1. On the Mode of Intrusion of Deep-seated Alkaline Bodies.

By

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1. Introduction.

In searching for a convenient term to give an exact idea of the intrusion-form of deep-seated bodies of alkaline rocks, the writer has met with some difficulties. Smaller bodies, whose features are easily surveyed in the field, have been characterised as stocks, plugs, pipes, etc. (*cf.* SHAND 28 b); larger ones have been defined as laccoliths (RAMSAY 27, SHAND 28 c) or even as batholiths (USSING 31). Although the form of the outer boundary line and also the position and dip of the contact plane in relation to the adjacent rocks have certainly been taken into consideration, a closer examination of the literature available shows that in most cases exact field observations concerning the outer delimitation of an alkaline body are scarce. The general conclusion as to the intrusion-form, as expressed in the characteristic name given to such a body, rests mostly on a few occasional field observations which were largely generalized. If the contact plane dips inward, towards the supposed intrusion centre, one speaks of a laccolith (SHAND a. o.); if it dips outward one is inclined to characterise the body as a batholith especially if its field dimensions are considerable (USSING 31); if the boundary features point to vertical junctions with the country rock, names such as stock, plug, pipe etc. are preferred, especially where the dimensions of the bodies are more or less restricted. Occasionally textural peculiarities of the rocks represented in the main intrusive body, pointing to a hypabyssal level of consolidation, are taken into account as a reason for selecting the term laccolith (RAMSAY 27).

The present writer has never devoted himself to the fascinating work of analysing either in the field or in the laboratory the variegated association and sequence of the interesting rocks which compose an alkaline body. Yet more than once he has had an opportunity of studying in the field the outcrops of several complexes which have become classical by reason of the thorough investigations and exact descriptions of which they have been the object (Alnö, Almunge, Norra Kärr, Monteregian Hills, Fen, Oslo). Again and again he has revisited some of these areas, attracted by the peculiar phenomena involved in their intrusion and differentiation. Study of the literature concerning more distant and transoceanic occurrences throughout many years have further increased his interest. The splendid field work carried out during the past 11 years by FERSMANN (14) and his excellent co-workers (21) on the massifs of Umptek and Lujavr Urt in the Kola Peninsula, in continuation of the classical pioneer investigations of RAMSAY (1887, 1891, 1892), and under extremely rough conditions and field hardship, has stimulated the writer's interest once more. From those localities, moreover, RAMSAY originally described a number of alkaline type-rocks, which now occupy the centre of interest amongst alkaline suites. The region is further noteworthy in constituting the largest known area of alkaline rocks and it may therefore be expected to exhibit the typical characteristics of alkaline bodies in their most striking form.

The far reaching and well planned investigations of FERSMANN and his co-workers (1926) have primarily proved that the interest attaching to areas of alkaline suites may be not only scientific but also practical and economical, for they have revealed on the Kola Peninsula, amongst other valuable mineral deposits, the greatest known concentration of nearly pure apatite rock. Thus they demonstrate once more that there is no investigation in geology that may not have, sooner or later, its practical importance. But as to the mode of intrusion of the complexes they have so far failed to provide a definite explanation.

Nevertheless, the orderly though variegated association of rocks, their constant field interrelations and similarly planned geometrical distributions, their uniform sequences in age and their similar textural developments, all point to a common mode of intrusion and to a special intrusion-form. In the following pages the writer proposes to make some general suggestions about the alkaline bodies and their rock associations with a view to developing a clearer conception of their *mise-en-place*. The discussion is centred around a series of conclusions drawn from the excellent Russian works on the Kola Peninsula occurrences. It is unfortunate that these publications are not accessible to a larger scientific forum.[1] Thus there is no intention to draw all known alkaline bodies into the discussion, but only to refer to some representative and well known prototypes.

[1] The outlines of this discussion were given in a lecture read before The Students' Geological Association at Upsala, Oct. 8. 1931.

2. Stereometry of the Alkaline Bodies.

The outer boundaries of the alkaline bodies as exposed on the earth's surface are roughly circular or elliptical. Irregular deviations from this ideal boundary are met with, but they are mostly due to structural complications of the wall rocks such as result from unconformable coverings of older or younger formations (*cf.* Ilimausak and Igaliko in the Julianehaab district, USSING 31), or alternations in the wall of rock materials having different qualities of resistance towards the act of intrusion.

In profiles the external boundary is mostly steep: in smaller bodies nearly or exactly vertical; in larger ones steeply dipping outward or inward, the orientation of dip not seldom fluctuating between both directions inside the same body (Greenland, USSING 31; Umptek on the Kola Peninsula, RAMSAY 27, KUPLETSKI 21 b, 14 a) possibly in consequence of occasional local irregularities of the wall rocks.

The surface areas range within broad limits, from the small »pipes» and »plugs» in South Africa with diameters of 500 m. and less (Leeuwfontein, SHAND 28 b) to the greatest known elliptical body of the Kola Peninsula (Umptek 36 km. N—S; 46 km. E—W).

The different rocks composing the bodies are distributed within the outcrop areas in concentric (USSING 31) or rather confocal (SHAND 28 e) zones of various breadths, the outermost being the narrowest. The central zone shows sometimes an irregular or patchy distribution of its rocks which is partly due to the exposure of different levels by erosion.

The junction of the zones is mostly sharp, but gradual transitions are also met with. Sometimes the boundary line of the inner zones presents evidence of the intrusion of one zone against the other. Yet the contact features point to so restricted a difference in time of the successive phases of the intrusion act, that the proof seems to be perfect that the rocks belong to the same magmatic cycle and rise from a common magma-reservoir.

The internal boundary surfaces of the confocal zones are of two kinds: the outer ones stand vertically and reproduce a picture of ring dykes or cone sheets (*cf.* THOMAS, RICHEY a. o. 29; BAILEY 3, a. o.), the composing rocks being of abyssal types, while the inner zones are bounded one against the other by horizontal or slightly inclined planes. These contrasted features are shown only in cases where the bodies have been strongly dissected by erosion so that natural vertical profiles of considerable height have been exposed through the central portions of the bodies. Such profiles are well seen in Greenland, where the latter structural peculiarities are strongly emphasized (USSING 31); and in the well dissected Umptek massif with its precipices of several hundred meters above the vegetation line (KUPLET-

SKI 14 e). Similar relations seem to hold in the bigger bodies of South Africa (Spitzkop, SHAND 28 a).

It is true that in some parts of the outer circumference of the confocal assemblage of rocks the outer vertical zones may be lacking, but this absence of evidence does not invalidate the common plan.

