A PETROGRAPHIC COMPARISON OF A TERTIARY ALKALINE IGNEOUS COMPLEX IN NORTHEASTERN GREENLAND WITH THE MONTEREGIAN HILLS OF EASTERN CANADA

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Abstract

A tertiary, alkaline, igneous complex occurs in eastern Greenland near the Atlantic coast at approximately 72° N latitude. The magma intruded a sequence of flat-lying, unmetamorphosed, arenaceous sediments ranging from Carboniferous to late Cretaceous in age. Thermal, metasomatic, and mechanical contact effects are very small.

Igneous rock types range from pyroxenite and peridotite through gabbro and monzonite to calc-alkali syenite, alkali syenite, nepheline syenite, and alkali granite. The basic types show with titanaugite, titaniferous hornblende, titanium-rich biotite, and plagioclase as major constituents, and with residual alkali feldspar a clearly essexitic character. Age sequence from basic to acid types is well proved by inclusions and apophyses. Both intrusions of separate, distinct magmas as well as differentiation *in situ* took place. The general trend of the Niggli-values in the variation diagram and the development along the MF line in a QLM triangle (atlantic differentiation) correspond well with the genetic sequence. Various kinds of volcanic and subvolcanic breccias are genetically and spatially related to the intrusives (mainly to the syenites) and prove the hypabyssal, shallow character of the latter.

Leucocratic dykes of mainly syenitic composition are considered to be comagmatic derivatives of the acid intrusions.

Basic dykes and sills are extremely numerous and comprise both alkali basalts and lamprophyres. Yet it is not possible to evaluate to what extent they may be related to the local alkaline intrusions or to the regional Greenlandic (Brito-Arctic) basalt cycle.

Pneumatolytic-hydrothermal alteration of both intrusive and sedimentary rocks, and deposition of disseminated sulphides and oxides are conspicuous throughout the whole complex. Economic deposits of molybdenite and wolframite of this phase are associated with the granite in the western part of the complex, while galena and sphalerite-rich quartz veins were found north and south of it.

The results of spectrochemical trace element study in minerals and rocks from the western part of the complex are discussed in detail.

Facts which are true for both the Greenland and the Monteregian igneous complex and which prove their close relation are: alkaline character (essexite-syenite), mineralogical paragenesis, trend of differentiation, age sequence, comagmatic dyke-swarms, formation of volcanic and subvolcanic breccia, near-surface intrusion level, small thermal, metasomatic, and mechanical effect against the wallrock, and atectonic emplacement.

In this paper some aspects of a Greenland igneous complex will be described and compared with the Monteregian Hills. Good geological and petrological summaries of the latter are given by O'Neill (1914), Dresser & Denis (1944), and Burri & Niggli (1945).

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General Geology

A belt of late Cretaceous to Tertiary intrusive rocks, extending over a distance of approximately 50 miles, occurs near the east coast of Greenland at 72° N latitude. It can be divided into the three units of the Werner Bjerge, Pictet Bjerge, and Traill Island (see Fig. 1).

