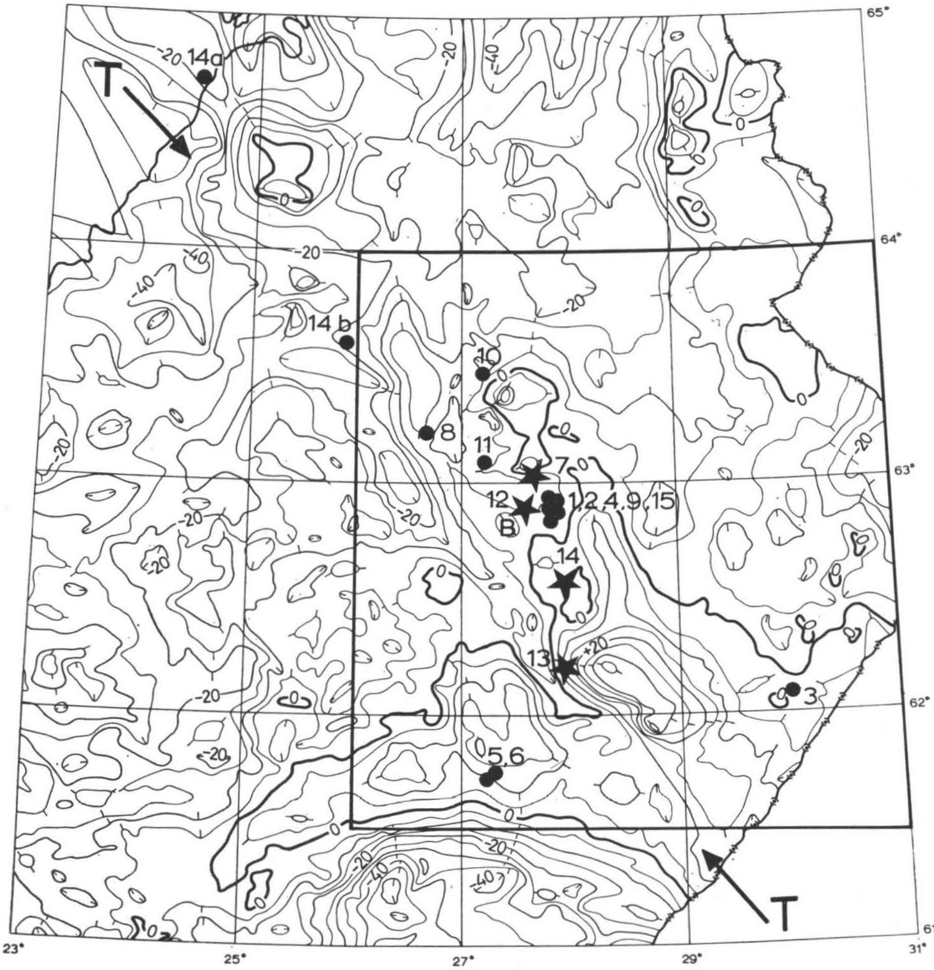


FIG. 18. Bouguer anomalies according to Honkasalo (1962). T—T is a gravity trough. The area 26°E—31°E and 61,5°N—64°N, from which all the known earthquake data of Table 4 have been gathered, is indicated. Events 14A and 14B are outside the area. They are nearly simultaneous with event 14. Dots denote superficial and asterisks normal deep earthquakes. Block 3 of Fig. 3 is indicated by B.

The most pronounced gravity high of the map is situated in the crossing area of the fracture zones in the southern part of Fig. 3. The gravity peak possibly results from heavier, basic, material present in this crossing.

Precise levelling

A high precision levelling line runs through the Kuopio area (Kääriäinen 1966). The location of this line is indicated in Fig. 23. Most of the bench marks on the

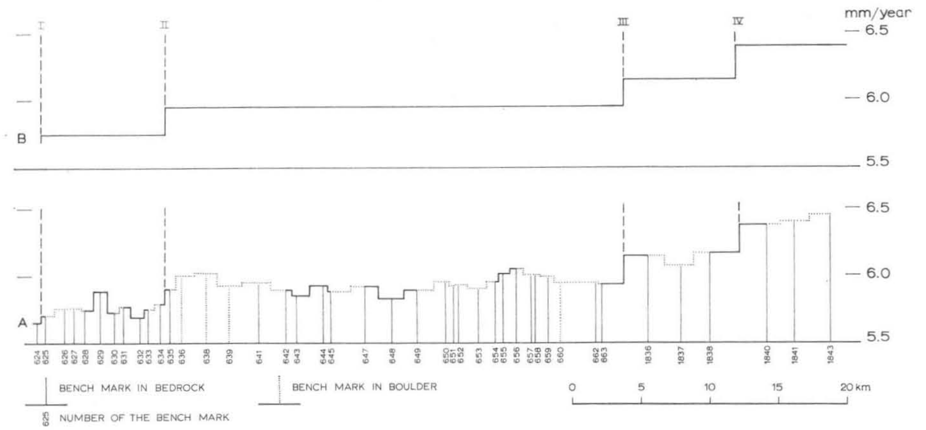


FIG. 19. Precise levelling line compiled from Kääriäinen's data (1966). Profile A represents the measured values and B shows the areas of relatively even uplift and of anomalous high uplift gradient (II, III, IV). The part II—III corresponds to block 3 of Fig. 3 (cf., Fig. 23).

levelling line are in Precambrian bedrock. The first levelling for the bolts 624—663 was carried out in 1897 and continued for bolts 1834—1843 in 1903. The second levelling for the whole line in Fig. 23 was done in 1946. Thus the interval between the levellings is 43—49 years.