The combination of vertical and horizontal structures is represented only in the bigger bodies; in the smaller ones the vertical concentric structures seem either to predominate or to be the only ones visible. Here also the variety of rocks and the number of zones in general is strongly restricted (Almunge, QUENSEL 26, a. o.).

The junction of the outer group, characterised by vertical structures, with the inner group, characterised by horizontal structures, is a complicated one; while the rôle of the upper members of the latter suite is undecided, the lowermost ones behave as intrusives with respect to the neighbouring outer ring (KUPLETSKI 14 e, USSING 31).

The rocks of the inner zones reveal an excellent horizontal jointing, and this, in combination with a primary banding of the igneous rocks or with their original horizontal structures in general, produces a sort of bedding resembling that of sedimentary rocks. A horizontal schistosity sometimes so accentuates this »bedding» as to lend to the formation a resemblance to a suite of metamorphic schists (Greenland, Kola, Spitzkop).

No systematic observations of joints of the outer vertical zone seem to have been recorded. A vertical jointing in two directions intersecting each other at about 90° seems to predominate (KUPLETSKI 14 e).

3. The Rocks and their Distribution.

For all deep-seated alkaline bodies the following rule seems to be valid: the larger the dimensions of the body, the greater becomes the diversity of rocks represented within its limits and the wider swings the range of their chemico-mineralogical composition. The post-intrusional dikes and later magmatic manifestations intersecting the body itself or its neighbourhood (marked by a pronounced time hiatus from the main intrusion) seem to follow a similer rule, but at another level of silification (13; 20).

The main range of rocks within a complex includes the following principal types in the zones of vertical structures; the types are enumerated below in order from the border to the centre: —

A. Wall rock (mostly gneisses)—(granophyric granite)—(lestiwarite and albitite)—umptekite—chibinite—trachytoidal chibinite—foyaite I (= aegirite-nephelite-syenite)—foyaite II (= arfvedsonite-nephelite-syenite)—foyaite III (mica-nephelite-syenite)—urtite and ijolite—apatite rock (Umptek—KUPLETSKI 14 e).

B. Wall rock (Devonian? sandstone and biotite-granite)—soda-granite—nordmarkite—augite-syenite—foyaite—naujaite, kakortokite, lujavrite (Ilimausak—USSING 31).

C. Wall rock (gneiss)—(fenite)—augite-syenite—nephelite-syenite—urtite—ijolite—different calcitic rocks including apatite rocks (Almunge—HÖGBOM 16).

D. Wall rock (gneissic granite)—(fenite)—urtite—ijolite, melteigite, vibetoite—different calcitic rocks (Fen—BRÖGGER 10).

E. Wall rock (quartzite)—åkerite—umptekite—foyaite (Leeuwfontein—SHAND 28 b).

F. Wall rock (granite)—lestiwarite?—foyaite (lujavrite)—ijolite—calcitic rock with apatite, magnetite etc. (Spitzkop—SHAND 28 a).

G. Wall rock (granites)—(fenite)—umptekite—canadite (Almunge—QUENSEL 26).

The central »stratification», as mentioned above, is plainly visible only in the greater and more deeply dissected bodies, e.g. of Greenland and Umptek. The rock succession in these »stratified» bodies from the top downwards proves to be almost identical with the sequence of rocks in the above enumerated profiles: —

A. Umptekite—chibinite—trachytoidal chibinite—foyaite III—foyaite II—foyaite I (Umptek).

B. Arfvedsonite-granite—quartz-syenite—pulaskite—upper foyaite—sodalite-foyaite—naujaite—lujavrite and kakortokite (Ilimausak).

The above examples are chosen on purpose from bodies which have been proved by geological survey to be in contact with walls free from carbonate rocks. The latter, as recorded for the Assynt (SHAND 28 f), Haliburton (ADAMS and BARLOW 1) and other occurrences, may have exercised some special influence upon the rocks and their distribution.[1] The interesting circular complex of alkaline rocks of the Los Islands (LACROIX 22) is omitted because its geology is little known and the wall rocks are invisible.

In the first of the above tabulations the outer rim of the series (marked by brackets) pertains to the rock wall where it has been altered by contact pneumatolysis, as pointed out by the respective authors. It must be born

[1] If one assumes that in the course of the intrusion act of a deep-seated body no assimilation of wall rock material of any importance has occurred, that supposition is valid only for the upper part of the intrusion path. Every deep-seated intrusion in its lower part passing through the supposed granitic shell of the earth may have done a great work of assimilation by replacement. Therefore it may be of some importance to include in the comparison of individualized bodies only those, whose field *milieu* is a granitic-gneissic one. The chemical conditions of their *mise-en-place* are not essentially changed when compared with the conditions farther downward.

in mind also, that the confocal inner zones are by no means always complete or continuous, for in larger (B) or smaller (C, D, F) sectors within the same body they may be entirely lacking, sometimes one or another member may die out locally and so cause irregularities in the distribution order. Other irregularities in the rock sequence also occur (C and D), especially in the areal rock distribution, but these do not affect the common principle.

The common principle governing the distribution of rocks seems to point to a gradual desilication of the rock suite from the wall inward and from the top downward: the core rock thus represents the most perfect grade of desilication. It may be stated also, that the greater the dimensions of the body, the farther has gone the cumulative undersaturation of the central zones (Umptek); and, in the case of smaller bodies: that the lower the grade of undersaturation shown by the central core, the more suppressed are the intermediate outer zones (Fen and Alnö compared with Leeuwfontein and Almunge).

4. Rock Sequence.

A feature common to all descriptions of well defined alkaline bodies is that, although there exists a certain sequence of rocks within the massif, no real time distinction can be made between the different rock groups, and only vague indications as to the probable order of their *mise-en-place* can be given. The difficulties so implied were revealed as soon as detailed field investigations were undertaken. Although the boundary between two rocks might be well defined and even sharp, there were no real contact phenomena to be observed such as diminishing grain size or exocontact-metamorphic influences. On the contrary the grain size was found to increase on one side or the other of the boundary plane. Thereupon arose a discussion of the possibility that the rocks were not sensibly different in their *mise-en-place*, but represented a different order of freezing (USSING 31). Yet it has been demonstrated by field and laboratory investigations of the Ilimausak body, that there are not a few indications of two different intrusions: (a) a slightly older and independent one represented by the arfvedsonite-granite—augite-syenite suite of rocks within the vertical structures, whose members show higher or lower degrees of oversaturation; and (b) a younger »agpaitic» suite (USSING) partly replacing the former and exposing distinct marks of undersaturation throughout, and in the central structures developing that perfect bedding which more than once as seen from a distance has been interpreted as pertaining to normal sedimentary or dynamometamorphic rock suites.