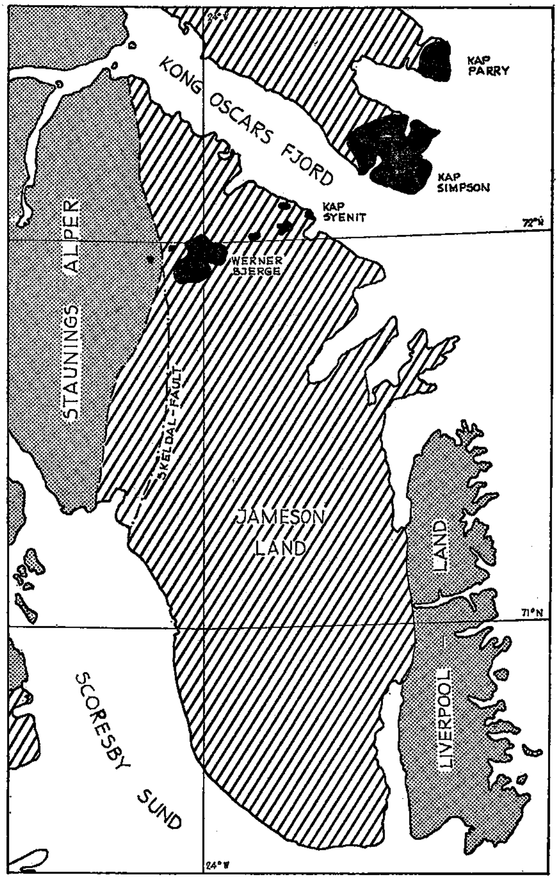

Fig. 1. General geology. Dotted: Caledonian belts of Staunings Alper and Liverpool Land; ruled: Palaeozoic and Mesozoic sediment basin of Jameson Land and Traill Island; solid black: Tertiary intrusions.

The Werner Bjerge massif on the west was first explored during the years 1953 and 1954 by P. Bearth and E. Wenk. It covers a total surface area of about 80 sq. miles (including permanent glaciers and firn). The intrusion of Kap Simpson and Kap Parry on southern Traill Island are at present being studied by H. P. Heres, and cover a surface area about twice that of the Werner Bjerge. Between these two marginal complexes four smaller, separate intrusions, each with an approximate surface area of ½ to 2 sq. miles, occur in the region of the Pictet Bjerge. They were investigated by the author during the years 1957–1959.[2] In the Werner Bjerge the highest mountain peaks reach 6000 feet, while an average of 3300 feet is usual in the Pictet Bjerge and on Traill Island. It is evident from geological, petrological, and geochemical relations that all these different intrusions are syngenetic products of one regional intrusive phase, and it is believed that they form only a link in the chain of the East Greenland granite-syenite intrusions.

The intrusions cut steeply through a sequence of flat-lying, unmetamorphosed, arenaceous sediments, ranging in age from Carboniferous (on the west) to Cretaceous (on Traill Island). Thus the complex can be dated to be post-Campanian (late Cretaceous).

Intrusive contacts are sharp and distinctly magmatic. A possible metasomatic origin (fenitization), as proposed for the alkaline batholith of Illimaussaq (S Greenland) is out of the question. Metamorphic contact effects are restricted to thermal baking and transformation of clay-like sediments to biotite-hornfels, and of sandstone into quartzite. Mechanical deformation or disturbance of the country-rock—except formation of volcanic breccia—is usually minor; the emplacement of the whole complex has a distinctly atectonic character. The sedimentary roof is entirely removed in the Werner Bjerge, but is well preserved in the Pictet Bjerge complex. In spite of the lack of volcanic flows it can be shown that the intrusion was very shallow and near surface. It is obvious that these relatively small igneous stocks are of hypabyssal, subvolcanic origin and do not justify the terms "batholith" or "pluton."

Facts which are true for both the Greenland intrusions and the Monteregian Hills are: the linear arrangement of a number of locally separated, independent stocks (necks?), the atectonic emplacement, the near surface shallow intrusion level, the small contact metamorphic and metasomatic effect against the wallrock, and the lack of volcanic flows. A recent biotite K/Ar determination of a nordmarkite from Brome Mountain gave an age of 122 million years.[3] The Monteregian province, which for a long time was considered to be post-late-Devonian would thus (according to the division of Kulp, 1959) fall into the lower Cretaceous. However, age determinations by the helium method, made on a tinguaite from east of Mt. Royal gave 57 ± 1.5 million years (Urry,

[2]The study of the whole complex was part of the investigations of the Danish East-Greenland Expedition, led by Dr. Lauge Koch, Copenhagen.

[3]Personal communication from Dr. A. S. MacLaren, Geological Survey of Canada.

1936), which would place it into early Eocene. Earlier, Osborne (1935) had suggested Tertiary age, from a consideration of the general lack of well developed pleochroic haloes. From palaeomagnetic evidence Larochelle (1958) suggests post-Triassic age for the Monteregian intrusions in general and for Yamaska Mountain in particular. The Greenland intrusions are of definitely post-Campanian (post-late-Cretaceous) age.

