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ON MIGMATITES AND ASSOCIATED PRE-CAMBRIAN ROCKS OF SOUTHWESTERN FINLAND

PART I THE PELLINGE REGION

BY

J. J. SEDERHOLM

WITH ONE MAP. 64 FIGURES IN THE TEXT AND
31 FIGURES ON VIII PLATES

HELSINGFORS 1923

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SCOPE AND METHODS OF THE INVESTIGATION.

The origin of all those rocks which have been termed gneissose has been long regarded as the most difficult problem of petrology. Nowadays we do not observe anywhere the formation of any rock masses similar to gneisses. Thus, if we try to explain their origin as due to the actual causes, it is only possible if we assume that these have been active at depths below the surface not directly accessible to our observations.

It has long been evident that the large group of rocks termed gneisses must comprise rocks of very different origin. For some of them very probable explanations have already been given.

There is no longer any controversy about the fact, that granites and other similar plutonic rocks can by mechanical action during mountain-forming processes, followed by chemical reactions between the minerals of the rock, be changed into sheared, gneissose rocks which Rosenbusch calls orthogneisses. The great work of Johannes Lehmann, Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine (1884), gave the clue to the proper understanding of these rocks. Lehmann even proposed to restrict the use of the term gneiss to sheared plutonic rocks. No doubt a greater precision in the nomenclature of gneissose rocks is desirable, and it may perhaps in the future be practicable to follow the proposal of Lehmann, i. e. to use the word gneiss only as a designation of a secondary texture. At the present moment, however, it seems hardly possible to avoid the use of the term gneiss in a more comprehensive sense, because its use as a »sack name» or »expression de l'ignorance» is so inveterate, and no generally recognised special names do exist for many of the rocks which are usually called gneisses.

Very interesting types of granitic gneisses, or gneissose granites, occur e. g. among the porphyritic granites of the lower Archæan of Finland. In these rocks the metamorphism has often mainly consisted of a mechanical crushing, whose gradual development we are able to follow by studying the changes of the porphyritic felspars. Along the shearing planes mica has crystallized.

In many granitic gneisses, however, the metamorphism has by no means been merely mechanical, but there have been formed, besides mica, other new minerals in a larger measure, either by reactions between the neighbouring primary minerals or out of material which has been transported from longer distances. Here also the question still often remains open which metamorphic agencies have been active, especially to what degree plutonic heat has been concomitant. Moreover it is often difficult to determine in which cases the parallel texture of the granitic gneisses may be of primary origin, due to movements in the magma during the process of its consolidation.

The problem of the genesis of granitic gneisses is in general by no means yet perfectly clear in all its details, although it may be regarded as solved in the main.

Other gneissose rocks, the p a r a g n e i s s e s of Rosenbusch, have been proved to have been originally sediments, either normal clastic sediments in a metamorphic state or such derived from tuffs which had been more or less changed by weathering before their deposition.

The question whether there is, among metamorphic normal sediments, a continuous series passing from argillites through mica-schists into gneissose rocks, and, in particular, whether the coarsely crystalline potash felspar, which is so important aud characteristic a constituent of the gneisses, has been formed by the metamorphism of sediments, has long been a matter of controversy especially in the German school of geology. Practically, it was a step forward when the petrologists, leaving aside this theoretical question, began to treat the schists proper separately from the gneissose rocks, and investigated at first the origin of the former by the aid of microscopical methods. In our opinion, however, many German petrologists went too far when they drew a very sharp demarcation-line between schists and gneisses, and regarded it as proved that there were no gradations between them.

Lately a new term has been introduced in the nomenclature of felspathiferous rocks which have been earlier designated as gneisses. Swedish petrologists have proposed to designate their fine-grained equivalents, earlier often called hälleflintgneisses, as l e p t i t e s. Chemically this term has even a wider comprehension than the word gneiss. Thus, while the latter comprises mainly rocks containing potash felspar, ranging from granites to felspar-bearing micaschists, the term leptite is made to cover both acid and basic crystalline schists, when they are finegrained in texture. The latter are called amphibolitic and syenitic leptites. As Högbom points out[1], the leptitic group »includes many genetically and structurally different rocks». Often they are derivatives of porphyries and their tuffs, in other cases they are derived from sediments, as for instance, from felsparbearing quartzites. Aplites and other boundary forms of granites may also in some cases have been transformed into leptites by metamorphism. The author has himself used the term leptite, originally introduced by Hummel, but for a long time not accepted by his fellow-geologists in Sweden, as the name of a special rock-type of known origin, occurring near Tammerfors, a highly metamorphic psammitic rock containing originally some clastic felspar. He gave, however, up the use of the term when the word was claimed again by his Swedish colleagues[2]. Such a comprehensive term as leptite, in its present definition, may be of some use as long as our knowledge concerning these rocks is still in a primitive stage, but then we ought clearly to remember that this new term also is only an »expression de l'ignorance», of the same character as, although more comprehensive, than the term gneiss, or the term metabasite which is used in Finland for metamorphic basic rocks not more exactly determined. Bäckström[3] compares the term leptite to a »basket in which everything which is not assorted may be thrown». In general the fine-grained metamorphic rocks seem often to be more easily interpreted, with the aid of the microscope, than the more coarse-grained. The former have, in most cases, never become metamorphic to a very high degree; in that case their fine grain generally vanishes. Thus both their chemical character, and, in many cases, also their original texture, are rather well preserved, and we are able to determine their origin with more or less certainty. Just as it would be advisable to restrict the use of the term gneiss as much as possible, to cover only some of the genetically different groups of rocks which have been called so, we might hope that increased knowledge will make it possible to take a great many of the leptites out of that petrographical sack or »basket» and place them in their proper compartment, so that genetically such different rocks as sedimentary

[1] A. G. Högbom, Precambrian Geology of Sweden. Bull. Geol. Inst. Univ. Upsala X, 1910, pp. 42—44.

[2] Om en ändring av nomenklaturen för våra granuliter eller hälleflintgneiser. Diskussion Geol. Fören. Stockh. Förh. Bd. 30, Mars 1908.

[3] l. c.

felspar-bearing quartzites, fine-grained ampibolites, and granitic aplites need not be referred to under a common designation.

Besides the gneisses of plutonic and those of sedimentary origin (including also those formed by the metamorphism of volcanic rocks intercalated with the sediments), many geologists have recognized the existence of gneissose rocks composed of a mixture of supercrustal rocks and injected granitic material which has risen from the depths (veined gneisses, injection gneisses, mixed gneisses, miktosites, migmatites etc.).

The first traces of such ideas are found as early as in the writings of Hutton, the father of theoretical geology[1], who believed in a subcrustal fusion of sediments and derived the granite from sediments which had undergone a complete fusion. Lyell believed that the gneisses were semi-fused sediments[2], while granites originated at still higher temperatures, or by a more lengthened exposure to the influence of heat. Delesse professed the idea that all plutonic rocks were of metamorphic origin[3], »not causing metamorphism, but originating through its influence». Such ideas were prevalent also among others of the older geologists on the continent.

This connection between the theoretical question as to the origin of the subcrustal magmas, and the mode of formation of deep-seated, often veined, gneissose rocks, was not propitious to their inductive study by petrological methods. At the present moment it seems advisable first to keep both these questions apart from each other, although they have a close theoretical connection. We prefer, so far, to take the plutonic magmas as a given fact, and to express no opinion about their origin, limiting our study to their relations to the older rocks which they penetrate. Later on we shall return to this question, and try to draw some conclusions concerning the way in which magmas have been formed at depth.

Among the older geologists there were some who studied in a purely inductive way the rocks formed by abysmal refusion or injection. Among them Durocher is especially prominent[4] who visited Finland and Scandinavia in 1858 and described many cases of a

[1] J. Hutton, Theory of the Earth, I, pp. 239, 317, 319.

[2] Ch. Lyell, Manual of Elementary Geology, V ed. 1855, p. 603.

[3] Delesse, Études sur le métamorphisme des roches 1861, p. 87.

Quoted by J. Roth, Über die Lehre vom Metamorphismus und die Entstehung der krystallinischen Schiefer. Abh. k. Akad. Wissensch. Berlin 1871.

[4] J. Durocher, Études sur la structure orographique et la constitution géologique de la Norvège, de la Suède et de la Finlande. Mém. Soc. géol. France, VI, 1, 1856.

very typical injection, even from the region now in question, viz. Southern Finland.

It is difficult to determine now in what measure these injection theories of the older French geologists have influenced the later French petrological school in its ideas about an intimate injection of granites into their neighbouring rocks, and the assimilation of the latter in the granitic magma. In any case, Michel-Lévy founded his theories about granitization on the firm basis of his own observations in the Archæan of France and also in the crystalline areas of a younger age of this country[1]. Almost at the same time also Barrois was led, by his study of the Paleozoic and Precambrian of Brittany and elsewhere[2], to draw similar conclussions, and Lacroix[3], Termier[4], Duparc[5] and other French and Swiss geologists have accumulated more evidence in the same direction.

Also in Germany there have been numerous adherents of the same idea, among them Johannes Lehmann whose observations were published as early as 1884, and, in later times, Chelius,[6] Erdmanns-

[1] A. Michel-Lévy, Note sur la formation gneissique du Morvan. Bull. soc. géol. France, 3 série, 7, 1882, p. 857.

——— Sur l'origine des terrains cristallins primitifs. Bull. soc. géol. France, 3 série, 16, 1888, p. 102.

——— Étude sur les roches cristallines et eruptives des environs de Mont-Blanc. Bull. Serv. Carte géol. France, 9, 1893.

——— Contribution à l'étude du granite de Flamanville et des granites français en général. Bull. Serv. Carte géol. France, 36, 1893.

[2] Ch. Barrois, Le granite de Rostrenen, ses apophyses et ses contacts. Annal. soc. géol. Nord, XII, 1884.

——— Aperçu de la constitution géologique de la rade de Brest. Bull. Soc. géol. France, 3 série, XIV, 1885—1886, p. 678.

——— Sur le massif granitique de Huelgoat. Ibid., p. 865.

——— Guide géologique en France, 7. VIII Congr. géol. internat. Paris 1900.

——— Sur les relations tectoniques des granites grenus et gneissiques de Bretagne. C. R. XI Congr. géol. Internat. Stockholm 1910, p. 597.

[3] A. Lacroix, Le granite des Pyrénées et ses phénomènes de contact. Bull. Serv. Carte géol. France 64, 1898, and 71, 1900.

[4] Pierre Termier, Les schistes cristallins des Alpes occidentales. C. R. IX Congr. géol. Internat. Vienne 1903.

——— Sur la genèse des terrains cristallophylliens. C. R. XI Congr. géol. Internat. Stockholm 1910, p. 587.

[5] L. Duparc et L. Mrazec, Recherches géologiques et petrographiques sur le Massif de Mont-Blanc. Mém. Soc. Phys. et Hist. nat. Genève. XXXIII 1, 1898.

[6] C. Chelius, Petrographische Untersuchungen im Odenwald, V. Centralbl. f. Min. 1906, pp. 763 ff.

dörffer[1], Gäbert[2], Gürich[3], Klemm[4], Lepsius[5], Philipp[6], Sauer[7], Schwenkel[8], Steinmann[9], Weber[10] etc.

The petrological school of Heidelberg opposed, as is well known, its world-wide influence to the idea of a local or regional injection or assimilation. By his study of the contacts of certain granites of the Vosges Rosenbusch thought that he was able to prove, that there had been no transfer of material from the granite into the adjacent schists, and he generalized this conclusion so as to hold good for all granite contacts of the world, persistently denying the possiblity that the schists could be permeable to the granitic magma, or its juices. Later investigations in the Black Forest showed, however, that there also mixed gneisses occur in a large measure. Schwenkel explicitly[8] says: zones of mixture and injection gneisses occur, and are certainly more common than hitherto was known.

In German Switzerland, Austria and Romania the injectionist school has many adherents, such as Grubenmann[11], Gutzwiller[12], Königsberger[13], Truninger[14], Reinhold[15], Reinhard[16] etc.

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[1] O. H. Erdmannsdörffer, Der Eckergneis im Harz. Jahrb. k. preuss. geol. Landesanst. 30, 1909, pp. 324—387.

——— Über Resorptionserscheinungen an Einschlüssen von Tonschieferhornfels im Granit des Brockenmassivs. Jahrb. k. preuss. geol. Landesanst. XXVIII, 1907, pp. 131—130.

——— Über Mischgesteine von Granit und Sedimenten. Sitz. k. preuss. Akad. der Wissensch. Berlin 1912, pp. 478—484.

[2] C. Gäbert, Die Gneise des Erzgebirges und ihre Kontakteinwirkungen. Zeitschr. deutsch. geol. Gesellsch. 59, 1907, pp. 308—376.

[3] G. Gürich, Granit und Gneis. Himmel und Erde, 17, 1905, p. 241.

[4] G. Klemm, Beiträge zur Kenntniss des krystallinen Grundgebirges in Spessart. Abh. hessisch. geol. Landesanst. 1895, p. 87.

——— Bericht über Untersuchungen an den sogenannten »Gneissen» und den metamorphen Schiefergesteinen der Tessinen Alpen. Sitz. k. preuss. Akad. Wissensch. Berlin (Phys.-math. Kl.) 1906, pp. 420—431, and 1907, pp. 245—258.

[5] R. Lepsius, Geologie von Deutschland und den angrenzenden Gebieten II.

[6] H. Philipp, Vorläufige Mitteilungen über Resorptions- und Injectionserscheinungen im südlichen Schwarzwald. Centralbl. Min. 1907, pp. 76—80. Cf. Monatsber. deutsch. geol. Gesellsch. 1907, pp. 189—171.

[7] A. Sauer, Das alte Grundgebirge Deutschlands etc. C. R. IX Congr. géol. Internat. Wien 1903, pp. 245-602.

[8] Hans Schwenkel, Die Eruptivgneise des Schwarzwaldes und ihr Verhältnis zum Granit. Min. petr. Mitth. XXXI, 1912, pp. 140—320.

[9] G. Steinmann, Gebirgsbildung und Massengesteine in der Kordillere Süd-Amerikas. Geol. Rundsch. I, 1910.

[10] M. Weber, Metamorphe Fremdlinge in Eruptivgesteinen. Sitz. k. bayer. Akad. 1910.

——— Studien an den Pfahlschiefern. Geogn. Jahresh. 23, 1910.

While the discussion between the Heidelberg school and its opponents was going on, the evidence in favour of the existence of mixed rocks accumulated from all parts of the world. In England, Scotland and Ireland similar phenomena were observed, and their explanations worked out, by Harris Teall[1], Barrow[2], Horne[3], Greenly[4], Cole[5] etc. In Australia Andrews[6] and others made similar observations. In Canada Lawson was the forerunner of a large number of petrologists[7] who explained the origin of veined rocks along quite the same lines as the French school. Some of them, as for instance

[11] U. Grubenmann, Die kristallinen Schiefer. 2 Aufl. 1910.

— — — Über einige tiefe Gneise aus den Schweizeralpen. C. R. XI Congr. géol. Intern. Stockholm 1910, p. 625.

[12] Emil Gutzwiller, Injektionsgneise aus dem Kanton Tessin. Inaug.-Diss. Lausanne 1912.

[13] J. Koenigsberger, Karte des östl. Aarmassivs und Text 1910.

— — — Die kristallinen Schiefer der zentralschweizerischen Massive und Versuch einer Einteilung der kristallinen Schiefer. C. R. XI Congr. géol. Intern. Stockholm 1910, p. 639.

— — — Über Gneisbildung und Aufschmelzungzonen der Erdkruste in Europa. Geol. Rundsch. III 1912, pp. 297—309.

— — — Bemerkung zu einem Aufsatz von J. J. Sederholm. Geol. Rundsch. Bd. V. H. 1. 1914.

[14] Ernst Truninger, Über das Grundgebirge im niederösterreichischen Waldviertel. C. R. XI Congr. géol. internat. Stockholm 1910, p. 617.

[15] F. Reinhold, Pegmatit- und Aplit-Adern aus den Liegendschiefern des Gföhler Zentral-gneisses im niederösterrichischen Waldviertel. Min. petr. Mitth. 29, 1910, pp. 43—147.

[16] Max Reinhard, Sisturile cristaline din Muntii Fagarasului, Anurul Inst. Geol. al Romȃnici, III, 1909.

— — — Der Coziagneisszug in den rumänischen Karpathen. Inaug.-Diss Bukarest. 1906.

[1] J. J. Harris Teall, The Evolution of Petrological Ideas. Presid. Address. Proc. Geol. Soc. LVII, 101, LXIII and Smiths. Rep. 1902, pp. 287—308.

[2] G. Barrow, On an Intrusion of Muscovite-Biotite Gneiss in the South-eastern Highlands of Scotland &c. Q. J. G. S. 49, 1893, p. 330.

[3] J. Horne and E. Greenly, On Foliated Granites and their Relations to Crystalline Schists in Eastern Sutherland. Q. J. G. S. LII, 1896, p. 633.

[4] G. Greenly, The Diffussion of Granite into Crystalline Schists. Geol. Mag. IV, 10, 1903, p. 207.

[5] Grenville A. J. Cole, On composite Gneisses in Boylagh, West Donegal. Proc. Roy. Irish Acad. XXIV B. 1902, p. 2.

[6] E. C. Andrews, The Geology of the New England Plateau &c. Rec. Geol. Surv. N. S. W. VII, pp. 130—216, 1904: and pp. 281—300, VIII, 1905, 19.

[7] A. C. Lawson, Report on the Geology of the Lake of the Woods. Ann. Rep. Geol. Surv. Canada. New Series, I, 1885.

— — — Report on the Geology of Rainy Lake Region. Ibid. III, 1887. cf. Mem. 40, 1917.

Adams[1], had earlier been doubtful as to the injection theory, but their own study in the field brought them independently to the same conclusions. In the United States similar ideas were prevalent even at an early date; at a time even prior to the publication of the papers of Michel-Lévy, J. D. Dana[2] thought that not only gneisses, but also granites, norites, diorites, hornblendites and pyroxenites originated through metamorphic action which had reached the stage of refusion. Hawes[3] also belongs to the earliest investigators of the injection phenomena. North America no doubt offers some of the most splendid opportunities for studying the geological problem here in question. Therefore many of its geologists as Barrell[4], Berkey[5], Cushing[6], Emerson[7], Fenner[8], Foye[9], Miller[10],

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[7] N. C. Lawson, The Archæan Geology of the Region Northwest of Lake Superior. Études sur les schistes cristallins. C. R. IV Congr. géol. internat. London 1888.

[1] Frank D. Adams, The Origin of the deepseated Metamorphism of the pre-Cambrian crystalline Schists. C. R. XI Congr. géol. Internat. Stockholm 1910, pp. 563—572.

— — — and A. E. Barlow, The Geology of the Haliburton and Bancroft Areas in Eeastern Canada. Rep. Geol. Surv. Canada. 1910.

— — — The Laurentian System in Eastern Canada Q. J. G. S. 1908, p. 129.

A. E. Barlow, Report on the Geology of Lakes Nipissing and Temiscaming. Ann. Rep. Geol. Surv. Canada, New Series, X, 1897.

I. Wm. Mc-Innes, Report on the Geology of the Seine River and Lake Shebandowan. Ann. Rep. Geol Surv. Canada, New Series, X, 1897 H.

W. H. C. Smith, Report on the Geology of Hunters Island, Ann. Rep. Geol. Surv. Canada. New Series, V, 1890—91. I — G.

[2] J. D. Dana, On the Geological Relations of the Limestone Belts of Westchester County, N. Y. Amer. Journ. Science 3:d series 20, 1880, p. 219. Cf. Manual of Geology. 1886, pp. 143—145.

[3] G. W. Hawes, The Albany Granite and its Contact Phenomena. Am. Journ. Sci. XXI, 1881, pp. 31—32.

[4] Joseph Barrell, Geology of the Marysville Mining District, Montana. Prof. Papers U. S. Geol, Surv. 57, 1907.

[5] Charles P. Berkey, Structural and Stratigraphic Features of the basal Gneisses of the Highlands. Bull. N. Y. State Mus. 107, 1907, pp. 361—378.

[6] H. P. Cushing, Geology of the Northern Adirondack Region. Bull. N. Y. State Mus. 95, 1905, pp. 71—453.

[7] Ben. K. Emerson, Porphyritic and Gneissoid Granites in Massachusetts. Bull. Geol. Soc. Am. I, 1890, pp. 559—561.

[8] Clarence N. Fenner, The Mode of Formation of Certain Gneisses in the Highlands of New Jersey. Journ. Geol. Chicago, XXII, 1914, pp. 594—612, 694—702.

[9] W. G. Foye, Are the »Batholiths» of the Haliburton-Bancroft Area, Ontario, correctly named? Journ. Geol. Chicago XXIV, 1916, pp. 783—791.

[10] W. J. Miller, Magmatic Differentation und Assimilation in the Adirondack Region. Bull. Geol. Soc. Am. XXV, 1914, pp. 245—264.

Whitney and Wadsworth[1], Alexander[2] and N. H. Winchell[3], are most decidedly on the side of the injectionist school of petrology, and Daly[4] has even, in numerous writings, carried its conclusions farther than anybody else. The opposition which here, as well as in Great Britain and Scandinavia, meets not only this radical form of the granitization theory, but also this doctrine in general, comes especially from the leaders of microscopical petrology of which many have been students at Heidelberg.

In Russia Loewinson-Lessing[5] has developed the theory of assimilation in a very logical manner, and the Russian petrologists have in general been adherents of the idea of an injection.

In Norway Kjerulf[6] independently reached the same conclusions

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[1] I. D. Whitney and M. E. Wadsworth, The Azoic System and its Proposed Subdivisions. Bull. Mus. Harvard Coll. Geol. Ser. T. 1884.

[2] Alexander Winchell, Some Results of Archean Studies. Bull. Geol. Soc. Am. I, pp. 357—394.

[3] N. H. Winchell, The Origin of the Archean Igneous Rocks. Am. Geol. XXII, 1898.

— — — Amer. Journ. Sci., XXI, 1881, pp. 31—32.

[4] R. A. Daly, The Geology of the Ascutney Mountain, Vermont. Bull. U. S. Geol. Surv. N:o 209, 1903.

— — — The Mechanics of Igneous Intrusion. Amer. J. Sci. 1903, pp. 269—298.

— — — Second Paper. Ibid. 1903, pp. 107—190.

— — — Third Paper. Ibid. 1908, pp. 15—50.

— — — The Secondary Origin of Certain Granites. Ibid. 1905, pp. 185—216.

— — — The Classification of Igneous Intrusive Bodies. Journ. Geol. Chicago, 1905, pp. 485—508.

— — — Abyssal Igneous Injection as a Causal Condition and as an Effect of Mountain-building. Amer. J. Sci. 1906, pp. 195—216.

— — — Okanogen Composite Batholith of the Cascade Mountain. Bull. Geol. Soc. Amer. 1906, pp. 329—376.

— — — The Differentation of Secondary Magma through Gravitative Adjustement. Rosenbusch-Festschrift, 1906, pp. 203—233.

— — — The Nature of Volcanic Action. Proc. Amer. Acad. Arts & Sci. 1911, pp. 67—108 and 119—122.

— — — Geology of the North American Cordillera at the Forthy-Ninth Parallel. Mem. Geol. Surv. Canada No. 38, I—III, 1912.

— — — Introductions to the Geology of the Cordillera and Annotated Guide Golden to Savona. Congr. géol. Intern. XII. (Ottava 1913). Guide-Book, pp. 111—167 and 202—243.

— — — Igneous Rocks and their Origin, 1914.

[5] F. Loewinson-Lessing, C. R. VII Congr. géol. internat. 1899, pp. 308—401.

— — — Geol. Mag. VIII, 1911.

[6] Th. Kjerulf, Udsigt over det sydlige Norges Geologi. Kristiania 1879, pp. 60 and 142.

as Michel Lévy at an early date, but the correctness of the observations on which he based his theories about the »foot granites» etc. has been since questioned. Reusch[1] applied the assimilation theory in 1888 on the rocks of Bömmelöen and Karmöen. In general, however, the trend of the Norwegian school of petrology has been rather in opposition than in favour of the idea of a regional granitisation. Its famous leader, Brögger, however, does not deny the theoretical possibility of those processes, at great depths under the surface of the earth, although he has been critical as to many applications of the injection theories. Goldschmidt[2] has lately given very convincing evidence for the assumption that certain »Norwegian injection gneisses» of the Caledonian mountain chain have originated by the injection of granitic veins into partly dissolved phyllitic schists.

In Sweden the idea of a regional granitisation of sediments, or sheared older granites, earlier met with very little favour, but has won considerable ground during later years. The present director of the geological survey, Dr. Gavelin[3], is a decided adherent of these ideas. Holmquist[4] admits the possibility of an injection in many cases, but he (in some cases also Gavelin) is inclined to explain many of the rocks containing pegmatitic and aplitic veins according

[1] H. Reusch, Bömmelöen og Karmöen. Norges geol. Undersök. 1838, pp. 256—305, 377 and 421 sequ.

[2] V. M. Goldschmidt, Die Injektionsmetamorphose im Stavanger-Gebiete, Vidensk.-Selsk. Skrifter, I, Math.-naturv. Kl. N:o 10, Kristiania, 1921.

[3] A. Gavelin, Kartbladet Loftahammar med beskrivning, Sver. Geol. Undersök. Ser. Aa, 1904.

— — — Till frågan om berggrunden på geologiska kartbladet Loftahammar, Geol. För. Stockh. Förh. 27, 1905.

— — — Om relationerna mellan graniterna, grönstenarna och kvartsitleptitserien inom Loftahammarområdet. Sver. Geol. Undersökn. Årsb. 1909, N:o 7.

— — — The Rocks of the Coast Regions of Loftahammar and Västervik. Geol. För. Stockh. Förh. 1900, pp. 988—1029 and Guides des excursions XI Congr. Géol. Internat. Stockholm 1910.

[4] P. J. Holmquist, Studien über die Granite von Schweden. Bull. Geol. Inst. Univ. Uppsala, VII, 1906, pp. 77—270.

— — — Ådergneisbildning och magmatisk assimilation. Geol. För. Stockh. Förh. Bd. 29, 1907, pp. 313.

Gneisfrågan och urbergsteorierna. Ibid. Bd. 30. Nov. 1908.

— — — The Archean Geology of the Coast-Regions of Stockholm. Ibid. Bd. 32, 1910, p. 806, and Guides des Excursions en Suéde 15. XI Congr. géol. Internat. Stockholm 1910.

Cf. Discussion sur la géologie des systèmes précambriens. C. R. Congr. Geol. Internat. Stockholm 1910, p. 734 and Diskussion anlässlich der Schärenfahrt der Excursion C I. Ibid. p. 1324.

to the older Swedish conception, as originated by metamorphic or »ultrametamorphic» changes, without any transport of granitic material from below. Högboms[1] standpoint seems to be near to that of Holmquist. He does not ascribe any very great rôle to granitization as a petrogenetical agent active among the Pre-Cambrian rocks.

In Finland where rocks containing granitic veins occur almost everywhere over wide areas, the idea of a regional injection has seemed so natural as to meet almost no objection. Since the author[2] began his geological field-work in 1883 he has used it as a working theory, and has published together with his colleagues, especially Frosterus[3], Hackman[4], Eskola[5], Wilkman[6] and Mäkinen[7], a number of pamphlets relating to this subject. At the beginning the authour had some doubts whether it was possible to explain, as suggested by Lawson, the absence of preserved basements in the older Pre-Cambrian by the assumption that they had been obliterated by refusion. Later field work, however, brought the author, as well as some of his fellow-workers, to the same conclusion.

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[1] A. G. Högbom, Precambrian Geology of Sweden, Bull. Geol. Inst. Univ. Upsala X, 1910.

— — — Fennoskandia. Handbuch der Regionalen Geologie, IV, 3. 1913.

[2] J. J. Sederholm, Beskrifn. till kartbl. N:o 18. Tammela Finl. geol. Undersökn. 1890, pp. 22—24.

— — — Om berggrunden i södra Finland. (Deutsches Ref.) Fennia 8, 3, 1893.

— — — Ueber eine archäische Sedimentformation im südwestlichen Finnland etc. Bull. Comm. géol. Finlande, 6, 1899.

— — — Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia (Engl. Summary). Ibid. 231 907.

— — — Ännu en gång urbergsfrågorna. Geol. För. Stockh. Förh. Bd. 31, 1909, pp. 75—93.

— — — Einige Probleme der präkambrischen Geologie von Fennoskandia. Geol. Rundsch. I, 1910, pp. 126—135.

— — — Om palingenesen i den sydfinska skärgården samt den finska urbergsindelningen. Geol. För. Stockh. Förh. Bd. 34, 1912, pp. 285—316.

— — — I urbergsdiskussionen. Ibid. 34, 1912, pp. 1—4.

— — — Über die Entstehung der migmatitischen Gesteine. Geol. Rundschau IV, 1913, pp. 174—185.

— — — Über ptygmatische Faltungen, N. Jahrb. f. Min., B.-Bd. XXXVI, 1913, pp. 491- 512.

— — — Die regionale Umschmelzung (Anatexis) erläutert an typischen Beispielen. C. R. Congr. géol. internat. Stockholm 1910, pp. 573—586.

— — — On Regional Granitization (or Anatexis). C. R. XII Congr. géol. internat. Canada 1913, pp. 319—324.

[3] B. Frosterus, Beskrifning till bergartskartan, sektion C. 2, St. Michel, Geol. Komm. Finl. 1902.

Although the opposition against the theories in question has had its main stronghold, as already pointed out, in the micropetrological school of Heidelberg, while French petrologists have been most prominent in developing this fruitful conception of a regional granitization, it would be wrong to regard the whole controversy as a national contest between German and French petrology. La science n'a pas de patrie, and, as results from the foregoing statements, there are petrologists from all countries on both sides. Like most scientific theories, the idea of a granitization at great depth can hardly be regarded as belonging entirely to any definite country.

Behind this difference of opinion, which has so long divided the petrologists of the world into two camps, there lies another difference, that of the starting-point, and this has probably been the main cause of the division of opinion.

Almost all the opponents of the granitization theories have been such petrologists as have used mainly the microscope for unravelling the mysteries of the origin of the rocks. They have therefore with predilection turned their attention to the study of such rocks as show characteristic and well preserved primary textures, and very often to such as possess an especially interesting mineralogical composition. In comparison with, for instance, the alkaline clans, that aristocracy among the rocks, whose study has so fascinated the attention of microscopical petrologists, the common granites have far less conspicuous peculiarities to show. Where such rocks have been studied microscopically, preference has often been given to those occurrences that show a homogenous composition and distinct, well preserved primary features in their texture.

Such rocks occur especially as effusive beds or in laccolithic masses, solidified in the upper portions of the earth's crust. The larger areas of granites and gneisses have appeared to the workers of petrological science by far less inviting. Moreover, many of the regions where microscopical petrology has been from the outset

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[4] V. Hackman, Beskrivning till bergartskartan, sektionerna C. 6, Rovaniemi etc. Geol. Komm. Finl. 1914.

[5] P. Eskola, On the Petrology of the Orijärvi Region etc. Bull. Comm. géol. Finlande 40, 1914.

— — — On the Igneous Rocks of Sviatoy Noss in Transbaikalia. Övers. Finska Vet.-Soc. Förh. LXII. 1920—1921, s. 1.

[6] W. W. Wilkman, Beskrivning till bergartskartan, sektionen D 3, Joensuu Geol. Komm. Finl. 1915.

[7] E. Mäkinen, Översikt av de prekambriska bildningarna i mellersta Österbotten i Finland. Bull. Comm. géol. Finl. 47, 1916.

most flourishing, offer very little opportunity for studying the abysmal rocks, i. e. those which most commonly show typical injection phenomena. Such rocks are characteristic of the great protaxes of Pre-Cambrian rocks in North America and North Europe, and these regions are the proper places for their study.

Therefore we think that the geologists who have taken different sides in this scientific conflict, have very often studied different cases, the microscopical school with predilection the effusive and hypabyssic rocks, and the field geologists of the other school, rocks that have originated at very great depths. Brögger has also emphasized the same idea, when saying:[1] ›Es wäre immerhin möglich, dass sich in grösserer Tiefe die Verhältnisse etwas abweichend gestaltet haben könnten› and further: ›ich will ausdrücklich hinzufügen, dass es mir wohl bekannt ist, dass in regionalmetamorphosertem Gebirge die Resorptions- und Lösungsfähigheit der Tiefenmagmen oft eine bei weitem grössere gewesen ist, als in nicht regionalmetamorphosierten Gebieten, wie das Kristianiagebiet. Es wäre somit denkbar, dass die ›Assimilations›-Tätigheit der Tiefenmagmen gewissermaassen (wenn auch kaum direct) eine Function des stattgefunden Druckes gewesen sei».

›Zu einem Durchschmelzen des flüssigen Erdinneren von der ewigen Teufe aus ist aber auch sogar im Grundgebirge gewiss ein weiter Sprung über die tiefe Kluft zwischen den Beobachtungen und der Hypothese›.

The author of the present treatise has been a student in the laboratories of Brögger and Rosenbusch, and thus belongs from the outset to the Heidelberg school, but his study in the field has made him, since the beginning of his scientific career, one of the most eager partisans of the granitization theory.

If what has been said above about the cause of the great dissensus of petrology is true, then the only way of arriving at a definite agreement lies therein, that those geologists who think that they have observed things unknown to others present their evidence more completely. If it has not yet been possible to convince every petrologist, the fault is with those who posses the array of facts necessary to prove it, and have not yet shown it to the world of science.

During many years, the petrological studies of the author concerned especially the origin of the schists proper, i. e. the Archæan

[1] W. C. Brögger, Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol. Vidensk.-selsk. Skrifter. I Math.-naturv. Kl. - Christiania, 1896, p. 116.

rocks of supercrustal origin, their petrology and stratigraphy. This study often brings the geologist to a point where he finds the schists grading into granite-invaded gneissose rocks. Especially at the surfaces of contact with other rocks, both with granites occurring over wide areas, and such rocks as presumably represent the basement of the sedimentary schists, such veined gneisses or »arterites» occur, and the geologist is here confronted with the problem of their origin. In these areas, however, the rocks in question play no very considerable rôle, and only possess a restricted distribution. In other areas, again, especially in the coast regions of south-western Finland, along the northern shores of the Baltic and the Gulf of Finland, these veined rocks, or *migmatites*, as the author has proposed to call them, occur over wide areas which then present the most confusing mixtures of different rocks, schists, basic eruptives and granites.

These areas have long appeared to the author so enigmatic, that he feared that they would remain unexplained as to the details at least during his lifetime, till he happened to find by chance some outcrops which promised to give a clue to their proper understanding. This happened in the summer of 1906 while he was staying at or in the neighbourhood of the Zoological station of Tvärminne near Hangö, on the northern shore of the Baltic. This station has been founded by the late Dr. J. A. Palmén, professor of zoology at the University of Helsingfors. He has given to the author much friendly assistance on this, as well as on many former occasions. He has been the centre of much of the study of Natural Science in Finland during several decades, and the theory developed in this treatise also is born under his sponsorship.

In the outermost of the numerous small rocky islands bordering the southern shore of Finland such outcrops of these mixed rocks occur as are probably not surpassed anywhere else. The rocks which have been worn and polished by glacial action and are continually splashed by the waves of the sea, present their surfaces in an almost ideal state of preservation, absolutely fresh and, near to the shore line, free also from covering lichens. On higher, less exposed places such plants occur, but may in some cases still be rubbed off with the aid of a wire-brush. Often rock-surfaces measuring more than 10,000 square metres are perfectly well exposed, and we can then observe all the features of their structure as far as this can be studied without the aid of the microscope.

During his investigations the author has been able to find some cases where a purely microscopical study of these rocks promises to give good results also. But in general the microscopical study of the mixed rocks is of little value in comparison with those observations which we are able to make in the field. It is different when we investigate the schists proper, where the study of the pseudomorphic minerals gives us the clue to the right understanding of the changes which the rock has undergone. There, often so much is preserved of its original texture, that it can be determined with more or less certainty. But in the migmatitic rocks the primary textures of the granite-invaded rocks have commonly been obliterated to such a degree that it is difficult to interpret them with the aid of the microscope. Moreover, the mixture of these remaining portions of the older rocks and of the granitic veins may have become so intimate as to make it difficult to determine which is which, and in this case the textures in both constituents are still more confused.

But even then so much may be left of the primary macroscopical petrological characters of the granitized rock as to make it possible to interpret them. The felspars, for instance, may, even when they are entirely granulated, still show their primary outlines fairly well preserved. Their arrangement may give some idea as to the original texture of the rock. Also the different stages of the granitization process are often exemplified in the rock-surfaces by so many typical instances that we are able to get an idea of the progress of this process simply by changing in one's mind the juxtaposition of things into a sequence of events.

Now there occurs, in the rocks in question near Hangö, a series of basic dykes which penetrate certain coarsely porphyritic gneissose granites. Both these rocks have been penetrated by veins of a younger granite, interwoven with the former in the most intricate way. Generally the basic rock has been less changed, during the process of the granitization, than the granites, and remains, even in the highly granite-invaded varieties, as necklace-like strings of fragments or as zones showing so much of the original chemical character preserved that the strike of the dykes can be ascertained. We thus are able, by using these basic dykes as tests, to determine what has happened when the granite penetrated, in a molten state, into the older rocks, and these were in a large measure refused. By mapping and picturing a great number of such rock surfaces we are able to find examples of all the stages of the granitization process in a manner somewhat recalling the sequence of the pictures of a bioscope.

The author has mapped many of the most typical exposures on a very large scale, most of them in 1 : 20. He proceeded with this work during the summers 1908—1910, using so much of his time as he could find available for this purpose. During the summer of 1910 he was assisted by Dr. H. Hausen who made together with him a great many drawings in the region east of Hangö. The rocks were crossruled with chalk, and a picture of each square meter was drawn separately on millimetre-paper. The author desires to thank Dr. Hausen here for his able assistance. The author has also used the photographic camera in large measure. He has thereby found it absolutely necessary to have a camera which can be easily turned downward and is very steady, allowing one to take photographs perpendicularly against the surface of the rock. Perspectivic photographs are of much less value.

His main purpose has been to work out a *method* for the study of such rocks, and their structure, in order to get a proper classification which can be used for mapping purposes. If even some of his conclusions should be wrong, he hopes that his methods will prove to be correct, and have followers.

In 1907, the author has already reported upon some of his observations from the region near Hangö, although his knowledge was then in a preliminary state. He has also made several later communications concerning this subject, at congresses or in different scientific journals, where he has reported upon the progress of his investigations, and has, on several occasions, shown the exposures in question to foreign colleagues who have visited Finland.

In another region lying more to the east, between Hangö and Helsingfors, around the Barösundsfjärd many phenomena were observed which had a more complicated character than those occurring in the region first studied.

Therefore it seemed desirable not only to study the basic dykes, and their changes during granitization, petrologically, as the author had mainly done till 1909, but also to determine, if possible, their exact age in relation to the neighbouring rocks, and in general, their mutual geological relations. For this purpose it became necessary to trace these formations in question to a region, where the granitization had been, at least locally, less intense, and where the primary petrological features, as well as the geological structure, were thus better preserved, and could be unravelled.

The author had long beforehand hoped that the region called Pellinge near Borgå to the east of Helsingfors, and the neighbouring archipelago, could give the clue to many of the geological and petrological questions which he had met in the region between Helsingfors and Hangö. Therefore he proceeded in 1911 with his investigation to the Pellinge region, leaving his study of the other areas partly incomplete, wishing at first to get a firm basis from which to start when judging the geology and petrology of the whole coast region.

The author was not deceived in his hope, as the Pellinge area showed itself to be a most typical clue region. It has in general been his experience when working among the rocks of the older Archæan, that the study of such a clue region is often many times more important than the indiscriminate mapping of great areas of less typical rocks.

In Pellinge the author not only found what he had expected, an area where many of the rocks of Southern Finland showed their original features remarkably well preserved, but here he was also able to study phenomena of granitization, caused by not less than five different granites, partly in their initial stages, while the rocks in the west had shown mainly stages of granitization which had progressed much farther.