A common feature of rocks belonging to the one or the other of the above mentioned bodies is the development of a coarse grain, either throughout a whole rock member (naujaite in the Ilimausak body, chibinite in Umptek, »white syenite» in Leeuwfontein a. o.), or as irregular stripes, streaks, patches or secretions within a rock of smaller grain. This »giant» granularity cannot be interpreted as a simple pegmatitic structure, partly because the mineral interrelations of felsic and mafic constituents in the rocks are those of normal magmatic freezing (USSING 31, SHAND 28 c), and partly because the streaks and other »segregations» of coarser minerals are so intimately grown together with the mother rock that there is no possibility of referring them to a later and more or less independent endogeneous phase of development. On the contrary, indeed, some of these coarse-textured masses show mineral interrelations which remind one of exogenic contact-pneumatolytic phenomena, with mineral intergrowths (*i.e.* the poikilitic sodalite-feldspar-intergrowth in the naujaite, a. o.) and constituents rich in volatile compounds. These streaks of coarser grain are dispersed through the whole alkaline rock areas as far as the outer zones (augite-syenite zone of Igaliko, Greenland, USSING 31) and at times they have yielded valuable mineral deposits, the minerals of which vary to some extent with the nature of the enclosing rocks. (Umptek, FERSMANN 14 f.)

Mention is also sometimes made of coarse gneissic structures within typical rock members of the alkaline bodies (Pilansberg, BROUWER[1] 11); these structures furthermore strengthen the assumption that »exometamorphic», *i.e.* pneumatolytic *in-situ*, influences from outside have acted upon the rock body after its initial consolidation.

Another remarkable and widespread peculiarity of the interrelations of the rocks is the appearance, side by side, with well defined and sharp boundary relations, of coarse-grained and fine-grained rocks (lujavrite—naujaite in the Ilimausak body, USSING 31; trachytoidal chibinite—chibinite at Umptek, FERSMANN-KUPLETSKI 14; lujavrite—urtite at Lujavr Urt, RAMSAY 27; katapleiite-syenite—lakarpite at Norra Kärr, TÖRNEBOHM 30; a. o.), the fine-grained (hypabyssal) one being marked by more or less pronounced fluxion structures, which may develop into something approaching perfect flow structures (kakortokite of »Kringlerne» at Ilimausak, USSING; a. o.). Inside these finer-grained rocks sheet-like bodies of nearly dense structure are met with (Lujavr Urt, RAMSAY); these have been interpreted as later intrusions which came into place when the enclosing rock had reached low temperature conditions. The fine-grained rocks have in part been considered as intrusions of later differentiation products, their fluxion structure being caused either by flow movements during the freezing of the mass, or by

[1] The Pilansberg intrusive body with its perfect circular and partly confocal arrangement of different alkaline rocks has not been referred to in the above comparison, partly because the wall rocks show extreme diversity (norite-granite of the Bushveld lopolith, Rooiberg quartzite) and partly because of the presence of a considerable amount of effusive rock which interferes with the original conditions of intrusion (SHAND 28 c).

the freezing of the crystalline paste under stress conditions impressed by the roof; even differential movements of the whole paste-like mass between two sheet-like rock-bodies of earlier consolidation have been postulated, the necessary slope for flowage having developed as a consequence of central subsidence after the act of intrusion (Ilimausak, USSING). The conclusion that movements in material in a semi-solid or semi-liquid state have been acting seems to be the prevailing one, the more so as both brecciation and partial assimilation of one or both side-walls has been observed. In the case of concentric (or confocal) structures of the outer vertical orientation, the finer-grained fluxion-structured rock brecciates the next outer member and this in turn is brecciated by the next inner member. Within the »bedded» inner structures the relations are somewhat variable: the fine-grained rock brecciates its roof rock (naujaite—brecciated by lujavrite, Ilimausak), while enclosing some rock members of undecided age-relation, which themselves display an excellent banded or flow-structure (kakortokite). The gneissose structures described elsewhere (nephelite-gneiss of Cevadaes, OSANN 25) may also be interpreted as a result of endogeneous differential movement in the semi-solid state, no real crush structures having been recorded. A typical representative of this kind is the principal rock of Norra Kärr (katapleiite-syenite, TÖRNEBOHM 30), whose fine-grained fluxion structure runs conformably with the outer wall, while the coarse-grained lakarpite behaves as a slightly later intrusive, without a chilled border.[1] The absence of chilled borders between the different rock members of the bodies is a common characteristic and may be due to special circumstances.

In the light of their extensive experience of the Umptek body FERSMANN-KUPLETSKI conclude that there have been three more or less independent magmatic intrusions at Umptek: 1) the oldest chibinitic one, with its border of umptekite, representing an assimilation product of the gneissic wall rock (RAMSAY), 2) the foyaitic one with its varieties; and 3) the urtite—ijolite suite with apatite rocks. The »varieties» in each of these suites differ somewhat in their *mise-en-place*, being later than and more or less dependent on their respective »parent» intrusion. The general plan of rock sequence is that of increasing dominance of the undersaturated mineral associations within the whole rock series, the most pronounced undersaturation being shown by the latest ones (apatite-rock!). This undersaturation proceeds step by step towards complete desilication of the rock suite, the carbonatic (Alnö, Fen, Spitzkop), apatitic (Umptek, Palabora, Spitzkop, Alnö)

[1] More than once the structural development of the main rock-type at Norra Kärr has been interpreted as a result of exogeneous deformative processes, an interpretation implying an early age for the »plug». Yet the plug-structure is completely independent of the deformation of the country rocks and big phenocrysts of eudialyte and katapleiite, *inter alia*, have remained free from any traces of crushing due to outside forces.

and iron-ore (Spitzkop, Alnö, Fen) rocks being in each case the last more or less independent member of a complete alkaline suite.

For these reasons the present writer is inclined to extend the scheme of FERSMANN-KUPLETSKI (three more or less independent concentric or confocal intrusions) regarding it as valid for all the rocks tabulated above as composing an alkaline body. In each locality these rocks constitute more or less independent phases in the intrusion history of the body, with the possible exception of the exo- and endo-marginal facies (fenit, and umptekite?). The varying rock structures and the regularly repeated mineral assemblages, the relatively strong individualization of each rock body, and their considerable size, all (excepting only the absence of chilled borders) lead to the conclusion that each one is due to a more or less independent geological act. There is also reason to believe that the carbonatic rocks behave as the latest piercing intrusives with respect to the preceding members of the body (HÖGBOM, BRÖGGER).