The uplift of individual bench marks in millimetres per annum is shown in Fig. 19, Profile A, where the steps show the differencies in uplift between neighbouring bolts (Kääriäinen 1966).

Profile B in Fig. 19 shows the places of anomalously large differences in the uplift. Such a place is situated between bolts 663 and 1 840 (indicated by III and IV in the profile). It coincides with the fracture zone between blocks 2 and 3 (Fig. 23). The profile indicates that the subsidence rate of bolt 663 has been 0.45 mm/year in relation to bolt 1 840. This totals a subsidence of two centimetres during the time between the levellings. Another anomalous uplift gradient is indicated by II in the profile.

The area of even uplift between II and III (Fig. 19 B) coincides with block 3 (Fig. 23) and the anomalous gradients of the uplift with the fracture zones bordering on the block. Hence, considering what is said earlier in the paper, the precise levelling data suggest that the uplift of the Baltic Shield is taking place blockwise following a block structure of Precambrian origin.

EARTHQUAKES

The region from which all the known earthquake data were gathered as well as the locations of the events and their serial numbers are presented in Fig. 18. The

TABLE 1
Characteristics of the earthquake of Aug. 1, 1963.

I_n	A_n (km^2)	r_n (km)
6	0	0
5	870	16.5
4	4 300	37
3	8 900	54

data for events 1—13 of this figure are from Rosberg (1912), Renqvist (1930) and Båth (1956). Earthquakes 14 and 15 have been investigated by the author.

The areas of perceptibility for the earthquakes in Fig. 18 are smaller than 800 km^2 or larger than 4 000 km^2. For the former, the epicentres can be determined rather accurately ($\pm$ 15 km). In the cases where the observations of the intensities are scarce and the isoseismal lines can be drawn only roughly, the accuracies of the focal depths and magnitudes contain considerable uncertainties. In principle, the earthquakes with the smaller areas of perceptibility are shallower and have a lesser magnitude than those with larger areas of perceptibility. The former are called superficial and the latter normal (deep) earthquakes. It is possible that the earthquakes with smaller magnitudes occur also at greater depths, but they are not felt or observed clearly at the surface.

The earthquakes studied are presented in Table 4 and in Figure 23.

The earthquake of Aug. 1, 1963

According to the microseismic study (Talvitie 1967), the origin time was 16h 02m 10.0s GMT and the coordinates of the epicentre 16.6°N/27.9°E. The event was registered over distances up to 1 000 km.

The observation conditions were ideal, and the area of perceptibility is populated evently enough to provide a reliable interview grid. The isoseismal map is presented in Fig. 21. The MM-scale (Modified Mercalli Scale, Richter 1958) was used for the determination of the intensities, taking into account the suggestion by Medvedev, Sponheuer and Karník (Sponheuer 1963) concerning the improvement and completion of the intensity scale. The intensity at every interviewing site was determined and is indicated on the isoseismal map.

The phenomenon was most severe in the area of maximum intensity. People in buildings were frightened and some persons lost their balance and felt the floor swaying (hallucination?). There were slight waves on standing lake waters. Well-built wooden structures are the rule in the region and they sustained no damage. However, some amounts of plaster fell from a stony building in the area of maximum intensity. The degree of fright and the fall of plaster suggest a maximum intensity I=6.

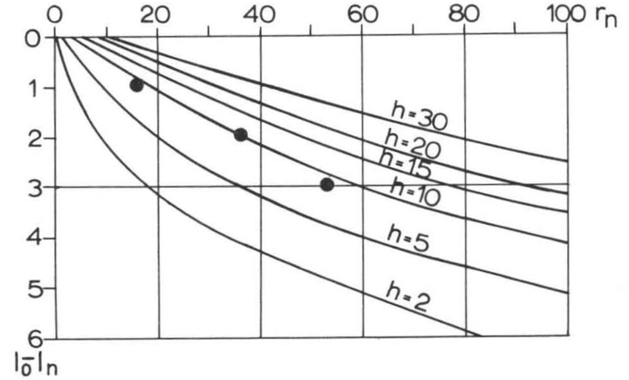


FIG. 20. I_0—I_n versus r_n for absorption coefficient $\alpha = 0.01$, h is the focal depth in kilometres. After Sponheuer (1960). Dots denote values for earthquake of Aug. 1, 1963.

Table 1 gives the areas (A_n) bordered by the isoseismals (I_n) and the isoseismal redii (r_n) for the earthquake. To calculate the focal depth, the method developed originally by Kövesligethy and presented for practical use by Sponheuer (1960) was used.

According to Sponheuer's method, the absorption coefficient determined from this earthquake is $\alpha = 0.01$. Fig. 20 gives a set of theoretical intensity-distance curves. Individual curves were computed for $\alpha = 0.01$, for a certain value of h and for varying values of I_o—I_n/r_n. This figure indicates a focal depth of 10 km for the earthquake. Thus the following characteristic values for the earthquake can be presented:

$$I_o = 6$$
$$h = 10 \text{ km}$$
$$\alpha = 0.01$$

Karník's (1969) equation gives the magnitude of the earthquake:

$$M = 0.5\, I_o + \log h + 0.35 = 4.3$$

Assuming the elastic wave front to propagate from the focus as a sphere in isotropic media, the isoseismal lines should appear as circles on the earth's crust. However, the isoseismals (Fig. 21) deviate considerably from a circle. Isoseismal I = 5 shows the greatest relative deviation. This may be affected to a certain extent by the source mechanism of the earthquake. However, the tectonic features of the area seem to correlate with the attenuation of the elastic wave energy. Thus the fracture zones (Fig. 3) are energy attenuators in respect to the blocks. On the other hand, wave propagation with less attenuation seems to occur in the direction of the strike of the rock foliation (Fig. 2) and of some granitoid masses (block 7 in Fig. 3). The general elongation of the macroseismic area is about 325° (cf., lineaments in Fig. 5 and the gravity trough in Fig. 18).