Petrology

In the Werner Bjerge massif variation of rock types ranges from pyroxenite through gabbro to alkali syenite, nepheline syenite, and alkali granite. A division into three units is evident: Acid rocks, mainly alkali granite and alkali syenite, form the northern part of the massif; nepheline syenite is restricted to the southwest; and the so-called "basic complex" is located in the eastern and southeastern part. The Pictet Bjerge complex varies from gabbro-diorite through monzonite to calc-alkali syenite, alkali syenite, and alkali granite. In contrast to the composite Werner Bjerge complex, the four sub-volcanoes here are usually built up of only one or two different rock types. The variation from basic to acid generally corresponds with a succession in age. The Traill Island intrusion on the east is again of composite type. Alkali syenite and alkali granite have the widest distribution.

Basic and ultrabasic rocks. In the "basic complex" of the Werner Bjerge, pyroxenite, peridotite, gabbro, gabbro-diorite, syenogabbro, and monzonite predominate. Acid residues, such as inhomogeneous granite- and syenite-schlieren penetrate and surround the basic rocks. They are considered to be *in situ* differentiates of the basic magma. Among different rock types both gradual transitions and sharp boundaries occur. Very often fragments of an earlier phase are enclosed and partly resorbed in later products of differentiation. Thus heterogeneity is a common characteristic of the "basic complex." Rhythmic or gravity layering was observed in places, but is never as conspicuous as, for example, in the Skaergaard intrusion.

A separate gabbro-diorite stock occurs in the central part of the Pictet Bjerge. In contrast to the Werner Bjerge "basic complex" this intrusion is very homogeneous and does not show evidence for *in situ* differentiation.

The mineral paragenesis: (olivine), titanaugite, titaniferous (basaltic) hornblende (syntagmatite), brown-red biotite, and plagioclase as major constituents, and alkali feldspar as a residual mineral, displays a much closer relation to essexitic types than to ordinary gabbros and diorites, in spite of the total lack of feldspathoids. The same similarity is emphasized by the chemical bulk composition, expressed by the following

Niggli-magmatypes: essexite-gabbrodioritic, normal theralite-gabbroid, normal essexitic, and essexite-akeritic. This is, however, a typical heteromorphism phenomena, well known from other alkaline intrusions.

Basic breccias and volcanic agglomerates of rather doubtful origin, with syenite fragments in a diabasic groundmass, are associated with the "basic complex" of the Werner Bjerge.

Syenite has of all rock types the widest distribution. Its petrographical variation covers practically the whole possible range of this rock family. Usually the rock is medium to coarse grained and in places grades marginally into an extremely porphyritic facies with phenocrysts of both orthoclase and plagioclase.

Calc-alkali syenite occurs in two separate, stock-like intrusions in the Pictet Bjerge; in a third one it grades into alkali syenite. However, it is completely absent in the Werner Bjerge (and probably on Traill Island). Major mineral constituents are perthite, soda-orthoclase, and andesine (quartz never exceeds 5%). Diopsidic pyroxene, brown biotite, and common (often uralitic) hornblende are present together and form up to 10% of the rock. Sphene is the main accessory. A striking feature is the relatively high average An content of 35–40% in plagioclase. Another characteristic is the general heterogeneity as shown by the following features:

A great variation in the plagioclase composition within a single hand specimen, which can easily cover a range of 40% An.

The high variability in the volumetric ratio alkali feldspar: plagioclase, displayed by the gradation into monzonite and alkali syenite types.

It is probable that this lack of homogeneity is at least in part caused by assimilation and marginal resorption of gabbroid fragments (for example, in the hybrid rocks of Kap Syenit). In addition, gradual transitions of calc-alkali syenite into alkali syenite suggest a certain amount of *in situ* differentiation.

Alkali syenite forms the major part of the Traill Island igneous rocks, of the central Pictet Bjerge intrusion, and of the northern part of the Werner Bjerge massif. In the latter, syenite grades imperceptibly into alkali granite, probably due to quartz assimilation.

Frequent change of grain size and texture, porphyritic and brecciated facies, as well as pegmatitic patches and schlieren are signs of a near-surface intrusion.