As to the exomarginal (fenitic) zone there is no doubt that its origin is to be referred to a partial remelting and pneumatolytic action of the intrusive body upon the wall rock (HÖGBOM, QUENSEL, BRÖGGER a. o.). The recognition of the umptekite as an endo-marginal assimilation zone was first announced by RAMSAY on the evidence of two marginal occurences at Umptek. USSING rejected this explanation because such an endomarginal facies was missing from considerable portions of the Ilimausak periphery, where, in his opinion, the double-intrusion hypothesis seemed better fitted to explain the field evidence. Yet since KUPLETSKI could trace the umptekitic marginal zone around the whole body of Umptek, the possibility of its being an independent intrusion cannot be so easily rejected (*cf.* Almunge); the divergent circumstances at Ilimausak, as also in other bodies, may be due to some different conditions or processes (*cf.* below).

5. Rock Differentiation.

USSING was the first to point out that the rock suite of the central (»bedded») core of Ilimausak was a result of a method of differentiation different from that found by BRÖGGER to govern the origin of the Kristiania-(Oslo-)suite of rocks[1], where the differentiation proceeds in the direction of the order of mineral crystallisation in the magma. He also (1911) first applied the crystallisation-differentiation and fractionation principle as affording an explanation of the rock distribution in the field, and directed attention to the early crystallisation of feldspars, nephelite, and other feldspathoids as compared with that of aegirite, and to the different temperature and time of crystallisation (and later movements, *cf.* above) of the sheets and »beds»

[1] This suite of rocks is also omitted from the above discussion because it was intruded under varying wall-rock conditions.

formed by this process of differentiation. He named this set of rocks the *agpaitic* series in consequence of its deviating differentiation sequence.

The peculiar conditions of an *agpaitic* differentiation have been clearly outlined by FERSMANN. In a cooling magma corresponding to a mixture of feldspars, feldspathoids and aegirite, the first minerals to separate are the feldspars (orthoclase) and the nephelite (at about 1100° C). These crystallisation products are unable to sink in the residual magma because of its higher specific gravity ($d = 3.4$ against $d = 2.5$—2.6 of the first minerals to crystallise); on the contrary they are forced to rise. As a result of the repetition of this upward movement at intervals crystals accumulate in the upper portion of the body, and these become more and more enriched in nephelite minerals the longer the action proceeds; so that finally the rocks formed at the top tend to have an urtitic composition.

In the residual magma, still fluid, of increasing specific gravity, and strongly approaching an aegiritic composition, the volatile constituents accumulate as a downward concentration in a basic *milieu*, in contrast to the conditions of the commoner granodioritic suite, where the volatile constitutents accumulate in the top portions of a more acid residue. These represent the concentrates remaining after the last crystallisations at the lowest temperatures; e.g. at the quartz-feldspar eutectic stage and at temperatures still further lowered by volatile admixtures. The first — agpaitic — type of differentation leads to a decreasing viscosity of the cooling magma, while the second type develops a residual magma in the top position with greater possibilities of gaseous escape and therefore of increasing viscosity.

In a valuable memoir KRANCK (20) discusses the origin of the interesting deep-seated melilite rock *turjaite* (~ uncomphagrite LARSEN 23) and touches on the differentiation of the ijolitic »stem». In accordance with BRÖGGER (Fen) he presumes an ijolitic composition for the mother liquid from which the various alkaline (nephelite) rocks have differentiated. In close analogy to BOWEN (6) he specifies a reaction series of minerals for this mother magma of the following kind: —

Diopside
↓
Aegirite diopside
↓
Aegirite diopside rich in Na_2O
↓
Aegirite rich in CaO
↓
Aegirite
↓

Nephelite
↓
Nephelite
↓
Nephelite Ortoclase
↓
K-Na-Feldspar
↓
K-Na-Feldspar (Albite)
↓

Residual liquid rich in SiO_2, $K_2O(Na_2O)$, H_2O, F(Cl), $CaCO_3$.

This scheme differs from that of BOWEN (6) in showing a continuous isomorphous series of mafic minerals, while the felsic series is a discontinuous one, just opposite to the relations in the prototype series. The great difference in density between the members of the left and right wings, a difference that increases with lowering temperature, seems to exclude the melilite-forming reaction (BOWEN) between diopside and nephelite, as KRANCK points out. He assumes that a strong rise of the gas pressure within the differentiating magma, especially of CO_2, would induce a breaking up of the remaining silicate minerals, so setting free the amounts of CaO necessary to form the melilitic minerals which in special circumstances characterise the later stages of differentiation of the alkaline suite (turjaite, alnöite a. o.). However, since this discussion by KRANCK the aegiritic end member (acmite) of alkaline pyroxenes has been shown to melt incongruently, at about 950° C (BOWEN, SHAIRER, WILLEMS 8, 9) breaking up to form Fe_2O_3 and a liquid of varying composition. There are indications that natural aegirites (*l. c.* p. 431), which always contain sensible and considerable amounts of CaO, have broken up in the same manner. If the bulk composition of the mother liquid still shows undersaturation tendencies, there is no chance for free silica to crystallise; in fact free quartz is nowhere to be found among the mineral associations of the later stages of development of the cited alkaline bodies.

The early and sudden crystallisation of feldspars (orthoclase) and feldspathoids and their strong tendency to rise in the thin yet heavy residual fluid leads to the formation of a film at the top of the advancing channel of the magma chamber in such a manner as to preclude an upward escape of gas. In consequence of this the pressure (and temperature) in the top film rises. The first crystallisations are thus exposed on a large scale to pneumatolytical actions, which contribute to the recrystallisation and pronounced grain increment of the existing mineral associations. Preceding the final recrystallisation the superheat with respect to the roof and wall rocks would induce a double reaction of 1) a pneumatolytic and partial remelting, and more or less in situ reduction (»fenitisation»), of the wall rock; and 2) an assimilation on a large scale of the gneissic country rocks conducing to progressive saturation and oversaturation of the intruding masses. The top rocks of the central suites and the rocks of the outermost rings of arvedsonite-granitic, nordmarkitic, umptekitic (and pulaskitic) composition bear witness to the fact that the influence of the wall rocks and of the earlier intrusions decreases with respect to the later and later injections of the mother magma.