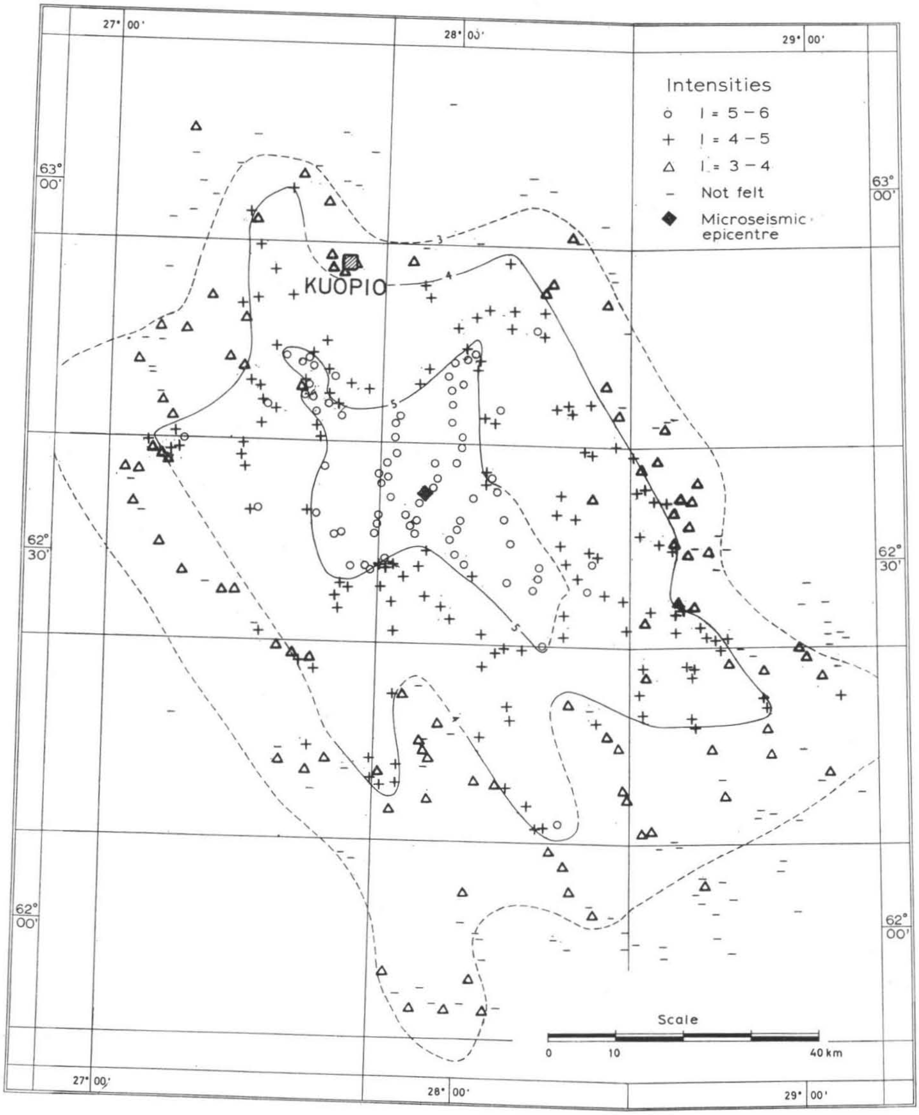


FIG. 21. Isoseismal map of earthquake of Aug. 1, 1963.

If the Plate 1 is superimposed on the isoseismal map, the epicentre appears to lie on the northern side of a tectonic unit characterized and bounded by 0° and 270° lineaments. The diameter of this unit is about 10 km and it is located in the fracture zone between the blocks 3 and 4 presented in Fig. 3. The fractures corresponding to the lineaments (0° and 270°) evidently extend down at least to the depth of 10 km,

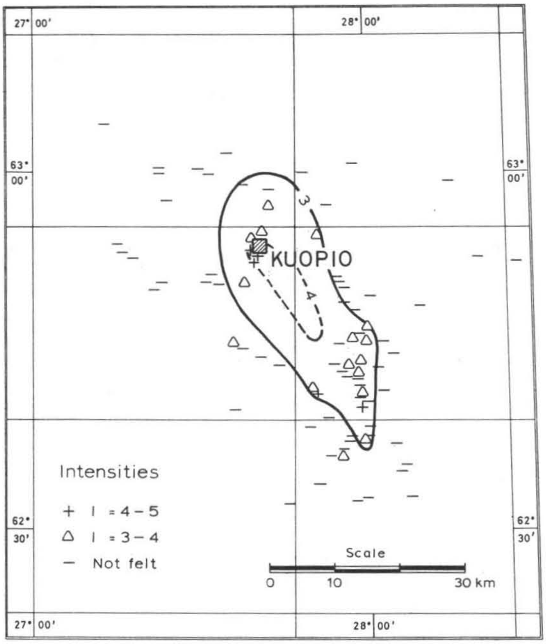


FIG. 22. Isoseismal map of earthquake of Jan. 11, 1964.

where the hypocentre, the structural floor of the tectonic unit or the barrier that stores elastic energy under relative dislocation of the blocks 3 and 4, for instance, are located.

The earthquake of Jan. 11, 1964

The isoseismal map is presented in Fig. 22. The origin time of the event was 13h 45m GMT. The earthquake was not registered; the nearest seismograph station is 140 km away. Sponheuer's method (1960) gave the characteristic values shown in Table 2.