Alkali feldspar (as extremely perthitic soda-orthoclase, albite, antiperthite, or anorthoclase) forms approximately 90% of the rock. Plagioclase occurs sporadically, but is usually absent. Mafics are minor, and in contrast to the dark minerals of the calc-alkali syenite they usually are of alkaline type (aegirine, aegirine-augite, arfvedsonite). In places, smaller quantities of feldspathoids such as sodalite, analcite, and natrolite may be present, and then the percentage of the mafics usually increases.

Main accessories are sphene, apatite, zircon, opaques, chlorite, quartz, and calcite. In a pegmatitic variety sphene may reach an amount of some few percent. Fluorite, chalcopyrite, sphalerite, pyrite, molybdenite, and wolframite occur in druses and pegmatitic schlieren.

Very often alkali syenite grades into dark-coloured, aphanitic (in places glassy) syenite porphyry which, however, does not represent a simple marginal facies of the coarse-grained syenite, but forms huge

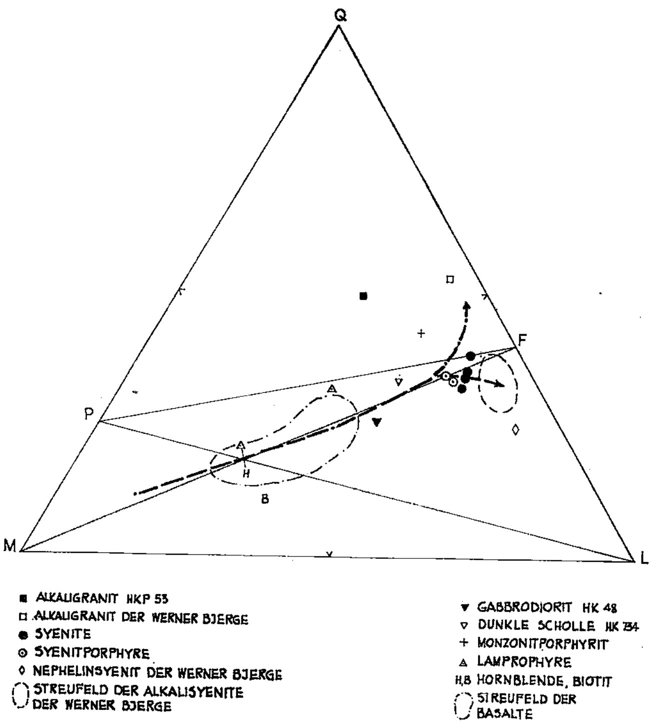

FIG. 2. QLM triangle: General trend of variation along the MF line is typical for atlantic differentiation. Q = Q, L = Kp + Ne + Cal, M = Cs + Fo + Fa + Fs + Ns Ru + Cp.

Q = 1 SiO_2	Fa = 1/3 $(2FeO.SiO_2)$
Kp = 1/6 $(K_2O.Al_2O_3.2SiO_2)$	Fs = 1/3 $(Fe_2O_3.SiO_2)$
Ne = 1/6 $(Na_2O.Al_2O_3.2SiO_2)$	Ns = 1/3 $(Na_2O.SiO_2)$
Cal = 1/3 $(CaO.Al_2O_3)$	Ru = 1 TiO_2
Cs = 1/3 $(2CaO.SiO_2)$	Cp = 1/5 $(3CaO.P_2O_5)$
Fo = 1/3 $(2MgO.SiO_2)$	

For further explanation on the calculation of basis norm and Niggli-values see C. Burri (1959): *Petrochemische Berechnungsmethoden auf aequivalenter Grundlage*, Birkhaeuser Verlag, Basle.

stocks up to 3000 feet high, again demonstrating the shallow intrusion level.

Nepheline syenite is restricted to the SW part of the Werner Bjerge. In fresh section it is usually a dark rock of varying grain size, texture, and homogeneity.

Main constituents are: alkali feldspar (microcline-microperthite, antiperthite, perthite), and nepheline with, in places, some sodalite, analcite and cancrinite. Mafics, usually less than 10%, are aegirine, aegirine-augite, barkevikite, arfvedsonite, and biotite, Rare minerals, mainly occurring in pegmatitic schlieren, include: låvenite, lamprophyllite, mosandrite, and narsarsukite. The volumetric alkali feldspar: nepheline ratio varies greatly so that in places all transitions from alkali syenite through pulaskite to nepheline syenite occur.