As a result of the crystallisation with top accumulation of felsic crystals, accompanied by gas accumulation below and its pneumatolytic upward action into the superincumbent crystal film and consequent rise of temperature, pronounced rhythms of periodical culminations tend to develope, *viz.*

intrusions at regular intervals. This process contributes also to moderate the contrasts of rock grain on both sides of the contact planes, wiping out the earlier tracks of pronounced differences, and favouring the growth of incidental mineral accumulations. It may also involve the development of parallel (»fluxion») structures within both the vertical and the horisontal structures partly by raising the pressure during the final crystallisation and partly by facilitating late fluxion movements within the intruded top masses.

Meanwhile the volatiles accumulate and their pressure gradually increases. The more or less individualized sheets of rocks enriched in primary and secondary sodalite (naujaite, tawite, sodalitite, different ijolites), cancrinite (särnaite, cancrinite-syenite) in the later portions of the intrusion testify to concentrations of Cl and CO_2; the scattered yet constant occurence and local concentration of late fluorite points to a similar though perhaps less marked concentration of F. Increasing amounts of apatite, occurring as granular streaks and nodules within the later members of differentiation give evidence of the increasing rôle of P_2O_5; the more so as the apatite with its high density tends to remain in the heavy fractions of differentiation and represents early as well as late crystallisations as already pointed out more than once (VOGT 32). The volatiles here again contribute to rhythmical crystallisation within individual beds and sheets, developing perfect banded structures of great persistence (kakortokite a. o.).

To sum up: the crystallisation-differentiation by gravity tends to separate the mother liquid into two sheet-like suites, the one of a felsic composition ascends to and congeals at the top region, while the other, still liquid and of a mafic (aegiritic) composition descends to deeper levels. The gas concentrations dependent on this separation tend to govern the fractionation so as to produce a rhythmical order of extrusion from the magma chamber, and the later fractions on their upward way tend to acquire a monomineralic (nephelitic) composition (= urtite). In consequence of the influence of the volatiles favourable conditions develop for rhythmical *in situ* crystallisation within individual sheets. In the mafic (aegiritic) concentrations of a lower level there proceeds an accumulation of CaO (of the aegirite) which in the bulk magma is in general rather low. Then the incongruent melting of aegirite comes into action as a result of the concentration of the volatiles including (CO_2). A vigorous formation of calcite and apatite takes place, together with precipitation of ferric and ferrous oxides (hematite, Ti-magnetite, Spitzkop, Alnö, Fen). If the content of the diopside molecule in the aegirite mineral be high, *i.e.* if the liquid be somewhat enriched in MgO, there develops conditions favourable to the formation of diopsidic rocks (Spitzkop, SHAND 28 a). The pronounced difference in density of the minerals now formed seems to preclude the attainment of the triple (or multiple) eutectic points of acmite (aegirite), hematite and sodium silicates (E_2, E_3, E_4; BOWEN 9), the former (heavy) minerals being removed by gravity fractionation in the very fluid volatile-rich liquid. The remaining silica which is formed by the splitting up of the heavy silicate minerals (aegirite) induces the formation of the pressure minerals: garnet (melanite), etc., and perhaps, under special conditions, of melilite (KRANCK 20). The later succession of materials of low density (carbonates) within the heavy layer forces its mobile monomineralic rock constituents upwards as the last infillings (in part pneumatolytical or hydrothermal) of the cracks and fissures which were opened in the roof formations by the increasing gas pressure brought about by consolidation. To the same category of rocks forced upward by the residual gas pressure to form the latest dyke rocks, belong the curious low silica mineral assemblages occurring in the neighbourhood of alkaline bodies (*cf.* v. ECKERMANN 13; KRANCK 20 a. o.). The intimate and orientated intergrowth of the minerals belonging to such of these associations as have been described from other areas (a. o. Alnö, HÖGBOM 16) points to very low and progressively falling eutectic temperatures within the pneumatolytic and hydrothermal ranges of development of the alkaline body (*cf.* also the discussion of BARTH 5 a, whose conclusions as to the age of the parental magmas may now be pushed farther forward in accordance with the discovery of Permian rocks in the Oslo-fiord region [HOLTEDAHL 18]).

The course of differentiation sketched above, based on the principle of gravitative fractionation and on the field descriptions and observations of the rock sequence in various bodies, principally of Fennoscandian occurrence, leads directly to the conclusion that the desilicated rock suites (carbonatites, apatitites, etc.) are the immediate descendants of a common silicate magma. The occurrences cited as proofs are chosen on purpose from countries where there are no outcrops of carbonatic rocks in the neighbourhood of the alkaline bodies; and where the surface structure of the areas concerned does not allow of any extrapolation of deep-seated carbonatic rocks. The areas surrounding the bodies are composed of a monotonous series of ancient acid rocks with the possible exception of the South African areas. In the latter localities the extrapolation of carbonate rocks at greater depths in contact with the igneous body may not be unreasonable (Spitzkop, Pilansberg, perhaps also the other ones). Nevertheless in the case of the Bushveld lopolith and its substructure in relation to Pilansberg (and Spitzkop) there remains some uncertainty as to the nature of the substructure. It is worthy of consideration that there may have been a certain amount of diapiric outward emigration of the mobile sedimentary carbonate formations under the immense load of the superimposed lopolithic masses and at the somewhat elevated temperature so implied. However, the carbonate rocks seem to remain at such depths that they may well be left out of discussion. In the other cases cited there is no real reason to discuss the origin of the alkaline suites as derivatives from carbonate rocks whatever the influence of the latter may have been (28 g).

The other end members of the suites, the saturated and oversaturated (silicic) rocks, have been regarded above as derivatives from a large scale assimilation process of the wall and roof rocks. There may be objections to this mode of genesis. It would seem simpler to explain them as derivatives from the lowermost triple eutectic (E_1) of the ternary system Na_2SiO_3-Fe_2O_3-SiO_2 (BOWEN 9) at $< 760°$ C, or from some alternative parent magma. Yet there are two observations which oppose such an explanation: 1) the broad and pronounced exocontact zone of the wall rock (»fenitisation», Alnö, Almunge, Fen) seems to be inconsistent with such low freezing temperatures; 2) in bodies protruding through country rocks of sedimentary origin, within which carbonate rocks play an important or dominating rôle, the alkaline rock suite develops otherwise, a sensibly basic rock being the oldest (outermost) intrusion (essexite in Mount Royal, first of 3 more or less independent intrusions, FINLEY 15, BANCROFT 4; Haliburton-Bancroft area, ADAMS & BARLOW 1; Oslo field, BRÖGGER), followed by a sequence of rocks ranging through foyaitic members to ordinary acid differentiation types. For this »sequence type» in which an influence of carbonate rocks on the differentiation process may be valid, FERSMANN (14) has proposed the term »*miaskitic* suite» to distinguish it from the *agpaitic* one.