After having studied this fascinating region during the greater part of three summers, the author found it most advisable preliminarily to put aside all the materials of observation gathered in the archipelago west of Helsingfors and to begin by describing the phenomena observed at Pellinge. Other works and especially circumstances connected with the world war have considerably delayed the publication of this memoir.

The author is very much indebted to Dr. E. Mäkinen who has made a number of chemical analyses of rocks from the region in question, and also calculated their mineral constituents.

Dr V. Hackman has also kindly assisted him by such calculations.

The accompanying drawings have been made with much discrimination and skill by Miss E. Åkesson. During much of his travelling in the archipelago the author has had an intelligent assistant in Mr Fr. Holmström, janitor at the geological survey who also made most of the thin sections. He has been of invaluable aid to the work in question by inventing a great many practical devices in the equipment of the motorboat, in the apparatus used for measuring and photographic work etc. The author desires to thank him here cordially.

PART I.

THE PELLINGE REGION.

GENERAL CHARACTER OF THE PELLINGE REGION AND OUTLINE OF ITS PRE-CAMBRIAN GEOLOGY.

The islands called Pellinge lie within the ship's course between Helsingfors and Wiborg, in the parish of Borgå, and are surrounded by an archipelago of some hundred small islands south of some promontories protruding from the mainland, partly in the parish mentioned, partly in the parish of Pernå. On the area of the map there are more than 1,000 islands, many of them being very small. The largest of these islands is Stor-Pellinge which has a length of 7 and a breadth of 4 kilometres.

The rocks protrude from under the covering masses of morainic debris, of gravel and sand washed by glacial rivers during the great Ice-Age, or of glacial clays, and often form very typical r o c h e s m o u t o n n é e s. However, when they are seen here amidst the waves of the sea, they do not remind one of sheep lying near to each other on a slope, as do the granitic hills protruding from a covering sheet of moraine, but rather of the backs of whales or of other maritime animals returning from a dive. The Swedish speaking coast people often call a small rocky island a k o b b which is probably identical with k o b b e, seal.

The large islands and a number of the small ones are forest-clad, displaying charming landscape-views, but those which lie in the open sea or near to large fjärds (a f j ä r d, pr. fiærde = firth, is a large area of water between promontories or archipelagoes of islands) consist often mainly of naked »whaleback-rocks», or groups of such, united by deposits of gravel or pebbles. The eroding action of the brackish water of the Gulf of Finland has since the Ice-Age been almost imperceptible, and therefore the rocks, in places where they have been splashed by the waves, are here preserved in a state of almost absolute freshness.

The rocks are so well exposed that it is almost everywhere possible to find contacts between the different rocks which allow of determining their relations as to age etc.

As shown by a glance at the map, the Pellinge area is geologically well defined, to the east by the western boundary of the great Wiborg area of Rapakivi granites (K on the map), to the west by the eastern boundary of a similar coarse, porphyritic granite, the Onas granite (J)[1]. Between the latter granitic area and the open sea which lies to the south of it, only a narrow strip of migmatitic rocks exists, connecting the Pellinge area with the region lying immediatly to the west of Helsingfors. In the north we find a monotonous area of microcline-granites (H), generally more or less migmatitic, belonging to the Hangö—Ingå group of granites which have been earlier often designated as younger Archæan, (or post-Bothnian granites). Between them and the Onas and rapakivi granites lies an area which has a more complicated geological structure, consisting mainly of supercrustal rocks, only locally penetrated by smaller masses and numerous veins of granite. Most of those rocks were originally basic volcanics, i. e. basalts with associated tuffs and agglomerates, sometimes grading into more acid volcanic rocks, andesites and even such rocks as contain potash felspar and quartz, the latter rocks, however, occurring only in small quantities. Also basic rocks with granitic texture, i. e. gabbros, occur in connection with the metabasalts.

All these basic volcanics, and associated plutonic or hypabyssic rocks, have later undergone metamorphic processes, wherein the most conspicuous change has been the alteration of the predominant pyroxenic constituents into amphibole, i. e. their uralitization. The basalts have thus been changed into metabasalts or uralite-porphyrites, while the gabbros have remained in part almost unaltered.

By the first mapping of the region, which was made as early as the year 1879, at a time when our general knowledge concerning the petrology of the pre-Cambrian rocks was still at a very imperfect stage, all the uralite-porphyrites of Pellinge were regarded as belonging to one formation. Even at an investigation of the region which was undertaken in the last decade of the 19:th century, by Mr C. E. Otto, Austrian Consul General at Helsingfors, and an as-

[5]) The coarse porphyritic granite of Obbnäs and Bodom, in the region W. and NW. from Helsingfors, is possibly of the same age, or also intermediate in age between the Onas granite and the following group H.

sistant of his, Mr N. T. Nyholm, the same conception seems to have been prevalent.

When the present writer began the renewed mapping in the year 1911, he was soon aware that there occurred at Pellinge two different formations of uralite-porphyrites. There is a granite, the Rysskär granite (F) which is intermediate in age between both these volcanic formations, penetrating the older of them, the Pernå formation (E) and forming with these rocks eruptive breccias which are intersected by dykes of the younger volcanic rocks which form the Pellinge formation (G).

In the basement of the older formation of volcanics there exist felspathiferous quartzites, the Rabbas formation (B). These rocks are altered sandstones or arkoses of a very high age. They are intercalated with some layers of limestone. Underlying these rocks, a formation of basic volcanic rocks, mainly plagioclase-porphyrites, occurs which has also originally had a basaltic or andesitic composition, and associated sedimentary schists. These oldest supercrustal rocks, the Sundarö formation (A) are separated from the older uralite-porphyrites by the intrusion of a gabbro, the Stadsland Gabbro (C), and a granite, the Våtskär granite (D). The granite forms veins, not only in the oldest schists of supercrustal origin, but also in the gabbro and quartzite. All these rocks, even the granite, have been intersected by dykes radiating from the older uralite-porphyrites. As results from the foregoing statements, the geological structure of these series of old supercrustal rocks can be unravelled, although only patches of them remain, and it shows itself to be very complicated. The oldest schists (A) which belong to the Svionian which comprises the greatest part of the »leptites» of middle Sweden and Southern Finland, have been deposited as beds, probably mainly of a tufaceous origin, and as lava flows, on an unknown basement. Among them conglomerates also occur, with pebbles consisting mainly of basic volcanic rocks. This formation has been overlaid by arkoses, (B) and it seems from their contact relations to the conglomerate of the oldest supercrustal formation, as if an unconformability, although not very well marked, existed between these rocks. Then followed the intrusion of the gabbros (C) and the granites (D) which latter does not seem to have happened at a very great depth, as the penetration phenomena are not so conspicuons as in the aureoles of the younger granites.

Then, after orogenetic movements which changed the granites into orthogneisses, and a long continued period of erosion, followed the eruption of the middle basaltic formation, or the older uralite-porphyrite (E), and the deposition of its associated tuffs and agglomerates. These rocks which the author is inclined to correlate with the Bothnian sediments of middle Finland and northern Sweden, come in direct contact with all the different older formations, belonging to their basement. Thus at the time of the volcanic activity, the region had already a complicated structure, the rock masses consisting of several formations of a very different origin.

The unconformability separating the older uralite-porphyrites from the younger and marked by the intrusion of the granite (F) does not correspond to any time interval of equally long duration. At the time when the younger volcanics (G) were deposited as surface-flows of lava, ashbeds and agglomerates, the erosion had not proceeded so far as to uncover this granite; therefore we never find the granite in immediate contact with the younger uralite-porphyrite at the boundaries of the continuous area. But dykes of the same type as those which radiate from this area are found, as already mentioned, penetrating the granite.

Later all these different rock-masses were sunk to great depth, in connection with mountain-forming movements, and the »younger Archæan» granite (H) penetrated all these different rocks, leaving only the middle parts of the area shown on the map better preserved. To the north, this granite is absolutely predominant, to the south and southwest it is intimately interwoven with the rocks of the volcanic group E.

Finally the eruptions of the granites J and K, the Onas granite and rapakivi, have taken place, both forming batholiths. These events happened in late Pre-Cambrian time, long after the close of the Archæan.

All these events are tabulated in the following scheme.

We will begin with the petrological description of the supercrustal rocks, starting from the youngest, and try also to explain their mutual relations, thereby only mentioning the granites in so far as it is necessary for the discussion of the stratigraphical problems. In a later part of the memoir we will describe the phenomena caused by the intrusion of the granites, and try to explain the process of granitization.

Table I.

Post-Jatulian	Rapakivi granite K and Onas granite J
	Hiatus
Middle Archæan	Hangö-Ingå granite H
	Pellinge formation of metabasalts and tuffs G
	Rysskär granite F
Bothnian (?)	Pernå formation of metabasalts and tuffs, meta-andesites, gabbros &c. E.
	Hiatus
Lower Archæan	Våtskär granite D (granitic gneiss)
	Stadsland gabbro C
	Rabbas quartzite B
Svionian	Sundarö formation of conglomerates, meta-andesites and tuffs, leptites and limestones A

PETROLOGICAL CHARACTERS AND STRATIGRAPHICAL RELATIONS OF THE SUSPERCRUSTAL AND ASSOCIATED HYPABYSSIC ROCKS OF THE PELLINGE REGION.

PELLINGE FORMATION (G) OF METABASALTS AND TUFFS.

The younger uralite-porphyrites, or metabasalts, are greenish-black rocks with a finegrained ground-mass containing more or less densely interspersed crystals of uralite measuring from 1 to 12 mm in diameter. Generally their size does not exceed 6 mm or a quarter of an inch. When protruding from the slightly weathered surface, they often show the short-prismatic crystal form characteristic of the augite of the basaltic rocks with the surfaces (100) (110) (010) (111).

In most cases the crystals are rather stout, while in others they are elongated along the axis b.

In the very typical variety from Sådholm, to the east from Lill-Pellinge, about 120—150 crystals are visible on each dm^2, or more than one on a cm^2, but very often the porphyritic crystals lie less densely, and sometimes they diminish in size so as to become almost imperceptible to the naked eye.

In thin sections are never found any cores of augite preserved, as is sometimes the case with the uralite-porphyrites of the Tammela-region, and the older uralite-porphyrites of the area now in question.

Twins are common, and there are often seen several twinning lamellæ in each crystal.

The newly formed hornblende often projects as protuberances beyond the limits of the primary augite crystals. In some cases the secondary hornblende is not orientated along the same crystallographical directions as the original augite, but forms irregularly interspersed bundles or sheaves.

The plagioclase-felspar does not form macroscopical phenocrysts. By microscopical examination we recognize, however, that there are often crystals of plagioclase measuring up to 1 mm in length which may be regarded as porphyritic constituents.

The plagioclase is generally andesine with 38—50 % An, but in some cases also a labradorite with 55—58 % An. Also a bytownite with 67 % An is occasionally found. Zonar structure has not been observed in this plagioclase.

The crystals are often broken and contain needles of uralite etc. which have penetrated from without. The arrangement of the felspar shows that it is a primary constituent of the rock, although its chemical composition may have been altered by the metamorphism which the rock has undergone. Zoisite and epidote are often found as substituents for the plagioclase, but are not very common. In the uralite-porphyrites of the Tammela region they possess a much greater importance, many of the felspars having undergone a kind of saussuritization.

The mass between the greater crystals consists mainly of hornblende showing the same characters as the uralite of the porphyritic crystals. It occurs either as crystals with imperfect prismatic delineation, or as fibers with more irregular forms.

The grain of the ground-mass is of varying size. It may sometime be aphanitic to the naked eye, but generally the length of most of the crystals is above 0,1 mm. The aphanitic rock-varieties occur also in the dykes of uralite-porphyrite which radiate from the main masses of this rock near to their contacts with the older rocks which they penetrate. The grain of the dyke rocks attains such minuteness, that it seems certain that they have been originally hyaline or vitrophyric.

That also the typical uralite-porphyrite has contained glassy material is shown by the fact that it is often a m y g d u l o i d.

A very typical amygduloid uralite-porphyrite occurs e. g. in the island Stor Brändholm, to the south-east from Lill-Pellinge.

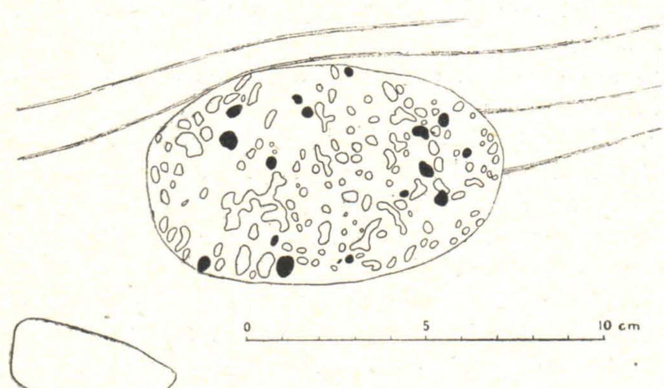

Fig. 1. Pebble of amygduloid uralite-porphyrite in a tuff from Älskholm in the parish of Borgå. About $^1/_2$ of the nat. size.

The amygdulae are often elongated, and some of them measure more than 10 cm in length. In the island Älskholm a pebble of very typical amygduloid uralite-porphyrite (Fig. 1) was observed in a stratified tuff.

Also on other places amygdulae are common in these rocks. They are filled with quartz only or associated with felspar which in some cases is a bytownite, approaching an anorthite (containing 67 % An). Very probably these vesiculae have been originally filled with calcite, or with zeolites rich in lime. Sometimes the quartz of the amygdulae is also mingled with grains of magnetite, or with small flakes of biotite.

The amygdulae are often surrounded by a rim rich in uralite which has probably been formed by the metamorphosis of the glassy mass which has coated the vesiculae.

Grains of quartz also occur outside the amygdulae, microscopically often appearing as strings filling fissures in the rock.

While many of those uralite-porphyrites consist mainly of plagioclase and green hornblende, in others also b i o t i t e is present as small flakes intermingled with the hornblende. They seldom occur in greater proportion than one fifth part of the hornblende. The author has never seen here aggregates of biotite flakes which could be regarded as p s e u d o m o r p h s a f t e r o l i v i n e, although such aggregates are very common in the uralite-porphyrites in the Tammela region. As the description of these pseudomorphs given by the author seems to have been overlooked[1], the reasons for the assumed change of olivine into biotite may be here repeated.

The presence of olivine as one of the primary constituents of the rocks of the Tammela region, which are now very typical uralite-porphyrites, is in itself very probable, as they have been originally basalts with a content of only 48 % SiO_2 and up to 7 % MgO. Now there occurs, e. g. in the very typical variety from Pikonkorpi in Kalvola, aggregates of biotite flakes with rather uniform size (1—2 mm in length) which do not show the sinuous outlines characteristic to amygdulae, but possess forms which sometimes remind one very much of crystals of olivine. Although it is true that also amygdulae occur which have been partly filled with biotite, it is not possible to assume that all aggregates of biotite could be of this character. On the contrary, there are definite

[1] Van Hise does not mention this observation in his great Treatise on Metamorphism, nor the previous statement of Foullon about the conversion of olivine into biotite. Cf. Min. u. petr. Mitth. XII. 1891, p. 106 and II. p. 481—484.

proofs of the occurrence of biotite aggregates of a different origin, viz. the fact that they occasionally occur as inclusions in the greater porphyritic crystals of uralite. In a rock from Raito in Urjala, near to the Matku railway station, amygdulae filled with quartz and aggregates of biotite flakes occur simultanously, and in this case there seems to be no doubt that the latter are pseudomorphs after a vanished mineral which has very probably been olivine.

The author has later found reasons to believe that the olivine has not been directly changed into biotite as he thought before, but that this mineral was at first filled with grains of iron ore, around which flakes of biotite later developed[1].

Also in the Tammela rocks, however, these pseudomorphs after olivine have in most cases altogether vanished, and the rocks then consist mainly of plagioclase and green amphibole. These rocks are entirely similar to the predominant rocks among the uralite-porphyrites of Pellinge. It seems probable, or almost certain, that olivine has been present also in the latter rocks, although it has been entirely obliterated during the metamorphism.

Grains of opaque ore are present in many cases. They have a bluish surface colour and consist either of magnetite or ilmenite, or mixtures of both. This ore seems to be always of late formation, occurring as inclusions in all the different minerals, and is certainly althogether of secondary origin. Primary ore crystals have no doubt existed, but they seem to have been everywhere obliterated during the metamorphism of the rock.

Small grains of titanite are also often present, aggregated to stripes or heaps. Their arrangement never suggests, as is so often the case with the titanite in the best preserved of the analogous rocks of the Tammela region, that they should mark the outlines or places of the original ore crystals, although no doubt the titanite has here been formed from ilmenite.

As the primary ore of the rocks of Pellinge has been altogether obliterated, it must have been either taken up in the amphibole or expelled during the process of metamorphism. Some varieties are entirely deprived of their ore contents; in others it is the latest formed of all minerals. It therefore seems probable that solutions or gases charged with iron have transported this metal through the rock masses during the process of metamorphism. As observations on contact zones around areas of granites and other

[1] Cf. J. J. Sederholm, On Synantetic Minerals. Bull. Comm. géol. Finl., N:o 48, 1916, p. 4.

rocks show, it has been a very general phenomenon that iron ores are deposited at the close of the eruptive activity. However it does not seem likely that any considerable part of the iron has been carried away. The iron content of these and similar effusive basic rocks, which have undergone the process of uralitisation, is as high as in the corresponding primary rocks. These facts seem to prove that the iron contained in the primary ores, as well as the magnesia of the olivine, has been taken up by the secondary amphibole. This reasoning brings us to the conclusion that the process of uralitization is by no means a simple »metasomatosis» or molecular rearrangement of the material of the primary augite. We shall return to this question later on, while discussing the chemical analyses.

In the rocks in question the more minute details of the primary texture are not well preserved (Fig. 1, Plate I). The textures of the younger uralite-porphyrites of the Pellinge area are in general rather monotonous, most of their more minute details having been obliterated during the metamorphism.

Beside the typical uralite-porphyrites which are no doubt metamorphic lavas, t u f f s also occur in the same volcanic area. In the latter rocks a distinct b e d d i n g may often be remarked. There are also, in several places in the area, a g g l o m e r a t e s belonging to the same group of volcanic rocks (Fig. 2). The beds are commonly nearly vertical.

We shall now discuss the primary mineralogical and chemical composition of these rocks, in order to determine their place in the petrological system.

The author has made some determinations of the relative amount of the constituents present with the aid of the Rosiwal method, measuring the diameter of the individual minerals in thin sections. In most of these rocks it meets considerable difficulty, because of the irregular outlines of the minerals and their entangled arrangement. In some cases, however, the minerals are better separated from each other, and then their volumes can be measured. In two varieties from the island Älskholm in Lill-Pellinge, and a neighbouring inland, an amount of 20—21 % plagioclase was found, while one of the rocks contains 79 % hornblende, the other 65 % weight's percent of this mineral and 15 % of biotite. The former rock contained less than 1 % ore, the second only trifling amounts of it.

The very typical uralite-porphyrite from Sådholm in Pernå has been analyzed by Dr E. Mäkinen.

Fig. 2. Vertical layer of agglomeratic tuff seen in a horizontal rock surface. Stor Brändholm, Pellinge. 1/7 of the nat. size.

Table II.

Uralite-porphyrite belonging to the group G. from the island Sådholm, Lill-Pellinge, analyzed by E. Mäkinen.

	%	Mol prop.	Norm				
SiO_2	56.06	934	Quartz	9.96	Q	9.96	Sal 58.09
TiO_2	0.92	11	Orthoclase	3.34	F	48.13	
Al_2O_3	13.97	137	Albite	17.64			
Fe_2O_3	1.41	9	Anorthite	26.97			
FeO	7.59	106	Diopside	16.95	P	37.35	Fem. 41.11
MnO	0.09	1	Hypersthene	20.40			
MgO	6.95	174	Magnetite	2.09	M	3.76	
CaO	9.48	170	Ilmenite	1.67			
Na_2O	2.06	34		99.20			
K_2O	0.63	6	Water	0.56			
H_2O	0.56	—		99.76			
	99.72						

Now a microscopical examination of the rock shows tha tit contains amygdulae filled with quartz and bytownite which forms bundle-like crystals. As has already been pointed out above, the amygdulae have probably been filled with arragonite or zeolites rich in lime which have been partly replaced by quartz, partly by felspar. The bundle-like crystals of bytownite resemble very much the secondary plagioclases common in crystalline schists in Lavia which have, as has been shown by the author elsewhere[1], undergone weathering, connected with the formation of abundant calcite, and a subsequent metamorphism.

In one variety the volume of the amygdulae was about 10 % of the whole.

Now part of the quartz may have resulted from the metamorphism of the immediately surrounding rock, and thus have taken part in its original composition. As the calculation of the mineral composition gives, however, a surplus of free silica, quartz has no doubt been added to the rock. It would probably not be correct to deduct the whole amount of quartz found by the calculation. A measurement of the volume of quartz gives about 7—8 %. Although these conclusions contain some arbitrary elements, we will try to deduct 8 % SiO_2 from the analysis. We then get the following results:

Table III

	%	Mol. prop.
SiO_2	48.06	800
TiO_2	1.09	14
Al_2O_3	16.62	163
Fe_2O_3	1.68	11
FeO	9.01	125
MnO	0.10	1
MgO	8.26	206
CaO	11.29	202
Na_2O	2.45	40
K_2O	0.77	8
H_2O	0.66	—
	100.00	

[1] J. J. Sederholm, Kontakten mellan de bottniska sedimenten och deras underlag vid Naarajärvi i Lavia. Geol. För. Stockh. Förh. 1913, p. 173.

— — De bottniska skiffrarnas undre kontakter. Ibid. 1915. p. 64 seq.

This is a typical basaltic composition. In general these uralite-porphyrites can be properly designated as m e t a b a s a l t s.

In an analogous rock, which contains porphyritic felspars, from Raito in Urdiala, in the Tammela region, the author found by microscopical determination 45 % plagioclase and 55 % hornblende, biotite etc. In general, the microscopical determination of these rocks shows smaller amounts of felspar than the analyses indicate.

As it was of great interest to know the exact composition of the uralite of the rocks in question, a chemical analysis of the porphyritic uralite crystals of the rock of Sådholm was made by Dr. Mäkinen.[1] The material was carefully sifted with the aid of methylene-iodide. The powder thus obtained was examined under the microscope and found to be free from impurities. The middle specific weight of the mineral powder was 3,118. The hygroscopic water was determined by drying the powder during two hours at 110° C., and the constitutional water by a subsequent heating of the powder in the blast furnace in a Penfield's tube.

The analysis gave the following results:

Table IV.

Uralite from the Uralite-porphyrite from Sådholm, analyzed by E. Mäkinen.

	Weight's %	Mol. prop.	
SiO_2	49.58	286	829
TiO_2	0.28	28	
Al_2O_3	6.82	67	88
Fe_2O_3	3.95		
FeO	12.35	21	
MgO	14.00	171	817
CaO	11.68	350	
Na_2O	11.33	280	
K_2O	0.28	5	
H_2O ÷	1.45	3	
H_2O —	0.50	60	
	100.62		

The calculation of the analysis gave the relation: $SiO_2 : (FeO + MgO + CaO + Na_2O + K_2O + H_2O) = 829 : 817 = 1 : 0{,}984$. Dr. Mäkinen remarks that the close approximation to 1:1 is in conformity

[1] Eero Mäkinen, Über Uralit aus Uralitporphyrit von Pellinge in Finnland. Geol. För. Stockh. Förh. 1915, p. 633.

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ERRATA.

Instead of Table IV on p. 30 the following table should be inserted:

	Weight's %	Mol. prop.	
SiO_2	49.58	826	829
TiO_2	0.28	3	
Al_2O_3	6.82	67	88
Fe_2O_3	3.35	21	
FeO	12.35	171	
MgO	14.00	350	
CaO	11.68	208	817
Na_2O	0.33	5	
K_2O	0.28	3	
H_2O + ...	1.45	80	
H_2O —	0.50	—	
	100.62		

p. 60. Fig. 21. The scale should be 1: 2 300.
p. 61. Fig. 22. The scale should be 1: 800.
p. 95 line 9 for eastern read western.

with the results of Penfield and Stanley and makes it probable that the water (and fluor) are essential constituents of the amphiboles. The material was too scanty to make it possible to determine the fluor, but it seems probable that the lacking 12 unities among the numbers of the molecular proportions for the monoxides refer to fluor. If this is true, its amount would be 0,20 %. According to the analysis the uralite is an actinolite approaching the hornblende in constitution.

Mäkinen also determined the optical constants in plates made with the aid of Wülfing's grinding apparatus. In the prism I one side was || (010), the refracting edge ⊥ $\mathfrak{c}$; in the prism II one side || (100), the refracting edge || (110); the plate III was ⊥ $\mathfrak{a}$. Because the colour was rather dark, especially || $\mathfrak{c}$ and || $\mathfrak{b}$, it was not possible to get sufficiently distinct signals in monochromatic light, and the determinations were therefore made in ordinary light. When determining the index of refraction, the yellow part of the spectrum was used. The axial angle was measured in the microscope in a »universal apparatus» between two hemispheres of glass.

The results of these determinations were as follows:

Table V.

Determination of the optical constants in the uralite from Sådholm, made by E. Mäkinen.

	Prism I	Prism II	Plate III
α	1.6416	—	—
β	—	1.6551	—
γ	1.6678	—	—
$\gamma - \alpha$	0.0262	—	—
2 v	—	—	83°57′

The optical character was negative and the optical orientation the usual: $\mathfrak{b} = b$; $\mathfrak{c} : c = 15°,5$. The absorption is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$, and the absorption colours in plates with a thickness of 0,4 mm: $\mathfrak{c}$ — very dark bluish green; $\mathfrak{b}$ — dark green, $\mathfrak{a}$ — olive green. In plates with a thickness of 0,023 mm the absorption in a direction $\mathfrak{c}$ and $\mathfrak{b}$ is only slightly stronger than $\mathfrak{a}$, and the colours: $\mathfrak{c}$ — very pale bluish green; $\mathfrak{b}$ — pale yellowish green; $\mathfrak{a}$ — from greenish yellow to colourless.

According to W. E. Ford[1], there is a regular relation between the middle index of refraction of the common amphiboles and their

[1] W. E. Ford, Beiträge zur optischen Kenntnis der Hornblenden. Zeitschr. f. Kryst. 54, 1914, p. 1.

chemical composition. Mäkinen has found that this law holds good also for the amphibole in question. By calculating the chemical composition according to the diagrams of Ford, he got a result very approximate to the identical composition.

The amount of uralite in the metamorphic rock calculated from the percentage of MgO of the uralite, is 59 %, calculated from the iron contents, a little above 60 %. Microscopical measurements give only 20 % or less felspar and very little ore, thus 79 % of uralite and 1 % of ore. The analysis of the rock gives an amount, in the norm, of 41,11 % of femic minerals. But on one side, the surplus of silica contained in the amygdulae ought to be deducted, on the other side the original augite has probably also contained some alumina.

In every case, it seems certain that the amount of the secondary femic constituents has increased during the metamorphism, making now at least 60 percent of whole, perhaps even more. This circumstance seems very natural when we remember that the primary rock certainly also has contained olivine or hypersthene and ilmenite which are now altogether obliterated. When these have been added to the uralite, it must have taken up silica and alumina from the felspar constituents, the amount of which has thus diminished. Tho whole process of uralitization is by no means to be regarded as a simple »metasomatosis» of the augite, but is a much more complicated process.

The greater plagioclases consist of oligoclase with about 21 % An. As Eskola remarks while discussing the origin of the amphibole in certain effusive amphibolites, the plagioclase in the metamorphic metabasites is never more calcic than a labradorite-bytownite, while in nonmetamorphic igneous rocks also felspars richer in calcium are of common occurrence. This is in accordance with the author's experience. For the nearer understanding of the processes here in question and their chemical formulae, the author refers also to Eskola's discussion[1].

On the whole the original chemical composition of the younger uralite-porphyrites, or meta-basalts, of Pellinge seems to have been very uniform. Variations in the chemical composition, however, occur, although they are not very pronounced. The lighter varieties are represented only by dyke rocks. In one of the small islands Dömansörarna, to the south of Tjurholm in Pernå, there is a

[1] Pentti Eskola, On the Petrology of the Orijärvi Region in Southwestern Finland. Bull. Comm. géol. Finl. N:o 40, 1914, pp. 124—130.

dyke, 1,8 cm broad, of a grey rock with a uniform fine grain. This rock contains the following weights per cent of minerals, determined microscopically: hornblende 47 %, oligoclase 40 %, quartz 6 %, biotite 5 % and ore 2 %.

Another rock, the composition of which differs from the ordinary, forms a dyke in the amygduloid uralite-porphyrite of Wester Saltören in Pernå, within the fairway east of Hasselö. According to determinations made by the Rosiwal method, this rock has the following composition: felspar 38 % of weight, biotite 35 %, quartz 30 %, epidote 5 %, titanite 2 % and magnetite 1 %. The quartz forms aggregates with rounded outlines consisting of several grains with varying optical orientation, and seldom measuring more than 1 mm in length. They are smaller and more regular in size than the amygdulae in the adjacent rock, and it seems uncertain whether they are such, or original crystals, or pseudomorphs after some entirely obliterated mineral. In any case, this rock must have had an original composition differing from that of the typical metabasalt, more resembling either an andesite or a quartziferous dacite.

PERNÅ FORMATION (E) OF METABASALTS AND TUFFS, META-ANDESITES, GABBROS &c.

URALITE-PORPHYRITES.

The older uralite-porphyrites are often petrologically so similar to the younger ones as to be distinguished from them only with difficulty. Their colour, however, is generally darker, with a less pronounced greenish shade than that of the first-mentioned rocks. They are also generally tougher, so that it is often difficult to chip good specimens.

Microscopically, the most conspicuous difference between these groups of rocks seems to be in the character of the hornblende. In the rocks now in question it often forms tufts, entangling all the minerals of the rock, but is less often fibrous than in the younger metabasalts. The uralite of the porphyritic crystals has sometimes lighter colours in thin sections than the hornblende of the younger uralite-porphyrites. In some cases cummingtonite seems to be present. Most of the hornblende, however, is of the same optical character as in the younger uralite-porphyrites.

As to the shape of the phenocrysts of uralite, they are sometimes smaller and also more sparse in the older rocks. Biotite, iron ore and titanite are also present here in varying amounts.

The plagioclase is commonly a labradorite, with 53 % An.

The above description applies especially to the rocks in the neighbourhood of the area of younger uralite-porphyrites along its northern boundary, where there are extensive areas of older metabasalts, and partly also S. of that area. West of the Pellinge islands, these metabasalts are more interwoven with granites, and then their primary character becomes somewhat altered. We shall describe these varieties later on.

The analysis made by Dr. E. Mäkinen, Table VI, of a typical uralite-porphyrite of this group, shows the normal composition of a basalt or an auvergnose, according to the American classification, with, however, a rather high content of magnesia and iron. The last-mentioned metal occurs in much greater quantity than in the younger uralite-porphyrite from Sådholmen.

Table VI. Uralite-porphyrite from Båtviken in Stor Pellinge. Analysed by Dr. Eero Mäkinen.

		Mol. prop.	Norm.			
SiO_2	50.18	836	Orthoclase	— 2.78	F 49.02	Sal 49.02
TiO_2	0.70	9	Albite	— 16.77		
Al_2O_3	14.58	143	Anorthite	— 29.47		
Fe_2O_3	1.27	8	Diopside	— 15.06	P+O 45.60	Fem 48.83
FeO	9.14	126	Hypersthene	— 27.60		
MnO	0.12	1	Olivine	— 2.94		
MgO	9.90	248	Magnetite	— 1.86	M 3.23	
CaO	9.60	171	Ilmenite	— 1.37		
Na_2O	1.98	32		97.85		
K_2O	0.49	5	Water	1.70		
H_2O	1.70			99.65		
	99.66					

PLAGIOCLASE-PORPHYRITES.

Varieties containing together with the uralites small porphyritic plagioclases are also very common among these uralite-porphyrites of the older group E. Associated with them occur also **plagioclase-porphyrites**, which contain large phenocrysts of felspar measuring 1—3 cm in length, but only 1—2 mm in thickness. Some of these are extremely thin at the ends, making almost needle-shaped sections. Sometimes they lie parallel to each other, while in other cases they are more irregularly interspersed (Fig. 3).

Fig. 3. Plagioclase-porphyrite from Öster Rysskär, Pernå. $^1/_7$ of the nat. size.

The plagioclase has a maximal extinction of 19° and is thus an andesine (37 % An). The groundmass is very similar to that of the uralite-porphyrites. These rocks are especially typical in the Rysskären islands in Pernå, where they are very much invaded by dykes of granite, forming with them eruptive breccias. Some parts, however, show macroscopically a very well preserved primary texture. The microscopical constitution of that rock is shown by Fig. 2, Plate I. It is composed mainly of green hornblende and plagioclase, together with grains of secondary magnetite.

This rock has been analysed by Dr. Mäkinen (Table VII).

The rock contains lesser amounts of magnesia and especially iron than the uralite-porphyrites, being a **hessose** while the latter are auvergnoses. In spite of the unusually low percentage of iron, the rock is more nearly related to the basalt-gabbro than to the andesite-diorite family.

Another typical variety of plagioclase-porphyrite occurs at Ednäs torp in the south-west of the Stor Pellinge island.

Table VII. Plagioclase-porphyrite from Öster Rysskär in Pernå. Analysed by Dr. Eero Mäkinen.

		Mol. prop.	Norm.			
SiO_2	50.78	846				
TiO_2	0.75	9	Orthoclase	— 6.12	F 64.29	Sal 64.29
Al_2O_3	18.08	176	Albite	— 26.20		
Fe_2O_3	2.80	18	Anorthite	— 31.97		
FeO	5.33	74	Diopside	— 17.87	P+O 28.43	Fem 33.98
MnO	0.11	1	Hypersthene	— 7.62		
MgO	5.72	143	Olivine	— 2.94		
CaO	10.80	193	Magnetite	— 4.18	M 5.55	
Na_2O	3.12	50	Ilmenite	— 1.37		
K_2O	1.00	11		98.27		
H_2O	1.06		Water	1.06		
	99.55			99.33		

At Hellmoholm in Pernå the plagioclase crystals of the plagioclase porphyrite are in places very much compressed.

A rock similar to these plagioclase-porphyrites occurs of several places in the eastern part of the region as an inclusion in other volcanic rocks.

On the eastern shore of Träskholm in S.E. Pernå the metabasalts are cut by two dykes of a fine-grained, dark rock which contains numerous fragments of a very typical plagioclase-porphyrite.

Some of these fragments measure one metre in diameter. Most of them are rounded, and they are so numerous as to form the greater part of the dyke rock. The northern dyke has a breadth of 7 m, the southern one of 2,5—4 m. Their direction is N. 60° E. At the southern contact of the broader dyke there is a zone measuring one metre in breadth which is almost free from inclusions.

Also in a little island S. of Bastö, S.W of the above, several dykes occur which in places contain numerous inclusions of a plagioclase-porphyrite, or a meta-diabase with a texture nearly related to that of the former rock. One of these dykes, which measures 3 m, is full of such inclusions while a neighbouring dyke, 3.5 m broad, contains none of them.

In the metabasalt of Flottaskär, S.S.W. of the former locality, small fragments of plagioclase-porphyrite containing large felspars occur as inclusions.

These facts seem to indicate that there were below greater masses of plagioclase-porphyrites belonging to the same volcanic formation. Fragments have been detached from these masses of rock and brought nearer to the surface by the rising magma.

AMYGDULOID METABASALTS, TUFFS, BRECCIAS AND PILLOW LAVAS.

Among the metabasalts of group E we also find very typical varieties of a m y g d u l o i d l a v a s. The vesiculae are of varying size and shape. In the porphyritic rock of Lilla Finnholmen in Pernå they reach a length of 10 cm, but are very sparse. The amygdulae are commonly filled with quartz, together with some felspar, uralitic hornblende &c. Sometimes the rock may be described as having been originally cavernous or scoriaceous. B r e c c i a t e d lavas also occur which seem to have been formed by the bursting of the surface during the cooling of the magma. The interstices between the fragments are filled either with a rock mass which is similar in constitution to that which forms the fragments, although often a little lighter in colour, or else by a mass richer in quartz, epidote or calcite. Such is the rock in the island Dokskär, to the S.E. of Lill Pellinge.

Intercalated with the lava beds there are t u f f s which are often well stratified. The dips are always vertical. Some of these rocks are fine-grained, while others contain also coarser fragments and grade into s t r a t i f i e d b r e c c i a s. These fragments are of very varying size, sometimes measuring more than a metre in diameter. They generally consist of metabasaltic rocks of almost the same composition as the cementing mass, but showing very varying texture. Uralite-porphyrites, plagioclase-porphyrites and amygduloid varieties alternate with fragments of older breccias. Sometimes also the fragments may be rich in epidote and then lighter in colour than the cementing mass. These rocks are occasionally agglomeratic in character (Fig. 4). In the agglomerate, or rather conglomerate which occurs at Lökö and Pellinge Tullandet, at a distance of about 500 m from the contact with the quartzite of the basement, small pebbles of quartzite are also visible.

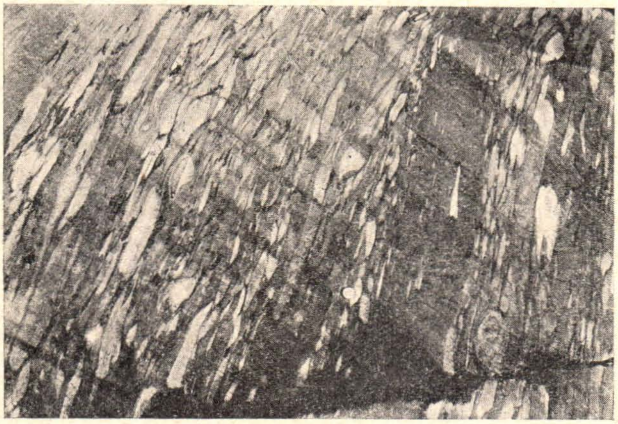

Fig. 4. Agglomeratic stratified breccia with vertical layers. Horizontal rock surface at Timmerholm, Pellinge. 1: 9.

The tuffs are very often rich in epidote. These parts, which have a light green colour, either form a network of veins, as is the case e. g. on Timmerholm, S. of Stor Pellinge, or occur as rounded inclusions in the tuff. In some cases, e. g. on Hamnholmen in Pernå, near Våtskär, those inclusions seem to play the same rôle as the rock fragments, or pebbles, of the agglomerates. Possibly the volcanic rock from which the pebbles were derived, was in some cases impregnated with arragonite or zeolites before the metamorphism began.

The stratified tuffs of the volcanic group E sometimes alternate with thin layers of limestone, e. g. in the island of Högskär, N. of Timmerholm in the region S.E. of Kungshamn in Stor Pellinge and in Tjurholm in Pernå (Fig. 5). The limestone is impure, containing much hornblende and epidote, and grades into the tuffs. In Sandskär, S. of Högskär, the limestone also contains garnets.

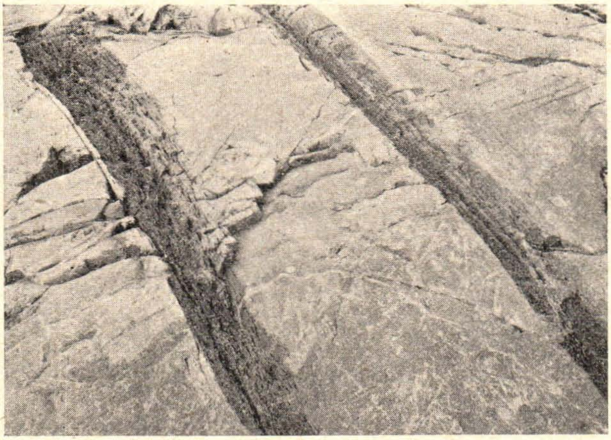

Fig. 5. Metabasaltic tuffs alternating with layers of very impure limestone. Tjurholm in Pernå. 1: 11.