TABLE 2
Characteristics of the earthquake of Jan. 11, 1964.

I_n	A_n (km²)	r_n (km)	Remarks
4.5	0	0	α = 0.01
4	67	4.7	h = 4 km
3	470	12	M = 3.2

5 12855—71

TABLE 3
Earthquakes indicated in the area bounded by square in Fig. 18.

No	Date	Origin time (GMT)	Epicentre °N/°E	Io	r^3 km	Q	h km	M	Remarks
1	1801, Dec. 27 ..	19—50	62.9/27.8	5	15	A	4	3.4	Renqvist 1930
2	1836, Dec. 24—26	—	62.9/27.8	5	15	A	4	3.4	»
3	1847, Nov. 12 ..	01—	62.1/30.0	5	10	A	3	3.3	»
4	1857—1858	Winter	62.9/27.8	5	15	A	4	3.4	» several events
5	1863—1864	New year	61.7/27.3	4.5	10	A	4	3.2	» »
6	1884, Feb. 25 ..	24	61.7/27.3	4.5	10	A	4	3.2	»
7	1887, May 2 ...	02—50	63.1/27.7	5.5	40	B	8	4.0	»
8	1887, Jun. 2—3 .	night	63.2/26.7	4.5	10	A	4	3.2	»
9	1887, Jun. 5 ...	00—10	62.9/27.8	4.5	10	A	4	3.2	»
10	1909, Jan. 8	23—50	63.5/27.2	4.5	10	A	4	3.2	Rosberg, 1912
11	1910, Aug. 11 ..	18—35	63.1/27.2 *)	4.5	10	A	4	3.2	Båth 1956
12	1911, Dec. 26 ...	08—55	62.9/27.6	5.5	70	A	18	4.3	»
13	1934, Nov. 2 ...	16—15	62.2/28.0	6	54	B	10	4.3	»
14	1963, Aug. 1 ...	16—02—10.0	62.6/27.9	6	54	A	10	4.3	present study
15	1964, Jan. 11 ...	13—45	62.9/27.8	4.5	12	A	4	3.2	»

*) Epicentre given by Båth is 63.2/27.3. Coordinates corrected by author.

The epicentre is located in the fracture zone between blocks 3 and 4 near their northern boundary (Fig. 3). If the interval of from 20 to 30 years between known times of activity in the Kuopio region (Table 4) is taken into account, the event can be considered as an aftershock of the earthquake that took place on Aug. 1, 1963. The difference in focal depth and magnitude in relation to the main shock probably corresponds to the smaller size of the dislocated tectonic unit and shallower position of the barrier, which stored released elastic energy. This unit may be formed by or situated in the Kallavesi dome (Fig. 2).

Other earthquakes

In Table 3 are given the earthquakes felt in the area 26°E—31°E and 61.5° N—64° N (Fig. 18). The table contains all the known tremors up to the present day. The data used are given in the section entitled remarks. I_0, r_3, Q, h and M are estimated and calculated according to these data by the present author.

The origin times are recorded in GMT. The epicentres mark the places where the maximum intensities were felt. These intensities (I_0) are estimated on the MM-scale to half a grade. The areas of perceptibility are small in general and in local tremors the maximum intensity may be easily underestimated. Mostly, only the maximum intensity (I_0) and the limit of perceptibility corresponding to the isoseismal radius r_3 can be determined. In such cases, theoretical intensity-distance curves were used to calculate the focal depths (h) according to I_0—I_3/r_0—r_3. The absorption coefficient $\alpha = 0.01$ was employed according to the detailed study of the earthquake of Aug.