There is no necessity to enter further into the interesting details of differentation within the alkaline series: the successive temperature appearance of the different potash, potash-sedium and sodium feldspars; the independent sodalite and the pseudomorphosing sodalite; the analogous cancrinite etc.; the different generations of titanite etc. The original publications of FERSMANN and his co-workers may be consulted on these matters.

6. Mechanism of Rock Intrusion.

The circular, elliptical, or occasionally less regular outlines of an alkaline body, nowhere projects as sharply as amidst the acid rocks of an ancient crystalline basement. The attempts to explain these intrusion forms are numerous yet contradictory. The explanation of the body as being the root of a great central volcano is, moreover, no explanation at all, and indeed recent volcanoes of this rock suite development are rather exceptional (Vesuvius, East Africa). The wide range of dimensional variability would seem to exclude any direct connection with a simple surface-extrusion apparatus.

SHAND (28 c) discusses at length the possibilities of intrusion by doming, stoping, blasting and melting (assimilation). He rejects all of them except stoping. Yet even here he admits the following difficulties connected with the stoping mode of intrusion: 1) there are comparatively few foreign blocks, if any, within an alkaline body; 2) the high specific gravity of the mother liquid increases downward and allows no submergence of stoped blocks or cylinders, whereas on the contrary there are relics of blocks which presumably have been floated upwards (Pilansberg, Spitzkop) from considerable depths; 3) the perfect und regular circular form of most of the bodies cannot have developed as a result of stoping activity alone.

Nor may the regular confocal distribution of the rock members inside a perfect alkaline body be connected with stoping activity at the top of a magma chamber: the stoping process would involve very irregular circulations within the ascending magma, and on the whole it would preclude any regular arrangement of mineral associations in the semi-fluid or semi-solid body. The regular distribution of rocks seems to be not only a characteristic of those portions of the bodies which by field evidences are recognized to belong to the upper parts of the intrusions (viz. Pilansberg, Ilimausak, perhaps even Umptek), but it is also to be traced where the deeper parts have been laid bare by erosion (N. Kärr, Almunge etc.). The picture of the above mentioned vertical structures reminds one of the concentric (or confocal) casings of a petroleum bore hole, while the rock bodies of horizontal arrangement may be compared with successive viscous outpourings at the upper end of these casings.

In a recent publication HOLMES (17) has suggested a cupola mechanism of basaltic intrusion in which, by convective circulation, an upward heat transfer available for fusing a steep dome-shaped funnel or cupola through the rocks of the granitic shell is procured; he explains in this way the genesis of the sharply contrasted association of acid and basic rocks in the British Tertiary Province and elsewhere, pointing out that the heat excess due to the circulative convection from below is sufficient to remelt the ancient granitic roof, so producing the acid top part of the association. He indicates also that, starting from a differentiating primary peridotite magma, the same kind of mechanism may be applied to the genesis of the feldspathoid rocks. The principle of the heat excess available at the top part of the intrusion is based upon the probability that the gradient expressing the rise of fusion point with pressure or depth is much steeper than the thermal gradient maintained by convection in a magmatic reservoir; in this way is procured a surplus of temperature of more than half a hundred degrees above the fusion point of basalt at the earth's surface, and therefore a still greater surplus relative to the fusion point of granite.

The mechanism suggested by HOLMES for basaltic intrusions is equally applicable to the case of the *agpaitic* suite of rocks. The first stage of crystallisation—differentiation of the agpaitic magma, with separation of a top layer of lighter alkali-feldspar—feldspathoid minerals, provides the fundamental conditions of the mechanism by closing up the top of the magma channel. The magma rises from beneath at some point of weakness in the yielding roof, accompanied by volatiles which lead to a radical lowering of the viscosity and thus make possible an intense convective circulation. A considerable temperature increment (far greater than in the case of basalt—granite) is available, inducing an intense reaction with the roof rocks and so resulting in the formation of an oversaturated, partly palingenic and contaminated magma of an alkaline affinity (different alkaline granites), which advances in the top front of the intrusion. During the early stages of this process, the volatiles being abundant and the density differences between the central rising magma and the top layer of feldspathoids not being too great, the first formed minerals (feldspathoids) may participate in the outer downward directed branch of the main circulation, so that the walls of the funnel may become coated with reaction products of felsic composition. However, the more the process advances the sooner the possibility of downward migration of the feldspathoid (and felsic) minerals comes to an end. The upward heat supply still continues, providing the felsic top formation with the temperature increment necessary for the retention of its partial mobility. A more or less independent convective circulation establishes itself (*cf.* HOLMES) in the felsic top formation with essential horizontal components of circulative movements, which contribute to a lateral enlargement of the cupola, with partial secondary assimilation of the wall-rock material. The outlines of this lateral enlargement of the felsic top formation do not in general retain the regular circumference of the original dome-funnel, being partly dependent on the structural irregularities of the wall rock. The rocks there developed may be characterised by a more pronounced undersaturation as compared with the top formation. The rocks resulting from these lateral enlargements as partial palingenetic descendants of the upper wall of the funnel may, indeed, reach a certain degree of oversaturation; they may be umptekitic, nordmarkitic, augite-syenitic, even pulaskitic in their composition. The earliest rocks of consolidation, the alkali-granitic ones, may or may not have been preserved laterally between the wall rock and this later rock formation, according to the nature of the relation of the newly formed outlines to those of the original funnel-dome.

There must certainly be a considerable time interval between the lateral expansion of the top formation (producing syenitic rocks) and the establishment of its more or less independent circulation with well pronounced horizontally directed components of convection. After this interval, during which the congealment of the outer (syenitic) shell takes place, bedding and fluxion structures (of foyaites, naujaites etc.) are likely to develop within an enclosed magma of pronounced undersaturation.