On the northern shore of Flottaskär a vertical bed of amygduloid lava, which has originally been very cavernous, shows a number of small faults which do not continue into the adjacent volcanic rock. It seems probable that they originated during the time of volcanic activity, when a lava bed was covered with other volcanic masses whose pressure caused it to become cracked and faulted.

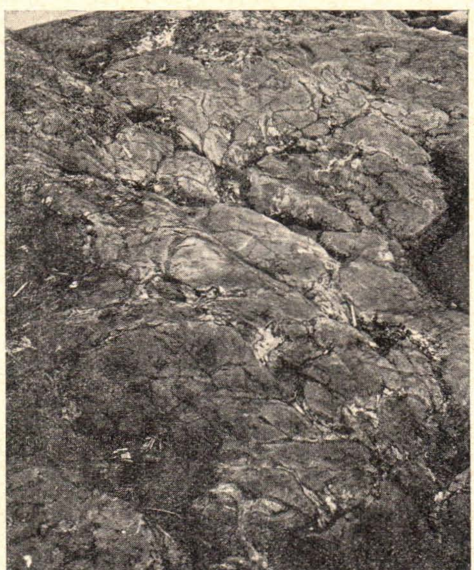

Fig. 6. Rock of pillow lava in the Stor-Digskär island in Pernå.

In the islands near Hamnholm in Pernå similar phenomena are visible. The volcanic rock, which shows small phenocrysts of plagioclase, seems to have formed several different lava beds whose contacts are in part very sharp. Next to such portions as show a brecciated structure, and have obviously originally been scoriaceous lavas, the rock is often amygduloid in character.

The Digskär-islands which lie in the open sea 15 km S. E. of the Pellinge islands, consist of a very typical pillow lava (Fig. 6—7). The individual pillows measure from 10 to 50 cm in diameter and generally show a darker border rich in hornblende. The mass filling the interstices between the pillows is composed of a mixture of quartz, calcite, epidote and light brown garnet (grossularite) in varying proportions. The garnet is often well crystallized.

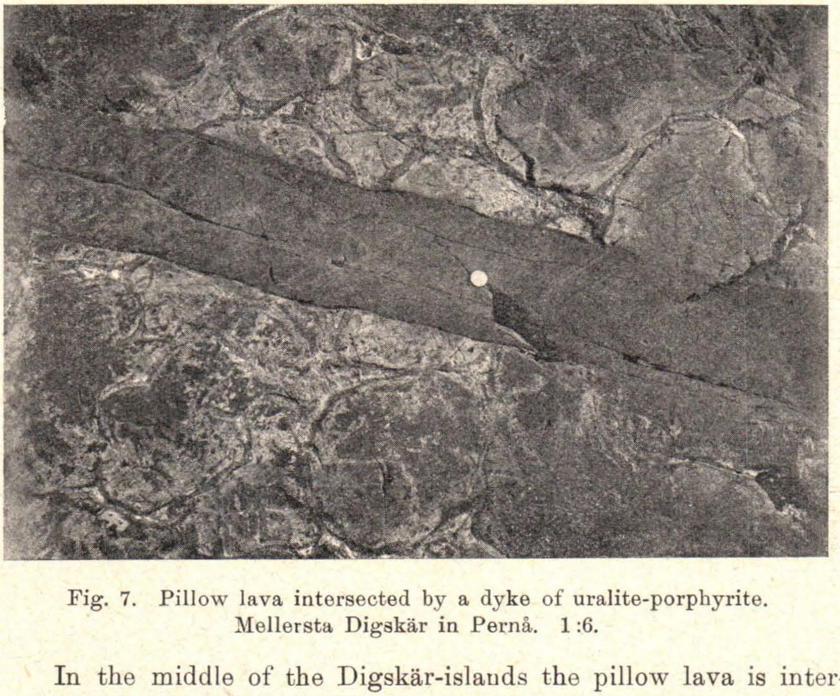

Fig. 7. Pillow lava intersected by a dyke of uralite-porphyrite. Mellersta Digskär in Pernå. 1:6.

In the middle of the Digskär-islands the pillow lava is intersected by a dyke of uralite-porphyrite (Fig. 7) which has a breadth of 10—20 cm and runs in the direction N.—S. The texture is porphyritic in the inner portions, but fine-grained and very dark at the contacts, where it has probably originally been glassy. At one place the fissure dyke shows an abrupt deviation.

This dyke wedges out and is continued by another dyke, beginning near to it.

DOLERITES, DIABASES AND METADIABASES, GABBROS, METAGABBROS AND GABBRO PEGMATITES.

At some places in the area mapped very interesting rocks occur which may be designated as dolerites, diabases, gabbros and gabbro pegmatites, and regarded as more deep-seated equivalents of the basic volcanic rocks belonging to the middle group. They seem to be connected by gradations with the uralite-porphyrites of the neighbouring larger islands.

The first-mentioned rocks occur e. g. on some islands in the south-east, Virskär, Bastö and neighbouring islands. Here the rock is of medium grain and of very uniform character. The primary mineral constitution is astonishingly well preserved. The interstices between the andesine (42 % An) laths are partly filled by an augite which is rather strongly pleochroic in light rose colours, partly by olivine and ore.

The olivine has crystallized earlier than the augite which fills up the interstices between the olivine and the plagioclase, sometimes resembling a »reaction rim» (Fig. 3, Plate I) as described by the author in an earlier memoir[1], but certainly of primary origin. At the contact with plagioclase the olivine is surrounded by coronas. Besides augite, diallage is also present, and brown hornblende may sometimes occur in the place of the pyroxene. In some specimens the only secondary constituents beside the synantetic minerals are green hornblende, biotite and some iron ore, mainly as featherlike or »dactylotype» skeleton crystals in the olivine. These secondary minerals often occur in very scanty quantities, and in spite of their presence the primary character of the rock is well preserved.

The rock shows a very typical ophitic texture (Fig. 3, Plate I, and Fig. 2, Plate V). It is a dolerite which originally differed from the other basaltic rocks of the region mainly in that no phenocrysts of pyroxene occurred. The more coarse-grained parts of this rock may be designated as a diabase.

In the southernmost part of Virskär the contacts between this rock and uralite-porphyritic tuffs are visible. The latter, which are agglomeratic or breccialike in character, are cut by dykes of the metadolerite, which also contains fragments of the tuff. Thus there is no doubt about the intrusive character and the younger age of the dolerite.

In Strömmingsgrund near Morumshällarna, about 6 km S. E. of Virskär, a metadiabase occurs which has originally had a rather coarse ophitic texture. The individual lath-shaped plagioclases measure about 5 mm in length and 1—2 mm in thickness. The interstices between them are filled with green hornblende and some biotite and ore. This rock seems to grade into a porphyritic variety.

[1] J. J. Sederholm, On Synantetic Minerals. Bull. Comm. géol. Finl., N:o 48, p. 36 seq.

The most typical hypabyssic rocks associated with the metabasalts of the middle group are those which occur in Tunnholmen and neighbouring islands, S. W. of the Pellinge islands.

Some of these rocks do not differ very much from the doleritic uralite-porphyrites which occur in the southwesternmost parts of Stor Pellinge, and even macroscopically show uralites between the plagioclase-laths of the ophitic rock. But the predominant rock in the islands in question is a very typical gabbro, which must have originally been very similar to the well known gabbros of Skye which are connected with tertiary volcanic rocks. It is medium-grained and often contains diallage crystals which are a little larger than the other minerals and therefore give the rock a spotted character. It also contains fragments of darker rocks which sometimes resemble uralite-porphyrites, but more often are rather coarse-grained and rich in diallage. Some of them have a peridotitic composition. They often form elongated zones which in places may be so sharply defined as more to resemble dykes than fragments. They send out apophyse-like protuberances into the surrounding rock. Occasionally such zones are sharply defined on one side and imperceptibly grade into the neighbouring rocks on the other, the diallages becoming gradually sparser. It almost seems as if a portion of the mother magma which was more basic than the rest must have segregated and begun to crystallize, so that the pyroxenes partly sunk into the neighbouring, still fluid magma.

The striped gabbro often shows fluxion structures which are similar to those which have been described from the gabbros of Skye.

The following analysis, made by Dr. Eero Mäkinen, shows the chemical composition of the normal rock which is an auvergnose according to the American classification.

Microscopically, the rock still shows the primary character of a gabbro astonishingly well preserved, being composed of plagioclase, pyroxene, brown hornblende, olivine and ore.

The plagioclase is an andesine with 35 % An. It contains numerous very small interpositions of green or brown colour, many of them needles or rods, arranged normally against 010. Most of them seem to consist of hornblende. It forms either short prismatic crystals or laths projecting into the pyroxene. The rock often shows a typical ophitic texture.

The pyroxene is in part an augite which is occasionally pleochroic with colours varying between light rose and greyish white,

Table VIII. Olivine gabbro from a small island S.E. of Tunnholm, Borgå.
Analysed by Dr Eero Mäkinen.

	%	Mol. prop.	Norm			
SiO_2	47.54	792				
TiO_2	0.75	9	Orthoclase	— 1.67		
Al_2O_3	15.88	156	Albite	— 9.96	F 48.88	Sal 48.88
Fe_2O_3	2.51	16	Anorthite	— 37.25		
FeO	6.60	92	Diopside	— 30.62	P 41.25	
MnO	0.18	3	Hypersthene	— 10.63		
MgO	8.54	213	Olivine	— 3.22	O 3.22	Fem 49.55
CaO	14.90	266	Magnetite	— 3.71	M 5.08	
Na_2O	1.20	19	Ilmenite	— 1.37		
K_2O	0.28	3		98.43		
H_2O	1.14		Water	1.14		
	99.52			99.57		

in part a diallage containing numerous small interpositions lying along the cleavage planes.

Brown compact hornblende also occurs and has, as the author has pointed out elsewhere[1], a rather puzzling character. It occurs in patches or as narrow rims around ilmenite-crystals. The hornblende is then entirely anhedral, filling the interstices between the plagioclase and augite crystals, and the outlines of the ore are often almost parallel with those of the hornblende rims. If the ore crystallized earlier than that mineral, it is difficult to understand why its limitation should be in so high degree dependent on the form of the interstices in which the hornblende has crystallized. The latter cannot here have originated as a secondary or »deuteric»

[1] l. c. p. 36–37.

mineral, »synantetic» between ilmenite and plagioclase, then it occurs also between ore and crystals of augite, or olivine. It therefore seems probable that the brown hornblende has crystallized earlier than the ore which has afterwards filled the innermost parts of the interstices coated with it, or else both minerals have crystallized simultaneously, ore at the centre of the remaining interstices, hornblende along their walls. In any case, the formation of the latter minerals seems to depend on the existence of a surplus of iron in the magma, and chemically the occurrence (Fig. 4, Plate I) is thus nearly related to that of such biotite as crystallizes synantetically around ore.

Brown hornblende, however, occasionally also occurs as patches in diallage crystals, whereby the crystallographical orientation is the same in both minerals. If this hornblende also is primary, then it becomes necessary to assume that there has been a recurrence of the circumstances which condition the formation of hornblende. A surplus of iron might have existed at several places in the magma, causing the formation of brown hornblende instead of pyroxene. But it is likewise possible that a part of the brown hornblende may be of secondary origin, as it is indubitably in other certainly metamorphic basic rocks described by various authors.

Around the crystals of primary ore biotite occurs, often forming rather large crystals which have in many cases certainly replaced plagioclase. In other cases it seems possible that the biotite has replaced brown hornblende, or diallage.

The olivine lies between the laths of plagioclase, either directly in contact with them, or more often surrounded by augite or diallage. In the former case it is anhedral, in the latter it is in part more idiomorphic. Where the pyroxene filling the interstices between olivine and plagioclase occurs only in scanty quantity, it may sometimes resemble a reaction rim (cf. Fig. 3, Plate I), but it is certainly not of that origin, as near by it may alone constitute the matrix between the felspars. The crystallization of the olivine seems to have begun and probably also ended earlier than that of the pyroxene.

The olivine is a variety rich in iron. It contains secondary limonite as minute interpositions which are often rather regularly dispersed, and also as coarser grains which have gathered in fissures and next to them. It is surrounded by very typical coronas (Fig. 5, Table I) which the author has described elsewhere.[1]

[1] l. c. p. 36 seq.

Beside the symplektites which the author has earlier described from this rock there occurs one which consists of iron ore, probably magnetite, together with a light mineral with high refraction which seems to be pyroxene. The ore forms slender rods whose distribution is the same as that of the sodalite in the »dactylotype» intergrowth of that mineral and orthoclase which Shand has described from a borolanite from Cnoc-na-Sroine in Scotland.[1] The author earlier thought, before he was aware of the fact that the ore is intergrown with pyroxene, that the former mineral had crystallized within olivine, but this does not seem to be the case. Although it occurs near to olivine containing ore particles, it show no gradations into that mineral, and it seems more likely that the implication of ore and pyroxene has replaced hornblende. In any case, it seems probable that it is of secondary origin.

It is an astonishing fact that we find here, among old Archæan basic rocks which usually have undergone such a complete metamorphism, rocks whose primary composition and texture have been so well preserved. Sometimes the metamorphic and non-metamorphic rocks may even be observed within the same thin section. There is no »armour» between the plagioclase and the augite, or diallage, of these basic rocks. Then the coronas have not such a character and could not have preserved the pyroxene from metamorphism An armour would be preservative only if the metamorphic changes were confined to an interchange of substance between the neighbouring minerals. But even in the formation of the synantetic minerals, and still more in other cases, the substances interchanged have obviously been in part carried from more distant places by solutions or gases which have penetrated the whole rock masses.

Perhaps it is not a mere chance that the best preserved portions of these old eruptive rocks are those which solidified as greater masses at a certain depth and possessed an ophitic or a gabbro texture. These rock masses are very homogeneous and tough and have probably been very little jointed, and they therefore gave much more difficult access to the metamorphosing solutions and gases than the effusive metabasalts which were very varying in composition, cracked, scoriaeous, and often intermingled with ashbeds which had a well developed parallel texture.

The younger metabasalts of the Pellinge group are much more completely uralitized than those of the Pernå formation, so that no

[1] J. Shand, Ueber Borolanit und die Gesteine des Cnoc-na-Sroine-Massivs in Nord-Schottland. N. Jahrb. XXII Beil. Bd. 1906, p. 429—433.

traces (except the crystal form) of the primary pyroxene, and still less of the olivine, can be detected. One would rather expect to find the older metabasalts, which have been penetrated by granites before the eruption of the latter, to be more highly metamorphic than them. It is very difficult to find any explanation of this different behaviour towards the metamorphosing agencies of these two basaltic formations. In any case, the circumstances noted prove that the metamorphic processes at a depth cannot simply be regarded as a function of temperature and pressure, but depend also on conditions more difficult to determine. When using laboratory experiences in order to explain them we have always to take this difference into account.

Fig. 8. Dyke of gabbro pegmatite in gabbro.
Tunnholm, Pellinge. 1:10.

In Bredskär and some adjacent small islands also another gabbro variety outcrops which has a different grain and a lighter and somewhat reddish colour, and shows a sharp contact against the main mass of the dark gabbro. It is composed mainly of oligoclase (26 % An) and hornblende, sometimes with a core of pyroxene filling the interstices between the felspar laths but occurring in rather small quantities. Some ore is also present. This rock probably belongs to the same co-magmatic series as the Tunnholm gabbro and the associated metabasalts, but seems to be somewhat older than either of them. It is intersected also by dykes of metabasalt.

In the gabbro of Tunnholm and adjacent islands dykes of a coarse p e g m a t i t i c rock are very common. This consists of crystals of plagioclase and hornblende which is possibly secondary. Some of these dykes are straight fissure dykes attaining a breadth of 0.3 m (Fig. 8) while in other instances (Fig. 9) a similar rock forms a network of narrow veins less sharply defined. This vein rock consists

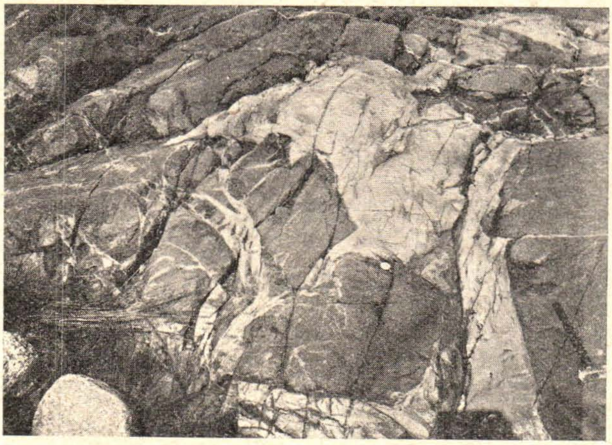

Fig. 9. Veins of gabbro pegmatite and »aplite» in gabbro. Tunnholm, Pellinge. C:a 1:12.

partly of a rather fine-grained mass rich in felspar and containing sparsely scattered small hornblende crystals, which may be compared

Fig. 10. Veins of gabbro »aplite» in gabbro. Bredskär, Pellinge. C:a 1:15 e.

to an aplite. This gabbro pegmatite is mainly composed of oligoclase (27—32 % An) and green hornblende. Ore grains are common in the hornblende, often forming a fine dust of minute particles, and so are also small grains of titanite. Crystals of chlorite, which has probably replaced biotite, occasionally occur. Epidote is often present, sometimes filling narrow fissures, and seems to be of later origin than the other constituents. Apatite often occurs. In some cases scapolite has also been observed.

In a gabbro pegmatite from a little island near Halsskär the hornblende still contains cores of diallage. Both in this mineral and in the secondary hornblende interpositions of a dark brown mineral are abundant. It is impossible to decide whether and in what quantity primary hornblende may also have been present in these gabbro pegmatites.

In the fine-grained »aplitic» rocks connected with the gabbro pegmatite the hornblende sometimes shows idiomorphic forms and is surrounded by fine-grained oligoclase. In some cases quartz is also present, especially in the veins in the gabbro in Bredskär, Pellinge (Fig. 10). Here, however, the contact with a younger granite is near, and it is possible that it has influenced the mineralogical composition of the vein rock.

Fig. 11 shows a horizontal rock surface on the western shore of Tunnholm where the gabbroid rock is intersected by several dykes of metabasalt. These again, are cut both by a coarse-grained pegmatitic rock which includes a fragment

Fig. 11. Faulted dykes of metabasalt in gabbro, intersected by gabbro pegmatite (in the upper part of the drawing) and aplite. Horizontal rock surface at the western shore of Tunnholm, Stor Pellinge. 1: 30.

of one of the dykes, and by fine-grained aplitic rock. This locality is of interest because it shows the close connection in respect to age between the gabbro and the fine-grained metabasalt which solidified here before the final consolidation of the gabbro pegmatite.

When the author uses the name aplite, it is of course only for want of a better designation, and because he does not like to encumber petrological nomenclature with a new term.

Also a lighter-coloured diorite-like rock with a medium grain occurs in Tunnholm as veins closely connected with the pegmatitic veins. It is composed mainly of plagioclase and hornblende in the same proportion as in the uralitized gabbro and in the gabbro pegmatite.

The chemical composition of this rock which has been analysed by Dr. E. Mäkinen (Table IX) is very near that of the gabbro; it is also an auvergnose according to the American classification.

Table IX. Light-coloured gabbro forming veins in typical gabbro on the vestern shore of Tunnholm in Borgå.

Analysed by Eero Mäkinen.

		Mol. prop.	Norm.				
SiO_2	49.00	817					
TiO_2	0.50	06	Orthoclase	3.89	F 52.12		Sal 52.12
Al_2O_3	16.39	161	Albite	11.53			
Fe_2O_3	0.77	5	Anorthite	36.70			
FeO	4.67	65					
MnO	0.17	3	Diopside	35.73	P+O 44.83	Fem. 46.80	
MgO	9.28	232	Olivine	9.10			
CaO	16.17	289	Magnetite	1.16	M 2.07		
Na_2O	1.36	22	Ilmenite	0.91			
K_2O	0.72	7		99.02			
H_2O	1.64		Rest of MgO	0.08			
	100.67			99.10			
			Water	1.64			
				100.74			

META-ANDESITES.

Close to the south-eastern margin of the area of younger uralite-porphyrites there is an area of porphyritic rocks associated with the older metabasalts which differ from them in chemical and mineralogical composition. They are fine-grained rocks whose surface colour is lighter and more brownish than that of the metabasaltic rocks, and which macroscopically show no distinctly porphyritic texture. Microscopically, however, we find well developed phenocrysts of oligoclase (about 29 % An) which often show a beautiful zonar structure. The primary crystals are sometimes surrounded by a narrow rim of secondary plagioclase.

These phenocrysts, whose dimensions are about 1 to 3 mm, are surrounded by a fine-grained groundmass consisting mainly of felspar which forms rounded grains measuring 0.01 to 0.1 mm. This felspar generally shows no twinning lamellation, but is, however, certainly mainly plagioclase of the same character as in the phenocrysts. Potash felspar, however, may also be present, although no individual grains can be determined as such. Grains of quartz are numerous. As femic constituents numerous flakes of biotite and prisms of green hornblende occur, sometimes forming large crystals. The dark minerals are arranged in bands, winding around the porphyritic felspars, distinctly indicating a characteristic fluxion texture (Fig. 6, Plate I). The rock also contains some grains of titanite, epidote and ore.

In a typical variety from a little island lying E.N.E. of Stor Måsholm in Pernå, the percentage weights of the different constituents, determined by the Rosiwal method, were as follows: felspar 65, biotite 19, quartz 8, hornblende 6 and titanite and epidote less than 2 per cent. This agrees well with the chemical composition which is shown by the following analysis (Table X) made by Dr. Mäkinen.

The rock is a t o n a l o s e according to the American classification. Its primary composition was rather that of an a n d e s i t e than that of a dacite. Most of the quartz shown in the mode is in fact contained in the biotite, epidote &c. Only a part of it is free, and this is probably of secondary origin.

In other rocks of this group the groundmass is more metamorphic and contains more numerous grains of quartz. Hornblende in some cases prevails over the biotite. Epidote occurs in varying quantities.

In the island of Dokskär in Pernå a meta-andesite which has a rather light, reddish surface colour intersects a tuff belonging to the

Table X. Meta-andesite from a small island E.N.E. of Måsholm in Pellinge.
Analysed by Dr Eero Mäkinen.

		Mol. prop.	Norm.			
SiO_2	63.68	1061	Quartz	19.92	Q 19.92	Sal 82.38
TiO_2	0.92	11	Orthoclase	11.68		
Al_2O_3	15.84	155	Albite	28.82	F 62.46	
Fe_2O_3	1.80	11	Anorthite	21.96		
FeO	4.55	63	Diopside	6.04	P 13.27	Fem 17.49
MnO	0.08	1	Hypersthene	7.23		
MgO	1.99	47	Magnetite	2.55	M 4.22	
CaO	5.93	105	Ilmenite	1.67		
Na_2O	3.42	55		99.87		
K_2O	2.02	21	Water	0.50		
H_2O	0.50			100.37		
	100.73					

metabasalts, and is itself cut by a narrow dyke of metabasalt (Fig. 12). The meta-andesite consists mainly of minute grains of plagioclase together with small flakes of mica and crystals of uralite. At this place it becomes evident that no distinct difference in age between the meta-andesite and the metabasalts exists, some of the latter rocks being older and others younger than the meta-andesites.

On the northern shore of Flottaskär contacts are visible between the meta-andesite and a dark rock which is in part rather coarse-grained, but is sometimes aphanitic and amygduloid at the contact. The meta-andesite contains a dyke of middle-grained uralite-porphyrite. This rock again is penetrated by a dyke of fine-grained metabasalt.

In the small island E.N.E. of Måsholm the meta-andesite is seen in contact with uralite-porphyrite of group E which is aphanitic at the contact with the andesite. The latter contains several well defined dykes of fine-grained or aphanitic uralite-porphyrite.

Also in the island of Trutkobben between Flottaskär and Måsholm, the andesitic rock is found in contact with the older uralite-porphyrite. The former rock prevails, but in the southern part of the island uralite-porhyritic rocks occur which penetrate the andesite at the contact. The latter contains also an aphanitic dyke of metabasalt. Thus here also the andesite is older than the uralite-porphyrite.

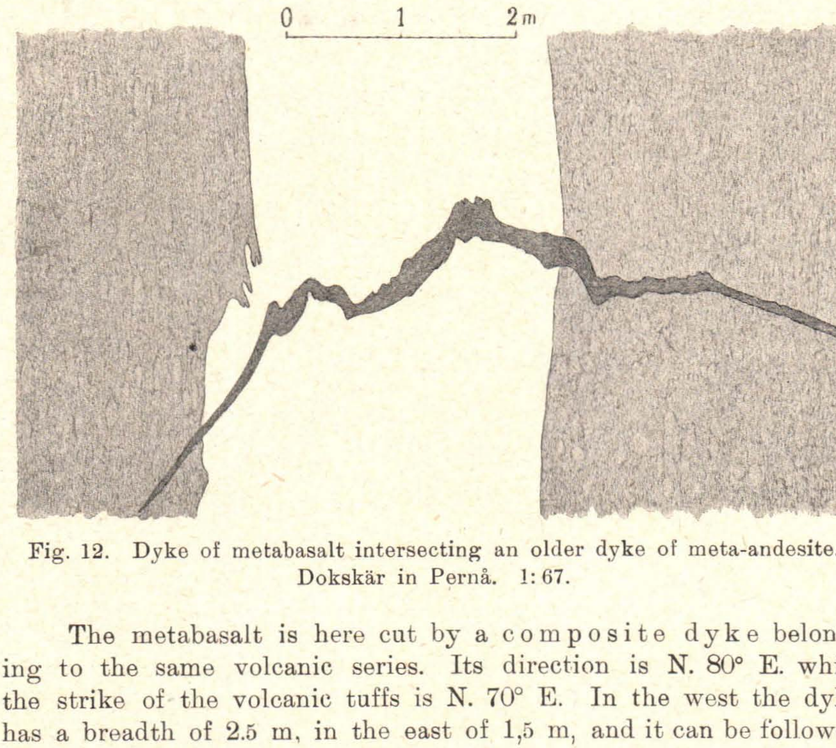

Fig. 12. Dyke of metabasalt intersecting an older dyke of meta-andesite. Dokskär in Pernå. 1:67.

The metabasalt is here cut by a c o m p o s i t e d y k e belonging to the same volcanic series. Its direction is N. 80° E. while the strike of the volcanic tuffs is N. 70° E. In the west the dyke has a breadth of 2.5 m, in the east of 1,5 m, and it can be followed for about 50 m. At its middle it is faulted.

The basic contact zones have a breadth of 10—30 cm. They consist of a black aphanitic metabasalt, while the central portion is composed of a more acid rock which is reddish at the surface. The contact between the two varieties is rather sharp at the southern side but more indistinct at the northern one.

Microscopically the rocks do not show any very conspicuous differences. The rock from the central portion is composed mainly of small grains of plagioclase mingled with some quartz and of green hornblende, epidote and ore in small quantities. In the main it has an andesitic character. The rock from the contact zones contains some more uralite, and some of the plagioclases form large crystals.

BRECCIAS CONTAINING PEBBLES OF METADACITE AND QUARTZIFEROUS METADACITE.

Sometimes also the fragments in the volcanic breccias in part consist of rocks which possess a more acid composition than the prevailing rocks, differing from them also in the lighter and more reddish colour of their surfaces. This is especially the case with the rocks of the small island S. of Furuholm, in the eastern part of the area mapped. Here the rock is a very typical breccia or

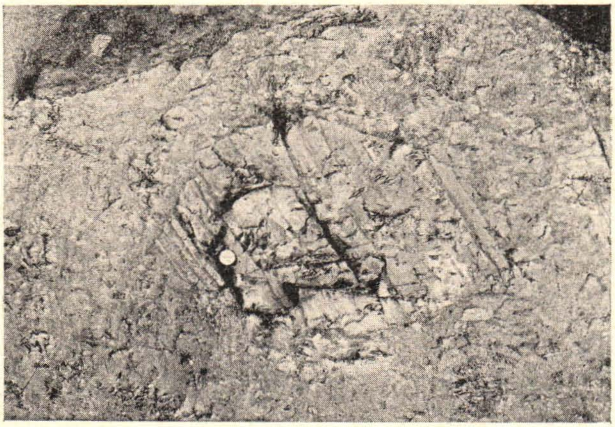

Fig. 13. Agglomeratic tuff containing a pebble of stratified tuff. Island south of Furuholm in Pernå. 1:8.

conglomerate of a polymict character, in which, however, most of the pebbles belong to the same series of basic volcanic rocks as the matrix. Plagioclase-porphyrites are common. These pebbles often show a lighter border, perhaps because they have weathered at the time when they were loose boulders. Some pebbles consist of medium-grained rocks whose lath-shaped plagioclases are arranged so as to suggest an ophitic texture. Between them there are well crystallized uralites. Pebbles and fragments of basic tuffs (Fig. 13), of rocks rich in hornblende and of lighter rocks rich in epidote and quartz also occur. Aphanitic rocks are common which are reddish at the surface, but almost black in fresh chips. Some of these fragments have a diameter of several metres. Other fragments consist of reddish rocks of medium grain which contain macroscopically visible quartz and red felspar. They show gradations into the aphanitic rocks just mentioned. The acid rocks often exhibit a very distinct fluidal texture which sometimes lies transversally to the schistosity of the breccia. Dykes of metabasalt with a maximal breadth of 12 m intersect this breccia. One of them is again penetrated by veins of the pegmatitic granite which forms dykes in the breccia. Some of the pebbles or fragments consist almost entirely of an epidositic rock variety.

Microscopically many of the rock fragments show a peculiar eutaxitic texture due to the occurrence of irregularly dispersed spots, in which the felspar has the same orientation all over each spot but different in neighbouring ones. These rocks are obviously vitrophyres which have been devitrified. The fluxion texture is often very distinct. In the red rock of the fragments the plagioclase, which is an oligoclase with 28 % An, is intergrown with quartz which is certainly of primary origin. These rocks seem to have originally been quartz-dacites while the others show gradations between dacites and andesites.

CONTACT RELATIONS BETWEEN THE PELLINGE FORMATION (G) AND THE ROCKS OF ITS BASEMENT.

A glance at the map shows that the Pernå formation E has a much wider distribution than the Pellinge formation G. The Rysskär granite F, which is intermediate in age between these formations, does not reach to their immediate contact-lines. But dykes radiating from the central area of youngest uralite-porphyrites intersect the eruptive breccias which originated when the volcanic rocks of the Pernå formation were penetrated by the Rysskär granite. They occur even at a considerable distance from this central area. The rock of these dykes often shows just the same petrological character as the uralite-porphyrites of the central area, or of dykes occurring at the contacts and directly connected with the younger volcanics.

The best locality for studying these phenomena is the little island of Ormskär in Pernå. It consists of an eruptive breccia in which fragments of uralite- and plagioclase-porphyrites, in part amygduloid, with associated tuffs and agglomerates, are cemented by granite and granodiorite. Most of these fragments are angular (cf. Fig. 57, p. 126). This eruptive breccia is intersected by several narrow fissure dykes of a fine-grained uralitized basaltic rock, which has the looser texture characteristic of the rocks belonging to series G, and in general the same petrological character as those rocks, although it does not show any porphyritic uralite crystals. One of these dykes (Fig. 14) has a maximum breadth of 0.5 metre and can be followed 35 metres. It has probably a continuation along a fissure which stretches further along the same line but where the rock is not visible. In the northernmost part of the island there are also several dykes, some of them very narrow, running in the same direction. On the southwest shore there is also a dyke which has a length of 15 metres. The rock of these veins is entirely uralitized, but they have not been deformed at all by mechanichal disturbances. Also in the island Korsholm, south of Ormskär, and adjacent small islands, several dykes have been observed which intersect the eruptive breccia and certainly belong to the younger metabasalt.

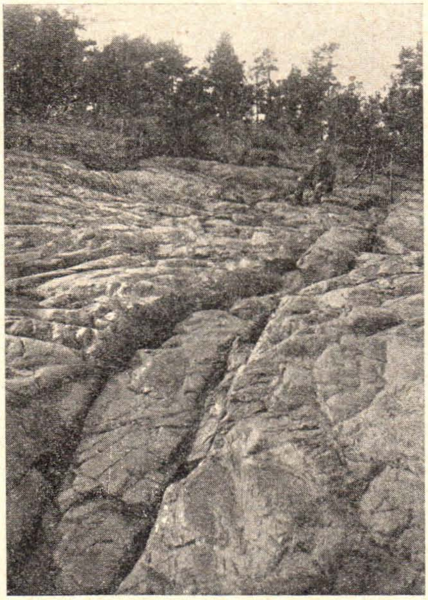

Fig. 14. Dyke of younger metabasalt intersecting an eruptive breccia containing fragments of metabasalts of the Pernå formation. E.-shore of Ormskär, Pernå.

In a little island situated between Lilla Finnholmen and Iglasön in Pernå, 2 km W.S.W. of Ormskär, a dyke of loose greenishblack uralite-porphyrite also occurs (Fig. 15), which intersects the granite veins that penetrate the older metabasaltic rock of that island. Dykes also occur here which are older, belonging to formation E and cutting the tufaceous schists of the same formation, but these are penetrated by veins of the granite F. Those are here common everywhere, and the older rock has thus in part the character of a migmatite. The contrast between the dyke interwoven with granite (Fig. 16) and the younger dyke which intersects the granitic veins is very striking.

In a little island one kilometre N. of Rysskär the eruptive breccia is intersected by a dyke of younger metabasalt which is 20—30 cm broad and runs in N.N.W.

The islands mentioned lie at distances of 2—4 km from the N.E. boundary of the area of younger uralite-porphyrite.

It is evident from the foregoing statements, that there are dykes of metabasalt younger than the Rysskär granite (F) which invades the older uralite-porphyrites of group E, and these dykes also occur at a distance of several kilometers from the central area of younger uralite-porphyrites. Nearer to it we find similar dykes whose connection with the last-mentioned rocks seems, in some cases, indubitable, as is evident from the detailed description which we will now give of the contact-lines of this volcanic formation, beginning with the southern contacts, and proceeding from west to east.

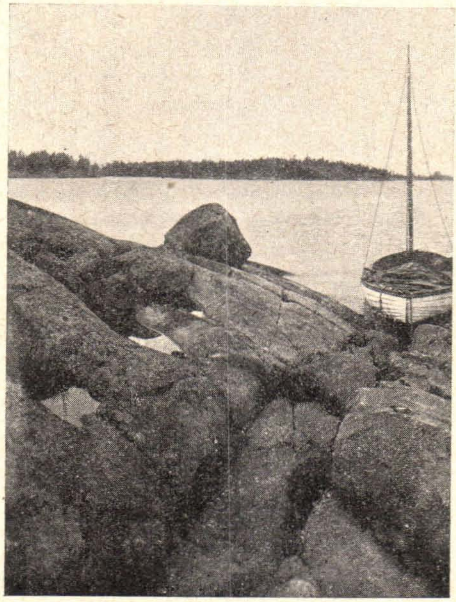

Fig. 15. Dyke of younger metabasalt intersecting older metabasalt and granitic veins which penetrate the latter. Small island E. of Iglasön, Pernå.

On the southern shore of the south-westernmost promontory of Stor Pellinge island, S. of Kungshamn, dykes of three different kinds occur in a horizontal rock. The predominant rock is a dark, schistose metabasite, probably a basaltic tuff, whose strike is N. 30° W. (indicated by the direction of the lines in Fig. 17). This rock is penetrated

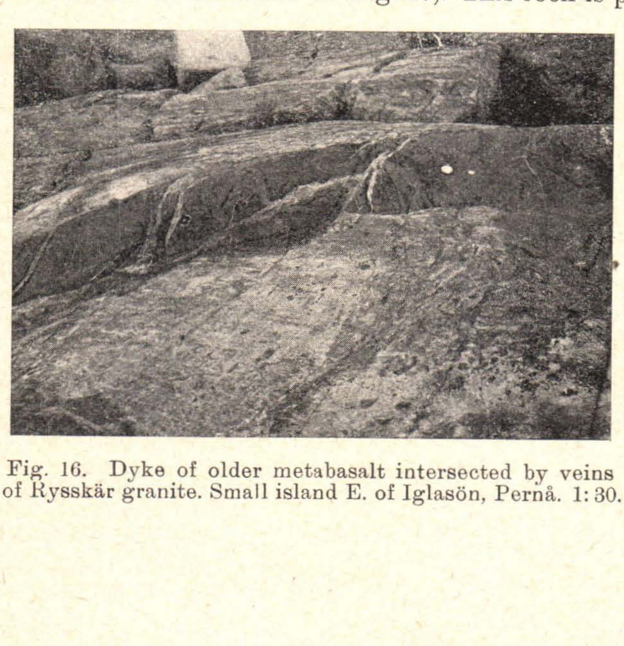

Fig. 16. Dyke of older metabasalt intersected by veins of Rysskär granite. Small island E. of Iglasön, Pernå. 1:30.

by a branching dyke of metabasalt, which is porphyritic in the midst and fine-grained near to the contacts. It certainly belongs to the older volcanic formation E. This dyke, as well as the tuffs, is cut

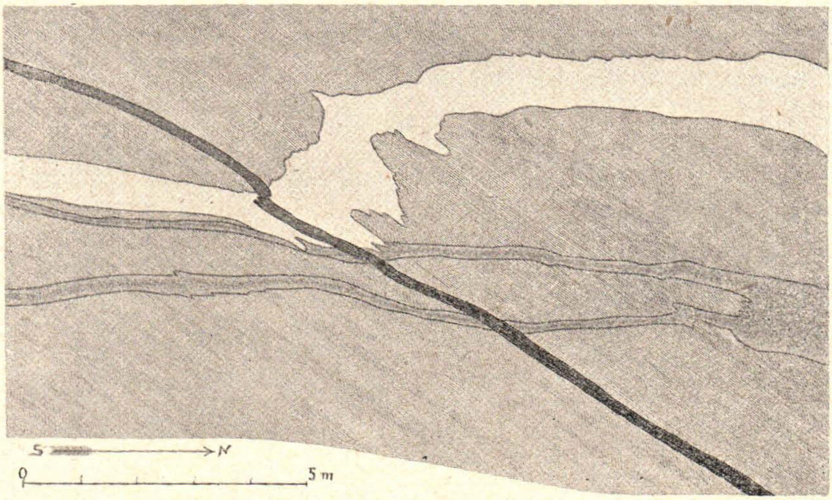

Fig. 17. Metabasalt of the Pernå formation penetrated by different dykes. Horizontal rock surface at the seashore S. of Kungshamn, Stor Pellinge. Scale c:a 1: 140.

by a broader vein of a medium-grained rock which has a pale colour at the surface. It is composed mainly of oligoclase (about 30 % An),

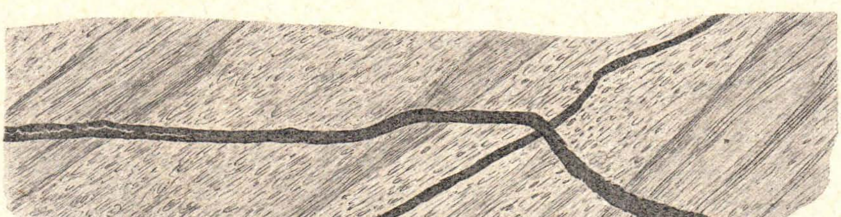

Fig. 18. Dykes of metabasalt intersecting tuffs of the Pernå formation. Horizontal rock surface on Timmerholm in Stor Pellinge. Scale 1: 200.

biotite, quartz and some garnet, and probably belongs to the Rysskär granitic formation (F). It has a parallel texture running in the same direction as the schistosity of the tuff. A third dyke cuts all the rocks mentioned. It is very fine-grained, dark and uniform in colour, and shows much similarity to some of the dykes already described which have been referred to uralite-porphyrites of the Pellinge formation (G).

In the harbour of Kungshamn the contact between older and younger metabasalts is seen on the shore. The former contains small porphyritic plagioclases while the latter is a uralite-porphyrite. Their difference in petrological character is not very pronounced, but the contact is sharp.