The genetic position of the nepheline syenite in the general trend of differentiation is still problematic. However, it is possible that this rock represents the latest product of a separate branch of differentiation, starting from an alkali basalt or syenogabbro original magma and leading through monzonite and calc-alkali syenite to alkali syenitic and nepheline syenitic end products (cf. QLM-triangle, Fig. 2).

Very often fragments of dark-coloured *monzonite porphyry* up to 1000 feet in diameter are enclosed in the syenite stocks and thus represent a pre-syenite phase. Their margins usually are resorbed and grade through hybrid monzonite-syenite into the host syenite. In places, this porphyry exhibits two distinct generations within the crystallization process: the first phase with phenocrysts of diopside, biotite, and andesine is of gabbrodioritic composition, while the second phase, the groundmass, is mainly composed of alkali feldspar and thus represents a pure alkali syenite. If a mechanical separation of solidus and liquidus is accepted in a cooling magma of this given composition, one might in that way derive the gabbroic and syenitic rock types.

Alkali granite occurs in all three complexes. In the Werner Bjerge massif it is associated with alkali syenite, into which it grades imperceptibly. In contrast to this the Pictet Bjerge granite represents a separate, distinct, and homogeneous stock-like intrusion without associated syenite. The mineral paragenesis with alkali feldspar, aegirine, aegirine-augite, and alkali hornblende is the same as for alkali syenite. Quartz in an average amount of 35% shows very strange (non-magmatic) textural features: in the Pictet Bjerge granite it corrodes and replaces feldspar and has an irregular, pseudo-granophyric texture. In the Werner Bjerge granite quartz occurs in two generations, as phenocrysts and as late interstitial exudations. The phenocrysts never show the shape typical in quartz-porphyry, but have much more the habit of rounded quartz sand grains. It is therefore probable that the quartz content of these granites originates from assimilation by a syenite magma. This assumption agrees very well with the chemical properties: The variation of the characteristic Niggli-values (*alk*, *k*)[4] between granite and syenite is very small. Especially the molecular sodium : potassium ratio is almost equal in both rocks; this is a strong evidence against magmatic differentiation. However, a further complication arises in the genetic explanation of the Pictet Bjerge granite. Due to very high Fe_2O_3 and low Al_2O_3 and CaO content its projection point falls far outside the common granite field in the QLM triangle, and for the same reason its Niggli-values do not at all tie in with the general trend of differentiation in the variation-diagram. The genesis of this granite is still problematic.

On the other hand the Pictet Bjerge granite displays clear evidence for a mainly mechanical explanation of the magma-emplacement. The sedimentary roof of the granite body is exposed in a thickness up to 2000 feet, and here faults, flexures, and blocks of tilted sediments show that the main factor in the granite-emplacement was a mechanical uplifting of the overlying sediments "*en bloc.*"

In the *Monteregian Hills* variation of rock types ranges mainly from essexite through nordmarkite and pulaskite to nepheline syenite. In contrast to the Greenland intrusive, granite does not occur (Megantic Hill?). On the other hand alnoitic and okaitic types, found as western outliers of the Monteregian Hills, are apparently lacking in Greenland. In spite of these minor differences a very close petrographic relation between the two provinces is proven by the following facts: the similar age sequence of different rock types, their clearly magmatic origin, as well as the complete similarity of their Niggli-value magma types; the essexitic and syenitic mineral paragenesis, the close optical and chemical relations of pyroxene, biotite, and hornblende; the unusual sequence of crystallization, in which hornblende forms after biotite; and the occurrence of extremely hybrid syenite with recrystallization of feldspar and formation of hornfels texture around the enclosed basic fragments.

Volcanic and subvolcanic breccia is conspicuous throughout the whole Greenland complex. With few exceptions this breccia is genetically and spatially related to syenitic rocks. Three different groups have been established: *tuff breccia*, *intrusion breccia*, and subsurface *vent breccia*. The tuff breccia group is problematic due to the lack of diagnostic features.