It must not be overlooked that the circulative centre of the top formation, which always receives a considerable amount of volatiles from beneath and therefore is in part dependent on the lower convective circulation, does not necessarly develope exactly on top of the central circulative axis of the lower dome system. This follows as a consequence of structural irregularities in the wall rock, for some lateral displacement is clearly unavoidable and will certainly tend to become more marked, the nearer to the actual surface the top formation has advanced. Certainly a corrective action is likely to establish itself so as to counteract the lack of correspondence. The dome-funnel containing the largest amount of heat, and still capable of supplying a surplus of heat from below under magmatic conditions of extreme mobility, will tend to promote this action by bringing about lateral migration of the upper circulative centre. This lateral migration of the top of the dome will be a consequence of one-sided fusion of its wall rocks and in this way fresh amounts of contaminated palingenic magma of a different grade of saturation will become available for intrusion into the top formation. This process explains the partial, yet incomplete recurrences in chemical and mineral composition of the rocks forming the diversity of an alkaline body. It gives also an explanation of the confocal rather than concentric arrangement of different rock members, to which SHAND has more than once drawn attention. Furthermore it makes intelligible the case of imperfect, interrupted rings or girdles of rocks, and also the case of rocks of later stages of evolution (of lower grade of undersaturation) which are in contact with the outer wall rock with no more than traces of transitional (saturated) rocks between; the missing material may have been removed by the lateral migration of the funnel. The readjustment of the original funnel in relation to the top masses may operate in repeated phases, producing several centres of confocal arrangement.

The final process of an agpaitic intrusion approaches completion in two different ways: 1) If the temperature sinks below the point of incongruent melting of the aegirite before the felsic upward fractionation be completed, the residual magma within the dome (and the upper chamber) will congeal with the production of rocks grading through every stage of undersaturation up to that of the original magma (a supposed ijolitic one); the residual volatiles will contaminate to a considerable extent the rocks of previously congealed suites. 2) If high temperatures continue to be maintained at the upper levels, the felsic fractionation proceeds and continues with the compounds corresponding to the breaking up of the aegirite. In this case silica-free (and jacupirangitic) mineral associations enter into the suite of intrusions; at this stage the volatiles become extremely concentrated and they threaten a catastrophe as the temperatures fall: the rocky roof may then be strongly shattered and injected by a series of dykes of extreme lamprophyric (basic) composition (13), including, amongst others, some rich in carbonates (20) and so leading on to formations of so-called hydrothermal origin. Under extreme conditions of high temperatures and great pressure the roof and the upper part of the funnel after an accelerated advance of the central wedge-shaped core may be blasted into the air; this form of evolution corresponds to the formation of the so-called »diamond pipes» (of South-African type) the connection of which with agpaitic intrusions was long ago suspected by FERSMANN, but the explanation of which has not hitherto been discovered.[1]

Further digressions in that interesting direction may be avoided; but in passing, we must not forget to mention the interesting mineral associations of the »pipes»; the carbonate dykes observed in the wall of the »pipes»; the doming of the Vredefort granite area; and also the doming of the circular Silurian area of Siljan in Central Sweden, a region of Fennoscandia in which, though at considerable distances from each other, the Almunge, Alnö, Särna, and N. Kärr areas occur.

It may be pointed out that the processes outlined above can by no means be considered as continually proceeding, without interruptions or disturbances. On the contrary, with such different and only partly related factors as variations of gas pressure and temperature, spontaneous crystallisations, fractionations, wall-rock influences etc. intervening in the process of intrusion there must be irregularities which control the more or less independent *mise-en-place* of the various members of an alkaline suite; the number of different and independent rocks composing an alkaline body serves as an indicator of these different kinds of disturbances.

The intrusion of an alkaline body as outlined above may be compared with a river of high competency and great load: small variations in the transportation process or seemingly unimportant irregularities in the river bed may lead to powerful cumulative adjustments or even to catastrophal disasters. The competency is to be compared with the amount of circulative heat convection, the load with the spotaneous crystallisation masses, their fractionation and the renewed action of the interfering palingenic mobilisations. The progress of the main intrusion, however, will generally be very slow.

7. Conclusion.

The mode of intrusion of alkaline bodies into an ancient crystalline (granitic) basement as sketched above on the principles (a) of convective heat circulation (HOLMES) and (b) of the *agpaitic* type of differentiation (FERSMANN) offers a sufficient succession of stages to explain the series of different rocks as descendants of more or less independent acts of intrusion.

[1] HOLMES suggests a similar hypothesis; from pockets of residual magma (a. o. ijolite, *cf.* below) derived from primary peridotite magma, wedge-shaped »dykes» penetrate the crust. On account of the high pressure due to accumulated volatiles there will be numerous points (where the »dykes» approach the surface) available for a final break through.

The greater the number of subsequent stages, the more complex becomes the intrusion form. In the lower parts of such a body there develops a sensible cone-in-cone or cylinder-in-cylinder-structure, the boundaries of the successive cylinders being obscured by ever later magmatic actions. The upper part broadens laterally and shows some rough analogy with an onion structure. The intrusion form thus strongly reminds one of a laccolithic one, of its head body with possibilities of local gravitative adjustments and of its feeding channel; yet the stages of development are more complicated, the feeding channel and the head body having to a great extent maintained a partial mutual communication throughout the whole magmatic activity. This communication is preserved by the heat excess of the convective circulation. In this special case of the agpaitic type of differentiation (with its upward fractionation of the lighter felsic crystallisations and its downward accumulation of the heavy, yet liquid, mafic components) it continues to be extraordinarily active even at the temperatures corresponding to the accumulation of gases under consideration. Assimilation of rocks of the side and top wall acting intermittently with the fractionation leads to the variability of the rocks, to some repetition of rock types and to recurrences in the rock suite.

The splitting up of the aegirite (and of some other minerals, *viz.* potassium feldspar) by incongruent melting in the final stage of development leads to the formation and intrusion of asilicic rock associations within the silicate suite, and to monomineralic end concentrations, accompanied by pressure culminations which in some regions result in circular blasting effects.

The complicated process of formation of an alkaline intrusive body within a crystalline (granitic) bed rock seems to differ from that of a typical laccolith in having the proportion: diameter of the body to diameter of the feeding channel, of an different order of magnitude, in some cases sensibly approaching unity. Therefore some of the alkaline bodies, even those with complex rock associations may represent feeding channels only, the top portions having been eroded away. In the development of the processes described above a broad feeding channel facilitates heat convection on the one hand, although on the other, it is itself the result of the processes involved.