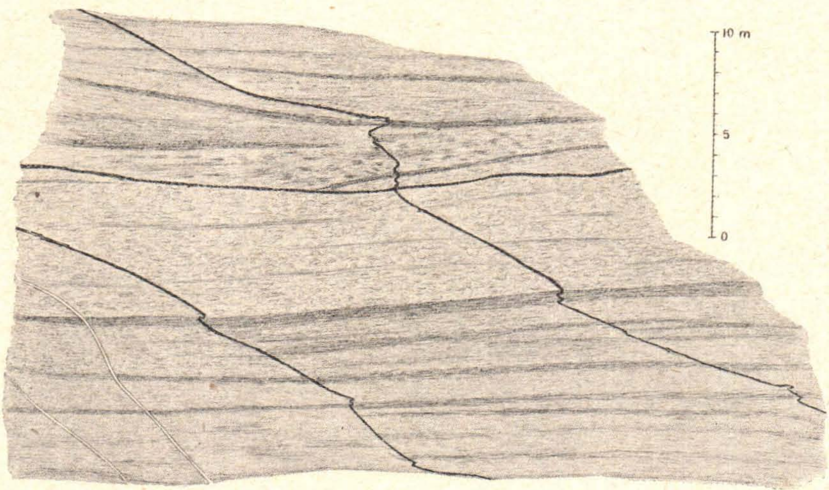

Fig. 19. Dykes of metabasalt intersecting tuffs of the Pernå formation. Horizontal rock surface on Timmerholm in Stor Pellinge. Scale c:a 1: 360.

In the island of Timmerholm to the S. there occur narrow dykes of metabasalt which also possibly belong to the younger volcanic formation. In the Figg. 18—20 some of them are shown. In the former a dyke of this character intersects another one of a rock which is harder and shows some similarity to dykes of group E. It is rather uncertain whether it belongs to them or to the younger dykes. The rock of the dykes is grey and fine-grained.

When we follow the southern boundary line farther to the east, we often find the older and younger uralite-porphyrites near to each other represented by very typical varieties, but the immediate contact-line is generally difficult to detect.

The island of Utterholm shows a very fine display of different varieties of uralite-porphyritic rocks, probably all belonging to the older group E. Typical uralite-porphyrites, amygduloid varieties, breccias or agglomerates &c. alternate, and very often the different rocks are very much faulted and dislocated. These dislocations, caused either by landslips or volcanic earthquakes, may have taken place either when these same rocks erupted or during the later epoch of volcanic activity in the region.

Stor Måsholm, N.E. of Utterholm, is certainly traversed by the boundary between the different porphyrites, but it is very difficult to determine the exact site of the contacts, although the rocks are well exposed. In the northernmost part of the island the younger uralite-porphyrite is very typical, while the rocks in the greater part no doubt belong to the older group. Brecciated lavas prevail, in

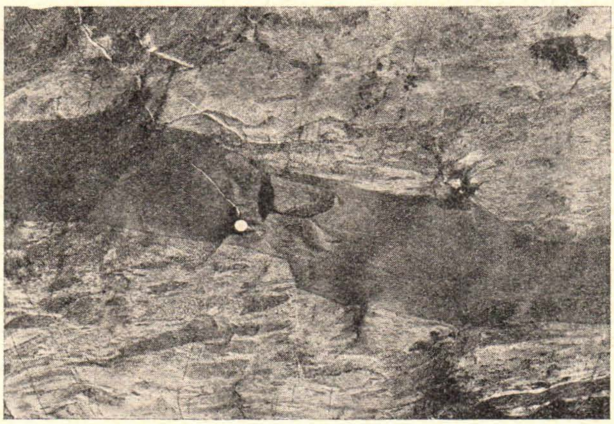

Fig. 20. Dyke of metabasalt intersecting tuffs of the Pernå formation. Timmerholm in Stor Pellinge. 1: 13.

alternation with tuffs, more typical uralite-porphyrites and metabasalts containing small phenocrysts of plagioclase. Parts which are rich in epidote are very common. Sometimes the different varieties show sharp contacts, either due to a succession of volcanic eruptions or to earthslips that have ocurred at the slopes of the volcanoes. On the southern side of a little bay on the western shore of the island there is a well defined dyke intersecting other volcanic rocks. It is cut by narrow veins containing orthoclase, quartz and epidote. It seems probable that this dyke belongs to the older volcanic group.

Stengropholm on the southern side of Pellinge Ölandet, is one of the best localities for studying the contacts between the two volcanic groups (Fig. 21). The predominant rock is an agglomératic tuff containing numerous fragments of amygduloid volcanic rocks. It certainly belongs to the older group E, and is also found in some adjacent islands more to the W. and S. W.

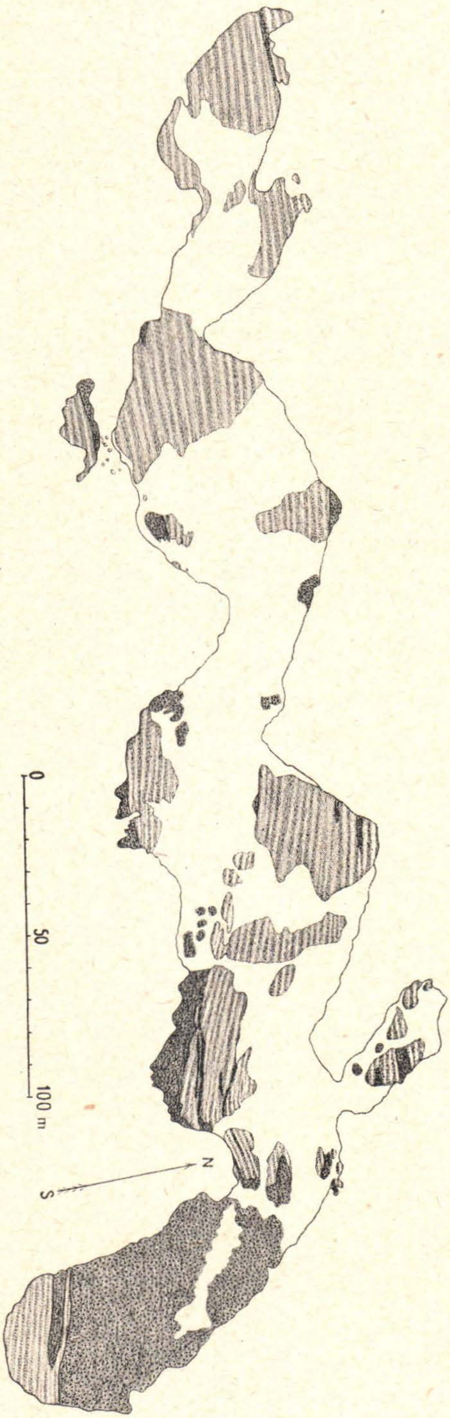

Fig. 21. Sketch-map of the island Stengropholm showing older metabasaltic tuffs, partly agglomeratic (banded dots) in contact with younger uralite-porphyrites (heavier dots). Scale 1: 2300.

The south-eastern part of the island is mainly composed of a typical uralite-porphyrite which is quite similar to the rock, certainly belonging to the younger group G, that occurs in the neighbouring, larger island of Ölandet. A similar rock also occurs along the southern shore of Stengropholm.

The contact between these different rocks in Stengropholm forms a broken line, the younger rock sending out a number of lobes into the older one. In some places the contact plane seems to lie rather flatly. The younger rock also occurs as dykes in the agglomerate which are partly continuous with the greater masses of uralite-porphyrite. This rock is often very typical, porphyritic in the broader dykes and sometimes aphanitic in the narrow ones, or along the contacts.

In the island N. N. E. of Flottaskär the andesitic rock is cut by several dykes, one of them measuring a metre in breadth, of a metabasalt which is rather loose in texture and possibly belongs to the younger group G.

Very interesting are the contacts in the little island of Rånghäll, W. of Sandö, in the south-eastern corner of the area of younger uralite-porphyrites, near to the place where its boundary abruptly turns in a northward direction (Fig. 22).

The older rock is here a meta-andesite while the younger volcanic formation consists of tuffs, in part agglomeratic, with intercalated lava beds. The contact plane dips 70° N. The dips are at an uncommonly low angle, on the northern shore of the island only 20° N. The strike is from N. 70° to N. 80° W. In the andesitic basement several dykes of metabasalt are observed which in part penetrate also into the younger volcanics. The petrological character of the broader dykes is quite similar to that of the volcanic lava beds in the younger formation.

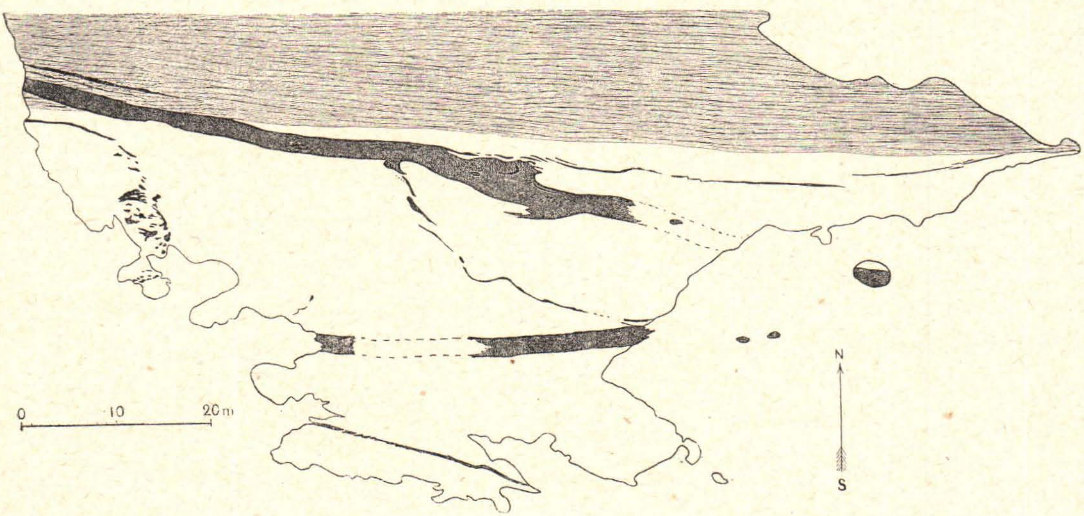

Fig. 22. Sketch map of Långhäll in Pernå showing contact between older and younger volcanic rocks and dykes of younger metabasalts intersecting both of them. Scale 1:8 000.

Most of the dykes are almost vertical. The narrow dyke in the western part of the rock has in places a more recumbent position. Here the dyke rock is aphanitic in texture and has certainly originally been glassy. The same is the case with the other narrow dyke branching out from the broadest one.

At the eastern boundary of the area of younger rocks the contrast between these and the older rocks is often very marked. The former are typical uralite-porphyrites and associated agglomeratic tuffs, while the latter are in part fine-grained doleritic or andesitic rocks, in general much more varying in their composition. It is, however, not always easy exactly to determine the contact line. In the north-east, it seems probable that it lies immediately S. of the island of Tjurholm, or perhaps traverses the southernmost part of that island. Here several dykes occur which certainly belong to the younger volcanics, while it is in other cases difficult to determine their age. A broad dyke in S. E. and another in the middle of the island certainly belong to the former category.

The small islands of Dömansörarna S.W. of Tjurholm, and Lill Brokholm consist of rocks which show more similarity with the younger uralite-porphyrites than with the older volcanic rocks. They are to a great extent agglomeratic, showing a great variety of fragments of volcanic rocks with different textures, porphyritic, aphanitic, amygduloid varieties, tuffs &c. They are cut by numerous dykes, sometimes showing zonar structure.

West of these islands, the northern boundary of the younger area may everywhere be determined with certainty, and the immediate contacts are also visible in some places.

In the northernmost part of Sådholm fine-grained older metabasalts occur, cut by a dyke of a rock showing porphyritic crystals of plagioclase. It has a breadth of 2 m and certainly belongs to the same volcanic formation. The main part of the same island is formed of loose, greenish black uralite-porphyrites, often showing very big phenocrysts. These rocks certainly belong to the younger series.

The same rock also predominates in the island of Baggholm. Only along the northern shore of that island older metabasalts occur which show different textures. They are sometimes very fine-grained and tough and occasionally contain small crystals of plagioclase.

On the western shore of the island of Lill Pellinge a sharp contact between the younger uralite-porphyrite and a fine-grained tough metabasalt of the older group is visible in a low horizontal rock exactly at the shore line. The younger rock is finer-grained next to the contact than elsewhere.

In the north of Ölandet there is, on the eastern shore, a small rock in which a sharp contact between the younger and older metabasalts is visible. The older uralite-porphyrite is darker next to the contact and seems to contain more numerous phenocrysts of uralite and plagioclase than elsewhere, but this fact is certainly not to be interpreted as a fluidal arrangement along the contact, but is due to some more occasional cause.

The younger uralite-porphyrite, which is fine-grained, shows a well marked contact zone which is certainly due to an arrangement of the constituents along the contact during solidification. Near to that contact runs a zone richer in uralite.

S.W. from that place the contacts are hidden. Rocks showing the characters of the older and younger metabasalts are often visible at a distance of ten to twenty metres.

It is obvious from the foregoing statements that the contact relations between the older and the younger volcanic rocks can be determined in many places with certainty, but are obscurer in other places, because the contacts are hidden, in some cases also because the similarity of the volcanics of different ages makes it difficult to discriminate between them.

At many contacts both volcanic rocks were originally basalts, now changed into metabasalts, or uralite-porphyrites. Although the older basalts have been intruded by granites, at a time prior to the eruption of the younger ones, this intrusion has not affected the parts lying at that moment near to the surface. Only in one place, S. of Kungshamn, have we found, near to the contact of the younger volcanic rocks, a dyke of a granitic or dioritic rock which seems probably to be genetically connected with the granites in question. The older basalts thus possibly were still unmetamorphic in their upper parts, at the time when the younger volcanic rocks were deposited on them. It is easy to understand that where basaltic lavas flow over a basement consisting of rocks with an almost identical composition, which were probably fissured and divided into blocks on the surface, the relations of both should become, in many cases, very intricate. Moreover, the two rocks may have been mixed, at the margin of lava flows, by smaller rockslips. The conditions at Utterholm where the older rocks seem to have been faulted and in part changed into debris which were again cemented, seem to indicate that such has happened.

In the central area we meet everywhere rock of a rather uniform character until we reach the boundary, where a formation showing much more variety abruptly begins.

The observations at the contact-lines would, however, hardly be sufficient to convince every sceptical observer, at a short visit to the region, of the existence of two different volcanic formations, were it not for the evidence of the dykes, which radiate from the younger area and penetrate also the eruptive breccias which consist of fragments of older metabasalts (E) cemented by the Rysskär granite (F). This fact proves that metabasalts younger than this granite exist. There is no reason to believe that there is more than one group of metabasalts younger than this granite. On the contrary, the great similarity between these dyke rocks and the metabasalts of the younger area, and especially the dykes directly radiating from it, at Stengropholm and Långhäll, seems to leave no doubt as to the fact that the whole central area of volcanics is younger than the granites penetrating the Pernå volcanic formation.

RELATIONS BETWEN THE VOLCANIC PERNÅ FORMATION (E) AND THE OLDER ROCKS.

It would be easier to understand the contact relations between the rocks of the volcanic Pernå formation and the older rocks when we have learnt to know in detail the oldest supercrustal rocks, the different granites of the region and the migmatites formed by their injection into the schists. The Rysskär granite especially, which is so intimately interwoven with these volcanic rocks, forming with them eruptive breccias, is here of interest. It would be difficult, however, to insert a description of the stratigraphical relations between the volcanic formation and its basement in the latter part of this memoir which mainly treats the injection phenomena. We will therefore give this description here, anticipating some of the results of the second part of the treatise. If the reader should feel it difficult, because of the complicated character of these phenomena, to form a decided opinion about the age relations of these rocks, we hope that he will return to this chapter later on, if he is sufficiently interested in this matter, after having studied the part treating granitization phenomena.

To the author, the relations between these volcanics and the rocks belonging to their former basement, in spite of the strong anatexis and dislocations which the rocks of the volcanic Pernå formation (E) have undergone at the time of the intrusion of the Rysskär granite (F), are so clear as to leave no doubt about their relative age. Along the contact lines which separate these effusive metabasalts from the neighbouring rocks north of them, dykes everywhere occur which show a complete similarity to the rocks of the volcanic Pernå formation and no doubt belong to them, but which penetrate all the adjacent rocks. They are in their turn cut by veins of the Rysskär granite.

The most convincing evidence is obtained in a locality situated on the southern shore of Stadslandet in Pernå. A horizontal rock surface shown in the sketch on Plate VII shows a Stadsland gabbro (C) which has been penetrated by numerous veins partly aplitic or pegmatitic in character. The composite rock is a migmatite in which the included fragments have become in part somewhat more basic than the rest of the gabbro. This migmatite is penetrated transversally to its strike by dykes of a metabasalt which shows exactly the same character as the uralite-porphyrite of the adjacent Pernå formation. In the broader dykes the rock contains phenocrysts of uralite, and the groundmass is fine-grained, while the narrower dykes are almost aphanitic and have certainly originally been glassy at the contacts.

Like the other dyke rocks which are older than the Rysskär granite (F), these metabasalts are very tough and brittle, thereby differing from the dyke rocks of the Pellinge formation with their looser texture.

No doubt these dykes are true fissure-veins which have originated during a period of volcanic activity, later than the period of plutonic activity during which the granite erupted.

The westernmost dyke can be followed for 50 m to the S. W. It is, on the area mapped, cut by a dyke and several narrow veins of a granite which shows all the peculiarities of the Rysskär granite (F) in such a characteristic form as to leave no doubt that we have to do with metabasalts older than that granite. Thus the relations of the dykes to the plutonic rocks of the region is the same as that of the Pernå volcanic formation (E). The westernmost dyke is interrupted, at a point which lies 30 m to the west of the area shown in the drawing, by a rather basic migmatitic rock, which shows a great similarity to some portions of the migmatite which is intersected by the basic dykes. On close inspection, however, we are aware that this basic migmatite is a portion of a narrow vein-like zone, which intersects the gabbro and is analogous to the other veins which are connected with the younger granite F.

In any case it seems certain that the dykes of metabasalt and the granite which forms the cement in the migmatite intersected by these dykes are of widely different age. Then the contacts of the granite are those of a plutonic rock while the dykes are true fissure dykes formed in the uppermost, brittle parts of the earth's crust. The volcanic rock has obviously been glassy at the contacts. The granite of the migmatite must belong to the Våtskär granite which is the only one observed in the region which is older than the Pernå formation.

In some neighbouring rocks, east of this place, we find, however, a gneissose granite resembling that of the migmatite, very intimately connected with another granite which certainly belongs to the younger group. Dyke-like zones of basic rocks also occur, but their relations to the other rocks are obscure. Probably an intense refusion has taken place which has obliterated the original features.

Further to the east, however, we find again, in several rocks on the southern shore of Stadslandet, dykes of metabasalt which without any doubt cut both the Stadsland gabbro (C) and veins of an old granite intersecting it, but are themselves cut by veins of a granite of Rysskär type.

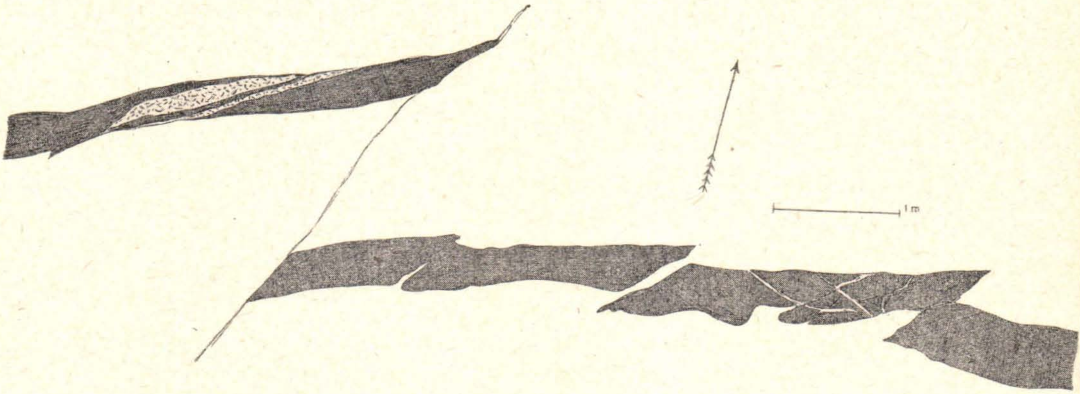

Fig. 23. Dyke of metabasalt in quartzite, faulted and penetrated by veins of granite. 1: 60.

In the quartzite occurring S.W. of Stadslandet, dykes of similar metabasalts are common. They are cut by granitic veins belonging to the Rysskär granite (F), and have very often been faulted, probably at the time of the intrusion of the granite (Fig. 23). Sometimes those dykes are conformable to the strike of the quartzite. They are very common near the contacts with the Pernå uralite-porphyrites (E). On the western shore of Tirmolandet (at Hästholmsudden) the quartzite is also cut by a basic dyke which is in its turn intersected by a pegmatitic vein, but this belongs to the Hangö granite (H), which is very much younger than all these formations, and the exact age of the basic dyke can therefore not be determined.

The small pebbles of quartz contained in the agglomeratic tuffs in the islands of Tullandet and Lökö, near to the northern boundary of the uralite-porphyrite formation E, are probably derived from the adjacent quartzite, and on Rabbaslandet a boulder was found near the contact between the two formations mentioned, in which fragments of the quartzite were cemented by the metabasalt.

Also in the region east of Stadslandet numerous dykes of fine-grained basic rocks are seen cutting both the gabbro, the schists belonging to the series A, and the intercalated volcanic rocks. In several places these dykes are penetrated by veins of the Rysskär granite (F). On Viasholm such dykes are numerous in the highly altered conglomerate of that island, as will be described in detail later on. Such dykes also intersect the metamorphic conglomerate at Sundarö.

On the southern shore of Hästö the meta-andesite belonging to the oldest Sundarö series (A) contains numerous dykes (Fig. 3, Plate V) of a dark metabasalt which shows complete similarity to the adjacent uralite-porphyrite of the Pernå formation (E), the northern contact of which lies only some hundred metres to the south. These dykes show very irregular outlines, a circumstance certainly in great measure due to the brittleness of the rock, which became fissured in some degree, and also to the fact that the dykes have afterwards been penetrated by numerous veins of the Rysskär granite (F). Thus here also the certificate of their age is not wanting. Although the fact mentioned determines their age only in relation to younger rocks, the dykes show, on the other hand, so much difference from the meta-andesites which they penetrate, and such a complete similarity to the dykes occurring elsewhere in the neighbourhood, as to make it indubitable that they also belong to series E.

Thus there seems to be no doubt that the rock masses lying immediately to the north of the uralite-porphyrite formation E, with the exception of the Rysskär granite (F) which occurs here too as numerous veins, and sometimes as greater masses, and, of course, also of the Hangö granite (H), are older than the volcanic Pernå formation, and originally formed the basement on which it was deposited as lava beds, or which it penetrated as dykes filling fissures.

The volcanic series E with its tuffs and lava flows is of course a supercrustal formation, that is to say was deposited on the earth's surface. The circumstance that the surface flows came in contact with so many different older rocks, shows that the geological structure of the basement, at the epoch of the formation of the volcanic formation E, was rather complicated. As plutonic rocks also form part of this basement, it is obvious that a long continued period of erosion, by which the granitic masses have been exposed, has preceded the formation of the supercrustal series E. The strike of the oldest supercrustal rocks A is, in the regions lying most to the east not always conformable with the contact line, but somestimes forms with it an angle of 15—20°. In general, the relation of the supercrustal rocks of the Pernå formation (E) to their basement of different rocks, is unconformable.

The length of the interval of time between the formation of the oldest supercrustal formation A, and that of the volcanic Pernå formation E is measured by the deposition of the sedimentary quartzite, by the intrusion of two plutonic rocks, the Stadsland gabbro C and the Våtskär granite D, by their metamorphism during a period of orogenetic movement and their subsequent erosion. The unconformability between the supercrustal series A and the Pernå formation (E) must in any case be much greater than that between the latter and the younger supercrustal (volcanic) series G, the Pellinge formation, because E and G lie in apparent conformability at their contacts.

THE RABBASÖ FORMATION (B) OF QUARTZITIC SCHISTS AND MICA-SCHISTS, WITH INTERCALATED LIMESTONE.

North of the Pernå formation of metabasaltic rocks, occurs a zone of quartzitic schists which show gradations into mica-schists and sometimes contain intercalations of an impure crystalline limestone.

The predominant rock is a quartzite which is sometimes rather pure, so as to leave no doubt about the fact that it has originally been a sandstone, formed by the weathering of rocks containing quartz.

On Stor Byttholm N. E. of Rabbasö the quartzite is purer than in most other places. On the eastern shore of this island lenticular fragments of limestone with a length of 2 m and a breadth of 0,5 m are found in the quartzite, which shows, near to that place, an unmistakable conglomeratic structure. At some places, again, the quartzite is very fine-grained. This rock consists mainly of rounded grains of quartz, with some microcline, cemented by muscovite. These grains, which probably still retain the original size of the clastic constituents, although the rock is now entirely crystalline, sometimes measure 0,03—0,2 mm, but on an average only 0,1—0,2 mm (Fig. 1, Plate II). The sediment has consequently been a fine-grained sand. Determined by the Rosiwal method, the quartz forms 76, the muscovite 24 percent of the whole, which gives, in weight percentage, about the following composition of the rock, calculated as waterfree:

SiO_2 84, Al_2O_3, Fe_2O_3 and FeO 12,5, K_2O 3,5.

If we use 14 analyses of typical sandstones and quartzites communicated by Rosenbusch[1] as a norm for determining the average composition of these rocks we get

$Si\,O_2$ 80,76, $Al_2\,O_3$ 6,24, $Fe_2\,O_3$ and $Fe\,O$ 3,46, K_2O 1,71, the rest being mainly CaO, $Na_2\,O$, $H_2\,O$ and $C\,O_3$.

In some of these rocks, however, the content of silica is below 70 %, that of alumina as high as 10—17 %, and that of potash 3—4,5 %. The composition of the rock from Stor Byttholm thus falls entirely within the limits of this group. No eruptive rock which has not undergone weathering could possess this composition. It is impossible to regard the rock as a "leptitic tuff" belonging to a metarhyolite. Nor are there any signs suggesting that it could have been originally a cherty rock originated by volcanic solfataric action. It has certainly been a normal sandstone.

Very interesting varieties occur also on the southern shore of Rabbasö in Pernå, where the rock occasionally shows an unmistakable, although indistinct cross-bedding marked by rows of mica. The rock has a middle grain and greyish or white, some times reddish colour. The latter variety occasionally contains well rounded grains of blue quartz recognisable even to the naked eye. These may possibly be originally clastic constituents. In general, however, the rocks are entirely crystalline.

This reddish rock is composed chiefly of grains of quartz and microcline, together with some flakes of muscovite with irregular outlines. The size of the quartz grains is in general 0,05—0,2 mm, but some individual greater grains measure 2—5 mm. When measured under the microscope, the quantities of felspar and quartz seem to be almost equal, with some preponderance of the former (about 5,5 : 4,5). The muscovite only forms a small percentage. As the quartz forms better individualized grains, it seems likely that they are rests or at least reminiscences of the original sand grains, while the felspar, which is almost exclusively microcline, occurring as smaller, more irregular grains, has probably been, at least in part, formed out of the cement which was perhaps a clay poor in iron.

In another rock from the same locality which occurs as numerous boulders, most of the quartz forms grains with irregular outlines, with a size of 0,05—0,2 mm. Some of them are bigger and may have a longer diameter of 1 mm, but then they are usually composed of several grains with different optical orientation and showing barbed outlines.

[1] H. Rosenbusch, Elemente der Gesteinslehre, 3 Aufl. 1898, p. 510.

Grains of plagioclase, seldom measuring 1 mm in length, also occur, and often include a great number of smaller quartz grains. Flakes of biotite lie between the other constituents. The greatest measure 1 mm in length, but they also include grains of quartz. Small grains of magnetite are rather common.

A rock from the sound between Sundö and Rabbasö consists mainly of grains of quartz measuring 0,02—0,2 mm, surrounded by grains of felspar, mainly microcline, which are in part smaller, flakes of biotite and small grains of epidote. Some calcite is also visible. By using the Rosiwal method, we get about 66 per cent of quartz, 22 of felspar, 10 of biotite and 2 of epidote and calcite. The composition of the rock, with about 80 per cent weight of silica, falls within the limits of the sandstone group.

In some cases also plagioclase is present in these quartzites and may be derived from tuffs, or else have been formed during the process of granitization which these rocks have undergone.

Other varieties contain mica in greater amounts, and thus grade into fine-grained mica-schists.

In the northwest the quartzite often alternates with dark, basic schists, and in some places also with thin layers of limestone. Such is the case on the northern shore of Sundö in Borgå, in Klovholm and Husuholm in Pernå and on Fölisöudd where there are several intercalated thin layers of limestone, between others of quartzite which measure several metres. In Kalkholm (= Limestone Island) N. of Fölisöudd no limestone was found in the rocks, but boulders were seen consisting of limestone alternating in thin layers with quartzite.

In another Kalkholm (S.W. of Björnholm) the quartzite is intercalated with layers of "skarn" consisting of garnet, malacolite, amphibole, pyrrhotite, pyrite, arsenopyrite &c.

In many places the quartzite is very much changed because of the intense granitization which it has undergone. On the western shore of Sundö veins of granite of two distinctly different ages are seen in the quartzite, and this is interwoven also with narrow felspathiferous veins which obviously belong to these granites. In many places the quartzite grades into gneissic rocks, which are certainly to be regarded as migmatites of quartzite and granites belonging to several different groups. Some of these rocks are thus to be designated as "polymigmatites".

The relations of the quartzite to the crystalline schists of the Hästö formation which outcrop north of it are those of an apparent conformability. No basal conglomerates nor any sharp boundary have been observed between these formations, and they seem to grade into and alternate with each other. On the eastern side of the quartzite area, however, where micaschists connected with that rock are in contact with a conglomeratic rock which obviously belongs to the oldest schists, their mutual relations are difficult to interprete under the assumption that both formations are entirely conformable. But as granitization has played a considerable rôle at the contact line in question, we will postpone the discussion of these relations till later, when the granitization phenomena will be described.

In any case the occurrence of arenaceous sediments shows that a shore has existed near to the place where they were deposited, and thus erosion processes may have taken place on a neighbouring continent.

This quartzite zone has a continuation outside of the region shown on the map, on the western side of the area of Onas granite, where it outcrops e. g. N. W. of the island Skyttenskär in the parish Sibbo. It is here glassy and mixed up with granitic veins, but the chemical character is anyhow well preserved. The strike is E. N. E.

THE SUNDARÖ FORMATION (A) OF OLDEST SUPERCRUSTAL ROCKS.

The oldest supercrustal schists of the Pellinge area form a zone with a breadth of 3–4 km north of the quartzitic schists and the metabasalts of the Pernå formation. Their strike is N. 60—80° E. in the west, while in the east they turn to a N. 60—70° W. direction. Here they are better preserved than in the west, where they have been in a high degree mixed with veins of the Hangö granite, and also with older granites.

Among the rocks in question fine-grained schists occur which may be called leptites, according to the Swedish nomenclature, although the author uses this term with the reservation mentioned on p. 3. But they may as well be termed hornblende schists.

They are dark, fine-grained rocks with a well developed foliation and consist mainly of hornblende, biotite, plagioclase and quartz in varying proportions. In some of them plagioclase (mainly andesine) is preponderant among the salic constituents, while the hornblende resembles the uralite of the metamorphic volcanic rocks, and is rather intimately interwoven with the felspar. Biotite is present only in small quantities. In other cases quartz predominates, while the hornblende forms more compact crystals (Fig. 2, Plate II). In some cases again, biotite becomes preponderant at the expense of the hornblende. Epidote and small grains of ore are also sometimes present.

There are some varieties of these leptitic rocks which are very near to mica-schists, but most of them, anyhow, are felspathiferous. In some cases both two varieties form alternating layers.

Some of the more basic hornblende schists very closely resemble the tuffs intercalated with the metabasalts of the same region, and probably have a similar origin. The other schists of the

Fig. 24. Meta-andesite from the island Ägghällan near Våtskär. 1:4.

Sundarö formation also very probably contain tuffaceous material, although it may have been changed by atmospheric agencies at the time of its transport and deposition.

Intercalated with these fine-grained schists, porphyritic rocks occur which are typical meta-andesites, showing in a very fine-grained, sometimes almost aphanatic groundmass short prismatic crystals of plagioclase (andesine with 30 % An) with a maximal length of 4—10 mm. Between them sparse and small crystals of uralite are visible. The porphyritic texture is macroscopically very typical (Fig. 24), but under the microscope only few signs of the original texture are visible. The phenocrysts consist of an andesine (33 % An) which is sometimes turbid because of the existence of a great number of minute mineral grains, as well as of larger grains of epidote, zoisite, calcite etc. The groundmass consists of small stalks or compact crystals of secondary green hornblende, flakes of biotite and grains of plagioclase &c. (Fig. 3, Plate II). Secondary quartz is also often present.

Chemically the rock shows the composition of a very typical andesite (a n d o s e according to the American classification). The following analysis (Table XI) has been made by Dr. Eero Mäkinen.

In many places in the middle part of Sundarö there is no sharp boundary between these meta-andesites and the surrounding schists which are probably tuffs. The former occur as smaller lenses in the latter. But dykes of meta-andesite have also been observed cutting the schists in the eastern part of the area, e. g. on the northern shore of Hästö.

Fig. 25. Horizontal rock surface showing an indistinct conglomeratic structure in the Sundarö schists. Western shore of Sundarö, Pernå. 1: 8.

The porphyritic meta-andesite is in part quite homophanous. (The author proposes to use this term instead of the indefinite words massive (or massic), or homogeneous, as a designation of a non-schistose texture (= richtungslos körnige Struktur, R o s e n b u s c h). In places it has been triturated in a more or less high degree, sometimes, as e. g. in some parts of the rocks of Ägghällan, near Våtskär, mylonitized.

At some places the oldest schists also contain intercalations of conglomeratic or agglomeratic rocks. Most of the pebbles consist of rocks belonging to the same eruptive series, such as meta-andesites with grain of varying size, uralite-porphyrites, fine-grained schists rich in amphibole, probably tuffs, and also light-coloured rocks rich in epidote which are either weathered portions of the same volcanic rocks or perhaps such as have been impregnated with

Table XI. Meta-andesite from Ägghällan in Pernå.
Analysed by Dr. Eero Mäkinen.

	%	Mol. prop.	Norm				
SiO_2	52.28	871					
TiO_2	0.87	11	Quartz	1.26	Q	1.26	Sal. 77.15
Al_2O_3	20.75	203	Orthoclase	8.90	F	75.89	
Fe_2O_3	2.35	14	Albite	31.96			
FeO	5.20	72	Anorthite	35.03			
MnO	0.10	1	Diopside	4.64	P	15.46	Fem 20.38
MgO	2.70	68	Hypersthene	10.82			
CaO	8.18	146	Magnetite	3.25	M	4.92	
Na_2O	3.82	61	Ilmenite	1.67			
K_2O	1.55	16		97.53			
H_2O	1.66		Water	1.66			
	99.46			99.19			

zeolites originated by solfataric action. The pebbles are in part well rounded and of very varying size, the biggest measuring about half a metre in diameter.

On the western shore of Sundarö such a conglomerate forms a layer which is several metres thick (Fig. 25). On the easternmost of the Långstrandsholmarna islands, west of Sundarö, there is another, thinner layer of conglomerate.

The greater part of the island of Viasholm also consists of a conglomeratic or agglomeratic rock which was originally of similar character, although it is now partly changed by anatexis in so high degree as to become a massive pseudo-eruptive rock. We will later on give a description of these highly interesting phenomena.

Also in the oldest schists, dykes of uralite-porphyrites occur which are often very much faulted and contorted, and do not resemble the dykes of the same region belonging to the Pernå formation of volcanic rocks. They are probably older than these, genetically connected either with the meta-andesites which are intercalated with the same schists, or else possibly with the Stadsland gabbro. They occur e. g. in Korsö (=Korssundsskatan) and Korsudd in Borgå and in Sundarö and Långstrandsholmarna in Pernå. In the latter place they occur near to the contact of the Stadsland gabbro. No connection with the plutonic rock, however, is visible, and it seems probable that they are older than that rock.

THE GRANITES AND ASSOCIATED PLUTONIC ROCKS AND THE MIGMATITES OF THE PELLINGE REGION

THE RAPAKIVI GRANITE AND ITS INJECTION PHENOMENA.

When now describing the plutonic rocks of the Pellinge region their contacts with adjacent rocks and the process of their injection by which migmatites have been formed, we will begin with the youngest granites belonging to the great rapakivi area of Wiborg whose western margin lies within the region shown on the map.

The rapakivi of Buckholm and the neighbouring small islands, near the Våtskär pilot station, is very typical (Fig. 26). It is a coarsely porphyritic granite, showing phenocrysts of a dark brownish red potash felspar with an ovoid form, coated by rims of green plagioclase, and surrounded by a granitic mass of rather coarse texture in which crystals of grey quartz are conspicuous. The length of the felspar ovoids is commonly 4—6 cm, while it may occasionally reach 10 cm (4 inches). Their breadth is about $^2/_3$ of their length. The plagioclase is an oligoclase with about 25 % An. It forms macroscopically visible borders around the orthoclase with a thickness of 3—4 mm, sometimes also several concentric inner zones due to a repetition of the same causes. The outer oligoclase border does not always possess as regular an ovoid form as the core of potash felspar, but often shows a tendency to the development of crystal surfaces.

On microscopical examination the potash felspar reveals itself as either microcline or orthoclase. The latter is more common. The substance of this potash felspar is very impure. It is intergrown with oligoclase in irregularly interspersed patches, and also contains quartz in so great a quantity that the microcline often may be regarded as a kind of skeleton crystal. The quartz fills interstices in the felspar whose forms are determined by the crystallization of the latter mineral. The walls of these interstices are sometimes cased with a felspar which is more transparent than the main crystal, and seems to have a different composition. Micropegmatite also occasionally occurs as a filling of these interstices. Small biotite crystals are likewise included in the felspar ovoids.

Fig. 26. Typical rapakivi. Small island near Buckholm, N. E. of Våtskär pilot station. 1: 5.

The intersertal mass between the ovoids consists of the same minerals as the latter, but biotite here occurs in greater quantity. It is entirely allotriomorphic against the quartz, but sometimes included in the felspars. Green pleochroic hornblende, which is often also intergrown with quartz, substitutes more or less completely for biotite. The oligoclase forms laths which are rather idiomorphic against the potash felspar, but include, however, grains of quartz. This mineral is, in general, the best individualized among the minerals of the groundmass. Fluorite also occurs, as the last crystallized ingredient. Small, well developed crystals of zircone are common in all rapakivi rocks.

The rapakivi shows very regular fissuration, and the rocks are generally divided into rectangular blocks. This granite has a great tendency to disintegregate by weathering, whereby the felspar ovoids detach themselves from the rock, and the latter gradually changes into a loose gravel (rapakivi = rotten stone). On the shore, however, where the rocks have been only exposed to the action of the atmosphere for a relatively short space of time, the weathering phenomena are less conspicuous than elsewhere.

Although this is not the place to discuss at any length the interesting problem of the cause of the peculiar texture of rapakivi, and especially of the ovoidal form of the orthoclase, the author wishes to say here a few words on the question, because the explanations given by other authors do not appear to him quite satisfactory.

The crystal form of the orthoclase in granitic rocks shows the predominant surfaces (010), (110), (001), (101), (201), (021) and (111), and is in itself very nearly ovoidal. It is only necessary that the sharpness of the angles and corners should become attenuated, in order to give the thicker felspar crystals nearly the form of an ovoid, slightly deformed by being protracted along the axes **a** and **c**. On a close inspection we find also that the ovoidal form of the phenocrysts of rapakivi is not always quite regular, but that an indication of the crystal form of orthoclase is often visible. The surfaces (010) and (110) especially are often well marked, when the outlines of the crystals are in part rectilinear.