[4]The Niggli-values *al*, *fm*, *c*, and *alk* represent the molecular equivalent numbers for Al_2O_3, $FeO + Fe_2O_3 + MgO + MnO$, CaO, and $Na_2O + K_2O$, calculated to total 100. *si* (SiO_2) is calculated in equivalent percents of $al + fm + c + alk = 100$. $k = K_2O/(K_2O + Na_2O)$

Intrusion breccia is formed by subvolcanic explosion of the upper parts of a cooling syenite magma hearth. Both fragments and matrix usually have syenitic composition, while fragments of sedimentary wallrock are rare. Intrusion breccia grades into homogeneous, non-brecciated syenite and dark syenite porphyry and thus displays its genetic origin.

Subsurface vent breccia is restricted to the Pictet Valleys and is characterized by the fact, that the vent is covered by a pre-explosive sedimentary sequence up to 1500 feet thick and apparently never reached its former surface. This breccia forms plug-like stocks of 200–500 feet in diameter, cutting with sharp contacts through the sedimentary wallrock. Most of it consists of numerous assorted rock and mineral fragments in an extremely heterogeneous matrix. Rock fragments of both rounded and angular shape include: ultrabasics, several varieties of gabbro, syenite, sediments, and basic polygeneous breccia. Mineral fragments are: titanaugite, clastic basaltic hornblende (syntagmatite), pseudomorphosed olivine and pyroxene, plagioclase, alkali feldspar, titaniferous iron oxides, apatite, and lenses of albite, calcite, and epidote. The matrix is—in places—a fine-grained powder of nearly all the above mentioned components. All the fragments must have been ejected as solid debris from depth into explosively opened cavities. The magma hearth, which caused the explosion, is not exposed.

Volcanic breccia of the *Monteregian Hills* is apparently as variable as the Werner and Pictet Bjerge breccia. Association with syenite, in places with grading contacts, is probably a common fact too. Explosion-vent breccia is known from the Oka region.

Leucocratic dyke rocks in both provinces are believed to be the comagmatic derivatives of the acid intrusions. In the Greenland complex both sills and dykes occur. Yet their abundance and petrographic variability never reach that of the basic dykes. In order of decreasing abundance the following types were found: various modifications of syenite, in places grading into dykes of granitic composition, felsite, leucocratic andesine porphyry, and quartz porphyry.

Basic dykes and sills are extremely abundant in the Greenland occurrence, cutting through sediments, intrusions, and each other. A great number of them form dyke swarms converging toward the intrusion centres of Werner Bjerge and western Pictet Bjerge and thus appear to be comagmatic products of the local alkaline plutonism. However, on petrographic and petrochemical grounds, it is impossible to separate them from dykes and sills related to the regional tertiary Greenlandic (Brito-Arctic) basalt cycle. Indeed the basic dykes of the area may be the products of either or both magmatic processes.

Four groups of basic dyke rocks have been established: basalts *sensu* *lato*, tilaitic dykę rocks, ultrabasics, and lamprophyres. Basalt and lamprophyre have the widest distribution.

Basalt *sensu lato* is divided into six subgroups, according to mineralogical composition and textural features: dolerite (in the meaning of medium-grained basalt), basalt *sensu stricto*, olivine basalt, plagioclase porphyry, augite porphyry, and diabase. Major constituents in the five first groups are: labradorite, titanaugite, and iron oxides; olivine and pigeonitic augite are minor. The diabase subgroup includes (by definition) the autometamorphic-epithermal alteration products of the five other types.

The basalt *sensu lato* group shows a distinctive trend toward subbasaltic and alkali basaltic types, both in modal and chemical composition. In the Niggli-value variation diagram the smooth *al*-, *fm*-, and *c*-curves are conspicuous.

The tilaitic dykes are characterized by a composition of 90% mafics and about 10% plagioclase. Pyroxenitic, ankaramitic, and montrealitic types were found. Major constituents in order of their crystallization are: olivine, titanaugite, biotite, labradorite, and basaltic hornblende as the latest.

Ultrabasic dykes are very rare and are either of pyroxenitic or of secondary hornblenditic type.