The mineral assemblages of the alkaline rocks, described elsewhere (DALY 12 etc.) as being in part (16 species) typical products of carbonate contamination of the magma, have been regarded as symptoms of carbonate assimilation. We see, however, that under the conditions here developed such minerals are a natural consequence of the complex processes of fractionation-crystallisation. Moreover, there are certain mineral associations which cannot be explained by the contamination hypothesis, although they play a characteristic rôle in some examples of the alkaline suites. Why, for example, are the zirconium minerals so enriched as to imply names such as zircon-syenites, eudialyte-eukolite-syenites, katapleiite-syenites, lujavrites, kakortokites etc., all found in alkaline bodies occurring in crystalline areas? These minerals and zirconium itself are completely absent from sedimentary carbonate rocks, whereas, on the other hand, the mineral zircon is a constant accessory mineral both in granites and in their dynamometamorphic descendants, the gneisses. In other magmatic rocks of the main suites the zirconium minerals play a very subordinate rôle, if indeed they are not totally lacking. The concentration of these typical minerals throughout the main rocks of the alkaline suite, and not only in local mineral segregations, may be the result of the melting and reassortment of the granitic wall rocks during the gradual or rhythmic intrusion of the body.

Yet this explanation does not count for the excess of Cl and P_2O_5 in these suites; they are also not compatible with a derivation from a carbonate contamination. The granitic rocks contain only very small amounts of them. In a recent investigation HOLMES (*cf.* below) suggests that high Zr may be a normal product of the extreme differentiation of primary peridotite, to be expected together with P_2O_5 *etc.*, only in the ijolite, —nepheline-syenite series, and in the corresponding potash series.

There are two difficulties arising from the mode of intrusion of an alkaline body sketched above. The first one is: where does the excess of silica go, resulting both from the final splitting of aegirite etc., and from the remelting of the granitic wall?

Even if the undersaturation of the mother magma be great it does not suffice to combine with all the silica generated so as produce mineral associations entirely free of quartz. A smaller amount is perhaps fixed in albite and in certain zeolitic minerals which characterise the late hydrothermal phase of the development of the body. But that is not enough. A review of the volatiles fixed by the latest mineral associations reveals great amounts of CO_2, of Cl, and of P_2O_5, yet relatively small amounts of F, although F may have been abundantly represented at one time.[1] Perhaps it is this F that is responsible for the fate of the SiO_2 that appears to be missing even from the mineral associations of the last crystallisation (KAISER 19).

The second difficulty is: what is the source of the ijolitic magma which is here assumed to be the mother liquid of all the alkaline intrusions under consideration?

So far no real explanation has been given of the derivation from basaltic magma of true alkaline rocks rich in sodium. The discussion of descent possibilities by BOWEN turns out to refer to the derivation of rocks enriched in leucite, which in any case are of minor importance. It seems to the writer that field tests should be made with a view to finding such

[1] *Cf.* the cryolite-body of Ivigtut, W of Ilimausak, Greenland.

explanations. The basaltic alkaline differentiation proceeds no further than trachytic rocks, such as are developed out of basaltic suites on oceanic islands as pointed out by HOLMES. Phonolites and nephelinites are rather rare and relatively poor in Na_2O (BARTH 5 b).

In the course of an investigation of the rock contents of the minor magmatic cycles connected with the phases of orogenic movements in the Andes of Southern Mendoza, Argentina, South America, the present writer (2) has observed, that every cycle beginning with andesites (or granodiorites) of relatively acid composition ends with rocks of decreasing silica content, and, moreover, that each cycle is marked by a late afterbirth of (dyke-)rocks showing increasing characteristics of an alkaline suite (sparse feldspathoids, aegiritic augite etc.; mica lamprophyres also). The post-orogenic extrusions marking the main concluding faulting processes are of a plateau-basaltic type, which have wiped out the later tracks of the preceding »alkalinity».

Now it has long ago been stated and recently repeated (MARCHET 24 *etc.*) that alkaline (»Atlantic») bodies (or extrusions) are connected in time with an orogenic process of their own age although they are situated outside the orogenic zone itself. It does not matter in such a case if the location of an alkaline body coincides with an older orogen, provided that the orogen has become a stable area.

The late orogenic magma referred to above has become to some extent abnormal by subtractive processes during synorogenic-synkinematic processes. It may have been enriched in certain volatiles by intimate partial intermingling with different sediments and its varying content of mobile matter during the deep down-foldings of the orogen, and other members of its constituents may have been fixed in the folding zone. The connection of these subtraction-magmas with the alkaline bodies in the foreland is hidden and can hardly be subject to direct observation in the field. In this connection it may be pointed out that the position of all the most typical alkaline bodies lies within the old stable areas, and that they are later in their *mise-en-place* than its structural deformation. The more the stabilisation has proceeded, the more regular are the outlines of an alkaline body.[1]

There are other possible objections to be raised against the outlines sketched above, for it seems to the writer that the process of formation

[1] HOLMES (*cf.* below) has gone further into details discussing, on the basis of a large rock collection from Uganda, the possible mother magma of the alkaline suites and of its subtraction types. He suggests a long-continued differentiation of primary peridotites to produce the rock types, in this case the leucitite, by removing, at very high pressure of 5 different grades, of olivine and/or enstatite in changing proportions. Rock-types produced from that residual magma range from nephelinite (ijolite) at lowest, yet still high pressure, through melilitic rocks to leucitites (biotite-pyroxenite, mica-peridotite) at the very highest pressure. The removed minerals were also traced in some of the rocks studied. [Petrology of the Volcanic Fields East and South-East of Ruwenzori, Uganda (With Analyses by H. F. HARWOOD). Abs. Proc. Geol. Soc. London, Nov. 13. 1931. No. 1236.]

of an alkaline body, with its complex structural and mineral relations, has hitherto been far too much simplified, whereas in fact its relations are peculiarly complex.

The mode of intrusion of deep-seated alkaline bodies differs thus in many respects from other modes of magmatic activity in the earth's crust. If the granitic intrusions in general may be characteristic of orogenic movements, or the revolution phases *(orogenesis)*, and the basaltic ones of epeirogenic movements, or the evolution phases *(epeirogenesis)*, the alkaline intrusions piercing through the very stable areas may be a sort of *epeirodiatresis*, a perforation of stable continental areas.

These three types illustrate the petrogenic theory maintained by HOLMES that magmatic activity originates not only from one parent magma, but from three main types of parental magmas formed respectively in the granitic, basaltic and peridotitic layers of the crust. Just as *orogenesis* and *epeirogenesis* are mutually dependent on each other's relative position and amplitude, so *epeirodiatresis* is intimately connected with each of the other two. Mixed magmatic types are therefore to be expected and in fact they are probably of common occurrence.

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