Although it may be true that the alternating layers of potash felspar and oligoclase indicate oscillations of the composition of the magma which surrounded the ovoids at the time of their crystallization, as has been suggested by Harker[1], the author does not think it possible to account for the rounded forms of the felspars by the assumption that a supersaturation of the magma with orthoclase and plagioclase substance in turn has caused these minerals to be alternately resorbed. The rounded form of the ovoids has existed during the whole time of their growth, and they are rounded both when formed by alternating layers of orthoclase and plagioclase and when composed of a microperthitic intergrowth of these minerals. In some cases they may even enclose a granitic core consisting of small grains of quartz and orthoclase. The author has observed a few cases where aggregates of these minerals formed heaps with a major diameter of more than a decimetre, which possessed the same

[1] Alfred Harker, The Natural History of Igneous Rocks. London 1909, pp. 267—268.

ovoidal form and were surrounded by borders of orthoclase and plagioclase.

The author regards the ovoids as imperfect crystals whose impurity accounts for the defective development of their crystal forms[1].

If the oval form were due to corrosion, we should expect to find crystals showing the usual Carlsbad twinning which would have been afterwards rounded, when the boundary between the twins

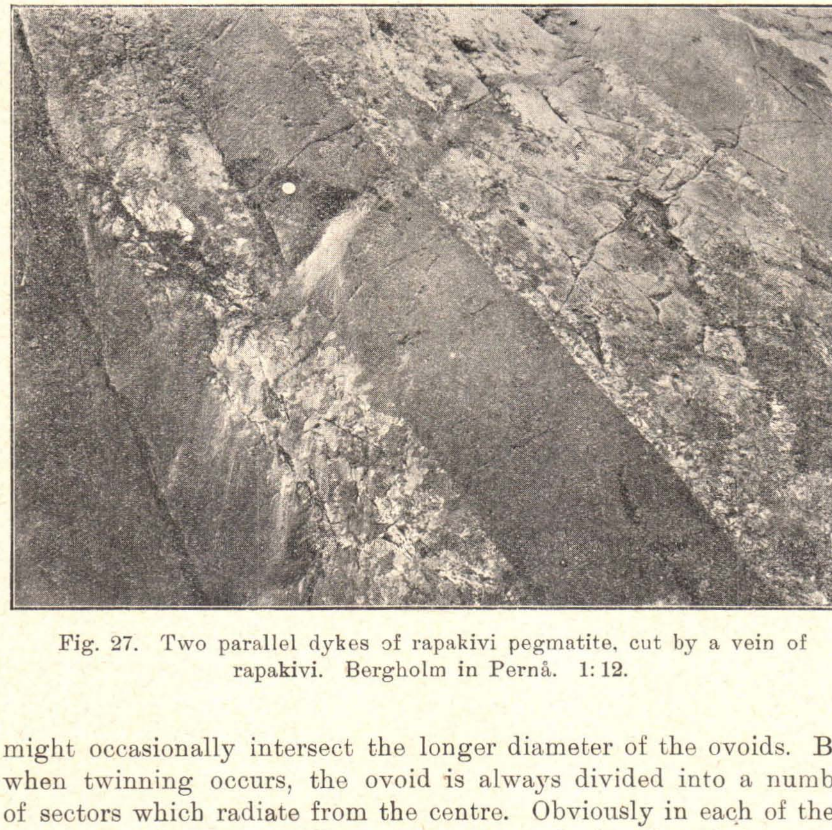

Fig. 27. Two parallel dykes of rapakivi pegmatite, cut by a vein of rapakivi. Bergholm in Pernå. 1: 12.

might occasionally intersect the longer diameter of the ovoids. But when twinning occurs, the ovoid is always divided into a number of sectors which radiate from the centre. Obviously in each of these sectors layer has been deposited upon layer during the whole growth of the crystal.

While most of the rapakivi of the region in question has this typical character, there are also varieties, e. g. in the Hamnholmarna islands, S.E. of Våtskär, which have a finer-grained groundmass. The felspar and quartz are here more intimately intergrown, and

[1] Cf. J. J. Sederholm, Über die finnländischen Rapakivigesteine. Tschermaks Min. u. Petr. Mitth. XII. 1891, p. 4.

the texture is in general more similar to that of a quartz-porphyry than it is in the coarse-grained rapakivi.

In the Buckholm island, N. of the Våtskär pilot station, the contact of the rapakivi with the oldest granite of the region is observed, at the western boundary of the granite area in question. The contact surface seems to dip at a low angle to the west under the covering older granite. At the immediate contact on the northwestern shore of the island a transitional zone between the rapakivi

Fig. 28. Rapakivi and rapakivi aplite showing transitional zones to the older granite. Bergholm in Pernå. 1:10.

and the older rock occurs, measuring only some decimetres in breadth. The rock in this zone has the same medium grain as the older granite, but contains small ovoids of felspar.

Also in the neighbouring island of Bergholm dykes of pegmatite and aplite belonging to the rapakivi intersect the oldest Våtskär granite (D), showing in part rectilinear boundaries. Fig. 27 shows two parallel dykes of pegmatite which are cut by a vein of fine-grained aplitic granite. The same fine-grained rock occurs as small bosses in which the rock at several places shows the rapakivi ovoids (Fig. 28). This aplite is in part sharply defined against the neighbouring gneissose granite, but in some places there are transitional zones between them in which the rapakivi aplite gradually passes into the older granite. Microscopically the rock of this transitional zone shows more similarity to the rapakivi aplite than to the older granite. Only occasional heaps of rounded quartz grains occur which resemble the granulated quartz of the gneissose granite. There is much more potash felspar in the rock than is usual in the Våtskär granite, and in general also the forms of the minerals are such as are characteristic of rapakivi. There are signs which seem to indicate that the felspars have crystallised within a partly solid rock. Myrmekite occurs in the midst of some plagioclases, surrounded by rims of a more transparent plagioclase (Fig. 4, Plate II). As myrmekite is usually formed at the expense of potash felspar, it seems probable that this plagioclase has encroached upon neighbouring microclines. At the centre of plagioclase crystals there is often a core, the substance of which is impure and also otherwise different from the surrounding felspar, and more similar to the felspar of the neighbouring gneissose granite.

In several small islands to the S.W. of Buckholm we are able to study the relations between the rapakivi and the meta-andesite which belongs to the oldest volcanic series A of the region. Although this is older also than the granite D occurring north of it, this granite has but very feebly affected the basic volcanic rock at the contacts; dykes or veins occur only in their immediate neighbourhood. Dykes of the Hangö granite occur in the meta-andesite, but they seem to be rare in the region in question.

All the phenomena of granitization which are visible in the small islands S.W. of Buckholm are solely due to the contact action of the rapakivi granite. This is proved by the fact that all granitic veins occurring here contain felspar with the characteristic peculiarities of the rapakivi minerals. Sometimes typical ovoids surrounded by a plagioclase border are seen.

The older volcanic rocks seem to have possessed a fairly uniform character before they were metamorphosed by the rapakivi. The predominant rock was the oldest meta-andesite described on p. 72. It is possible that dykes of the uralite-porphyrite next younger in age (E) have occurred also in this region, for they are common west of the locality. The main contact of this rock lies only some hundred metres more to the south. In one place also a clastic sedimentary rock which seems to contain leptitic fragments occurs, intercalated with the volcanic beds.

Southwest of Buckholm, between this island and Våtskär, there are several small islands, the greatest of which measures about 100 metres in length. In these islands we are able to study the relations between the rapakivi granite and the meta-andesite. These low rocky islands, which are continually splashed by the waves in stormy weather, are entirely devoid of any covering soil or vegetation.

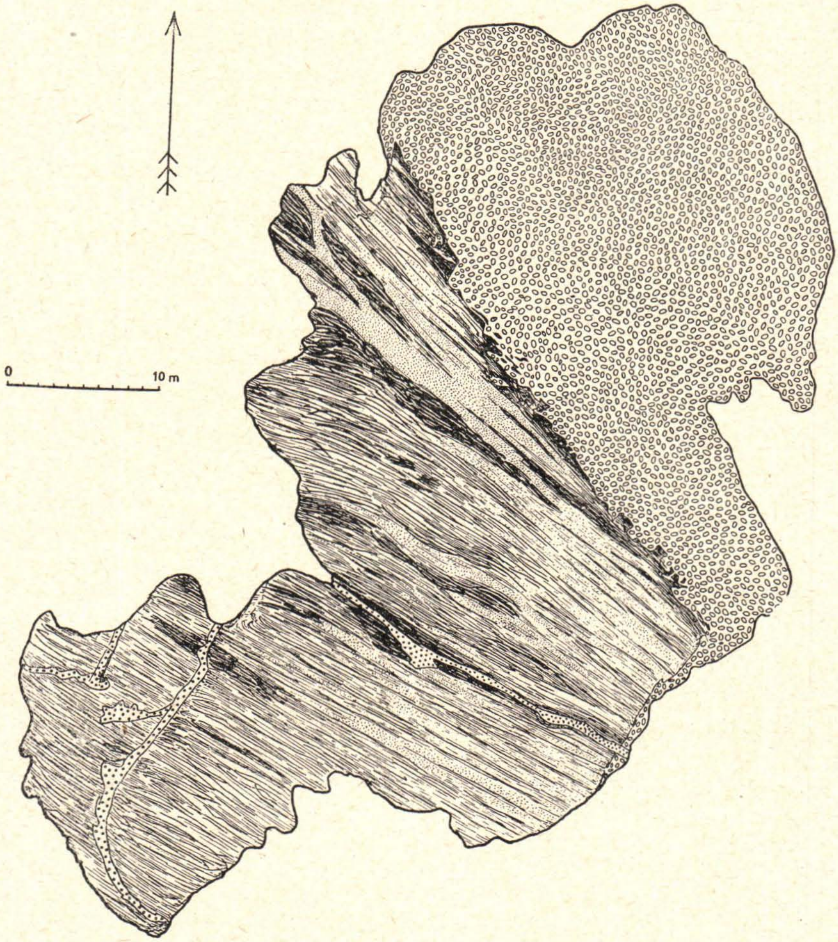

Fig. 29. Map of a small island S. W. of Buckholm in Pernå, where the contact is visible between rapakivi (ovoids), and schistose meta-andesite (lined) penetrated by veins of aplite (bigger dots), and in places strongly granitized (small dots). Scale 1: 500.

In one of them the immediate contact between the two rocks is visible, as shown in the map (Fig. 29). The rapakivi retains its typical character immediately at the contact and shows no diminution of the grain or other sign of an exogenous contact action. On the southern shore we are able to determine that the contact surface dips under the covering schistose rock. It has on the shore an inclination of about ten degrees to the south-west, but it is probable that its dip may be steeper towards the west. This fact, which is in accordance with observations made at the contacts of the rapakivi granites east of Ladoga and in Ångermanland in Sweden, seems to indicate that the rapakivi forms a laccolith or rather batholith under a cover of older crystalline rocks. No dykes of typical rapakivi are seen penetrating the neighbouring basic rocks as apophyses from the greater mass, but a great number of aplitic dykes

Fig. 30. The contact in the small island S. W. of Buckholm in Pernå, seen rom the south. R = rapakivi; S = schistose meta-andesite and tuffs; A = aplite.

and veins, the minerals of which are similar to those of the rapakivi, have been injected into the meta-andesite. In a few places we find, in these veins, the rounded orthoclases, bordered by an oligoclase rim, which are characteristic of the rapakivi. In the rock which is shown in the map one of these aplitic dykes is seen penetrating also the adjacent rapakivi (cf. Fig. 30), but there is no doubt that they belong to the rapakivi magma.

Dykes of pegmatite, whose orthoclase and quartz are entirely similar to those of the rapakivi, are found in the neighbouring island of Ägghällan at a distance of about one kilometre from the contact of the rapakivi. Also nearer to the contact, at a distance of some hundred metres from it, some of the veins are pegmatitic and then rather well separated from the rock which they traverse. Most of them, however, are here aplitic and very intimately interwoven with the basic rock, forming with it migmatites.

These migmatites can be well studied in two small islands north of Risholm (Våtskär pilot station). The predominant rock is here also very basic. Only on the northern shore is there an intercalation of a schistose rock with a different composition, which shows an indistinctly preserved conglomeratic or agglomeratic structure.

Fig 31. Meta-andesitic schists penetrated by veins of rapakivi aplite and pegmatite. Small island N. of Risholm (Våtskär pilot station), in Pernå. 1: 10.

These older rocks are penetrated by numerous veins of granite. In some cases the basic rock is simply brecciated and the fissures filled with granite which is partly pegmatitic, partly a fine-grained aplitic variety (Fig. 31). Some of these veins have a breadth of less than a millimetre (Fig. 32), while the broadest measure a decimetre or more. These are often straight and well defined, and the granite is then frequently rich in black mica at the contact (Fig. 33). Sometimes they are enlarged so as to form greater masses with angular forms, suggesting the idea that a brecciated portion has been solved away by the granite (Fig. 34). Some of the veins end abruptly at one end (Fig. 35). In some cases the fissures in the brecciated portions have been filled partly by granite, partly by a light green pyroxene. The rock in the neighbourhood of the veins is also

Fig. 32. Narrow veins of rapakivi pegmatite in meta-andesitic schists. Small island N. of Risholm 1: 8.

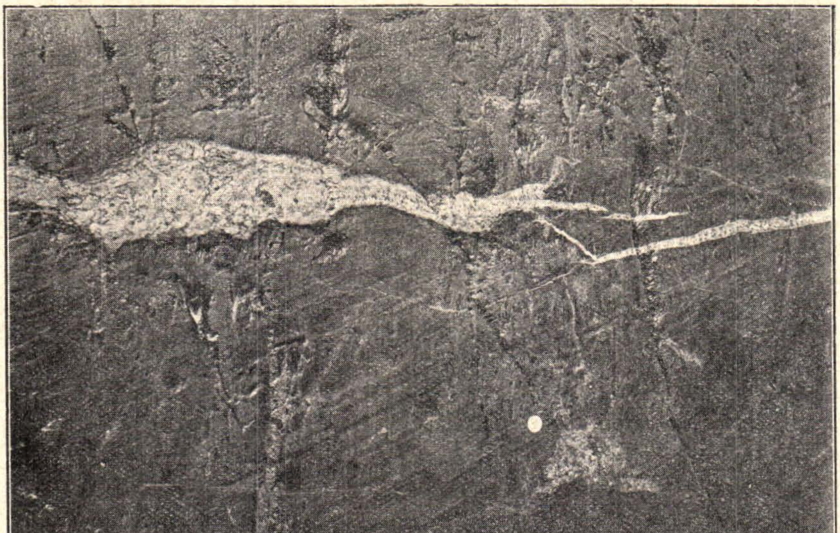

Fig. 33. Veins of pegmatite in meta-andesitic schist which shows a border zone rich in biotite. Small island N. of Risholm. 1: 10.

often rich in such pyroxene. Some of the veins contain small cavities which have perhaps been filled by calcite. In some cases the veins rock is very rich in quartz (Fig 36). Besides the well defined veins there is a number which show faded contours. They have obviously permeated the neighbouring schist with their magma. In this case the schist becomes lighter in colour and very much changed. Sometimes it has a certain resemblance to a hälleflint or "leptite", but that character is here certainly due to secondary changes.

Such a rock with more uniform non-porphyritic character is especially common in the southern island. It sometimes contains

Fig. 34. Veins of pegmatite in meta-andesitic schist. Small island N. of Risholm. 1:10.

lenses of granite, the minerals of which show all the peculiarities of the rapakivi minerals. This granite-like rock grades into the surrounding schist.

Veins of pegmatite or aplite which are straight and well defined when they intersect meta-andesite that shows a better preserved primary texture, occasionally exhibit, when they reach this hälleflint-like rock, the peculiar kind of folding which the author has called ptygmatic and which he thinks is due to undulatory movements in a semi-molten medium (Fig. 37). This is also a sign

[1]) J. J. Sederholm, Über ptygmatische Faltungen. N. Jahrb. f. Min. Geol. u. Pal. Beil.- Bd. XXXVI, 1913, pp. 491—512.

that the hälleflint-like rock has undergone a stronger metamorphism, accompanied by granulation of the porphyritic minerals, than the other parts of the schist.

In the island where the main contact is visible these phenomena of granitization are still more pronounced. Among the rocks older than the rapakivi here too a plagioclase-porphyrite is predominant. It is highly metamorphic and resembles in part the hälleflint-like rock mentioned bove. Alternating with it there are layers of a darker rock rich in hornblende. This alternation may be due to a primary intercalation or, which seems more probable, to a migration of the basic mineral constituents into certain parts of the schistose rock. The aplite veins often show here also a darker border which is rich in hornblende (cf. Fig. 38), like some

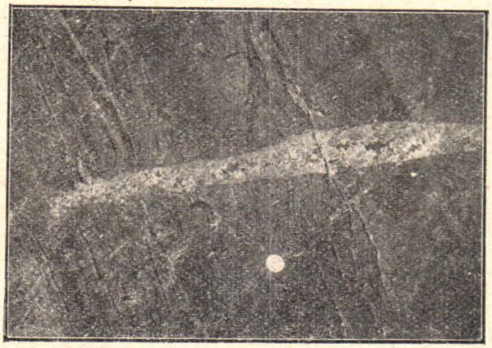

Fig. 35 Pegmatitic vein ending abruptly. Small island N. of Risholm. 1: 10.

Fig. 36. Veins of pegmatite rich in quartz. Small island N. of Risholm. 1:8.

of the fragments in the breccia of the contact (Fig. 39). The schistose rock is intersected by dykes of aplite which partly traverse the schistosity. They are not always sharply defined in this case either, but the granite has, at the contacts, permeated the neighbouring rock so completely as to change it into an acid, "leptitic" variety showing no schistosity (Fig. 40). In those portions of the schist which are

Fig. 37. Veins of rapakivi aplite which have undergone »ptygmatic folding». Small island N. of Risholm. C:a 2: 5.

next to the contact there are also acid parts whose composition grades between that of the aplite and the acid "leptitic" rock, and

Fig. 38. Aplitic veins with a dark border zone, rich in hornblende, penetrating the schistose rock near its contact with the rapakivi. Small island S. W. of Buckholm. 1: 8.

which are rather to be regarded as highly granitized parts of the schists, than as granitic dykes proper. Where this rock is in contact with the rapakivi, it is brecciated and behaves as something foreign to the magma in which it is included as fragments. In Figg.

39 and 40 we remark such brecciated parts next to the main contact, together with fragments occasionally containing within their limits ovoidal orthoclases with oligoclase rims. This fact proves that the schistose rock has been permeated by the granitic magma.

In Fig. 26 is also seen an indistinctly preserved fragment of a highly granitized rock, which lies in the rapakivi some metres from the contact. In general, however, the granite is remarkably free

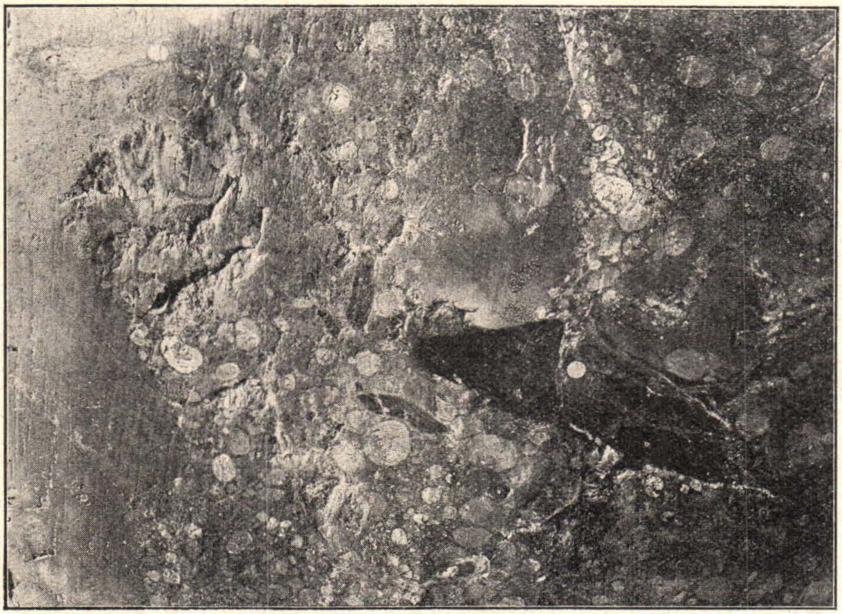

Fig. 39. Contact between rapakivi and meta-andesitic schists. The fragments of schist are in places strongly aplitized, while some of them are rich in hornblende. Within the limits of the former felspar ovoids have been formed. Small island S. W. of Buckholm. 1: 9.

from inclusions, which proves that the fragments that have been entirely detached from the schistose rocks have been rapidly solved by the granitic magma.

In some other small islands which lie to the north of the one where the main contact is visible, a meta-andesite occurs which has in part a well preserved primary texture, but is penetrated by narrow fissure veins of granite.

No geologist could visit these localities without being convinced that the granitic magma is able intimately to permeate neighbouring rocks. Even macroscopically we find here the most irrefutable proofs of an intense granitization "par apport", and we are enabled to add more facts to this evidence by studying the same phenomena microscopically. This circumstance is of great value, because it is in general rather rare to find granitized rocks which retain so much of their primary texture as to allow its recognition. It is therefore, in most cases, difficult to follow the course of the changes which the rocks have undergone at their granitization. But here we have an opportunity of studying gradations between more or

Fig. 40. Contact between rapakivi and meta-andesitic schists showing intimate penetration of the rapakivi magma into the schists. Small island S. W. of Buckholm. 1:9.

less strongly granitized rocks and determining the way in which the process has taken place.

At the contact of more sharply defined veins of rapakivi aplite occurring in the island of Risholm, the plagioclase-porphyrite shows macroscopically the same texture as elsewhere, but the study of thin sections reveals the fact that the femic minerals of the porphyrite have been replaced by small flakes of biotite, while small grains of quartz have become abundant among the salic constituents. The aplite is rather rich in plagioclase and sparsely contains small garnets, an unusual mineral in the rapakivi rocks.

In the small islands next to the main contact, the plagioclase porphyrite occasionally shows its earlier composition very little altered even next to the narrow veins of aplite. The porphyritic andesine crystals especially are often well preserved, and the groundmass also occasionally shows a texture which is not very different from that of the same rock farther from the contact (Fig. 1, Plate IV), although sometimes the porphyritic felspars have been granulated (Fig. 2, Plate IV),.

Where the rock is dark, it is rich in crystalline, strongly pleo chroic, green hornblende either as homogeneous crystals or intergrown

Fig 41. Contact of the broadest aplite dyke visible in Fig. 29 with the adjacent schists, which are in places highly granitized. Small island S. W. of Buckholm. 1:8.

with small grains of quartz. Other varieties are richer in salic constituents. It can also be proved microscopically that the composition of the rock has been changed by the injection of aplitic or pegmatitic magma. The rock of the narrower veins still shows much affinity to that of the broader dykes of rapakivi aplite or pegmatite. The character of the minerals in the former is often quite identical with that of more typical granite, and also the texture shows much resemblance. The narrow veins which traverse the basic rock, contain, however, much more oligoclase than the broader dykes. The narrowest veins especially, which have sometimes indefinite boundaries to the surrounding schist, are rich in plagioclase and also contain crystals of biotite, and sometimes a pale pyroxene (diopside). The orthoclase is not quite as highly idiomorphic as these minerals, while the quartz, which is often abundant, is altogether allotriomorphic (Fig. 3, Plate IV). Tourmaline is common in many of these veins and often in the surrounding schist.

Where the magma of the veins has more completely permeated the surrounding rock, the latter contains salic minerals in greater amount, and the femic constituents begin to form better developed crystals. In some cases chiefly hornblende and biotite occur, while in others diopside is also present either as individualized crystals or as groups of such. The salic and the femic constituents are either uniformly dispersed or form alternating stripes (Fig. 4, Plate IV) which are occasionally undulating.

In a variety which was very rich in tourmaline, the larger crystals of microcline and also of quartz were full of small inclusions of plagioclase grains (Fig. 5, Plate III), reminding one of the poikilitic texture, although probably not originated in the same way.

In the most highly aplitized, palecoloured varieties of the rock next to the contact the femic constituents are almost entirely obliterated. Only small grains of ore occur, marking the parallel texture of the rock, which is also elsewhere very distinct. This variety consists chiefly of small grains of quartz and plagioclase, possibly also some potash felspar.

The rock of the veins which show ptygmatic folding consists of orthoclase and quartz. The quartz crystals are composed of a number of grains with different optical orientation, but they do not show any influence of mechanical pressure (Fig. 6, Plate IV).

The existence of sharply defined pegmatitic dykes at a distance of about a kilometre from the contact shows that fissuring has occurred in the walls of the batholith, at the time when the magma was still fluid. There is also evidence of movements in the rock-masses which have been granitized in a higher degree. If the rocks were solid, these movements caused a local brecciation, if they were semi-fused, or plastic, they became folded. In the same measure as the covering rocks were brecciated they became impregnated with the magma and very soon solved. It must be emphasized that the neighbouring rocks were penetrated not only by ,,juices" from the granite but by the magma itself. The former process would have caused mainly a recrystallization of the older rocks, which in that case would have retained their basic composition.

Here, however, an analogon to metamorphism ,,par apport", that is to say an impregnation of the older rock with granitic magma, has occurred.

That gases have been concomitant to this process, is shown by the presence of tourmaline in several of the veins. Fluorite is also a common mineral in all rapakivi rocks. However, it seems rather probable that the emanation of boric acid, fluoric acid and other gases has rather accompanied granitization than been the cause of it, and it does not seem correct to design the process in its entirety as pneumatolytic.

COMPARISON WITH OTHER CONTACTZONES OF THE RAPAKIVI GRANITES.

For comparison, some contact phenomena at the borders of the rapakivi granites in other regions may be here briefly described. In general, these granites form rounded areas which are well defined, and where dykes occur only in the immediate neighbourhood. Only at the northwestern boundary of the great Wiborg area are there dykes connected with these granites which intersect the neighbouring rocks to a distance of more than 20 km. The texture of the dyke rock is then porphyritic.

At the northern and western limits of the area east of Nystad in south-western Finland, a rather intense granitization of the neighbouring older rocks has taken place. These are granites of the Hangö group, some even older, together with schists and basic rocks. Both the latter are often intricately interwoven with the Archæan granites, forming arteritic migmatites At the northern contact of the rapakivi, the author has studied the relation between the older rocks and this granite near to the Vuojoki railway station.[1] Up to a distance of some hundred metres from the rapakivi, we find in the older granites and also in the basic rocks characteristic minerals and textures and sometimes also veins of rapakivi. It is often impossible to draw any sharp demarcation-line between these veins and the older rocks.

These phenomena are still more conspicuous at the western boundary of this rapakivi area where the contacts have been studied by Eskola, together with whom the author has visited the most important localities, and also later by Hackman. In many places the granite is here surrounded by an aureole measuring some hundred metres in breadth, where all the older rocks are brecciated and permeated by a grey aplite which certainly belongs to the rapakivi magma. It occasionally contains rounded orthoclase crystals with a rim of oligoclase, and shows other rapakivi peculiarities.

[1] J. J. Sederholm, Beskr. t. Bergartskart. B 2, Tammerfors, 1911, pp. 100—101.

The older rocks sometimes form distinct fragments, but more often patches with indefinite outlines which are surrounded by purer granite. They are to be regarded as an eruptive breccia with highly digested fragments. Veins of pegmatite occasionally occur farther from the granitic area. They are also often vaguely defined against the older granites.

In one place, on the high road about 6 km east of Nystad, a contact occurs where the typical rapakivi grades through a striped granite containing garnets and enclosing highly digested portions of the older rocks, into a micaceous gneiss-like migmatite with indefinite veins of grey granite which at some places shows the characteristical ovoids of the rapakivi. This is the locality af present known where the contact action of the rapakivi has been most intense.[1] In general, the anatexis of the older rocks which it has caused, has not reached the same degree as is common where the Archæan granites have penetrated the neighbouring rocks. There we find migmatites, almost at every contact, often on a very large scale. At the rapakivi contacts, on the contrary, true migmatites, showing a very intimate mixture of the different components, occur more locally, and those migmatites which show the characteristic fluidal (ptygmatic) folding are especially rare.

Also at the northwestern boundary of the Wiborg rapakivi area, however, phenomena of granitization occur which have been described by Frosterus.[2] Here, too, the process has sometimes reached a considerable intensity. Diabases, diorites, gneissose granites and micaschists show sinuous boundaries at the contact with the rapakivi, because of the solvent action of its magma, and eruptive breccias, consisting of fragments of older rocks and veins of rapakivi granite, are very common. The basic rocks in particular have been very intimately interwoven with veins of this granite, and their individual minerals show also very characteristic corrosion phenomena. In some places, however, rectilinear, sharp contacts occur. Next to them the rapakivi becomes more fine-grained than elsewhere.

The inclusions of basic rock in rapakivi granite which occur in the neighbourhood of the railway station Simola, W. of Wiborg, are also of very great interest. They form masses with a diameter of several hundred metres having in part still the same consti-

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[1] In the summer of 1921 the author studied rapakivi rocks in the archipelago between Åland and Åbo where the contact action of the rapakivi magma on the older rocks has been still stronger. These interesting phenomena will be described in a later memoir.

[2] Benj. Frosterus, Beskr. t. Bergartskart. C 2, S:t Michel. 1902, pp. 64, 88 seq.

tution as the original rock, which is a metadiabase, often containing large phenocrysts of a basic plagioclase. But this basic rock has been almost entirely recrystallized and has now a texture reminding one of contact-metamorphic rocks, although the minerals are coarse. Minerals characteristic of rapakivi granite occur, however, also in the basic masses, and near to them the granite is generally dark, often almost black in colour. This is due to the occurrence of innumerable inclusions in the felspar. Synantetic minerals are common and, as the author has shown elsewhere, have been formed in connection with a migration of material, at a time when only parts of the magma were fluid.

It is of great interest to note how important a rôle this migration of certain constituents of the rocks has played even at the end of the consolidation of the magma. This suggests the idea that movements of certain parts of the magma have taken place in a still larger measure at the time when a great portion of it was still fluid. At a moment when the main part of the potash felspar and quartz had already crystallized, iron, magnesia, lime and sodium may have still existed in solution and have been easily carried away every time they increased in quantity by the fusion of resorbed fragments. These may either have been distributed, by ascending waters, in overlying rocks, or sunk to greater depth where they formed a basic magma deeper below, or also simply been evenly distributed in the granitic magma which was in process of crystallization.

At the eastern boundary of the rapakivi area E. of Ladoga dykes of aplite belonging to this laccolith occasionally occur even at distances of 2—3 km from its boundaries. Juices which have accompanied the magma have acted very intensely upon the neighbouring crystalline limestones at these distances and even farther from the contacts. It has impregnated the limestone with magnetite, pyrites, galena, sphalerite and tinstone. In general, however, the granitization at the contacts of the Ladoga rapakivi has been very feeble, and its margins are sharply defined. All these phenomena have been described in a masterly way by Trüstedt.[1]

Phenomena of impregnation and solution occur also at the contacts of the rapakivi areas in northern Sweden, especially in the Ragunda region where the granite forms a typical laccolith or batholith.[2]

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[1] Otto Trüstedt, Die Erzlagerstätten von Pitkäranta am Ladoga-See. Bull. Comm. géol. Finl. N:o 19. 1907.

[2] Cf. the figure in the author's memoir Om granit och gneis. Bull. Comm. géol. Finl. N:o 23. 1907, p. 30.

The study of the textures of the rapakivi granites has in many cases given the clue to the right understanding of the primary textures of the older Archæan granites of Fenno-Scandia. In the same way, the study of their contact action throws much light on the more intense contact action which the older granites of the same region have exercised in the rocks which they have penetrated.

THE ONAS GRANITE AND ITS CONTACTS WITH THE NEIGHBOURING ROCKS.

The Onas granite which occurs in the ~~ea~~western part of the Pellinge region forms an outcrop with rounded outlines, which has an area of about 270 km² and extends to the north into the immediate neighbourhood of the town of Borgå.

This granite resembles very much some granites from the typical rapakivi areas. It is composed of large, rounded crystals of reddish brown microcline separated by grains of plagioclase, blue quartz and black hornblende, together with some biotite.

The larger felspar crystals have a length of one to two centimetres. They are mixed with plagioclase in parallel intergrowth, but the same mineral occurs also as separate crystals with a maximum length of 8 mm. It is an oligoclase with a maximal extinction in the zone perpendicular to 010 of 12°, thus containing about 29 % An. Beside the larger patches of oligoclase the microcline also contains narrow winding stringers of an acid plagioclase which seem to be secondary. It also contains inclusions of quartz whose outlines are partly determined by the forms of the felspar, while other quartz crystals are more idiomorphic. The greater part of the quartz lies between the larger felspars and is entirely allotriomorphic. Each individual is divided into a number of grains with different optical orientation which show undulatory extinction. The quartz which is included in the larger felspar does not show, however, this phenomenon in any marked degree, obviously because it has been protected against mechanical pressure by the surrounding felspar.

The femic constituents occur as heaps with a diameter of some millimetres. Green hornblende predominates, but also a highly pleochroic biotite occurs. In some hornblende crystals there is a core of quartz grains mingled with fluorite. Among the femic constituents there are some ore grains. Zircone occurs in the rock as small crystals.

Myrmekite is common in places where microcline and oligoclase meet, especially at the borders of the greater felspar crystals, but sometimes also in zones penetrating them. It is probably at least in large measure a "deuteric" constituent[1].

In the region shown on the map no contacts between the Onas granite and the older rocks are visible. More to the north the author has found contacts at the eastern boundary of this granite area on the island of Bergholm in Långfjärden, south of Fagersta in the parish of Borgå. The neighbouring rock is an old granite with veins of pegmatite. At the contact with the Onas granite this older rock is broken into fragments which form together with the younger granite, which is here medium-grained, an eruptive breccia. Veins of the same granite penetrate the older rocks in the neighbourhood of the breccia, but do not occur very far from the contact.

At the western margin of the same area of granite there are, west of the Onas islands, very interesting contacts between the granite in question and the neighbouring older rocks. The author has studied these localities several times during more than ten years, often in company with Professor Borgström who has investigated this region in great detail and will report upon his observations in the future. We will here only briefly mention some circumstances which are of interest for the subject here treated.[2]

The older rocks are metabasites and granites of at least two different ages, corresponding to the groups D and H of the Pellinge region. The younger of them forms eruptive breccias and other migmatites with the older rocks. At the western boundary of the Onas granite veins connected with it penetrate all the neighbouring older rocks, forming eruptive breccias within a zone that has a breadth of several hundred metres. The granite which cements these breccias is finer-grained than the main mass of the Onas granite. At the contacts with the metabasites the granite has sometimes assimilated hornblende and is dioritic or syenitic in composition. The fragments of older rocks often show by their forms that they have been corroded by the magma. In the breccia of Brunskär, where this rock is best developed, the author has found in one place granitic portions with rounded outlines which also seem to be due to the solvent action of the granitic magma. It has probably enlarged fissures, in places where they have intersected each other, into rounded cavities.

When pegmatite belonging to the Onas granite intersects veins of older pegmatite, the contacts are not always quite sharp. This must be due to refusion or palingenesis of the older rock.

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[1] Cf. J. J. Sederholm, On Synantetic Minerals &c. Bull. Comm. géol. de Finl. N:o 47. p. 142.

[2] Cf. J. J. Sederholm, Om granit och gneis. Bull. Comm. géol. Finl. N:o 23, p. 31.

Here, too, the batholith has a rather well defined limitation against this surrounding zone of eruptive breccia and is remarkably free from inclusions. The solution of the fragments of the brecciated older rocks seems to have taken place mainly within this brecciated zone. When the fragments have sunk into the larger mass of granitic magma they have rapidly been entirely solved.

Borgström has described a quartz-porphyry[1] from the region west of Onas, 16 km from the western boundary of the Onas granite. This rock shows some peculiarities which distinguish it from the quartz-porphyrites commonly connected with rapakivi which occur in southern Finland. Borgström thinks it probable that this dyke is genetically connected with the Onas granite.

If this assumption is correct the occurrence is of great interest, because it shows that the temperature of the older rock masses, in regions neighbouring to the Onas batholith, was so low, at the time of the intrusion of this granite, that a rapid cooling was possible. In any case the refusion which the Onas granite has exercised upon the adjacent rocks has been restricted in extent in the same way as that caused by the rapakivi magma, not regional in the widest sense of the word, as the anatexis which has taken place in connection with the intrusion of several of the Archæan granites.

THE HANGÖ GRANITES (H) AND ASSOCIATED MIGMATITES.

Among the granites occurring on the southern coast of Finland those which have the widest distribution are the granites rich in microcline, earlier designated by the author as "post-Bothnian", also as "coast-granites". The best known types among them are the red granites from Hangö and Ingå, which have been largely used as monumental stones, and the coarse-grained porphyritic granite from Perniö (Bjernå) which has been described in detail by Eskola, the red granite from Åbo and the grey granites from Hitis and the neighbourhood of Nystad.

The geological designation "post-Bothnian granites" refers to the fact, that they are younger than all the Archæan supercrustal rocks of western Finland, including the uralite-porphyrites of the Tammela area, W. of Tavastehus, and all the uralite-porphyrites of the region described in this memoir. The volcanic rocks of Tammela

[1] L. H. Borgström, Granitporphyr från Östersundom. Bull. Comm. géol. Finl. N:o 22. 1907.

have been tentatively correlated by the author with the old "Bothnian" formation of metamorphic sediments and volcanic rocks of the Tammerfors region,[1] as well as with the similar schists, mainly consisting of metamorphic volcanics and their derivatives, which outcrop in Ostrobothnia in Finland and the Skellefteå region in Sweden and have been described by Mäkinen,[2] Högbom,[3] Eklund,[4] and others.

But while the author thought before that the supercrustal rocks of Bothnian type were y o u n g e r than the hornblende-granites, diorites &c. which have a wide distribution in the region between Tammerfors and Tammela, he has later found that most of these plutonic rocks, and not only the granites of Hangö type and associated rocks, penetrate the Bothnian schists of Tammerfors, as well as the uralite-porphyrites of Tammela. The latter volcanic rocks thus seem to have a position analogous to that of the older uralite-porphyrites (the Pernå formation) of the Pellinge region, which are also penetrated both by a group of hornblende-granites and by the Hangö granites. It therefore seems more likely that the older uralite-porphyrites are to be correlated with the uralite-porphyrites of Tammela and Tammerfors, rather than those of the younger, Pellinge formation.

If that is true, then the Hangö granites would be not only post-Bothnian, but even younger than another group of granites of post-Bothnian age, which is separated from the Hangö granites by the supercrustal formation to which the youngest volcanics of the Pellinge region (i. e. the Pellinge formation) belong.

In any case these »coast-granites» occurring on the northern shore of the Gulf of Finland form, geologically and petrographically, a well defined group, comprising those granites which are intermediate in age between the rapakivi, the Onas, the Obbnäs granites &c., and the older granites of the same regions.

The Hangö, or post-Pellinge granites, are here represented by several types differing in composition, colour and texture, but all connected by gradual transitions. They are mostly pale red or reddish brown, in some cases grey or nearly white. Other varieties

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[1] J. J. Sederholm, Über eine archäische Sedimentformation &c. Bull. Comm. géol. Finl. N:o 6, 1897, pp. 203—207.

[2] Eero Mäkinen, Översikt av de prekambriska bildningarna i mellersta Österbotten. Engl. Summary of the Contents. Bull. Comm. géol. Finl. N:o 48, 1916.

[3] A. G. Högbom, Precambrian Geology of Sweden. Bull. Geol. Inst. Upsala, Vol. X. 1910.

[4] Josef Eklund, Skellefteåfältets geologi (Preliminary communication). Geol. För. Stockh. Förh. 1923, pp. 219—224.

have a deeper red colour. These colours are mainly determined by that of the predominant microcline. The quartz is generally pale grey and has therefore very little influence on the colour. The relative amount of biotite has a certain influence on the more or less dark shade of the rock. Often these granites contain g a r n e t s (almandine) sometimes associated with, or replaced by c o r d i e r i t e. These minerals appear on the surface as dark spots.

The prevailing varieties of these granites are medium-grained, but they grade into coarser-grained rocks which often become pegmatitic. The coarsely porphyritic varieties which are elsewhere common among these granites, are not represented in the region now in question in any specially typical form.