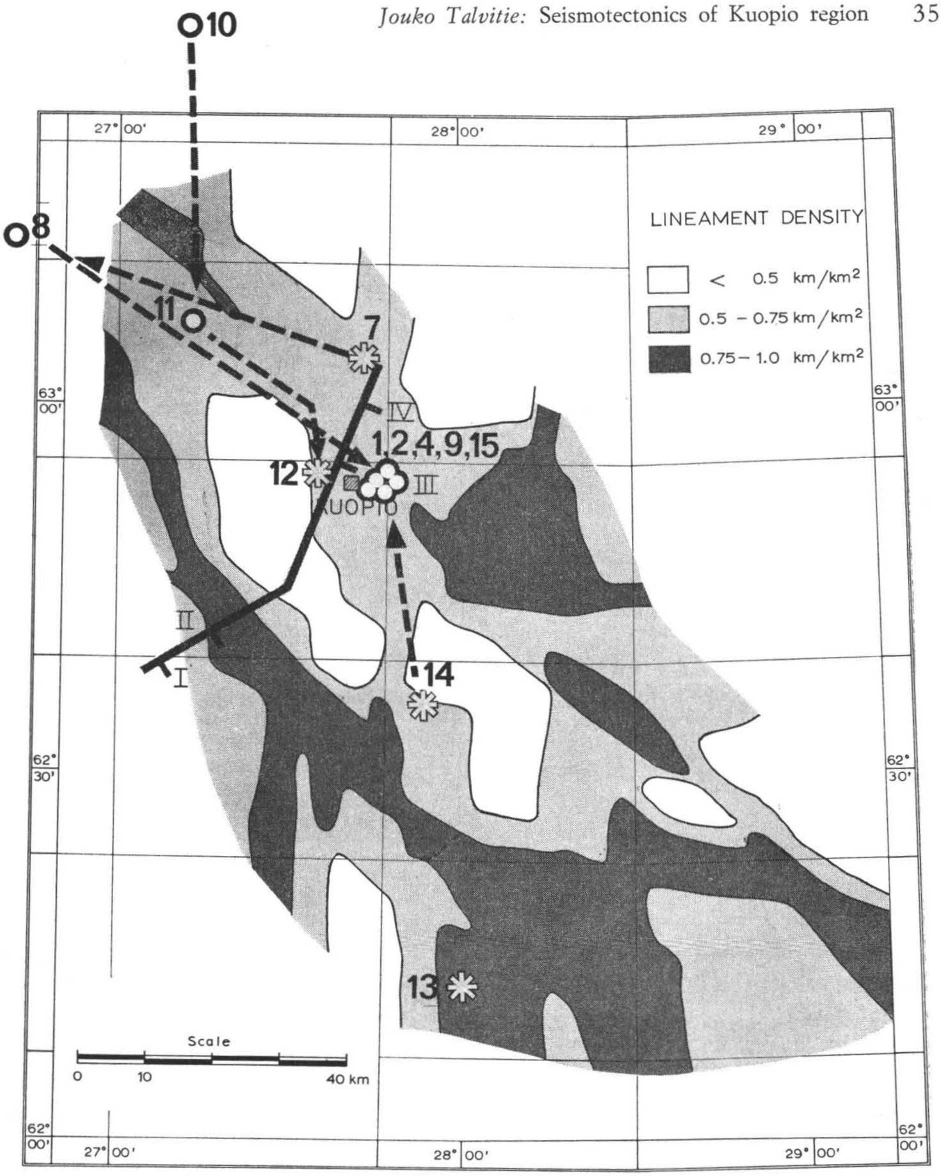


FIG. 23. Location of the precise levelling line and earthquakes. Line I—IV is the levelling line described in Fig. 19. Circles denote superficial and asterisks normal deep events. The broken arrows connecting the earthquakes (7—15) indicate the time-space shift direction of individual periods of activity in Table 4.

1, 1963. Column Q gives the accuracies in the epicentre locations in great circle arcs according to the following scheme:

A = location error $\geq 0.2°$
B = » » $\geq 0.2°$ but not exceeding r_3.

6 12855—71

The earthquakes in Table 3 are superficial or normal (p. 30), ie., they are all in the upper crust. The superficial shocks (h = 3—4 km) have magnitudes of M = 3.2—3.4 and the normal ones (h = 8—10 km and 18 km) magnitudes of M = 4.0—4.3. The epicentres are plotted in Figs. 18 and 23.

CRUSTAL THICKNESSES

For the present study, it should be important to know about the crustal structures of the area and the structural floors of the blocks presented in Fig. 3. No detailed seismic survey has been carried out in the Kuopio region to estimate the relation between crustal discontinuities and the focal depths. The mean depths of the Conrad and Mohorovičić discontinuities in Finland are, as reported by Penttilä (1968), 21 ± 3 km and 39 ± 3 km, respectively.

A three-layer crustal model has been submitted by Luosto (1967) for SW Finland. This model gives the discontinuities at the depths of 12 km, 30 km and 42 km. It was also used as a basis for model ULO 56, which agrees quite well with the surface wave dispersion results for Finland as a whole (Noponen *et. al.* 1967).

If the discontinuity of 12 km reported by Luosto does exist in the Kuopio region, it possibly has some connection with the structural floors of the blocks in Fig. 3 and also with the space distribution of the normal deep earthquakes.

SEISMOTECTONICS

In relation to the earthquake energy released, the Baltic Shield belongs to inactive stable masses of the crust (Gutenberg and Richter 1954). However, earthquakes do occur in the shield and are scattered more or less irregularly within its different tectonic units (Miyamura 1962). The hypocentres lie in the crust and seldom under Moho (Båth 1953). Fig. 18 shows that the Kuopio region seems to be practically the only seismoactive area in southeastern Finland.

The time-space distribution of the events is shown in Table 4 and in Fig. 23. The arrows in Fig. 23 indicate the direction of the time-space shift of individual active periods.

TABLE 4

Times of activity and tectonic units in Kuopio region.

Year of event	Earthquake No.	Lineament set of Figs. 4 and 5
1887	7, 8, 9	F—F and the intersection with B—B
1909—1911	10, 11, 12	A—A and F—F and their intersection
1934	13	intersection of B—B, D—D, J—J and G—G
1963—1964	14, 15	B—B and the intersection with F—F

The rapid movements generating the earthquakes seem to have occurred periodically at intervals of from 20 to 30 years. The earthquakes have taken place in the fracture zones (sets B—B and F—F) and particularly in the NE corner of block 3 (intersection of sets B—B and F—F). A special feature is that every time of activity has a normal deep event in set B—B or at its intersections with other sets. Outside this fracture zone, which forms the eastern boundary of block 3, there have only occurred superficial shocks.

The precise levelling line (Figs. 19 and 23) indicates in the NE corner of block 3 an anomalous high uplift gradient, i.e., a relative subsidence of the block. On the other hand, the levelling suggests dislocation movements of the block as a whole. This agrees with the observation that all the earthquakes are located in the fracture zones bordering the block on its northern (set F—F) and eastern (set B—B) sides, where the relative dislocation between the levellings probably has been largest. The dislocation of block 3 (Figs. 3 and 23) may initiate the seismic activity which is not in immediate contact with it (events 10 and 13 of Fig. 23) and some shift of the energy release takes place between adjacent blocks, as described by Teisseyre, Penttilä, Tuominen and Vesanen (1968).

Block 3, with its surrounding fracture zones, seems to be a seismogenic unit (see, Gubin 1967, pp. 110—111). It is composed of an aseismic block and its deeply fractured border zones, the latter being seismically active.