Lamprophyres are defined on the basis of mineralogical and textural features; genetic criteria have not been considered to be critical. Thus basaltic rocks with more than 10% of hornblende or biotite were strictly considered as lamprophyres. The mineralogical variability is remarkable: minette, kersantite, hornblende-vogesite, augite-spessartite, extremely porphyritic hornblende-spessartite, and camptonite were observed. Gradual transition of lamprophyres into dykes of basaltic composition is characteristic in places and indicates one possible explanation for their genesis. On the other hand the variation diagram of the Niggli-values shows that some of the tilaites and lamprophyres fit very well in the trend of differentiation of the Werner Bjerge "basic complex" and therefore may be considered as its comagmatic apophyses.

In the *Monteregian* province most dyke rocks are clearly comagmatic with the essexitic and syenitic intrusions. In contrast to the Werner and Pictet Bjerge complexes, syn-intrusive basalts are absent. Whether this suggests that there exists *no* genetic relation between alkaline intrusives and basalts in the Greenland occurrence, cannot be decided.

Extensive *pneumatolytic-hydrothermal* activity is the last manifestation of the magmatic cycle. Zones of strong mineralization are usually associated with acid (syenitic) intrusions. They are very conspicuous due to multicoloured, red, vermillion, ochre, and black staining of both igneous and sedimentary rocks. Two different effects of hydrothermal activity are evident.

(1) A diffuse alteration of uniform rock masses, mainly affecting the mafics and often accompanied by introduction of diffuse iron oxides, pyrite, and fluorite.

(2) An impregnation of fissures and cracks with ore-bearing solutions.

Typical hydrothermal minerals are: hematite, limonite, pyrite, manganese oxide, chlorite, fluorite, siderite, calcite, strontianite, barite, and quartz.

Spectrochemical studies show that, compared with non-impregnated rocks, mineralized samples from the Werner Bjerge area are generally enriched in Fe, Ti, Mn, Zr, and Nb (100-1000 ppm.), while for Ag, Sn, and Pb increase is doubtful. Mineralized samples from the Pictet Bjerge show a remarkable increase in Cu and Pb, while Ag, Mo, W, and Sn occur in concentrations scarcely higher than the limit of detection. In highly mineralized samples, for example in iron coatings and limonitic interstitials, rare earths and Mo show distinct enrichment (100–1000 ppm.). However, it is believed that at least part of these trace elements were initially contained in the syenitic mafics, and that their concentration in hydrothermal solutions is—except for Fe and Mn—caused by leaching of altered mafics.

Spectrochemical analyses of minerals and igneous rocks show that: (*a*) Sr is enriched in nepheline and alkali feldspar; (*b*) rare earths are distinctly concentrated in some biotite and sphene from alkalisyenite; (*c*) Nb is a regular accessory of zircon; (*d*) Cr, Co, Ni, and Cu show continuous enrichment from acid to basic and ultrabasic types for V this trend is not as clear; (*e*) U could not be detected in any noteworthy concentration.

Economic deposits of molybdenite and wolframite of pneumatolytic origin, associated with alkali granite, occur in the western part of the Werner Bjerge complex. The mineral paragenesis and the occurrence of several metasomatic phases display a striking similarity to the well-known cassiterite-molybdenite-bearing mineralization of the Erzgebirge and to the molybdenum deposits of Climax (Colorado).

Silver-bearing galena-sphalerite-quartz veins occur in the sediments north and south of the igneous complex (Mesters Vig). It is believed that these deposits are also genetically related to the alkaline Werner and Pictet Bjerge province.