Typical pegmatites and aplites are also very common, both as dykes penetrating the neighbouring older rocks and as large masses in migmatites where the granitic constituent predominates.

Because of their richness in microcline these granites almost constantly show a high amount of potash. No analyses have been made of such granites from the Pellinge area, but their composition seems to be in general almost identical with that of the granites from Hangö, Skarvkyrkan by Tvärminne, east of Hangö, and Perniö (Bjerno) analyzed before. These are Dellenoses or Toscanoses, according to the American classification, and possess a high amount of silica (71,75—73,91 %), nearly 14 % Al_2O_3, a low amount of iron, magnesia and lime, but 5,85 to 6,53 % potash. There are, however, in the region now in question, some varieties richer in biotite or in garnet, which probably contain more iron than the most common types. On the other hand, aplitic varieties occur in which femic minerals are almost absent, or only represented by a few scattered garnets.

These granites show to the naked eye, where they are homogeneous, almost no traces of schistosity. When they are striped, that phenomenon is usually caused, as the author pointed out as early as 1893, by the occurrence of more or less completely resorbed inclusions of foreign rocks, whose femic constituents partly remain as stripes of mica. In some cases also a fluidal arrangement of the salic minerals may have occurred, although no typical instances are known to the author from the region now in question.

In general these granites of the coast-type are very inhomogeneous, including a large number of fragments of foreign rocks in all stages of dissolution. Over wide areas they are so mixed with older rocks which they penetrate that it is difficult to say which constituents of the migmatites predominate.

Although the mountain-making processes in which these granites have taken part have not been strong enough to give them any schistosity, the minerals show, especially under the microscope, visible signs of pressure. Even macroscopically we find that the larger felspars, e. g. in the pegmatitic varieties, do not possess entirely unbroken cleavage surfaces, but are broken in a number of portions which show slight differences in their orientation. The quartz is also a good deal crushed.

The author has studied the granitization phenomena connected with the intrusion of these post-Pellinge granites in greatest detail

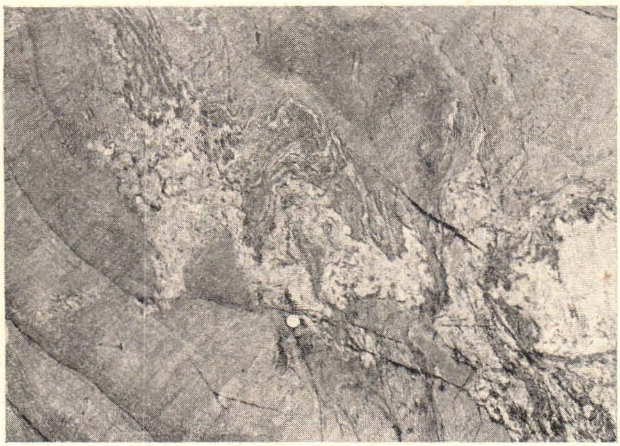

Fig. 42. Migmatite of Hangö granite and hornblende schist. Northern shore of Sundarö in Pernå. 1:12,

in the regions W. of Helsingfors, especially in the neighbourhood of Hangö. By drawing a number of large scale pictures of eruptive breccias in which the fragments of foreign rocks include basic dykes of characteristic appearance, he has, as already mentioned, been able to follow the movements which have occurred in the molten magma. The region here in question does not afford equal opportunities for the study of these Hangö granites, but even here they show phenomena of much interest.

In the northernmost part of the area mapped these granites predominate, sometimes rather homogeneous, but more often also here including clusters of more or less completely resorbed foreign rocks.

At the contact with the zone of old schists belonging to the Sundarö formation (A) and outcropping south of this area of granite, very typical migmatites occur. Fig. 42 shows a horizontal rock surface in the northwest of Sundarö, where the schist is penetrated by a large number of veins of pegmatitic granite, which are contorted in the peculiar manner so common in these granites. The most typical instances of "ptygmatic" folding, which the author has already described, also belong to granites of the same group, outcropping west of Helsingfors.

When the quantity of the granitic constituent of these migmatites increases, the composition becomes gradually almost entirely granitic, although serpentinizing narrow stripes of a darker schistose rock richer in biotite still are left (Fig. 43.). Such rocks occur

Fig. 43. Striped migmatitic granite. Steinars torp S. of Gäddrag, Borgå. 1: 5.

everywhere in the northern granitic area, especially where there are numerous fragments of schists.

In the southern part of the area mapped we find again similar granites intermingled with the basic effusive rocks belonging to the Pernå formation (E). In the southwestern islands these migmatitic rocks are especially typical. Such migmatites of basic rocks and microcline granites continue farther to the west along the southern boundary of the Onas granite area, and they form the greater part of the rocks in the archipelago between the Onas area and Helsingfors.

Migmatites of microcline granite and quartzite, or of this granite and hornblende-schists, possessing the same character as the schists in the Hästö formation (A) in the Pellinge region, and migmatites consisting of several different granites, also occur in the archipelago east of Helsingfors.

We will here describe a number of typical instances of granitization caused by these granites, beginning with those in which the two constituents are better separated and ending with the more completely mixed rocks.

On the western shore of the Stor Pellinge island and in the small islands to the west of it, a pegmatitic granite of group H occurs, forming a number of broad dykes, and aplitic granite is also common as dykes, veins or small bosses. Both granites also occur more intimately mixed with the uralite-porphyrites. The strikes of the latter rocks show here a sudden change in their direction, from E.N.E. to N.W. which proves that severe dislocations have occurred at this place.

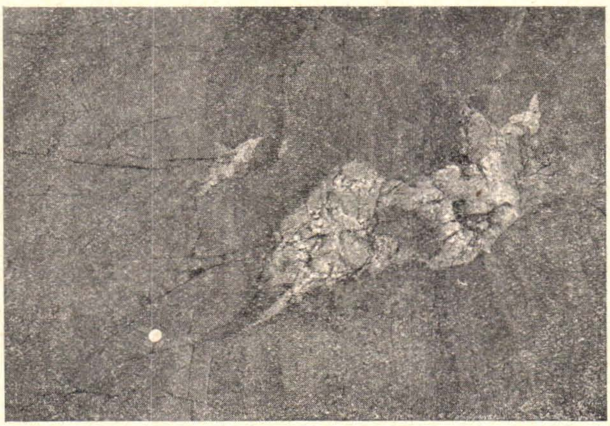

Fig. 44. Pegmatite filling irregular cavities in the metabasalt. Ednäsudd, Stor Pellinge. 1:12.

In the island N y t t i s h o l m and on Point E d n ä s u d d (Edisudd) the phenomena of granitization may very well be studied. The predominant rock is a uralite-porphyrite which is rather strongly metamorphic, i. e. a porphyritic schist whose texture sometimes approaches that of a hornblende gneiss.

The drawing in Plate VIII gives a picture of a system of granitic dykes and veins visible in the rocks on the south-western shore of Nyttisholm. The length of the surface is 11.6 metres, the breadth 5.6. It slopes at a low angle towards the south.

As we are aware, narrower veins branch off from the main dyke at all sides. No doubt the formation of a fissure has marked the beginning of the injection of the granite, and some of the ramifying narrower veins have the character of fissure fillings, but it is not possible to account for the forms of all these veins which penetrate the surrounding rock in such an intricate way, simply by the assumption that the rock has been mechanically fractured and the fissures filled with granitic magma.

Beside the straight veins which meet each other at high angles, there are some which possess very irregular forms, clearly indicating a magmatic corrosion, and a great number of smaller lenses of granite which show no visible connection with the broader dykes. Most of the straight veins are nearly parallel with each other, and in some cases they also run parallel with the schistosity of the basic rock. In general, however, their direction is not entirely coincident with that of the schistosity.

The narrower veins only seldom intersect each other in such a way as entirely to detach fragments from the main mass of the rock. Very often transversal veins end at a short distance from another vein, so as to leave a narrow stripe of basic rock as a connection between them and the main masses of uralite-porphyrites from which they have been torn away. Only in very few instances do these highly lacerated marginal portions seem entirely detached; commonly they rather resemble promontories projecting from a mainland than islands. Moreover, in the latter case they may possibly be connected with the larger masses at a level which lies below or above the surface of the rock. Rocks appear very differently when they have been shattered in connection with dislocations that have taken place in the uppermost, brittle parts of the lithosphere. In such cases commonly great parts of the rock are entirely brecciated, and the fragments detached from each other.

In the present case slow torsional movements are more likely to have taken place than sudden ruptures. All the fissures have not originated at once, but they have been opened during the gradual destruction of the basic rocks, and obviously in connection with a process of solution caused by the granitic magma. All those veins which end blindly, and the smaller lenses, are certainly due mainly to solution.

But the author may let the picture speak for itself. It can hardly be interpreted under the assumption that a rock which has been fissured beforehand in a purely mechanical way, has simply been cemented by granite. The solution phenomena are so conspicuous as to allow of only one explanation.

Most of the vein filling is a pale granite of medium grain, but a part, especially of the narrower veins, is filled by coarse-grained pegmatite (dotted in the figure). This rock seems to occur with predilection in the straight veins. It seems to be a general rule all over the world that dykes and veins of pegmatite, where they have not later undergone "ptygmatic" folding, are more often regular and straight than other granitic bodies. Perhaps the explanation is that these dykes have been formed at the end of the solidification of the granite, when the time for widening and disfiguring the fissures by resorption was limited. Probably the pegmatite also has crystallized more rapidly than the larger masses of granite. The same circumstances may also account for the implication texture of the pegmatite.

The granite of Ednäsudd is partly pegmatitic, partly aplitic. A great part of the pegmatite does not occur as dykes, but as

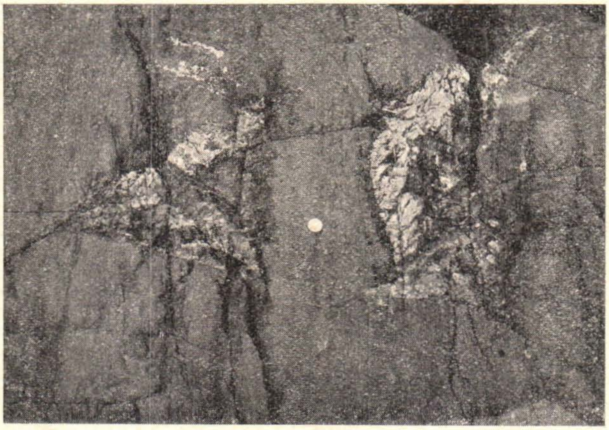

Fig. 45. Pegmatite filling irregular cavities in metabasalt. Ednäsudd, Stor Pellinge. 1: 10.

irregular masses with angular forms, looking as if they had filled cavities in the basic rock. (Fig. 44). Sometimes these pegmatitic portions show no visible connection with other parts of the granite, or with any fissures through which they could have been fed, but in other cases they are arranged in rows which obviously belong to one and the same fracture zone and in part are connected by narrower veins of granite. Their forms are often rectilinear, and then they look as if they had been limited by fracture lines. Cf. Fig. 45 where there is a narrow vein of granite connecting the two bigger, lump-like portions. The author thinks it most probable that these inclusion-like pegmatite dykes have originated by the leaching out of such portions of the basic rocks as became broken up during granitization.

In other cases the forms of the granitic portions are more irregular (Fig. 46), and the granite is then impurer and shows in places indistinct boundaries against inclusions of the basic rocks, which it seems to have impregnated and partly absorbed.

These occurrences exhibit gradations on the one hand into eruptive breccias (Fig. 47) in which the smaller fragments have also in a large measure been absorbed by the granite, on the other hand into rocks which more resemble the veined gneisses common in the region west of this locality (Fig. 48). Further, there are varieties in which aplite occurs as small lenses or as narrow veins

Fig. 46. Metabasalt injected by pegmatite and aplite. Ednäsudd, Stor Pellinge. 1:12.

(Fig. 49), which seem to be due to torsional movements in the rock during which certain parts have been crushed and then leached out by the granitic juices.

Some of the narrow veins branching out from the pegmatite dykes contain quartz and epidote which latter mineral sometimes forms bundles of radially arranged small crystals.

Where the pegmatite veins occur near to vertical surfaces, or their surface portions have been leached out by the sea water, it is possible to determine that their boundaries have a steep dip, from 45° to 90°. It is thus not possible to explain e. g. the pegmatite dykes shown in Fig. 45 as portions of a horizontal dyke whose main part has been solved away.

The basic rock has been penetrated, at an epoch previous to the intrusion of the granite, by dykes of a rock variety which differs from it mainly in grain and often also in colour, being often darker than the main rock. When these dyke rocks are fine-grained, they occasionally contain more numerous small lenses of aplite than the surrounding rock. This circumstance seems to be due to the greater brittleness of the dyke rock. In other cases, again, the dyke rock has a paler colour than the rock which it penetrates. Also in this case it sometimes contains either more or less granite than the latter. In the islands lying farther to the southwest the

Fig. 47. Eruptive breccia formed by the injection of pegmatite and aplite into metabasalt. Ednäsudd, Stor Pellinge. 1:12.

mixture between the basic rocks and the granite becomes still more intricate. E.g. in the island of Stenskär, in the southwesternmost corner of the map, the migmatite consists of a granite with fragments of dark metabasite and veins of pegmatite belonging to the same granite. In a rock more to the west the metabasite again predominates, but is here brecciated, showing fragments cemented by red granite.

In the island of Bredskär S. W. of the Pellinge islands, the gabbro belonging to the Pernå formation is interwoven in such a way with veins of gabbro »aplite» and granitic aplite as to make it sometimes difficult to decide which of them belong to the gabbro and which to the granite. As the network of veins filled with a rock rich in plagioclase is intersected by a dyke of metabasalt which certainly belongs to the Pernå formation and shows sharp contacts against the veins, it seems certain that these veins are genetically connected with the gabbro. The veins shown in Fig. 9 (p. 47) also

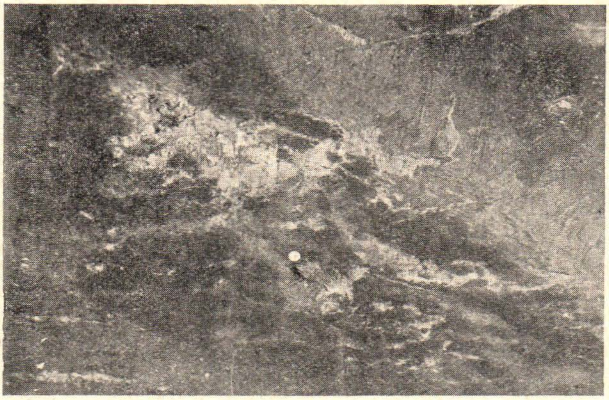

Fig. 48. Migmatite in which the basic rock and the granite show fading outlines. Stenskär S. W. of Tunnholm, Stor Pellinge 1:15.

belong to the same group. Along the southern shore of the island, again, there is a similar network of veins, whose origin seems more uncertain, because they contain in places quartz and potash felspar.

Fig. 49. Lenses of aplite in metabasalt. Nyttisholm, Stor Pellinge. 1:15.

A rejuvenescence of older veins at the time of the injection of the granite seems in this case, as the author has earlier pointed out (cf. p. 48) not to be improbable. At least there are, in another rock on the same island, veins which certainly belong to the »gabbro aplite», intersected by others which are typical microcline aplites connected with the Hangö granite. The latter veins are easily distinguished from the former, as may be seen in the photograph in Fig. 50, by their lighter colour. As we are aware, the vein of granitic aplite which intersects the two faulted veins in the lower part of the photograph, has been injected along the contacts of the narrower vein (to the right in the figure). The granitic aplite has here replaced the material of the older vein, which is rich in plagioclase.

Fig. 50. Horizontal rock surface showing a gabbro with a network of veins of »gabbro aplite» intersected by narrow veins of granitic aplite. Bredskär, S. W. of the Pellinge islands. 1:7.

This injection along the rims of the vein may, however, in part be due to mechanical causes, the boundaries of rocks of different grain giving easier access to the magma, or its accompanying solutions. In any case the rarity of such phenomena shows that they do not play the rôle which Holmquist and other Swedish petrologists are inclined to ascribe to them, believing that the formation of granitic veins in migmatitic rocks is due in most cases to a more acid composition of the material in these parts of the injected rock.

Chemically these migmatites are of interest in several ways. The great difference in composition between the granite and the basic rock which it invades, makes it absolutely impossible to derive the material of the aplitic and pegmatitic veins from the latter. Moreover, the pegmatite and the aplite show complete similarity to dykes of the same rocks which occur in the neighbourhood and which grade into larger masses of granite.

As the process of assimilation is so indubitable, it seems strange that the composition of the granite has not been changed when it has absorbed so much basic material. In some cases, e. g. on Nyttisholm, the narrower veins contain hornblende which has obviously been derived from the surrounding basic rock. In general, however, the granite of the vein is very acid even next to the contacts, which proves that a lively transfer of the solved material has taken place.

In a low little rock, Lökskärshällan, at the west-beacon between Lökskär and Glosholm, a red dioritic rock occurs which shows in its general characters much affinity to the microcline granites of the same region, but contains much hornblende, together with a plagioclase which has a maximal extinction of 7°, and thus is an oligoclase (22 % An). Part of the felspar is antiperthitic, consisting of an oligoclase with a fine twinning lamellation intergrown with microcline (Fig. 5, Plate II). The rock contains several big fragments of gabbro, and is cut by veins of aplite which often lie at the margin of the gabbro fragments. Very probably the dioritic character of this rock, which is no doubt genetically connected with the Hangö granite, is due to an assimilation of basic material.

On the northern shore of Timmerholm, which lies 1 km to the east, a narrow vein of aplite is visible, whose middle part is very rich in biotite, while the rock nearer to the contact is a pale aplitic granite (Fig. 51). The continuation of the same vein is found on the neighbouring island of Högskär. Here the darker portions resemble fragments of a schistose rock. Possibly the darker portions of the dyke in Fig. 51 are more completely assimilated fragments of a basic schistose rock. In the southwest of Timmerholm veins of a similar fine-grained grey granite rich in biotite also occur, and are continuous with veins of aplite. The latter veins are sometimes found intersecting the veins of grey granite, but both rocks also occur together in the same fissure.

These phenomena are signs of incipient differentiation processes in a magma which is itself migmatitic. The vein shown in Fig. 51 is a kind of »composite dyke» although it is uncommon that the contact zones are more acid than the middle portion. The author has later studied granites in the western parts of the coast regions which contain very typical composite dykes, as well as lamprophyric dykes. These also are connected with the formation of migmatites.

In the region W. of Helsingfors, e. g. in Ingå and in the neighbourhood of Hangö, where the non-porphyritic Hangö-granites occur in their most typical forms, they seem to be everywhere more or less migmatitic in character, always containing more or less completely assimilated remnants of older rocks. The general impression which the rockmasses here give, is not that of a plutonic rock working its way by »overhead stoping», but that of magma intim-

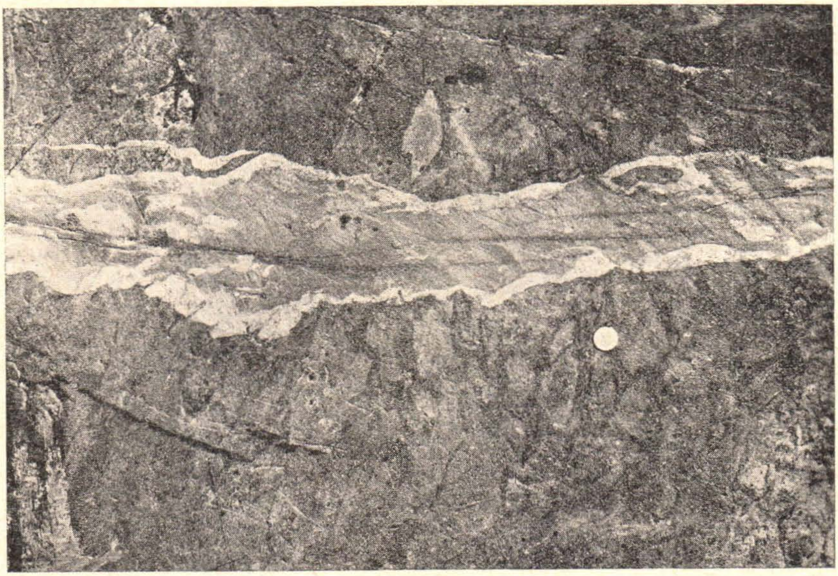

Fig. 51. Horizontal rock of metabasaltic tuff intersected by a vein of granite which is rich in biotite at the midst and aplitic at the margins. Timmerholm, Stor Pellinge. 1:7.

ately permeating older rockmasses which retain in the main the position they had when granitization intervened. The same seems to be true also as to the present region, where the granites of Hangö type almost invariably show signs of having assimilated older rocks.

Microscopically the granites in the north of the present area show much similarity to the Hangö and Perniö granites and associated granites which have been described from other regions by the author and later by Eskola. The main difference between the Hangö granites of the present region and the Perniö granite lies in their nonporphyritic character.

These granites of Hangö type are very rich in microcline, which forms about a third part of the constituents. It shows the usual lattice lamellation, somewhat irregular, as is often the case in granites which have undergone changes during or after their consolidation. Carlsbad twins are common. A great part of the microcline is microperthitic. The stripes of albite are in some cases curved and often rather irregularly dispersed. The plagioclase, which occurs as crystals in much lesser amount than the microcline, is an oligoclase. Its twinning lamellae are sometimes broken or bent, although not in a very high degree. The quartz, which occurs in about the same quantity as the microcline, is anhedral while the felspar often shows good crystal forms (Fig. 6, Plate II). The microcline crystals may often be enclosed on one side in other crystals of the same mineral. They are often euhedral where bordering on and especially where surrounded by the quartz. The plagioclase crystals are commonly euhedral against the microcline, but when they come in contact with the quartz they often show corrosions forms. Also when bordering on microcline they occasionally exhibit more irregular forms, sometimes also a fringe of myrmekite. The outlines of the microcline againts the quartz often show a curvature, although not so pronounced as that of the plagioclase.

The small rounded quartz grains included in the felspars seem to be, at least in most cases, merely sections through round corrosion channels penetrating from the outside into the felspars. They sometimes show the same optical orientation as the surrounding quartz. Possibly many cases of the formation of s.c. poikilite have a similar origin.

Biotite occurs in varying amount and often as euhedral crystals enclosed in all the other minerals, including the felspars, and may in this case have crystallized earlier than most other constituents. It also sometimes shows corroded outlines against the latter. But both biotite and muscovite may also occur as much later crystallizations. They occur as interpositions in the plagioclase, often seemingly parallel to its twinning lamellation, forming rather broad flakes traversing the whole crystal. In other cases they form a fine dust in the felspar and are then, if not secondary in the strictest sense of the word, at least constituents formed during the last period of eruptive activity.

Both biotite and muscovite, however, also occur between grains of quartz or other minerals, filling up their interstices, so that they seem to be late crystallizations. In those granites which show a parallel texture, owing to the arrangements of the primary mica, that mineral also often occurs as rows winding between the other minerals, sometimes even intersecting them, and especially in that case it seems certain that it is a late constituent. The same is particularly true of the muscovite, whose occurrence is still more irregular than that of the biotite.

Biotite in some cases also occurs as pseudomorphs after garnets which have been replaced by a number of small flakes of mica. The author has not been able here to make any observations elucidating the origin of the garnet, which is an almandine, but he does not think it possible to imagine that this mineral would have been the first to crystallize, and then replaced by biotite, before the crystallization of any other mineral. He thinks that the formation of these pseudomorphs is a process of comparatively late date, belonging, however, to the epoch of the crystallization of the same granitic magma, or its juices.

Accessory constituents, such as zircone, apatite, titanite and iron ore, are present only in very small quantities or entirely absent.

While most of the granites in question possess a medium grain, with felspars measuring 1—5 mm, some varieties contain microcline crystals which are much larger, so that the rocks become rather coarse-grained. But there also occur, especially among the vein rocks, varieties which are fine-grained. In these the felspars and quartz often forms small, rounded grains which are in part cemented by somewhat larger felspars.

As the author has pointed out long ago, »these granites do not show any marked phenomena due to mechanical pressure or kataclasis».[1] Their parallel texture is generally not due to formation of mica on trituration zones, but to a parallel arrangement of the biotite during the crystallization of the magma. In part it is even prior to the crystallization of the greater part of the minerals, being a reminiscence of older schistose rocks which have been more or less completely refused, or rather changed by anatexis. Eskola when describing granites of the same type, also particularly emphasizes the absence of dynamometamorphism, and thinks that their texture is a true texture of consolidation, with no secondary features.[2] He thinks that even the undulatory extinction of the quartz may be regarded, in many cases, as a primary feature, due to the unequal contraction of the minerals during the cooling of the rock. He mentions also, however, the circumstance that deformation structures

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[1] J. J. Sederholm, Om bärggrunden i södra Finland. Fennia 8. N:o 3, 1893, pp. 17—18.

[2] P. Eskola. On the Petrology of the Orijärvi region &c. Bull. Comm. géol. Finl. 40, 1914, p. 25.

are by no means rare in ser-Archæan granites, to which he reckons the Hangö-granite, and communicates a good picture of a pegmatite belonging to the same group which has been sheared.

The author has also, as pointed out by Eskola, explained the undulatory extinction of the felspars in certain granites as possibly due to primary causes. But on the other hand, he has observed cases where the Hangö granites are intersected by trituration zones of the most typical character, filled by small grains of crushed quartz and felspar together with minute grains of mica, and then the strain shadows in the adjacent grains of quartz seem to stand in connection with these shearing zones. The circumstance that all the other minerals, including the mica, which is often bent, also show signs of mechanical pressure, makes it probable that the undulatory extinction of the quartz has the same cause. These influences of pressure, however, have seldom been very strong.

Moreover, it seems probable that at least some of the movements which have caused the deformation of the minerals, have taken place before the complete consolidation of the same granitic masses, and are thus not to be designated as dynamometamorphic in the strict sense of the word, if thereby is meant changes caused by mountain-making processes acting on solid rocks.

THE RYSSKÄR GRANITE (F) AND THE ERUPTIVE BRECCIAS (AGMATITES) IN WHICH IT FORMS THE CEMENT.

The Rysskär granite, which over a great area forms the cement in eruptive breccias in which the fragments consist of metabasalts belonging to the Pernå formation, is almost never represented by varieties free from any inclusions. It would be difficult here to quarry a block of entirely homogeneous granite even of a size sufficient for a tombstone. Everywhere the rock is full of inclusions which have undergone resorption in a greater or lesser degree, whereby also the composition of the magma has been changed through the assimilation of basic material. Besides the granitic varieties, therefore, occur some containing more hornblende and plagioclase, and grading into hornblende-granites, monzonites, diorites &c. On the other hand, there also occur in connection with this granite pegmatitic and aplitic rocks which contain but very small amounts of the femic constituents, and consequently have a rather acid composition. Because of the Proteus-like changes of the rock masses in question it is difficult to say which variety of this granite ought to be regarded as possessing a typical composition. In order to get a starting point we will begin with the description of some granites outcropping in the Rysskären islands in Pernå. The same types are common also elsewhere.

The Rysskär granite has a greyish red colour with a more sombre hue than the granites of Hangö type, and is always even-grained. Porphyritic varieties do not occur. It is characterized by the prevalence, in most cases, of plagioclase over microcline, by the euhedral forms of the felspars, especially the plagioclase, and the anhedral forms of the quartz.

The plagioclase forms short prismatic crystals with a length of 1—3 mm which are entirely idiomorphic against the surrounding quartz, and also against the microcline crystals when such are present. The prevalent plagioclase shows a maximum extinction of only a few degrees and is thus an oligoclase with about 20 % An. It often shows a zonal structure which is certainly primary. The outer layers are more albitic than the inner ones, and there is often a rim of pure transparent albite. The inner parts of the plagioclase crystals are often turbid, which is due to the occurrence of small interpositions of epidote, zoisite and probably also mica. The same minerals also often occur as large grains or flakes in the plagioclase, when the mica, which is either biotite or muscovite, is sometimes arranged along the cleavage planes of the felspar. The microcline is present in rather great quantity as a primary constituent in the lighter, more acid rock varieties. The cross-hatched twinning lamellation is often very irregularly dispersed, so that great parts of the crystals are free from it. The crystals are idiomorphic against the quartz. At the boundaries of plagioclase and microcline, myrmekite, consisting of oligoclase and quartz, as usual occurs and is often very typical.

The quartz is commonly subdivided into a great number of smaller grains with irregular, serrated outlines, each of them showing a more or less undulatory extinction. This character of the quartz seems to be due to mechanical crushing and subsequent healing by recrystallization of some of the crushed portions.

Among the femic minerals a dark, strongly pleochroic biotite is predominant in the more acid varieties. It is sometimes replaced by chlorite. Together with the biotite a green hornblende often occurs and becomes prevalent in the more dioritic varieties. The biotite sometimes forms large crystals with a major diameter of 2—3 mm. They seem not to be idiomorphic against the felspars, but are surrounded by anhedral quartz. The crystals have sometimes been flattened out into lens-like aggregates of smaller flakes which are intermingled with small grains of quartz, sometimes also interwoven with that mineral at the margins in myrmekite-like implication. Small grains of epidote also often occur. A part of the biotite is often changed into chlorite.

The hornblende is more euhedral than the biotite. The latter mineral sometimes occurs within the hornblende crystals in such a way as to make it probable that it has replaced hornblende.

Besides epidote orthite is also found, either alone or surrounded by a rim of epidote.

Titanite occurs both as large, probably primary crystals with rather strong pleochroism and also as small grains with a pale brown colour, in which case it has probably been derived from ilmenite. Opaque ore, most of it magnetite, is also sometimes present, but it seems uncertain whether it is primary or secondary.

Apatite is present only in a small quantity.

Two granites of this group have been analysed by Dr Mäkinen. One of them (Table XII), which outcrops in Öster Rysskär, is an alkali granite uncommonly rich in silica. The microscopical constitution of this rock is shown by Fig. 1, Plate III. It is composed mainly of quartz, microcline and plagioclase, with trifling amounts of biotite. It is a t e h a m o s e according to the American classification. The other granite (Table XIII) which outcroups in Wester Rysskär, is a t o s c a n o s e with almost equal amounts of potash and sodium. Microscopically, it is composed of plagioclase, a small amount of microcline, quartz, biotite, hornblende and accessorily titanite, epidote and magnetite.

In the hornblende-granites and diorites into which these granites grade, the plagioclase and hornblende gradually begin to predominate over microcline and biotite. The plagioclase forms short prismatic crystals with a maximal length of 2—3 mm and varies in its composition between an oligoclase (22 % An) and an andesite (34 % An). Its idiomorphism is very well developed, while the quartz is entirely anhedral. The hornblende forms rather well developed crystals (Fig. 2, Plate III). The biotite gives often the impression of having been formed as crystalloblasts after the crystallization of the other minerals.

Some parts of the more basic rocks connected with this granite are no doubt portions of the basic volcanic rock masses, which have been refused or resolved in the granitic magma and have afterwards

Table XII. Granite from Öster Rysskär, Pernå.
Analysed by Dr. Eero Mäkinen.

	%	Mol. prop	Norm.				
SiO_2	75.64	1261	Quarz — Q —	40.98	Q	40.98	Sal 95.30
TiO_2	0.30	4	Orthoclase	17.24			
Al_2O	12.34	121	Albite	25.68	F	54.32	
Fe_2O_3	1.78	11	Anorthite	11.40			
FeO	1.19	17	Hypersthene	1.66	P	1.66	Fem 4.82
MnO	0.03	—	Magnetite	2.55	M	3.16	
MgO	0.57	14	Ilmenite	0.61			
CaO	2.27	41		100.12			
Na_2O_3	3.06	49	Water	0.38			
K_2O	2.92	31		100.50			
H_2O	0.38						
	100.48						

recrystallized. We will therefore describe them in connection with the eruptive breccias.

The analysis in Table XIV of a rock of this group shows a tonalitic composition. It is a t o n a l o s e according to the American classification. Microscopically, the rock is composed of plagioclase, microcline, quartz, biotite and hornblende, togetheter with some titanite and epidote.

E r u p t i v e b r e c c i a s hardly outcrop anywhere in Fennoscandia in more typical and varying forms than in the area in southwestern Pernå where the Rysskär granite occurs intermingled with the older metabasalts.

The different forms and quantities of the fragments of basic rocks included in the granite, and the different degree in which these parts have been changed by the action of the granitic magma cause the great variety of the mixed rock.

Table XIII. Granite from Wester Rysskär, Pernå.
Analysed by Dr. Eero Mäkinen.

	%	Mol. prop	Norm.				
SiO_2	70.31	1172	Quartz	24.84	Q	24.84	
TiO_2	0.38	5	Orthoclase	28.91			
Al_2O_3	15.45	151	Albite	27.77	F	66.97	Sal 92.73
Fe_2O_3	0.25	2	Anorthite	10.29			
FeO	2.30	32	Corundum	0.92	C	0.92	
MgO	1.15	29	Hypersthene	6.20	P	6.20	
CaO	2.40	43	Magnetite	0.46	M	1.22	Fem 7.76
Na_2O	3.33	53	Ilmenite	0.76			
K_2O	3.91	52	Apatite	0.34	A	0.34	
P_2O_5	0.08	1		100.49			
H_2O	0.62						
	100.28						

As these migmatites consisting of fragments of older rocks cemented by granite are genetically and petrologically very different from many of the rocks that have been called eruptive breccias many of which are volcanic rocks, the author proposes to designate this group of migmatites as *agmatites* (from ἄγμα, fragment).

One of the best opportunities for observing these agmatites is afforded by the small Rysskären islands in Pernå. Even when we regard these rocky islands, especially the steeper roche moutonnée of Wester Rysskär, from a distance, we become aware that they are as heterogeneous as possible. Great masses of dark metabasalt alternate with lighter granitic portions, forming irregularly shaped dykes and veins, but these again contain fragments of dark rocks in varying forms and different stages of refusion. When we investigate this petrological mish-mash more nearly, we find that it is composed mainly of two ingredients: a metabasalt which shows

Table XIV. Hornblende granite (tonalite) from Söderskatan in Sundarö. Analysed by Dr. Eero Mäkinen.

	%	Mol. prop	Norm.			
SiO_2	66.20	1103	Quartz — Q	22.62	Q 22.62	Sal 84.00
TiO_2	0.49	6	Orthoclase — Or —	15.01		
Al_2O	14.95	146	Albite — Ab —	28.30	F 61.38	
Fe_2O	1.73	11	Anorthite — An —	18.07		
FeO	3.16	44	Diopside — Di —	6.50	P 11.32	
MnO	0.04	—	Hypersthene — Hy —	4.82		Fem 14.78
MgO	1.79	45	Magnetite — Mt —	2.55	M 3.46	
CaO	5.23	93	Ilmenite — Il —	0.91		
Na_2O_3	3.38	54		98.78		
K_2O	2.52	27	Water	0.76		
H_2O	0.76			99.54		
	100.25					

slender porphyritic crystals of plagioclase, and granites grading into diorites.

The plagioclase-porphyrite is often very typical, especially in Öster Rysskär, and shows even macroscopically a well preserved porphyritic texture. It is then entirely homophanous. It is the same rock whose description and analysis has been given on p. 35.

In Wester Rysskär fragments have been observed which consist of a fine-grained, dark, schistose rock in which besides the distinctly visible bedding there is also a schistosity transversal to the former.

Sometimes narrow volcanic dykes, consisting of varieties with a somewhat different texture, are seen intersecting the plagioclase-porphyrite. Amygduloid varieties also occur, and in some places in the islands tuffs, in part agglomeratic, are found intercalated with the volcanic rocks. The dips of the beds are as usual vertical, or nearly so.

Where this plagioclase-porphyrite is intersected by very narrow veins of granite, it is often but slightly changed next to them. Only at the immediate contact is the texture of the basic rock destroyed. Here slender crystals of green hornblende have accumulated, while the plagioclase has been almost entirely obliterated.

Some of these narrow granitic veins penetrating the basic rock have sinuous and irregular forms, and thus give the impression that the magma has slowly percolated the rock and solved it along certain lines. They intersect the plagioclases of the basic rock, but its uralite crystals may remain undamaged in these narrow veins,

Fig. 52. Fragment of metabasalt in Rysskär granite.
S. E.-shore of Öster Rysskär. C:a 1:8.

often even still showing sharp crystal angles. The metabasalt is also often cut by very narrow, vein-like stripes consisting mainly of hornblende. These veins have probably been formed at the same time as the granitic veins. Where there are primary veins of aphanitic metabasalt, their contacts may sometimes be marked by granitic material, which has penetrated along the boundaries, or they may in their whole breadth contain more granite than the rest of the rock. This is certainly a secondary phenomenon, and cannot be interpreted as due to an original genetical connection, because similar veins never occur in such portions of the rock as have not become granitized.

Some of the angular fragments of basic rocks, e. g. that shown in Fig. 52, may in parts possess a well preserved primary texture, while other parts of the same fragments are lighter in colour and show a granitic texture, having obviously been impregnated with granite and recrystallized.

The northern part of Öster Rysskär shows the greatest variety of eruptive breccias. Often the fragments of basic rock are quite angular, and distinctly exhibit the primary features of the original porphyritic, amygduloid or agglomeratic rock (cf. Fig. 53), while they have, in other cases, been very much changed, both in forms and also chemically, through the influence of the granitic magma. By comparing portions of the eruptive breccias lying near to each other, we are able to follow the gradual change of the original composition

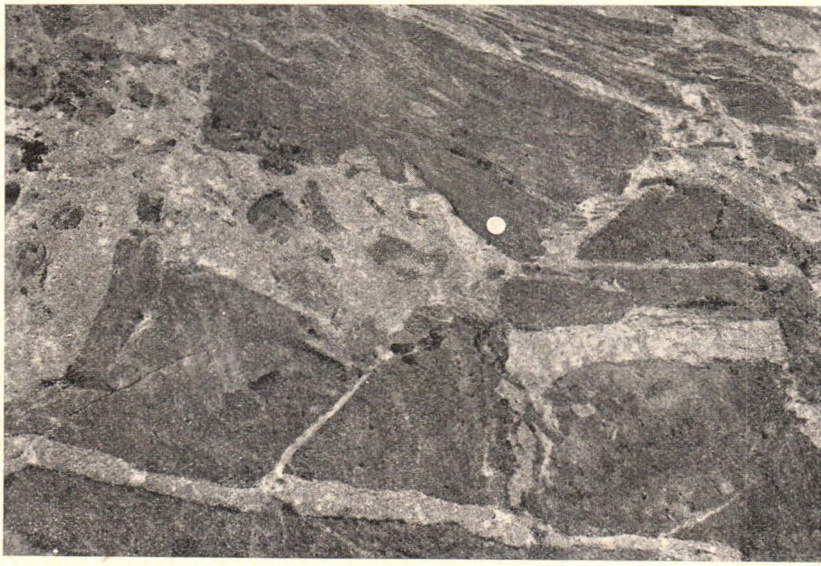

Fig. 53. Eruptive breccia in which the fragments are in part well preserved. Island in Rysskärsfjärden. 1: 8.

of the fragments, until the stage when only faded remnants of them are left. The eruptive breccia is then changed into what the author has called a n e b u l i t e, i. e. a rock containing only "ghostly remnants" of the included fragments. Even in these highly changed portions the original porphyritic texture may be well preserved on one side of the fragments. In some cases the fragments become so completely assimilated by the surrounding granite that an indistinct spottedness is the only reminiscence of the breccia structure. The rock is then dioritic rather than granitic in composition. This nebulitic migmatite, however, may contain fragments of another breccia which shows greater contrasts between the fragments and the cementing material (Fig. 54). This fact shows that some parts of the eruptive breccia had already become entirely solid at a time when refusion was still going on in the neighbourhood.

The fact that the fragments included in a granitic magma thus gradually become impoverished in their femic constituents, is in itself a proof of a process of differentiation. In some cases the faded basic fragments show a darker rim because of an aggregation of the femic constituents next to their contacts.

Fig. 54. Nebulitic variety of the eruptive breccia containing fragments of another variety which shows a marked contrast between well preserved, dark fragments and a light granite. N-shore of Öster Rysskär, Pernå. C:a 1:10.