The barriers, where the stored elastic energy is periodically released through rapid faulting, are located at depths of between 3 and 10 km. Secular or accelerated fault creep without earthquakes (see, Mesherikov 1968) is also possible outside the barriers. The magnitude of an earthquake is probable in relation to the size and the depth of the barrier. The earthquake frequency justifies the prediction that an event of magnitude 4.0—4.3 will occur every 20th or 30th year, being influenced by the same seismogenic unit. This event will probably be located in the eastern or northern fracture zone of this seismogenic unit.

The earthquakes 14 A, 14 B and 14 (Fig. 18) took place within a time interval of four days (Korhonen and Talvitie 1964). This time-space correlation suggests that in the direction of the gravity trough (Fig. 18) and the 325° lineaments (Fig. 5) there happened on a fairly large scale a nearly simultaneous triggering of the stored energy. The gravity trough probably is the manifestation of a larger zone of crustal weakness and of a seismogenic zone inside which block 3, with its surrounding fracture zones (Figs. 3 and 23), is a minor seismogenic unit.

CONCLUSION

The lineaments studied are manifestations of deep shear and fracture zones of Precambrian origin. The fracture zones and the blocks between have greatly influenced the lithological and structural picture of the region investigated. The structural picture indicates that the 305°-direction affected as a wrench direction of the first order. One of the blocks, with its surrounding fracture zones, is at present a minor seismogenic unit. The future earthquake risk of the Kuopio region can be estimated on the basis of the seismotectonic picture outlined.

ACKNOWLEDGMENTS

The author wishes to acknowledge his gratitude to all the many persons who gave him assistance and useful advice during the work on the present study. Special mention in this connection is deserved by professor Heikki V. Tuominen of the University of Helsinki.

The positive stand toward the study taken by the following persons enabled the author to collect the necessary data and to accomplish the task as a whole: Helge Haavisto, managing director, and Heikki Paarma, chief geologist of the Rautaruukki company; Paavo Haapala, chief geologist, Veikko O. Vähätalo, deputy chief geologist, and Pauli Isokangas, head of the exploration department of the Outokumpu company; Eijo Vesanen, director of the Institute of Seismology, University of Helsinki; Lennart Kaje, col., and Heikki Raevaara, lieut.-col., engin., of the Topographic Service of the Finnish Defence Forces; Maunu Puranen, chief of the Geophysics Dept, Geological Survey of Finland; Tauno J. Kukkamäki, director of the Geodetic Survey of Finland. For the valuable support received from these people and many of their associates, I am pleased to express my appreciation. Warm thanks are due to Mrs. Leena Orilähde and Mrs. Liisa Kelkka for preparing the illustrations for publication.

I am grateful to Dr. Herman Stigzelius, director of the Geological Survey of Finland, for accepting my paper for publication in this series.

Financial aid from the Foundation of the Outokumpu company afforded me the opportunity of concentrating on this research project.

REFERENCES

BADGLEY, P. M. (1965) Structural and tectonic principles. Harper and Row, New York. 521 p.

BÅTH, M. (1953) Seismicity of Fennoscandia and related problems. Gerlands Beitr. z. Geophysik, Vol. 63, Heft 3.

—»— (1956) An earthquake catalogue for Fennoscandia for the years 1891—1950. Sveriges Geol. Unders., Ser. C 545.

BILLINGS, M. P. (1960) Structural geology. 2nd ed., Prentice-Hall, New York. 514 p.

ESKOLA, P. (1963) The Precambrian of Finland. *In* »The Precambrian», ed. by K. Rankama, Vol. 1, pp. 145—263. Interscience Publs.

FROSTERUS, B. (1903) Vuorilajikartan selitys C 2, Mikkeli. [General geological map of Finland, 1: 400 000.] 102. p. Helsinki.

—»— and WILKMAN, W. W. (1920) Vuorilajikartan selitys D 3, Joensuu. [General geological map of Finland, 1: 400 000.] Helsinki. 189 p.

GAÁL, G. (1964) Jatul und Karelische Molasse im S-Koligebiet in Nord-Karelien und ihre Beziehung zum Gebirgsbau des Prekambrischen Orogens. Bull. Comm. géol. Finlande 213.

GUBIN, I. E. (1967) Lecture notes on basic problems in seismotectonics. Intern. Inst. of Seism. and Earthquake Engin. Tokyo.

GUTENBERG, B. and RICHTER, C. F. (1954) Seismicity of the earth and associated phenomena. 2nd ed. Univ. of Princeton Press, New Jersey. 310 p.

HACKMAN, V. (1933) Kivilajikartan selitys D 2, Savonlinna. [General geological map of Finland, 1: 400 000.] Helsinki. 176 p.

HÄRME, M. (1960) Kivilajikartan selitys B 1, Turku. English summary. General geological map of Finland, 1: 400 000. Helsinki. 78 p.

—»— (1961) On the fault lines in Finland. Bull. Comm. géol. Finlande 212, pp. 437—444.

—»— (1966) On the block character of the Finnish Precambrian basement. Ann. Acad. Sci. Fenn., Ser. A III, 90, pp. 133—134.

HEMPHILL, W. R. (1958) Small-scale photographs in photogeologic interpretation. Photogr. Engin., Vol. 24, pp. 562—567.

HEPWORTH, J. V. (1967) The photogeological recognition of ancient orogenic belts in Africa. Quart. Journ. Geol. Soc. London, Vol. 123, pp. 254—292.

HOBBS, W. H. (1911) Repeating patterns in the relief and in the structure of the land. Bull. Geol. Soc. America, Vol. 22, pp. 123—176.

HONKASALO, T. (1960) On the land uplift in Fennoscandia. Geophysica, Vol. 7, pp. 117—119.