In the *Monteregian Hills* the effect of hydrothermal-pneumatolytic activity apparently is much less. So far no major ore deposits have been found. A further parallel, however, is displayed by the fact that Nb, which is generally enriched in mineralized samples of the Werner Bjerge,

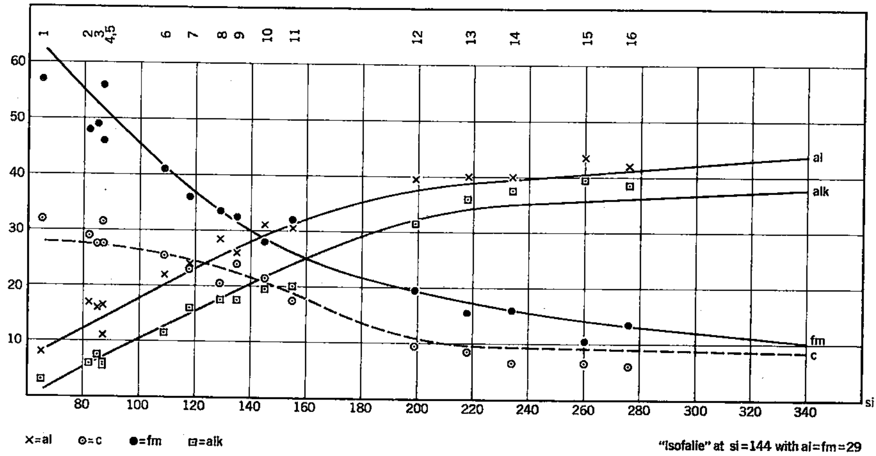

FIG. 3. Variation diagram of the Niggli-values. The four curves represent the trend of differentiation for *al*, *fm*, *c*, and *alk* in the Werner and Pictet Bjerge province. Crosses, circles, dots, and squares represent the Niggli-values of 16 Monteregian rocks (analyses in Burri & Niggli, 1945). The "isofalie" (value of *si* for which $al = fm$) is typical for an atlantic differentiation. *al* (Al_2O_3), *fm* ($FeO + Fe_2O_3 + MgO + MnO$), *c*($CaO$), and *alk* ($Na_2O + K_2O$) are calculated as molecular per cents to the sum of 100 and plotted along the ordinate against *si* (SiO_2); the latter is calculated in molecular per cent on the basis of $al + fm + c + alk = 100$.

No. 1 Pyroxenite, Mt. Royal
No. 2 Pegmatitic mafraite, Mt. Royal
No. 3 Andesine gabbro, Mt. Royal
No. 4 Montrealite (olivine essexite), Mt. Royal
No. 5 Essexite, Mt. Royal
No. 6 Porphyritic mafraite, Mt. Royal
No. 7 Camptonite, Montreal
No. 8 Essexite, Beloeil Mountain
No. 9 Nepheline syenite, Mt. Royal
No. 10 Metaessexite, Mt. Royal
No. 11 Essexite, Shefford Mountain
No. 12 Pulaskite, Mt. Johnson
No. 13 Pulaskite, Shefford Mountain
No. 14 Syenite, Brome Mountain
No. 15 Aplite, Mt. Royal
No. 16 Nordmarkite, Shefford Mountain

is concentrated in large deposits in the Monteregian Hills (for example, Oka), probably due to a similar hydrothermal-pneumatolytic metasomatism. Further data on trace elements are not available from the Monteregian province so far.

Apart from all geological and petrographical agreement, the best evidence for the close relation between the Werner Bjerge – Pictet Bjerge province and the Monteregian alkaline province is displayed by a conspicuous similarity in the trend of differentiation from basic (essexitic) to ultrabasic (pyroxenitic) and acid (syenitic) magmas. In the Niggli QLM triangle (Fig. 2) this common trend is shown by a smooth distribution along the MF line (atlantic differentiation). In the variation diagram of the Niggli-values agreement is almost complete: In Fig. 3 the trend of differentiation for the Werner and Pictet Bjerge province is represented by four curves (*al*, *fm*, *c*, *alk*, plotted against *si*). The respective projection points of 16 Monteregian rocks fall either on or very near these curves, and their average deviation lies well within that of the Greenland province (*al* ± 1.5, *fm* ± 2.5, *c* ± 1.75, *alk* ± 1.75). This, however, means that the general trend of differentiation was the same in both provinces. A single slight difference, which is also shown by the modal properties, arises from the fact that, within the syenite field, the Monteregian differentiation tends to slightly more alkaline character, displayed by *al*- and *alk*-values lying somewhat above the Greenland average, while *c* is consequently lower. However, the striking overall similarity is not affected by this minor deviation.

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