Sometimes parts of the granitic or dioritic veins may intersect others. This also shows that they all belong to the same period of granitization. But even the basic material, which has in general been more rigid and less fusible than the granitic, has in some cases undergone such a refusion that it became able to penetrate already solidified parts of the eruptive breccia. Fig 55 shows a vein of such a »palingenetic» basic rock which i n t e r s e c t s t h e e r u p t i v e b r e c c i a, b u t i s i t s e l f i n t e r s e c t e d b y v e i n s o f a g r a n i t e which has exactly the same character as the rocks cementing the fragments in the neighbourhood and no doubt belongs to the same period of granitization. The vein has a breadth of 4—10 cm and can be followed for 5.5 m. An analysis of this basic rokc has been made by Dr. E. Mäkinen, with the following result:

Table XV. Palingenetic basic vein-rock from Öster Rysskär.
Analysed by Dr. Eero Mäkinen.

	%	Mol. prop.	Norm.			
SiO_2	53.28	888	Quartz — Q —	7.80	Q 7.80	
TiO_2	1.82	23	Orthoclase — Or —	10.56		Sal 65.49
Al_2O_3	15.73	154	Albite — Ab —	20.44	F 57.69	
Fe_2O_3	3.03	19	Anorthite — An —	26.69		
FeO	8.05	111	Diopside — Di —	8.82	P 24.65	
MnO	0.06	1	Hypersthene — Hy —	15.83		
MgO	4.40	110	Magnetite — Mt —	4.41		Fem 32.56
CaO	7.50	134	Ilmenite — Il —	3.50	M 7.91	
Na_2O	2.44	39		98.05		
K_2O	1.82	19	Water	1.70		
H_2O	1.70			99.75		
	99.83					

Microscopically, this vein rock is composed of plagioclase, hornblende and biotite, with small amounts of titanite, epidote and ore.

When we compare the composition of this rock, which is an andose according to the American classification, with that of the plagioclase-porphyrite (Table VI) we become aware that the difference mainly lies in a higher amount of iron in the vein rock. The amount of calcium is slightly lower in the latter. Otherwise both analyses show so great an analogy as to make it highly probable that the vein rock really consists of refused metabasaltic rock. We shall in the following pages learn to know other examples of the same phenomena

The increase of the iron constituents is obvious also in other rocks of similar origin.

In the island of Finnholm, which lies 3 km S.W. of Rysskären, a similar basic rock occurs as veins which can be followed over a considerable distance. They are more irregular in breadth than the vein of Öster Rysskär.

In a small island S. W. of Ytterholmarna, N. E. of Öster Rysskär, we observe the direct change of a metabasalt into a refused rock

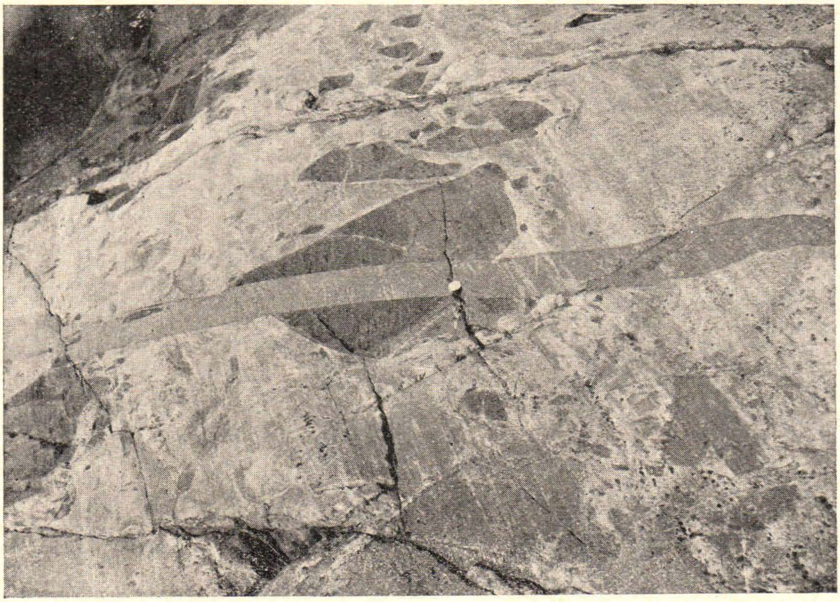

Fig. 55. Eruptive breccia intersected by a basic vein. Öster Rysskär, Pernå. 1:13.

grading into the surrounding granite and showing the same texture as the latter rock. The granite here also contains numerous fragments of metabasalt.

The analysis in Table XVI, of the refused rock shows that it has very nearly the same composition as the unmelted plagioclase-porphyrite (cf. Table VII, p. 36). It is a h e s s o s e, but rather near to an auvergnose. It consists mainly of plagioclase, hornblende and biotite, with some quartz, apatite and secondary ore. Its microscopical texture is very near that of the rock shown in Fig. 2. Plate IV, from an adjacent island. The latter rock, however, has a more acid composition.

Table XVI. Basic rock originated by the refusion of plagioclase-porphyrite, from small island between Rysskär and Ytterholm. Analysed by Dr. Eero Mäkinen.

	%	Mol. prop.	Norm.					
SiO_2	51.78	863	Quartz	5.04	Q	5.04	Sal	61.96
TiO_2	1.83	23	Orthoclase	7.23	F	56.92		
Al_2O_3	16.18	159	Albite	19.39				
Fe_2O_3	1.99	13	Anorthite	30 30				
FeO	8.77	122	Diopside	9.74	P	29.55	Fem	36.07
MnO	0.10	1	Hypersthene	19.81				
MgO	5.26	132	Magnetite	3.02	M	6.52		
CaO	8.46	151	Ilmenite	3.50				
Na_2O	2.34	37		98.03				
K_2O	1.21	13	Water	1.71				
H_2O	1.71			99.74				
	99.63							

Also in the islands lying E. and W. of Rysskären the breccia is often typical. A rock in Sundarö island shows in a very striking way the gradual splitting up of the basic rock, which in several places distinctly exhibits the texture of a uralite-porphyrite. We are often able to remark that some granitic veins which intersect the greater part of a fragment stop near to the opposite margin, a peculiarity which we have noted already before on Nyttisholmen (cf. p. 103) and elsewhere. Here also a fragment of a pale rock occurs which shows a distinct bedding and possibly belongs to the quartzite' outcropping in Rabbasö and neighbouring islands.

On another neighbouring island, Ytterholm, the photograph given in Fig. 56 was taken. The right hand fragment still distinctly shows the amygduloid texture of the metabasalt. We here observe how the fragments have been gradually split up by fissures, beginning from the margins. The right hand fragment shows forms which remind one of those of quartz crystals which have undergone resorption in a magma, while the left hand one has been subdivided into a cluster of small fragments showing all stages of destruction.

As well in Ytterholm as in the small islands lying south of it we find some fragments which are very dark and retain their original chemical composition, while others are pale in colour and

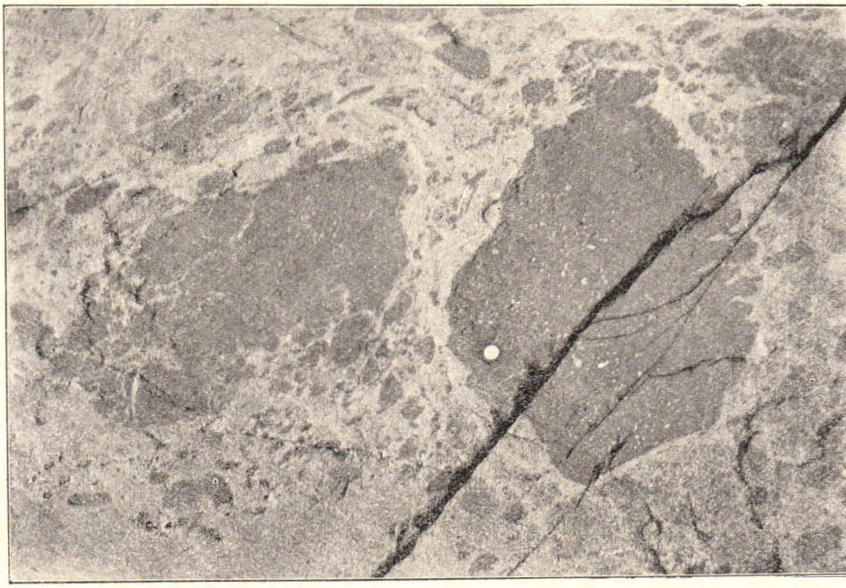

Fig. 56. Eruptive breccia showing fragments of amygduloid uralite-porphyrite changed by resorption. Ytterholm near Sundarö in Pernå. 1:10.

as acid as certain parts of the surrounding grano-dioritic rock. Sometimes a fragment shows on one side well preserved primary features, such as the porphyritic textures, while it is, on the other side, changed into a pale granodioritic rock. Both are connected by gradual transitions, and there is not the slightest doubt that the basic rock fragment has been gradually changed into a more acid rock, having been intimately penetrated by the granitic magma.

Where the anatexis has gone further, the nebulitic migmatite often looks like a granite or granodiorite containing "Schlieren" of a more basic material.

Such rocks occur also west of the Rysskär islands. But here also typical breccias with angular fragments are common and all these varieties grade as usual into each other. The author has taken a great number of photographs of these migmatites in order to be able to visualize these phenomena and allow the reader to draw his own conclusions, but it is of course not possible to print an unlimited number of illustrations, especially at the present time when the cost is so high. This circumstance has already forced the author to reduce the size of some of the figures, which has caused an incongruity.

Fig. 57. Eruptive breccia with pegmatitic veins between the fragments. W.-shore of the Ormskär island, Pernå. 1:15.

When anatexis has proceeded far, the granitized basic rock has often acquired a granitic texture even if it was originally a metabasalt. In this case it may often be impossible to distinguish the fragments of metabasaltic rocks from such as originally consisted of gabbro. Therefore it is sometimes difficult to determine with certainty where the eruptive breccia consisting of metabasalt and granite gives way to an analogous rock with gabbro fragments.

This case is, however, exceptional. As a general rule it may be said that it is in most cases possible to determine the character of the constituents in the migmatites of the coast regions of southern Finland.

The granite which forms the predominant constituent of the eruptive breccia is sometimes pegmatitic, especially in veins which lie between the different parts of a broken fragment. Thus we find in the island of Ormskär in Pernå, where the eruptive breccia is very typical and contains fragments of a number of different varieties of metabasalt, uralite- and plagioclase-porphyrites, amygduloid varieties, tuffs, agglomerates &c., a fragment which has been split into several pieces by fissuring. Only in these cracks does pegmatite occur (Fig. 57).

We shall meet with other examples of the same phenomenon later on. These sheltered interstices, between broken fragments which became separated because of a flowing motion of the surrounding magma at the end of its consolidation, are just the places where the granitic juice ought to have assembled.

The Rysskär granite (F) has also in a large measure penetrated the Stadsland gabbro (B) at its southern contacts, as well as the Rabbasö quartzite (B) and the oldest schists (A). Agmatites of the latter mentioned rocks and the Rysskär granite F occur e. g. on the isthmus connecting the Sundarö and Hästö islands in Pernå.

As all these rocks have also occasionally been penetrated by the Våtskär granite (D), it is sometimes difficult to say whether the granitization is due to that granite or to the Rysskär granite. In the western part of the quartzitic area veins of the oldest granite certainly occur, together with others consisting of Rysskär granite, and sometimes also of Hangö granite. However, the greater part of the granitization of the quartzite seems to be due to the action of the Rysskär granite. Then, as already mentioned on p. 67, veins of that granite penetrate also dykes of basic rocks which no doubt belong to the Pernå metabasalt (E). In Fig. 23, p. 67, a basic dyke of that character is shown which has been faulted and deformed at the time of the subsequent granitization. As the quartzite was probably already schistose at the time of granitization, it has generally divided along its cleavage, and the migmatite has rather the character of a gneissose rock than that of an eruptive breccia.

In spite of the great variety of the agmatites consisting of metabasites belonging to the Pernå formation, cemented by veins of the Rysskär granite, they never show gradations into "arteritic" rocks, with the "ptygmatic" folding which is often characteristic of migmatitic rocks. The basic rock has been a refractory material, which has melted only where it was intimately permeated by the granite. The magma of the Rysskär granite was not in the same measure as the Hangö granite associated with aplites and pegmatite. Further, we observe mainly such parts of the granite in question as have solidified nearer to the earth's surface, and the reaction of the granite on the metabasalts has probably thus not lasted during a very long period. Moreover, the metabasalts of the Pellinge region have been brittle rocks, and devoid of a well developed schistosity which would cause a more intimate "lit par lit" injection. All these circumstances explain why we observe mainly such stages of granitization where "agmatites", i. e. breccias with angular fragments were formed.

However, in the same area migmatites consisting of Rysskär granite and fragments of older rocks also occur, in which the latter have been changed in such a degree that rocks similar to ptygmatic arterites have been formed, at least locally. This is the case in the quartzitic area, and in the island of Viasholm where a conglomeratic schist has been changed by the granitic action.

In this case, which we will now describe, the magma of the granite has been pegmatitic in higher measure than elsewhere.

THE CONGLOMERATIC ROCK OF VIASHOLM AND ITS PALINGENESIS BY THE ACTION OF THE RYSSKÄR GRANITE.

In most cases where a "refusion" of solid rocks has taken place, the products are so different from the rocks which have undergone the changes that they may be said to form a substiantially new, younger rock. By the opponents of the idea of an anatexis, the assertion has been made that it can be proven only if we are able to show gradations from unmelted to melted rocks in which the original chemical character has been retained. We have already (p. 124). described a case where a metabasaltic rock has been simply refused without materially changing its composition. Among the migmatites in the Pellinge region, there are other rocks which have originated by the older rock, in this case a conglomerate, simply undergoing a palingenesis, that is to say being changed by a process surpassing metamorphism, into a new magma which has later again solidified.

The conglomeratic rock of Viasholm in Pernå is very similar to that which occurs on Sundarö and which is there intercalated with the oldest schists. (cf. Fig. 25, p. 73). The latter rock also consists of pebbles of varying size, up to one metre or more in diameter. Most of them measure, however, only 5—20 cm. Many of them are well rounded, others elongated. These forms are sometimes due to pressure, sometimes original. This is shown by the fact that they occasionally lie with their longer axis transversally to the schistosity of the rock. (Fig. 58). Most of them consist of basic rocks, mainly meta-andesites, but showing very varying textures. As the rock consists of fragments which belong mainly to one and the same eruptive series, it could be called agglomeratic, but it has certainly not been formed only by the accumulation of loose volcanic debris. The materials have been transported frome some distance and are waterworn. The author therefore prefers to call it conglomeratic. Some pebbles differ

Fig. 58. Conglomeratic schist at the N. E.-shore of Viasholm in Pernå. 1:8.

considerably from the majority, being lighter in colour and looser, resembling some varieties of the »skarn» which accompanies the Swedish iron ores. They are probably fragments of rocks which have been calcareous, either because of an infiltration of material from hot volcanic sources or from having been weathered.

On the southern shore of Stadsland, north of Viasholm, there is a small outcrop of a dark metabasitic rock which contains small pebble-like inclusions of glassy quartz. It may possibly belong to the same formation.

In the rock of Viasholm the original structure is in some places very well preserved (cf. Fig. 58), while in others the conglomerate is changed to a gneiss- or micaschist-like rock in which the conglomeratic structure gradually fades away. This happens especially in places where veins of pegmatite are common. These veins belong to the Rysskär granite (F) which forms the cement of the eruptive breccias in the region immediately south-east of Viasholm. But beside these pegmatitic veins, which differ in chemical composition from the surrounding rock, there are rocks which behave like eruptives, penetrating the neighbouring conglomerate, but are obviously only portions of the same rock which have undergone fusion. They still contain in places patches which have been incompletely fused and distinctly show the original conglomeratic structure, while in other cases the original pebbles appear only as indistinct spots. These spotted rocks which behave as eruptives are entirely similar to other portions in the midst of the conglomeratic masses which are continuous with the main mass of the rock.

Dykes of basic rocks probably associated with the volcanic rocks of the adjacent Pernå formation are common, and often intersect the conglomerate in directions transversal to its parallel structure. It is very interesting to study the relations between these basic dykes and the surrounding conglomeratic rocks, at places where they have been changed in a high degree by "anatexis", or what may be conveniently, although perhaps not quite exactly called refusion.

Fig. 1, Plate VI, shows one of these basic dykes occurring on the eastern shore of Viasholm. It intersects a rock which shows in its southern part an unmistakable conglomeratic structure which gradually fades away in the northern portions, in the same degree as pegmatitic veins become more numerous. These granitic veins often show, especially in the southern portion, darker margins rich in biotite.

Not only these pegmatitic veins, but also the main mass of the conglomeratic rock, where it has lost its original texture, behaves as an eruptive or semi-eruptive rock. It has obviously taken part in fluidal movements at a time when the basic dyke rock, while retaining its rigidity, had broken in pieces. In connection with this fracturing process, pegmatitic magma which has permeated the whole rock has penetrated both the solid and the semi-fluid rock, corroding the former so as to enlarge the fissures. Here again we are aware of the strange fact noted before, that some granite veins do not intersect the whole fragment, but end near to one of its margins. Some of them even end blindly on both sides, so as to suggest the idea that they have been formed mainly by the solution of parts of the older rock. In the northernmost part the schistose rock is more migmatitic than elsewhere, and here it shows also the ptygmatic folding characteristic of semi-molten rocks.

It is remarkable that the pegmatite occurs especially in the immediate vicinity of the basic dyke. Whenever a fissure has been formed in the brittle dyke rock, the ubiquitous pegmatitic juice has filled it, and it has obviously enlarged many of these fissures by corroding the basic rock. The fact that the present composition shows no influence of this solution process can only be explained by assuming a rapid removal of the material solved. Such veins are not equally numerous in the surrounding palingenetic rock, which is perhaps explained by the assumption that it has been viscous during the greater part of the time of the formation of the pegmatitic veins.

The author refers to the figure in Plate VI which speaks for itself better than words.

On the western shore of Viasholm we find a counterpart of these phenomena. Here a mica-schist is in contact with the conglomerate. To the petrological problem is here added a stratigraphical one, as it seems probable that we here observe two formations of different age in contact. The main part of the Viasholm island consists of conglomeratic rock in a more or less altered state, but containing no intercalations of other sediments. A glance at the map shows that quartzitic rocks occur west of this conglomerate, and that their eastern boundary follows a direction which is transversal to the general strike both of the quartzite and associated rocks and of the Viasholm conglomerate. The leptitic schist which is in contact with the conglomerate probably belongs to the same formation as the quartzite which alternates with such schists especially in the northern part of the area.

As we approach younger rocks when passing from the north to the south, it seems probable that the quartzite was originally superposed on the amphibolitic schists of the Hästö formation.

Their relation to each other is apparently that of conformability, the strikes of the rocks being parallel. But even if the quartzitic sediment was deposited, in apparent conformability, on the older rocks of tuffaceous origin outcropping north of the quartzite zone, it is by no means certain that it could not have been at other, neighbouring places deposited on sediments with different composition and different strike or dip.

Now the main direction of the contact line on the western shore of Viasholm, which runs from north to south, coincides with that of the eastern boundary of the quartzite, and it seems therefore not unlikely that we observe here the original contact between the bottom layers of this sedimentary formation and the conglomerate.

The original contact line is disfigured by the intense folding which has occurred later and caused its sinuosity. The contact is also cut by dykes of metabasalt which intersect both the schist and the conglomerate and probably belong to group E.

The traces of stratification which are left in the conglomerate follow the general east and west strike of the rocks in the neighbourhood. In the southern part of the rock surface shown on Fig. 4, Plate V, this stratification ends abruptly at the contact with

Fig. 59. Contact between mica-schist and conglomeratic schist which is changed into a massive rock at the contact. W.-shore of Viasholm in Pernå. 1:7.

the leptitic schist, whose strike intersects it at a high angle. The schist here contains lenses of impure limestone. Also more to the north there are several places where the strike of the schist at the contact cuts the stratification of the conglomerate (Cf. the map in the plate and Fig. 59). If we are entitled to draw any conclusions at all from observations of rocks which have undergone so great changes, they would seem to suggest that the original relation of the schist and the conglomerate has been that of an *unconformable superposition*. The phenomena described may at least serve as an example of how such an unconformability might appear in a region which has undergone regional anatexis.

It is noteworthy that on the small island of Smultronhäll lying about 2 kilometres more to the south, i. e. at the presumable eastern boundary of the quartzite, fragments occur in the granitic breccia in which similar contacts between a leptitic schist and a rock resembling the conglomerate of Viasholm are visible. Their relations are identical with those on the latter island, although still more obscured by granitization. The prevalent rock on Smultronhäll is a fine-grained leptitic schist containing broken layers of a calcareous skarn-like rock and penetrated by dykes of metabasalt, which are often subdivided into a number of angular fragments. The strike is also here in part N. 10° E., thus parallel with the supposed boundary against the older rocks.

In the contact rock of Viasholm the schist contains narrow veins of quartz and of aplitic or pegmatitic rocks which in part also intersect the conglomerate. But there are also rock varieties which are more or less massive and behave as eruptives, but grade into the conglomerate and are indubitably to be regarded as parts thereof which have been more or less entirely refused. This rock occurs especially in the northern part of the rock immediately at the contact (Fig. 59) where it contains patches of incompletely fused conglomerate. In the southern parts of the rock (lying next to the first 30 metres of the scale) a rock variety occurs whose character is intermediate between the entirely massive, "palingenetic" rock and the conglomerate. It still retains the spottedness of the latter, but its relation to the schist is that of an intruding eruptive. This case where a refused conglomerate behaves as an eruptive rock is really a very typical example of palingenetic eruptivity.

In order to get an idea of the changes which the rock has undergone during the anatexis some analyses have been made by Dr. E. Mäkinen (Tables XVII—XIX). The conglomerate seems to have a very uniform composition on the whole. It has therefore been possible to determine its average composition by analysis, by crushing and quartering large specimens, according to the methods used when taking average samples of ore. The first analysis, Table XVII, shows the composition of the best preserved variety of conglomerate from the N. E. shore of Viasholm, the second analysis, Table XVIII, gives the composition of the semi-eruptive rock which intrudes the schist in the contact rock on the western shore of that island; the third analysis, Table XIX, gives the composition of the palingenetic conglomerate from the eastern shore, from a place which lies on the area mapped in Fig. 4, Table V, to the west of the number at the metre scale.

As we are aware from the analyses, the rocks whose composition is shown by Tables XVII and XVIII are chemically very nearly related, one of them possessing the composition of a b a n d o s e, the other of a t o n a l o s e according to the American classification, while the third rock, (Table XIX) which has a higher content of silica and a lower of alumina and lime, has the composition of a s i t k o s e, near tonalose.

The "refusion" of the conglomerate has no doubt taken place in connection with the intrusion of the Rysskär granite (F), and an intermingling of its magma with the palingenetic basic rock has occurred. But the granite has not here acted as a solvent in the same measure as elsewhere. A part of the conglomerate has simply been "refused" without any addition of granitic material.

Table XVII. Meta-conglomerate from the N. E. -shore of Viasholm in Pernå.

Analysed by Dr. Eero Mäkinen.

	%	Mol. prop.	Norm			
SiO_2	60.30	1005	Quartz	— 21.18	Q 21.18	Sal. 76.59
TiO_2	1.18	15	Orthoclase	— 8.34	F 55.41	
Al_2O_3	15.90	156	Albite	— 16.77		
Fe_2O_3	0.95	6	Anorthite	— 30.30		
FeO	7.23	100	Diopside	— 1.64	P 17.84	Fem 22.18
MgO	2.64	66	Hypersthene	— 16.20		
CaO	6.87	122	Magnetite	— 1.39	M 3.67	
Na_2O	2.00	32	Ilmenite	— 2.28		
K_2O	1.44	15	Apatite	— 0.67	A 0.67	
P_2O_5	0.28	2		98.77		
H_2O	0.88	—	Water	0.88		
	99.67			99.65		

Table XVIII. Palingenetic conglomerate, penetrating the mica-schist on the western shore of Viasholm in Pernå.
Analysed by Dr. Eero Mäkinen.

	%	Mol. prop.	Norm				
SiO_2	60.98	1016	Quartz	19.26	Q	19.26	
TiO_2	1.06	14	Orthoclase	10.56			Sal 78.04
M_2O_3	15.28	150	Albite	25.15	F	58.78	
Fe_2O_3	2.72	17	Anorthite	23.07			
FeO	7.21	100	Diopside	3.50	P	15.15	
MgO	1.73	43	Hypersthene	11.65			
CaO	5.80	104	Magnetite	3.94	M	6.07	Fem 21.89
Na_2O	3.02	48	Ilmenite	2.13			
K_2O	1.76	19	Apatite	0.67	A	0.67	
P_2O_5	0.31	2		99.93			
H_2O	0.66		Water	0.66			
	100.53			100.59			

All those varieties of conglomeratic rock which show in the outcrops the general character of a crystalline schist, also retain the texture of a schist microscopically. They consist of green hornblende, biotite, plagioclase and quartz in very varying amounts, together with titanite and ore as accessory constituents, usually in very small amounts. Epidote and zoisite also occur, in some cases in such quantities as to become prevalent. Most of the minerals form rounded grains with no signs of any crystal form. In some cases the plagioclase contains numerous small interpositions of femic minerals. The macroscopically visible conglomeratic structure may also reveal itself under the microscope by the existence of spots with varying amounts of the different mineral constituents, but these spots are by no means clearly defined. The

Plate XIX. Palingenetic conglomerate from the northern part of the rock shown in Fig. 1, Plate VI, on the eastern shore of Viasholm in Pernå. Analysed by Dr. Eero Mäkinen.

	%	Mol. prop.	Norm			
SiO_2	68.23	1137	Quartz	31.50	Q 31.50	Sal 83.09
TiO_2	0.89	11	Orthoclase	9.45	F 50.88	
Al_2O_3	13.00	127	Albite	27.25		
Fe_2O_3	0.95	6	Anorthite	14.18		
FeO	5.72	79	Corundum	0.71	C 0.71	
MgO	1.36	34	Hypersthene	11.58	P 11.58	Fem 15.65
CaO	3.37	60	Magnetite	1.39	M 3.06	
Na_2O	3.26	52	Ilmenite	1.67		
K_2O	1.57	17	Apatite	1.01	A 1.01	
P_2O_5	0.40	3		98.74		
H_2O	0.82	—	Water	0.82		
	99.59			99.56		

rock whose analysis is given in Table XVII, is composed mainly of plagioclase, green hornblende and quartz, with some biotite, titanite and magnetite.

Even that rock on the eastern shore which behaves almost like an eruptive and whose analysis was given in Table XVIII, still shows the general character of a crystalline schist. It is complosed of biotite, plagioclase and quartz, with some epidote and magnetite. Also the metabasalt of the dyke has entirely the character of a schist, being composed of small grains of plagioclase and stalks of green hornblende lying parallel to each other.

Only those rocks from the western shore which have become quite homophanous (massive) and which behave like eruptive rocks, show microscopically a texture which is very different from those of the crystalline schists, and possess in fact a very peculiar character. They consist mainly of andesine (35 % An), biotite and quartz, with very small amounts of ore. The andesine crystals are arranged somewhat like the laths of plagioclase in an ophitic diabase, but they are in part intergrown with quartz in such a way as to make them sometimes resemble skeleton crystals. Also the biotite is often similar to crystalloblasts, containing grains of the other minerals irregularly dispersed. The greater part of the quartz is decidedly allotriomorphic. Titanite, epidote and ore are present in trifling amounts. The texture is in some cases very near to that of the basic rocks which have originated from the refusion of the metabasalts, although the mineral constitution is different. Both mineralogically and in the texture this rock (Fig. 3, Plate III, analysis Table XIX) is a hybrid between a metamorphic and an eruptive rock, although nearer to the latter.

THE VÅTSKÄR GRANITE (D) AND ITS RELATIONS TO THE ADJACENT ROCKS.

The oldest Archæan granite of the region outcrops in its most typical form in the island of Våtskär, north of the pilot station with the same name, and stretches westward from that place as a zone which measures 6 km in length and 3 km in breadth. In the westernmost part of the area mapped another small outcrop of the same granite exists, and it also occurs in some small islands in the open sea, south of the Pellinge islands.

The rock of Våtskär is a grey, indistinctly porphyritic granite which shows a pronounced gneissose texture, owing to the parallel arrangement of the minerals. This is at least in part due to stress which has acted upon a solid rock. The greater felspars seldom measure more than 1 cm in length and possess irregular forms, having been more or less crushed. The main part of the rock has a medium grain and consists of lenses of felspar with a length of 2–10 mm, together with biotite and hornblende in almost equal parts, arranged in stripes between the felspar, and granulated, glittering quartz. The gneissose character is so pronounced that the rock may perhaps better be designated as a granitic gneiss than a granite. This conclusion is confirmed by a microscopical examination (Fig 4, Plate IV).

The predominant felspar is an oligoclase with a maximum extinction of about 10° (27 % An). The twinning lamellation is irregular but does not indicate any distinct fractures; obviously a healing of the felspar by recrystallization has taken place during the process of metamorphism. Microscopically the plagioclase has the »dull» appearance common to plagioclases of gneissose rocks, showing between crossed nicols no lively contrasts between different lamellae and nothing individual in the outlines, which are commonly rounded and do not show any crystal forms. The microcline is characterized by a very irregular »lattice» lamellation and is often broken. The quartz does often not show that flamy extinction which is usual in rocks that have undergone a purely mechanical metamorphism and no subsequent stronger recrystallization. Here the fractures have obviously afterwards been healed. The quartz now forms rounded grains with varying optical orientation, often arranged in lenses which sometimes lie on opposite sides of a cataclastic zone and by their forms and sizes reveal themselves as portions of large primary quartz crystals which have been crushed and broken whereafter the torn portions have been separated by gliding movements along a fissure. Sometimes the quartz grains have been elongated into string-like lenses. Biotite flakes and stalks of hornblende also often lie along the same gliding planes, winding between the other minerals and bordering the elongated quartz lenses. Another part of the biotite forms large irregula rcrystals which are sometimes bent. The light green hornblende is in quantity about equal to the biotite. The latter mineral sometimes encroaches upon the plagioclase, showing more or less irregular outlines against it. At some places the hornblende occurs as large crystals measuring even several centimetres in length.

At the boundaries between oligoclase and microcline barbed outlines occur, but myrmekite seems to be rather rare. The general metamorphism of the rock has gone so far as to obliterate, in a large measure, both the delicate structures mentioned and other features which originate at the beginning of a period of metamorphism.

In a strongly sheared gneissose rock from Hästholm, S. of Våtskär, myrmekite, however, is rather common, and here also the plagioclase shows still more conspicuous evidences of a mechanical crushing than at Våtskär.

No distinct features of the primary texture are left in these gneissose granites. Sometimes quartz grains are observed which show rounded outlines against the greater felspars and remind one of such primary quartz grains as are observed in many granites. But the greater felspar crystals also contain smaller grains of felspar with different optical orientation which possess the same rounded outlines and whose secondary character seems indubitable.

The chemical composition of the gneissose granite from Våtskär is shown by the following analysis, made by Dr. Eero Mäkinen. The relation between potash and sodium is different from that in the youngest granites of the same region. It has a more granodioritic composition, or is a l a s s e n o s e according to the American classification.

Table XX. Gneissose granite from the eastern shore of the island of Våtskär.
Analysed by Dr. Eero Mäkinen.

	%	Mol. prop.	Norm.			
SiO_2	67.36	1123				
TiO_2	0.61	8	Quartz	— 22.44	Q 22.44	Sal 88.55
Al_2O_3	15.20	149	Orthoclase	— 18.35		
Fe_2O_3	0.85	5	Albite	— 33.01	F 66.09	
FeO	2.80	39	Anorthite	— 14.73		
MnO	0.06	1	Diopside	— 1.86	P 7.70	Fem 10.08
MgO	1.30	32	Hypersthene	— 5.84		
CaO	3.40	61	Magnetite	— 1.16	M 2.38	
Na_2O	3.93	63	Ilmenite	— 1.22		
K_2O	3.12	33		98.63		
H_2O	0.84		Water	0.84		
	99.47			99.47		

Pegmatite and aplite connected with this granite sometimes occur, although not in very great quantities. In a granitic vein which probably belongs to this granite, intersecting the gabbro in Klovholm in Pernå, the rock shows a very typical micropegmatitic texture (Fig. 5, Plate III), well visible in spite of the strong mechanical metamorphism which the rock has undergone.

The author has followed the contact line between this granite and the schists of the Sundarö formation (A) from the region of Våtskär 6 km eastward. On Bergholm, east of Bockholm, several dykes of pegmatite which belong to the youngest Archæan granite (H) occur in the neighbourhood of the contact, which circumstance makes the relations of the older rocks less clear, but more to the west we generally find only the oldest granite and the schists, and their immediate contacts are visible in several places.

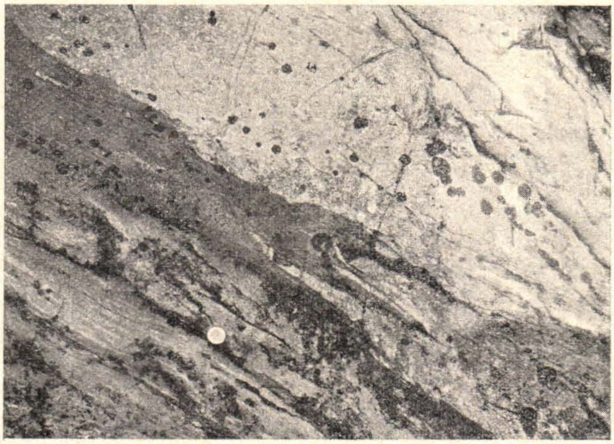

Fig. 60. Horizontal rock surface showing the contact between Sundarö schists and Våtskär granite. Island S. W. of Juponholm in Pernå. 1: 8.

The contact traverses the southernmost parts of Hästholm and Sotäktsholm, and the little island S. E. of Juponholm. Here several dykes associated with this granite are visible near to the contact, which is parallel to the strike of the schist. The granite is very rich in black mica. On the western side of the northernmost promontory of Hästö, the contact is visible east of the isthmus connecting it with Sundarö along a length of several metres. The granite is fine-grained and rich in mica. The boundary is nearly parallel with the schistosity of the schist, but the granite also intrudes the former rock as narrow wedges (Fig. 60). A narrow stripe of strongly sheared pegmatite, which no doubt belongs to the old granite, is visible at the contact. In the neighbourhood of the contact vein-like stripes of felspatic material which probably belongs to the granite, occur in the schist.

On the southern side of the isthmus there is an eruptive breccia of granite including numerous fragments of schist and meta-andesite, but this granite certainly belongs to the Rysskär formation (F) and not to the oldest Våtskär granite (D) now in question.

The gneissose granite is well exposed east of Sundarö pier, where the rock contains numerous small lense-like fragments of schist. The contact is not visible.

The rock has here a peculiar appearance. It consists of a grey felspar and a cementing chocolate-coloured mass containing minute flakes of chlorite and epidote. Even macroscopically it shows signs of having undergone strong mechanical disturbances.

Microscopically the felspar reveals itself as an albite, with a maximal extinction of about 15° in sections perpendicular to P M (5 % An). The twinning lamellation is very irregular, and trituration zones cut the felspars almost everywhere. Mainly between the felspars, especially in these trituration zones, occur numerous flakes of chlorite which is probably, at least in part, altered biotite, together with grains of epidote and smaller crystals of titanite. The rock is a soda syenite, similar in composition to those which have been described from the Kiiruna-Gellivaara region in Sweden by Geijer, and from Ostrobothnia in Finland by Mäkinen. Chemically and mineralogically it also has a resemblance with the Helsinkites described by Laitakari which are chiefly composed of albite and epidote. He regards them as primary magmatic rocks, but also lays stress on their near connection with pegmatites.

The Våtskär granite also is sometimes intersected by narrow fissures filled with epidote. Near to them, the biotite of the rock has been partly changed into chlorite. Sometimes the biotite also seems to have been replaced by epidote.

It is thus possible that the formation of the epidote and the chlorite is a process of later date than the general metamorphism of the rock, as has been made probable by Väyrynen in the case of similar rocks from the neighbourhood of Tavastehus.[2]

The author has subsequently studied the formation of fissures filled with epidote and of epidotiferous portions of granites in other regions, and will later report on these observations. He has also ascertained the near connection of these phenomena with the formation of pegmatitic veins. From these veins juices rich in carbonates have emanated, percolating the neighbouring rocks and changing some parts of them into aggregates rich in epidote. Chemically this process has great interest, but both petrologically and geologi-

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[1] Aarne Laitakari, Einige Albitepidotgesteine von Südfinnland. Bull. comm. géol. Finl. N:o 51, 1918.

[2] Medd. från Geol. För. i Helsingfors 1917 och 1918, p. 5.

cally these masses are very vaguely defined and cannot be regarded as forming a special type of magmatic rocks, in the strict sense of the word.

Fig. 61. Migmatite of Sundarö schists and Våtskär granite. Haverholm in Borgå.

In the westernmost parts of the zone of schists belonging to the Sundarö formation, we find, at its southern margin, another small

Eig. 62. Migmatite of Sundarö schists and Våtskär granite. Haverholm in Borgå. 1:8.

area of gneissose granite which certainly belongs to the same group as the Våtskär granite. It is here outcropping in the Småholmarna and Timmerholm islands W. of Sundö.

The rock is here still more sheared than on Våtskär, a perfect gneiss, consisting mainly of small rounded grains of felspar and quartz, together with flakes of biotite. More to the west, on Haverholm, the granite forms migmatites with fragments of schist (Figg. 61 and 62.) Many of the granite dykes and veins are straight and parallel with the schistosity of the fragments, but they often also intersect the lamellation. Numerous small faults are visible (Fig. 62). In the schistose portion of this migmatite epidote is abundant. This migmatitic rock has a characteristic appearance and is very different from the eruptive breccias associated with the younger granites.

In the area of gabbro (C) lying between the two outcrops of the granite F, migmatites of gabbro and gneissose granite also occur, especially at the southern margin. This granite also belongs to the Våtskär group, so that its age is determined by its relations to the metabasalts of group E which intersect it, as has been described in a previous chapter. Also in the quartzitic area west of this gabbro, dykes of the Våtskär granite are certainly found. They are visible e. g. S.W. of Tirmo. But as this area is in large measure permeated with granite belonging to group F, it is sometimes difficult to identify dykes belonging to the older granite. Finally there occurs in some islands which lie in the open sea south of the Pellinge area, a gneissose granite which shows a similar character and has a position analogous to that of the Våtskär granite in relation to other rocks of the region.

These islands, Kummelskären, which lie about 3 km S. of Stor Pellinge, consist of a migmatite of a peculiar character. Numerous veins of an aplitic granite penetrate the older rocks (Fig. 63), among which at least two different constituents can be distinguished, one a dark «metabasite» and another a gneissose granite which is sometimes indistinctly porphyritic. Although the basic rock generally forms fragments in the aplite, they are often so arranged as to suggest the idea that the fragments are parts of a dyke which has been torn in pieces. On the southern shore of West Kummelskär better defined dykes of the metabasite actually appear, which intersect the gneissose granite in a direction transversal to its schistosity. In most places, however, the basic rock is highly brecciated and intermingled with a granite which belongs either to the Hangö granite or, less probably, to the Rysskär granite. The veins show the effect of fluidal folding which they have undergone together with the fragments. In the little island of Bockholmgrund, E. of Kummelskär and about 3 kilometres south of the Pellinge islands, a porphyritic granite occurs which is penetrated by numerous veins of aplite and pegmatite of the Hangö type. The porphyritic granite has a gneissose character and is penetrated by an indistinctly preserved dyke of metabasite. It seems probable that it is a porphyritic variety of the same gneissose granite which occurs in Kummelskären. The metamorphosing influence of the younger granite on the gneissose granite has obviously been very strong. Hereby also the porphyritic felspars have been recrystallized, in the same way as is often the case with the porphyritic granite occuring in the Tvärminne region, east of Hangö, as will be described in a later treatise.