—»— (1962) Gravity survey of Finland in the years 1945—1960. Veröff. Finn. Geod. Inst. 55.

HUHMA, A. (1970) Short description of the geology of the Outokumpu district. Bull. Geol. Soc. Finland 42, pp. 59—66.

KÄÄRIÄINEN, E. (1966) The second levelling of Finland in 1935—1955. Veröff. Finn. Geod. Inst. 61.

KAHMA, A. (1956) On K-A age determinations of some Finnish granites and gneisses. Norsk Geol. Tidsskr. 36, p. 78.

KARNÍK, V. (1969) Seismicity of the European area. Part 1. D. Reidel Publ. Dordrecht. 363 p.

Korhonen, H. and Talvitie, J. (1964) Seismological notes 1962—1964. Geophysica, Vol. 9, pp. 97—98.

Kouvo, O. (1958) Radioactive age of some Finnish Pre-Cambrian minerals. Bull. Comm. géol. Finlande 182.

—»— and Tilton, G. R. (1966) Mineral ages from the Finnish Precambrian. J. Geol., Vol. 74, pp. 421—442.

Laitakari, I. (1969) On the set of olivine diabase dikes in Häme, Finland. Bull. Comm. géol. Finlande 241.

Lattman, L. H. (1958) Technique of mapping geologic fracture traces and lineaments on aerial photographs. Photogr. Engin., Vol. 24, pp. 568—576.

Luosto, U. (1967) Preliminary results of a seismic refraction study of the earth's crust in SW-Finland. Inst. Seism., Univ. Helsinki, Publ. 82.

Mescherikov, J. A. (1968) Recent crustal movements in seismic regions: Geodetic and geomorphic data. Tectonophysics, Vol. 6, pp. 29—39.

Metzger, A. (1959) Svekofenniden und Kareliden. Acta Acad. Aboensis, Mathem. et Phys. 21.

Mikkola, A. and Niini, H. (1968) Structural position of ore-bearing areas in Finland. Bull. Geol. Soc. Finland 40, pp. 17—33.

Mikkola, T. (1953) Peruskalliogeologian näköaloja. Geologi, 5 vsk., p. 29.

Miyamura, S. (1962) A note on Fennoscandian seismicity. Inst. Seism., Univ. Helsinki, Publ. 50.

Moody, J. D. and Hill, M. J. (1956) Wrench-fault tectonics. Bull. Geol. Soc. America, Vol. 67, pp. 1207—1246.

Neuvonen, K. J. (1970) Paleomagnetism of the dike systems in Finland V. Remanent magnetism of the Åva intrusives. Bull. Geol. Soc. Finland 43, pp. 101—107.

Noponen, I., Porkka, M. T., Pirhonen, S. and Luosto, U. (1967) The crust and mantle in Finland. J. Phys. Earth, Vol. 15, pp. 19—24.

Paarma, H. (1963) On the tectonic structure of the Finnish basement, expecially in the light of geophysical maps. Fennia 89, 1, pp. 33—36.

—»— and Marmo, V. (1961) Eräistä suurrakenteista Suomen geologiaan sovellettuina. Terra, Vol. 73, pp. 78—86.

—»—, Raevaara, H. and Talvitie, J. (1968) On the interpretation of ektachrome infrared aerofilm type 8443 photographs used in mineral reconnaissance and geological survey. Photogr. J. Finland, Vol. 2, 2, pp. 1—22.

—»— and Talvitie, J. (1968) High altitude false color photointerpretation in prospecting. *In* »Manual of color aerial photography», pp. 431—438. Am. Soc. Photogrammetry.

Penttilä, E. (1963) Some remarks on earthquakes in Finland. Fennia 89, 1, pp. 25—28.

—»— (1968) A report summarizing the velocity of earthquake waves and the structure of the earth's crust in the Baltic shield. Geophysica, Vol. 10, pp. 11—23.

Preston, J. (1954) The geology of the Precambrian rocks of the Kuopio district. Ann. Acad. Sci. Fenn., Ser. A III, 40.

Puustinen, K. (1968) Siilinjärven apatiittimuodostuman geologiasta. Unpubl. Lic. Thesis. Univ. of Helsinki.

—»— (1971) Geology of the Siilinjärvi carbonatite complex, Eastern Finland. Bull. Comm. géol. Finlande 249.

Ramsay, W. (1931) Geologiens grunder II. 3. uppl., Schildt, Helsingfors. 481 p.

Rauhamäki, E. (1965) Pohjoisen Haukiveden alueen intrusiivikivilajeista. Unpubl. Master's Thesis, Univ. of Helsinki.

Renqvist, H. (1930) Finlands jordskalv. Deutsches Referat: Erdbeben in Finnland. Fennia 54, 1.

Richter, C. F. (1958) Elementary seismology. Freeman and Co., San Francisco. 768 p.

Rosberg, J. E. (1912) Jordskalf i Finland 1904—1911. Deutsches Referat: Erdbeben und Erschütterungen in Finnland 1904—1911. Fennia 32, 5.

SAVOLAHTI, A. and KURKI, J. (1964) Observations on the nickeliferous ore block of Niemilahti in Kangaslampi and on small ultrabasic and basic bodies in the Rauhamäki—Kuronlahti district, Finland. Bull. Comm. géol. Finlande 215, pp. 171—192.

SEDERHOLM, J. J. (1913) Weitere Mitteilungen über Bruchspalten mit besonderer Beziehung zur Geomorphologie von Fennoskandia. Bull. Comm. géol. Finlande 37.

—»— (1932) Über die Bodenkonfiguration des Päijänne-Sees. Bull. Comm. géol. Finlande 100.

