

Campignien or Early Neolithic Beach. This proved warping, however, has a magnitude of only an inch or two in the mile, and is moreover in the wrong direction to serve as an explanation of the submergence on the shores of Loughs Bannus and Avehy. The smallest tilt that would cover the observed facts should amount to about 50 feet to the mile in the case of Bannus and 20 feet to the mile in the case of Avehy. If such an enormous movement as this has affected the district in general it ought to show itself on the sea-coast, unless indeed the shore-line of the forest period now lies so far beneath the sea that the tilting nowhere brings it above the surface. It is clear that an explanation based on tilting would strain our conceptions of post-glacial warping to the utmost.

There remains the explanation adopted by certain Swedish geologists to account for the same phenomenon in their own country. This is that the lakes during the growth of the forests had no overflow and sank beneath the level of their outlets. They ascribe this to the relatively dry climatic conditions which they suppose facilitated the growth of forest instead of bog. It is impossible to discuss here the merits of the climatic theory of the peat-bog succession, but it seems reasonable to assume that, if the Swedish cases are due to a period of dry climate, the Irish cases are to be explained in the same way.

Personally I do not feel at all certain that the mere existence of dense forests over the catchment area of these small lakes might not reduce the amount of water brought in by the tributary streams to such an extent as to lower the level of the lake, or even dry it up altogether except during exceptional floods. If, however, future advances in the study of the economy of forests should prove this idea to be untenable, there would seem to be but small chance of escape from the hypothesis of a very considerable change in the climatic conditions of the regions in which these submerged forests are found.

VII.—THE LATE PALÆOZOIC ALKALINE IGNEOUS ROCKS OF THE WEST OF SCOTLAND.

By G. W. TYRRELL, A.R.C.Sc., F.G.S., Assistant to the Professor of Geology, Glasgow University.

(Concluded from the February Number, p. 80.)

2. ESSEXITE. (a) *Carskeoch type*.—A small boss of essexite, of rather basic type, pierces the agglomerate of the Carskeoch vent, near Patna, Ayrshire. Macroscopically it is light grey, compact, and fine-grained. In thin section it shows a plexus of fluxionally-arranged plagioclase laths of the composition $Ab_1 An_1$, the interstices being filled with subhedral augite of a nearly colourless variety, and fresh olivine. Here and there minute angular interspaces are occupied with turbid isotropic matter, the form and arrangement of the particles of which suggest the former presence of nepheline. A few broad plates of pale augite and crystals of olivine interrupt the general trachtyoid fabric. Ilmenite and biotite occur sparsely, and a little orthoclase may be detected on the margins of the plagioclases, extending irregularly into the interspaces. This rock has a distinct individuality,

and resembles neither the essexites of Lochend and Craigleith in the Lothians, nor the Crawfordjohn type described below. It is poor in alkali-felspars and feldspaths, is devoid of purple augite, and has a well-developed trachytoid fabric.

(b) *Crawfordjohn type*.—This type, which was first described by Teall, is named after the famous locality for curling stones in South Lanarkshire. The type-rock apparently comes from one of the long north-west-south-east dykes which are believed to be of Tertiary age. It is, however, so exactly identical with rocks from Lennoxtown and Patna, and so incongruous with the Tertiary suite that there seems no alternative than to regard the rock as belonging to the Late Palæozoic alkaline types. The Lennoxtown occurrence forms a massive irregular dyke intrusive in Calcareous Sandstone lavas on the southern slopes of the Campsie Hills; the Patna occurrence is a small boss intruding the agglomerate of the Late Palæozoic vent of Carclout Hill, and therefore establishes the age of this type. The latter occurrence is congruous with the presence of alkaline intrusions in other vents of the same district, and the Late Palæozoic age of the entire suite seems to be well established.

As the Crawfordjohn and Lennoxtown rocks have been previously described by Allport, Teall, and Bailey, only the new occurrence at Patna falls to be described here. In hand-specimens it is greyish, compact, fine-grained, carrying numerous lustrous black phenocrysts of augite. Microscopically it is composed of a plexus of broad laths of plagioclase (Ab_1 , An_1), which are idiomorphic to abundant and often beautifully fresh nepheline. Limpid analcite occupies some of the interspaces and encloses the euhedral terminations of feldspar laths. Titanomagnetite is aggregated into groups of euhedral crystals associated with flakes of biotite. In the above, as groundmass, numerous large phenocrysts of deep purple titanaugite and fresh olivine are set. The pyroxene moulds and encloses olivine, and occasionally also the terminations of the felspars. In size it ranges up to half an inch in diameter. The olivine rules much smaller, and should perhaps be associated descriptively with the groundmass. Apatite occurs in great abundance enclosed in nepheline and analcite. Nepheline occurs in the Lennoxtown and Crawfordjohn rocks, as described by Lacroix,¹ and Bailey.² It is sometimes, as in the Patna rock, so abundant as to make it a question whether the rock should not be described as a theralite. Mr. Bailey, however, has placed the Lennoxtown occurrence in the essexite family on account of its very close resemblance to Brogger's essexite from Brandberget, Christiania district.²

3. *KYLITE*.—This well-individualized type occurs as a homogeneous and abundant set of sills and bosses in the Kyle district of Ayrshire, from whence it derives its name. It is an olivine-rich ultra-femic theralite or essexite. The chemical and mineralogical composition is quite distinctive; and as the rock is not a mere differentiation-facies of theralite or essexite, but forms numerous independent sills, it has been thought advisable to mark its individuality by giving it a new name.