12 km more to the E. S. E. in the open sea, lie the small islands of Gaddarna at a distance of about 10 km from the more densely

Fig. 63. Migmatite consisting of gneissose granite and metabasite penetrated by veins of younger granite. West Kummelskär in Borgå. 1:15.

lying islands. These consist also of a grey, very schistose granite which is coarser in grain than the Hangö granite, and is penetrated by veins which prossibly belong to that granite. The gneissose granite is cut by several dykes of a fine-grained metabasitic rock, partly branching. These are certainly true fissure dykes (Fig. 64). They are older than the granite of the veins, which intersect both them and the gneissose granite. The basic dykes probably belong to the volcanic group E.

Both in the islands lying to the west of Kummelskären and to the east of Gaddarna the older granites and migmatites are interwoven with veins of microcline-granite and pegmatite belonging to group H. If the rocks were not to such a great extent hidden under the water of the sea, we should be able here to study very typical »polymigmatites» consisting of at least two different granites and one basic rock.

The oldest granite D seems to have been subject to a rather strong mechanical pressure. The oldest basic dykes occurring in the Hästö formation often show, especially when they run transversally to the strike of the schists, signs of having undergone strong disturbances. But the dykes belonging to the Pernå formation (E) have not been faulted, even when they run in a direction transversal to that of the strike of the rocks (cf. Fig. 64), and the Rysskär granite (F) is never gneissose, although the minerals show signs of having undergone mechanical pressure.

Fig. 64. Slightly inclined rock surface of gneissose granite cut by two dykes of metabasalt. Gaddarna in Pernå. 1: 15.

These circumstances prove that the gneissose texture of the granite has originated before the eruption of the volcanic Pernå formation (E).

The author was earlier inclined to think that the gneissose texture of the Våtskär granite was entirely due to a dynamometamorphism which had acted on the rock after its solidification. Observations which he has made later in south-western Finland seem to prove that the parallel texture of similar gneissose granites of these regions is in many cases due to the circumstance that the magma has assimilated older schistose rocks. It is possible that part of the parallel texture of the oldest granite of the Pellinge area may have a similar origin.

The circumstance that dykes of metabasalt, of the same character as those occurring in the Pernå formation, are so common in the adjacent areas, even at distances of many kilometres from that area, proves that the volcanic formation mentioned has earlier had a wide extension over neighbouring areas. Then those dykes whose rocks are fine-grained and sometimes even aphanitic, cannot have solidified very far from the surface of the earth. They filled fissures which were opened at the same time when the lavas composing the supercrustal Pernå formation erupted. Although the metamorphosed lava beds are now vertical or nearly so, the surface which separates this formation from its basement may be, in the main, nearly horizontal, and so is probably also the position of the volcanic rock masses taken in their totality.

Whenever we meet similar volcanic dykes in other, more westerly regions of the southern shore of Finland, the conclusion seems warranted that they indicate nearness to a former Archæan surface on which volcanoes and extensive basaltic beds probably existed in many places, although remains of them now are left only in a few regions.

THE STADSLAND GABBRO (C).

The old gabbro of Stadslandet (Rösundsö) and adjacent islands in Pernå is a typical intrusive rock of plutonic character which penetrates the Rabbas quartzite and the Sundarö schists, but is decidedly older than all volcanic rocks of the Pernå and Pellinge formations and also than the Våtskär granite (D) and all younger granites.

The prevalent rock is of medium grain and has on the surface a brownish red colour, which is determined mainly by that of the felspar constituents and not so dark as could be expected in such a basic rock. It shows an indistinct parallel texture which is probably secondary. It often contains inclusions of rock varieties with identical composition but very varying texture, most of them porphyritic, showing phenocrysts of plagioclase or uralite in a groundmass of varying grain. They seem to be fragments of rock varieties belonging to the same magma as the main part of the rock, but which have solidified earlier than it. Sometimes these fragments are so numerous and manifold as to form with the main mass of the gabbro a typical eruptive breccia.

The typical gabbro consists mainly of plagioclase and hornblende. The felspar usually shows a maximal extinction of 12—16° and is thus an andesine (30—31 % An). The lamellae have often been bent and broken, and the extinction is therefore somewhat irregular. This felspar forms laths with a breadth of 2—4 mm. Between them lies hornblende which under the microscope is pleochroic in green to yellowish or yellowish-red colours, some quartz and often also magnetite, apatite and titanite in varying amounts. It has irregular contours, is sometimes sheaf-like, sometimes subdivided in a number of small rounded grains. The larger crystals are often intergrown with irregularly dispersed patches of a hornblende with identical composition, but a different optical orientation. In some cases biotite is also present, replacing part of the hornblende (Fig. 6, Plate III).

Vague reminiscences of an original ophitic texture are sometimes visible in the distribution of the minerals, but in general the strong metamorphism which the rock has undergone has entirely veiled the primary textures.

This gabbro shows very typical eruptive contacts with those neighbouring rocks which are older, but is not injected into them in the same intimate way as the granitic rocks of the same region. This is a remarkable fact which is repeated at most other contacts between plutonic basic rocks and the rock masses surrounding them. The absence or rarity of rocks, corresponding to the migmatites, at the contacts of deepseated basic rocks (the author does not know any instance where typical basic migmatites would occur), seems to indicate that the formation of migmatites is not due mainly to a mechanical »stoping» of the adjacent rocks, but depends essentially on the chemical character of the magma.

The delimitation of the gabbro area is very peculiar. It forms a narrow zone following all the sinuosities of a line which seems to indicate the original boundary between the oldest schists and the volcanic rocks of the Pernå formation. This suggests the idea that the gabbro originally formed a thin sheet which did not solidify very far from the earth's surface.

N. of the greater gabbro area there is a small outcrop of the same rock which has more indefinite outlines.

The following analysis, Table XXI, made by Dr. E. Mäkinen, shows the composition of this gabbro, which is an *auvergnose* according to the »American classification», as we have called it in this memoir, that is to say the classification of Cross, Iddings, Pirsson and Washington.

Table XXI. Gabbro from the N. E-shore of Stadslandet in Pernå. Analysed by Dr. Eero Mäkinen.

	%	Mol. prop.				
SiO_2	48.08	801	Orthoclase 6.12	F 59.86		Sal 59.86
TiO_2	1.46	18	Albite 16.77			
Al_2O_3	18.00	176	Anorthite 36.97			
Fe_2O_3	2.38	15				
FeO..........	8.94	124	Diopside 3.72	P 31.18	Fem 38.07	
MgO	6.93	173	Hypersthene 27.46			
CaO..........	8.70	155	Magnetite 3.48	M 6.22		
Na_2O	2.00	32	Ilmenite 2.74			
K_2O..........	1.01	11	Apatite 0.67	A 0.67		
P_2O_5	0.26	2	97.93			
H_2O 110° + ..	2.02		Water 2.31			
H_2O 110° — ..	0.29		100.21			
	100.07					

CONCLUDING REMARKS

The basic dykes have given to the author the Ariadne thread which he has followed when trying to solve the riddle of the migmatitic rocks which is so closely connected with some of the greatest petrological problems, and he is confident that this clue has not led him astray.

The special question which he proposed to solve in the Pellinge region has been answered: it has been possible to determine the origin and age of the basic dykes for this particular region, and their age relations to other rocks. They are connected with supercrustal volcanic rocks, of which especially the older (i. e. the Pernå formation) still have a wide extension, and probably had a still greater formerly. It is most likely with this Pernå formation, not, as the author thought before, with the younger Pellinge formation, that the main portion of the volcanic dykes occurring in the western parts of the coast regions is genetically connected. But even if there were any incertitude as to this point, the circumstance does not play any considerable rôle. Then in the western regions the granites of Rysskär type seem to have a very unimportant extension, if any at all, and the basic dykes there come in age everywhere between gneissose granites, corresponding to the Våtskär granite of the present region, and the granites of Hangö type.

More important is the fact that these basic dykes are everywhere true volcanic fissure dykes, and occur all over the coast regions in such multitude and so intimately connected with each other as to make their correlation certain. Not only in the Pellinge region but also at another place, in the same area of migmatitic granites of southern Finland, viz. at its northern margin, near Tavastehus (Hämeenlinna), the metabasalt forms extensive surface flows, and in the archipelago of Åland it occurs as thick horizontal sheets which possess the same texture as the rock of the narrow dykes, and certainly have crystallized near to the earth's surface.

The old metamorphic volcanic rocks which we have studied here show, in their primary features, no difference from modern volcanic rocks, and in an analogous way we have also found, among the supercrustal rocks of the Pellinge region, sandstones which are products of a normal weathering, indicating climatic conditions similar to those of later ages.

We have further found that the determination of the relative age of the Archæan rock masses, even when they are so highly metamorphic and in part so interwoven with granites as in the present region, is not necessarily a hopeless task. On the contrary it may, if the outcrops are as excellent as in the coast regions, be completely successful.

The succession which we have arrived at here, in this fragment of a vanished world which is the Pellinge area, seems to hold good also for the western part of the coast regions, and may be used as a time scale.

The metamorphism of these rocks has been mainly chemical. A purely mechanical s. c. dynamometamorphism has in most cases been of very little importance. Even the oldest volcanic rocks often show only the slightest influence of dynamic alteration.

The main part of the metamorphism has taken place in obvious connection with the eruption of granites; it can be defined as a regional contact-metamorphism.

Thus most of the granites may be described as non-dynamometamorphic. Where they are gneissose, this is mainly due to the fact that they have absorbed older schistose rocks. Only the oldest gneissose granites have in part become sheared by dynamic action. But also here the parallel texture is probably to a large extent due to the assimilation of older schistose rocks.

The aplitization of older rock masses which plays such an important rôle in the formation of veined gneisses, can in no case be explained, in the present region, as due to an «ultrametamorphism» independent of the eruption of granites. Every aplitic or granitic vein is genetically connected with some special granite outcropping in the same region, and it is in most cases possible to determine with certainty to which of the different granites it belongs.

By the study of these four or five different granites (the author is doubtful whether the Onas granite is genetically separated from the rapakivi) we have already been able to elucidate many of the problems whose solution is the purpose of this investigation. We have here met some of the most important types of migmatitic rocks. Many of those types are so characteristic and so different from each other, that it seems quite possible to recognize and identify the same types in other, adjacent regions. Moreover, the fragments of the older rocks which have been penetrated by the granites are, even in the greatest areas of migmatites, occasionally astonishingly well preserved, so that it may be feasible to determine their primary characters and relations to each other. Thus the correlation even of rock formations which are in the most intimate way interwoven with granites is by no means impossible.

We have often been able, while recording our observations, to draw immediate conclusions as to the mode of formation of migmatitic rocks, and the mechanism of eruption of abyssic granitic magmas, hereby also correcting many prevalent errors.

The author reserves, however, his final theoretical conclusions to a later memoir. He will first publish the results of his later studies on the same subject in the western parts of the coast regions, as soon as he can find leisure for this continuation of his petrological work. He hopes that every attentive reader of this memoir will at least admit that such studies are necessary and may be fruitful. The problem of regional granitization is not solved through the creation of some terms or catch-words. It ought to be studied in great detail in all regions where the rocks in question are sufficiently exposed.

Purely theoretical deductions, whether they may be based on geophysical or chemical considerations, cannot lead to any definite solution of these problems, nor can laboratory experience do so.

The safest way in geology is the old way of inductive science, by studying nature's methods in her own great workshops, where they are available to our direct observation. Only by such field studies, conjoined with microscopical research, and of course giving due consideration to the important results of modern physico-chemical science, can we reach a better knowledge of the petrogenesis of the depth.

EXPLANATION OF THE PLATES.

All microphotographs have been taken by Mr. W. W. Wilkman.

PLATE I.

Fig. 1. Uralite-porphyrite of the Pellinge formation. Sådholm, Lill Pellinge. Section A 1001. Ordinary light. × 11. Detailed description pp. 23—24.

Fig. 2. Plagioclase-porphyrite of the Pernå formation. Öster Rysskär, Pernå. Section A 1037. Crossed nicols. × 12. Mainly andesine and hornblende with some ore.

Fig. 3. Dolerite (diabase) of the Pernå formation. Våtskär, Pernå. Section A 1103. Crossed nicols. × 50. Olivine crystal surrounded by a primary coating of augite. Detailed description p. 41 and Bull. N:o 48, pp 37—38.

Fig. 4. Gabbro of the Pernå formation. Small island S. E. of Tunnholm, Borgå. Section A 979. Crossed nicols. × 13. Andesine, diallage, brown hornblende and olivine.

Fig. 5. Olivine crystal surrounded by coronas of tremolite and green hornblende in olivine gabbro of the Pernå formation. Small island S. E. of Tunnholm, Borgå. Section A 979. Ordinary light. × 40.

Fig. 6. Metabasalt of the Pernå formation. Långhäll, Pernå. Section A 1142. Crossed nicols. × 12. Description p. 50.

PLATE II.

Fig. 1. Quartzitic schist (meta-psammite) of the Rabbasö formation. Stor Bytthölm, Pernå. Section 1069. Crossed nicols. × 13. Quartz, microcline and muscovite.

Fig. 2. Hornblende-schist of the Sundarö formation. Fölisöudd, Pernå. Section 1113. Ordinary light. × 20. Hornblende, biotite, quartz and plagioclase.

Fig. 3. Meta-andesite of the Sundarö formation. Loitholmsviken, Pernå. Section 1101. Polarized light. × 11. Description p. 72—73.

Fig. 4. Oligoclase with a core of myrmekite in granite of the Våtskär group, recrystallized trough the action of the rapakivi granite. Northern shore of Bergholm, Pernå. Section A 1126. Polarized light. × 45.

Fig. 5. Diorite probably formed by syntexis of Hangö granite and Pernå metabasalt. Section A 963. Crossed nicols. × 12. Lökskärsklacken near Glosholm, Borgå. Oligoclase, anthiperthite, hornblende intergrown with quartz, titanite.

Fig. 6. Granite of Hangö type. W. of Rödhäll, Kitsudd, Pernå. Section 1056. Crossed nicols. × 11.

PLATE III.

Fig. 1. Granite of Rysskär type. Öster Rysskär, Pernå. Section 1042. Crossed nicols. × 12. Oligoclase, microcline, quartz, trifling amounts of chloritized biotite.

Fig. 2. Dioritic rock. Small island between Rysskären and Ytterholmarna. Section A 1050. Crossed nicols. × 13. Andesite, hornblende, biotite, quartz.

Fig. 3. Rock originated by palingenesis of a conglomeratic schist. W.-shore of Viasholm, Pernå. Section A 1082. Crossed nicols. × 13. Description p. 137.

Fig. 4. Gneissose granite of Våtskär type. E.-shore of Våtskär, Pernå. Section A 1158. Crossed nicols. × 12. Description pp. 137—138.

Fig. 5. Micropegmatite in vein belonging to the Våtskär granite. Klovholm, Pernå. Section A 1146. Crossed nicols. × 17. Oligoclase and quartz.

Fig. 6. Gabbro of the Stadsland type. N. E.-shore of Rösundsö (Byön), Pernå. Section 1033. × 13. Description p. 147.

PLATE IV.

Fig. 1. Meta-andesite of the Sundarö formation. Small island N. W. of Risholm. Crossed nicols. × 12. Idiomorphic crystals of labradorite surrounded by a mass rich in uralite.

Fig. 2. Meta-andesite strongly metamorphic through the action of aplite. Small island S. of Bergholm. Crossed nicols. × 12. Plagioclase interwoven with actinolite and quartz.

Fig. 3. Aplitized schist. Small island N. of Risholm (Våtskär pilot station). Section A 1188. Ordinary light. × 12. Alternation of femic and salic stripes. The former consist of diopside, actinolite, biotite and magnetite, the latter of plagioclase.

Fig. 4. Aplitized schist at the main contact with rapakivi. Small island S. W. of Buckholm. Section A 1073. Crossed nicols. × 12. At the midst a veinlike stripe. Diopside, biotite and oligoclase, all more or less idiomorphic, surrounded by xenomorphic quartz and orthoclase.

Fig. 5. Contact between aplitic vein and aplitized schist. Small island S. W. of Buckholm. Section A 1187. Crossed nicols. × 15. Microcline and quartz containing numerous minute grains of oligoclase.

Fig. 6. Ptygmatically folded vein in aplitized schist from small island N. of Risholm. Section 1178. Crossed nicols. × 12. Quartz and microcline showing no influence of pressure.

PLATE V

Fig. 1. Vitroporhyric metabasalt in contact with meta-dolerite. Virskär, Pernå Section A. 1102. Ordinary light. × 30.

Fig. 2. Doleritic basalt. Virskär, Pernå. Section A 1103. Crossed nicols. $\times 17$. Augite, plagioclase, olivine (0).

Fig. 3. Dykes of metabasalt belonging to the Pernå formation, (dark) intersecting a meta-andesite of the Sundarö formation (dotted), both being penetrated by veins of Rysskär granite (white). Horizontal rock surface at Hästö in Pernå. 1: 73.

Fig. 4. Map of a horizontal rock surface at the western shore of Viasholm, showing conglomeratic schist in contact with mica-schist. Both are cut by dykes of metabasalt and intimately penetrated by aplite (dots). In some places next to the contact the conglomerate has been changed into a massive rock (sparse dots). 1: 1 000.

PLATE VI.

Fig. 1. Map of a horizontal rock surface at the eastern shore of Viasholm, showing conglomeratic schist cut by metabasalt of the Pernå formation (dark); both are penetrated by aplite and pegmatite (white) belonging to the Rysskär granite. 1: 40.

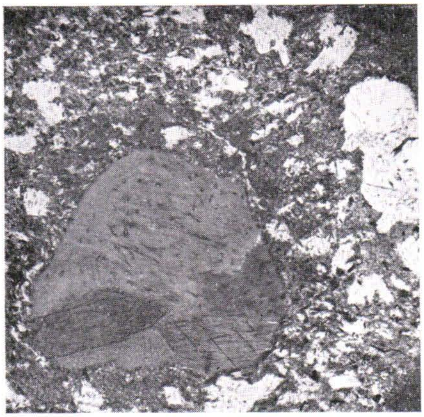
PLATE VII.

Fig. 1. Map of a horizontal rock surface at the southern shore of Stadslandet, showing migmatite of Stadsland gabbro and Våtskär granite, both penetrated by metabasaltic dykes of the Pernå formation. These dykes are cut by veins of Rysskär granite. 1: 91.

PLATE VIII.

Fig. 1. Uralite-porphyrite of the Pernå formation (dark) penetrated by aplite (white) and pegmatite (dotted), belonging to the Hangö granite. Southern shore of Nyttisholm in Pernå. 1: 25.

PLATE I.



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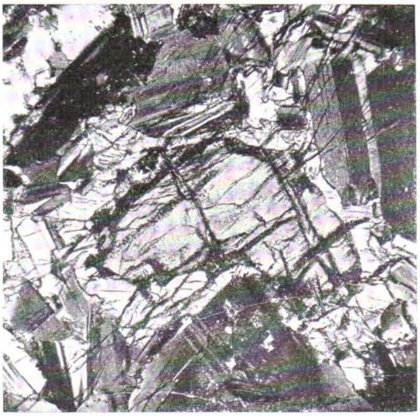

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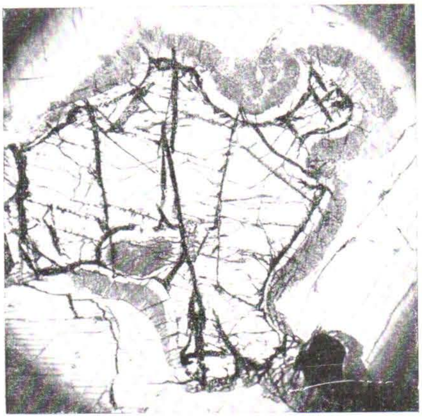
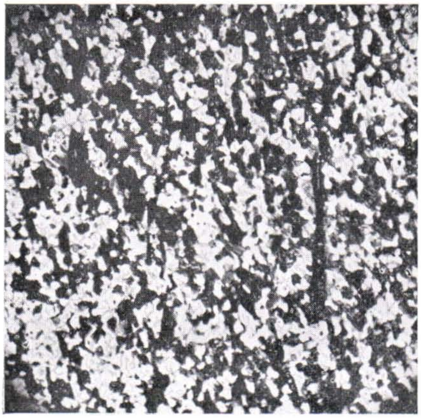


Fig. 5.

Fig. 6.

Photo. W. W. Wilkman.

J. J. Sederholm: On Migmatites.



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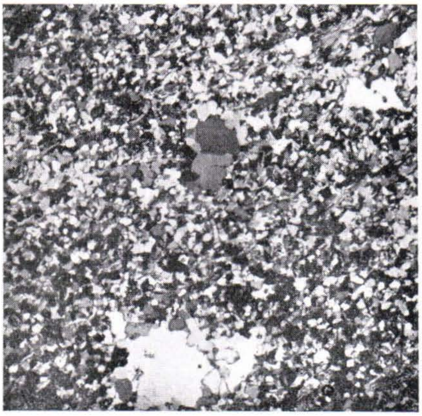

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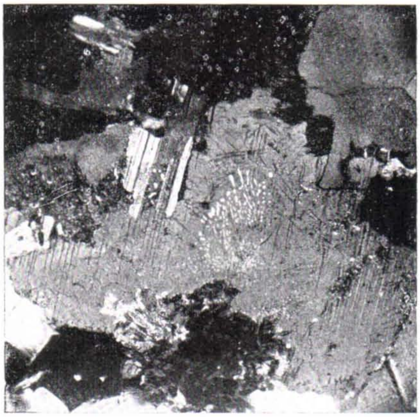

Fig. 4.

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PLATE III.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

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Fig. 6.

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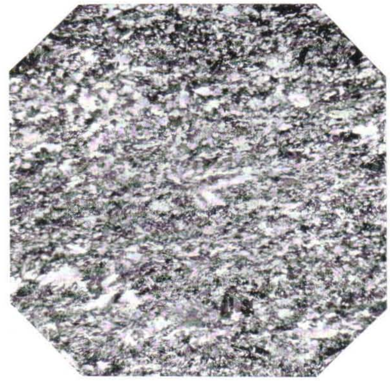
PLATE IV.

Fig. 1.



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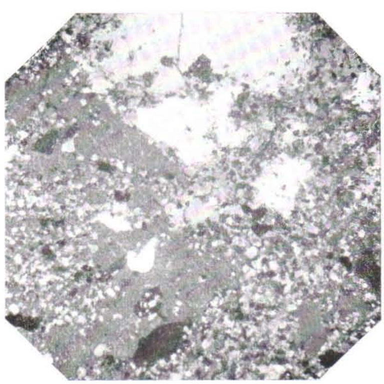

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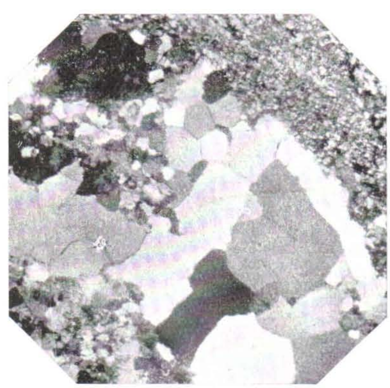

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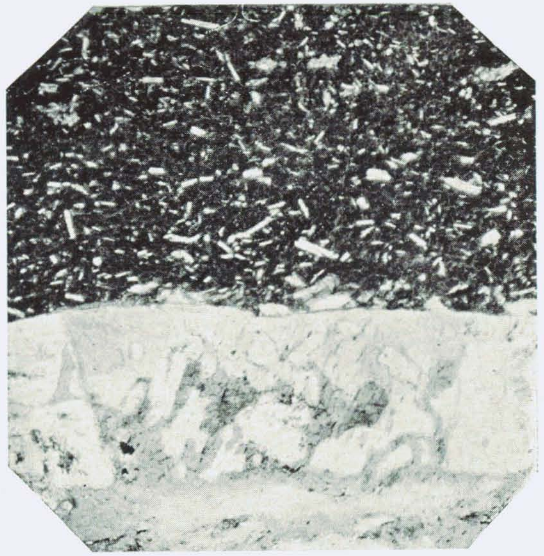

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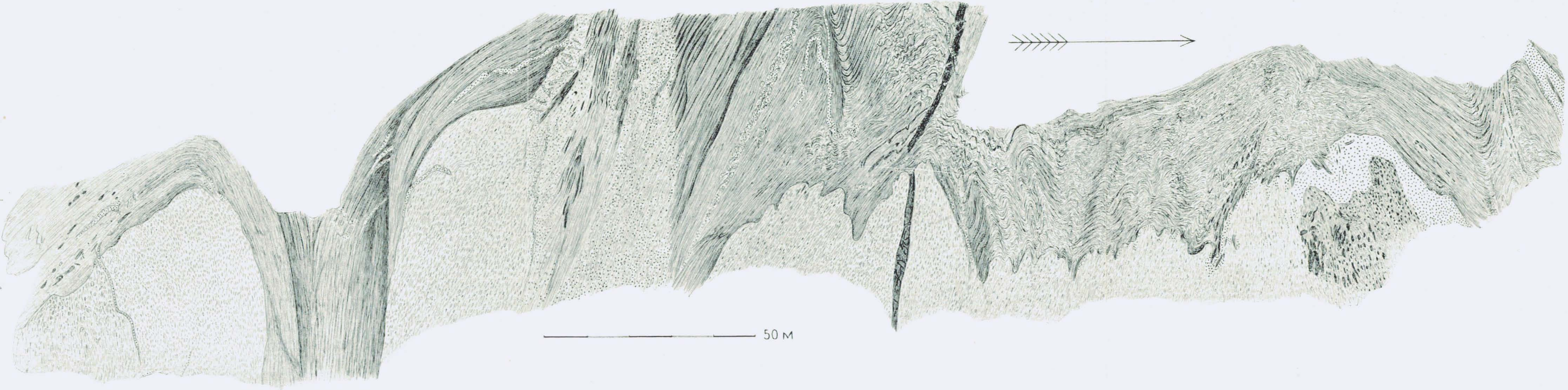
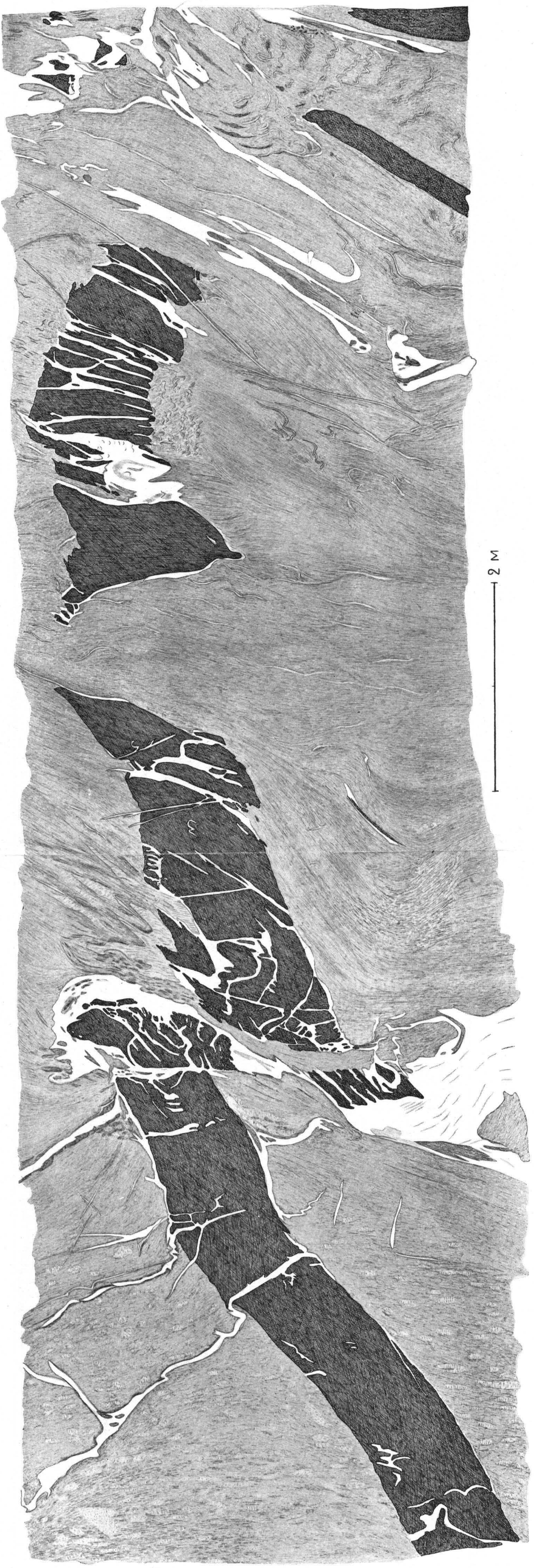


Fig. 4.

PLATE VI.



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J. J. *Sederholm:* On Migmatites.

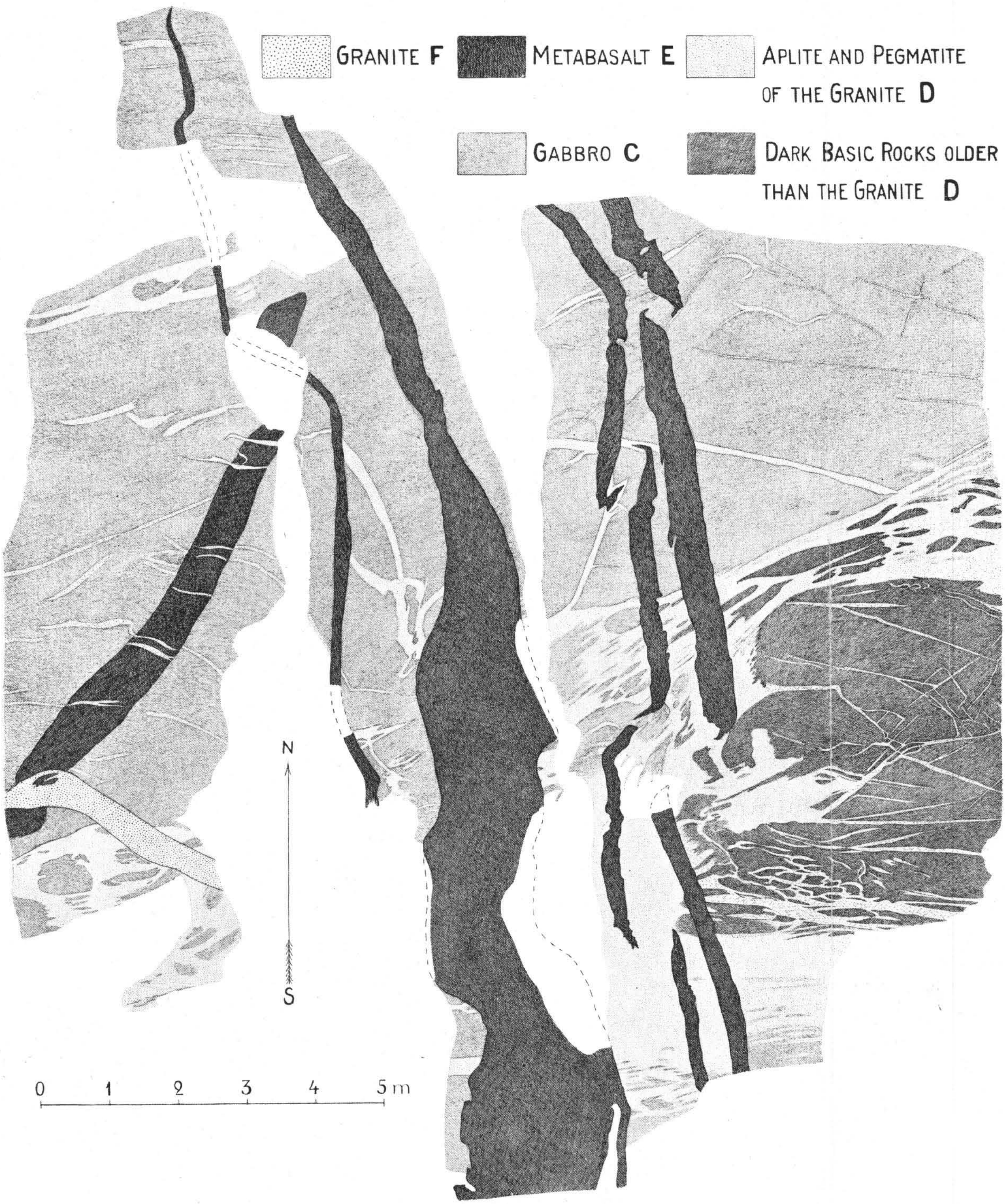
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Fig. 1.

PLATE VIII.

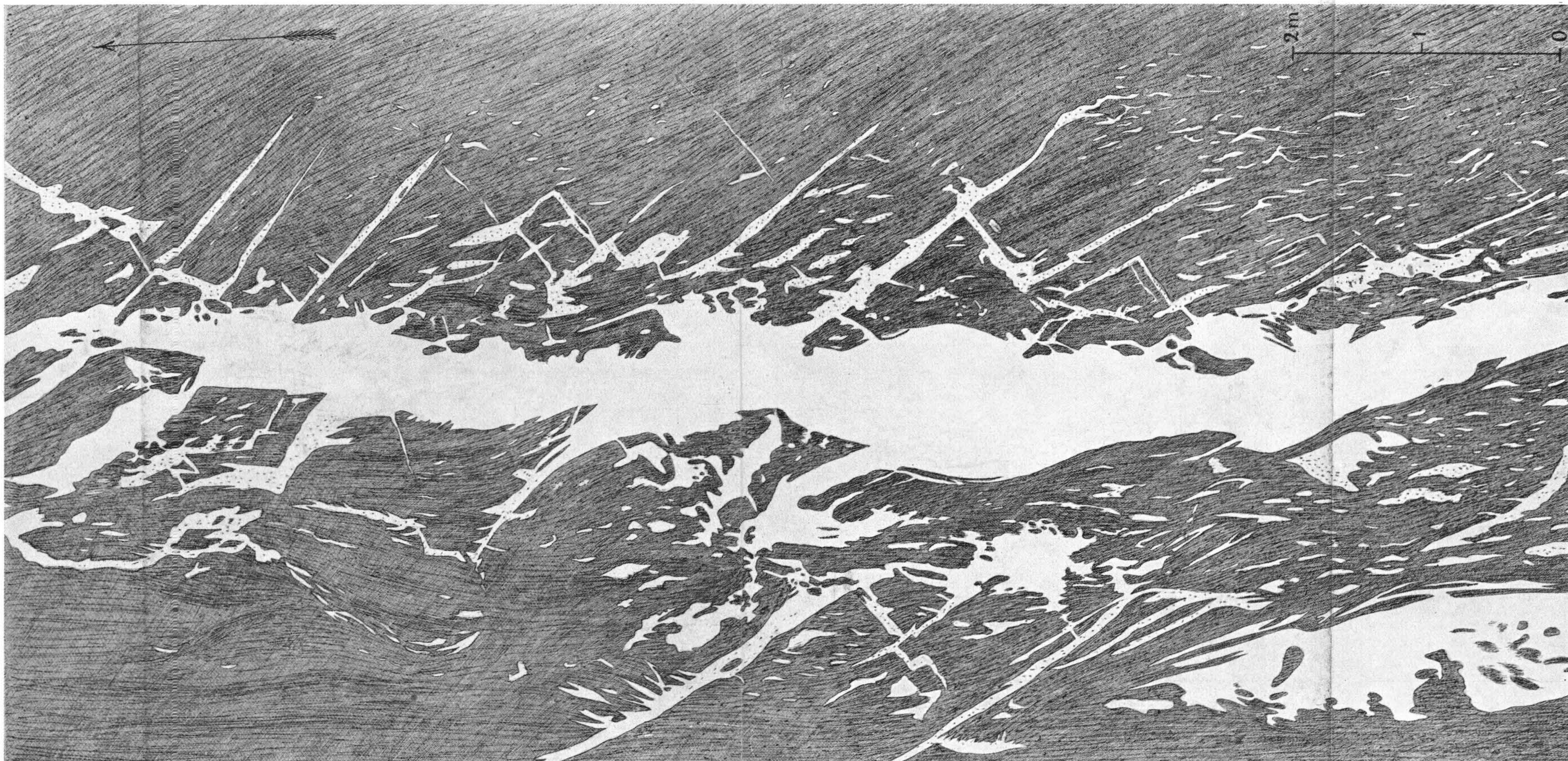
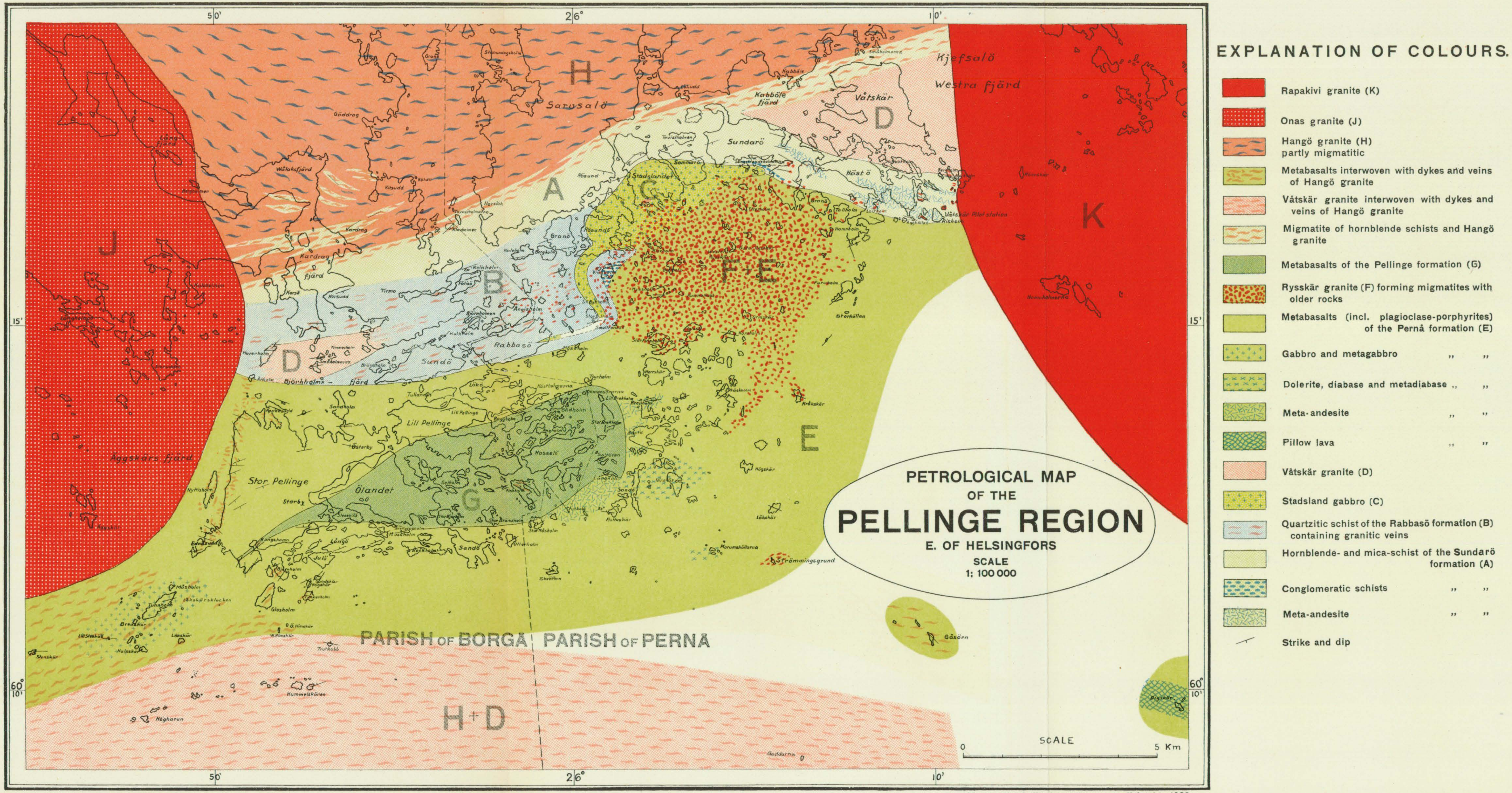


Fig. 1.

J. J. Sederholm: On Migmatites.



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