SIMONEN, A. (1960) Pre-Quaternary rocks in Finland. Bull. Comm. géol. Finlande 191.

—»— (1962) Alter und allgemeine Charakteristik des finnischen Grundgebirges. Geologische Rundschau, Bd. 52, pp. 250—260.

SPONHEUER, W. (1960) Methoden zur Herdtiefenbestimmung in der Makroseismik. Freiberger Forschungsh. C 88.

—»— (1963) Seismische Skala. Rundschreiben, Inst. f. Bodendynamik und Erdbebenforschung, Jena.

TALVITIE, J. (1965) Fennoskandian seismotektoniikasta. Unpubl. Lic. Thesis, Univ. of Oulu.

—»— (1966) Fennoskandian seismotektoniikasta. *In* »Geofysiikan päivät 21—22. 6. 1965», ed. by P. Tuomikoski, pp. 92—100. Oulu.

—»— (1967) Kuopion maanjäristys 1. 8. 1963: mikroseisminen tutkimus. *In* »Geofysiikan päivät 20—21. 6. 1966», ed. by P. Tuomikoski, pp. 67—73. Oulu.

TEISSEYRE, R., PENTTILÄ, E., TUOMINEN, H. V. and VESANEN, E. (1968) The horizontal spread of cratonic earthquakes and the corresponding block movements. Geophysica, Vol. 10. pp. 55—68.

TUOMINEN, H. V. (1957) The structure of an Archean area: Orijärvi, Finland. Bull. Comm. géol. Finlande 177.

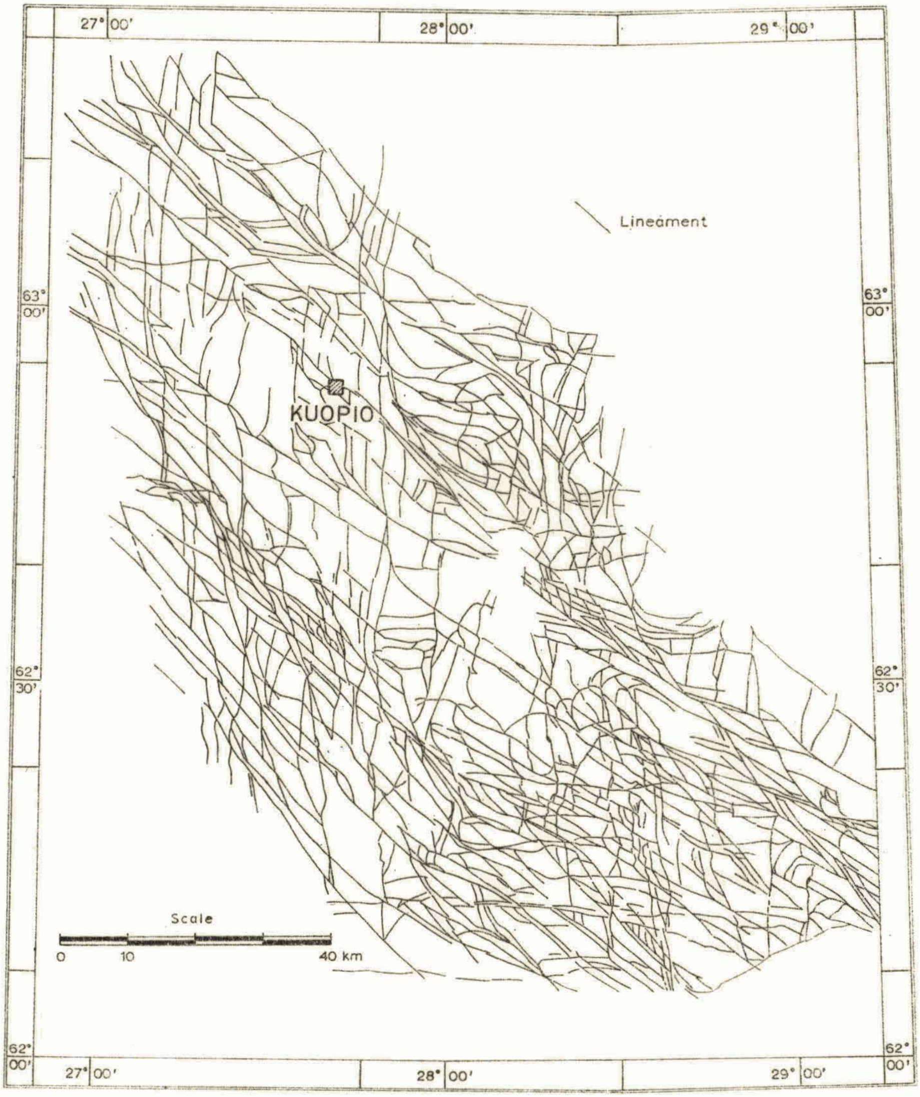
—»— (1961 a) The structural position of the Orijärvi granodiorite and the problem of synkinematic granites. Bull. Comm. géol. Finlande 196, pp. 499—515.

—»— (1961 b) On the role of faulting, a reply. Bull Comm. géol. Finlande 204, pp. 1—4.

—»— (1966) On synkinematic Svecofennian plutonism. Bull. Comm. géol. Finlande 222, pp. 387—392.

VÄYRYNEN, H. (1939) On the geology and tectonics of the Outokumpu ore field and region. Bull. Comm. géol. Finlande 124.

WILKMAN, W. W. (1938) Kivilajikartan selitys C 3, Kuopio. English summary. General geological map of Finland, 1: 400 000. Helsinki. 171 pp.



Jouko Talvitie: Seismotectonics of the Kuopio region, Finland.