¹ *Compte Rendu*, cxxx, 1900, p. 1273.

² Bailey, loc. cit.

The massive sill of Benbeoch, near Dalmellington, is taken as the type - occurrence. Macroscopically the rock is compact, fresh, phanocrySTALLINE, and rather fine-grained. The dominant tint is grey or greenish grey, the latter when olivine is very abundant. In thin section the rock is composed of dominant olivine in fresh rounded crystals, and titanite forming large anhedral to subhedral plates and prisms much indented by the terminations of laths of labradorite. Many small rounded grains of olivine and some of ilmenite are poikilitically enclosed in the augite. Labradorite and subordinate nepheline form a kind of groundmass to the somewhat larger-sized ferro-magnesian constituents, which tend to form poly-somatic groups, and thus take on a pseudo-porphyrific aspect. Some later feldspars are zonal and range in composition from Ab_4An_5 to Ab_5An_3 . Orthoclase may be detected on careful examination, bordering the lime-soda feldspar. The nepheline is somewhat decomposed, but is recognized by the usual distinctive characters (p. 79). A little clear analcite was the last constituent to crystallize. The only other minerals seen are skeletal ilmenite associated with scraps of reddish biotite, and a little apatite. The general fabric is evenly granular. The rock has been analysed by Dr. Dittrich, of Heidelberg, with the result given in column I, Table IV below. Four other analyses are tabulated for comparison.

TABLE IV.

	I.	II.	III.	IV.	V.
Si O ₂	44·18	42·87	48·57	40·32	44·42
Ti O ₂	1·30	—	1·48	2·66	1·63
Al ₂ O ₃	10·67	10·93	10·51	9·46	13·33
Fe ₂ O ₃	·97	3·44	2·19	4·75	9·14
Fe O	10·03	10·14	9·45	7·48	6·35
Mn O	—	trace	·16	·25	—
Mg O	17·77	16·27	17·53	18·12	5·74
Ca O	9·75	9·11	8·06	10·55	10·60
Na ₂ O	2·37	·92	1·59	2·62	5·60
K ₂ O	1·23	·13	·34	1·10	1·81
H ₂ O — {	·97	·57	·10	·57	1·75
H ₂ O + {		2·87	·37	1·25	
P ₂ O ₅	·38	trace	·19	·68	·35
C O ₂	trace	trace	none	—	—
S	—	—	—	·01	·18
Ni O, Cr ₂ O ₃ , etc. .	—	—	·18	·27	—
	99·83	99·95	100·72	100·09	100·35

Sp. gr. 3·05 — 3·065 3·148 —

- I. Kylvite, Benbeoch, Dalmellington.
- II. Hornblende-picrite, Ty Croes, Anglesey. Bonney, Q.J.G.S., vol. xxxix, p. 256, 1883.
- III. Ultra-femic olivine-basalt, lava-flow of 1852, Mauna Loa, Hawaii. Daly, *Journ. Geol.*, vol. xix, p. 296, 1911.
- IV. Nepheline-basalt, Uvalde County, Texas. Cross, Bull. U.S. Geol. Surv., No. 168, 1900, p. 62.
- V. Theralite, Flurhubl, Duppau, Bohemia. F. Bauer, T.M.P.M., vol. xxii, p. 281, 1903.

The Benbeoch analysis is remarkable for low alumina, very high magnesia, ferrous iron, and lime, combined with comparatively high alkalies. It does not correspond exactly with any known analysis. Its nearest affinity is the ultra-femic nepheline-basalt of Uvalde County, Texas. Analyses II and III correspond fairly well with it in all except the alkalies, which are much lower than in the Benbeoch rock. This is accounted for by the absence of feldspathoids in these rocks. Compared with a typical theralite the kyllite analysis shows a considerable diminution in alumina and alkalies, but contains almost three times as much magnesia for about the same silica percentage. Kyllite therefore appears to fall into place as the plutonic equivalent of an ultra-femic nepheline-basalt.

The quantitative mineral composition, as estimated by the Rosiwal method, is given in column I, Table V below, together with mineral analyses of the principal variations of the rock. The labradorite in each case includes a little orthoclase, perhaps 2 or 3 per cent.

TABLE V.

	I.	II.	III.	IV.
Labradorite . . .	26·8	33·1	32·3	17·0
Nepheline . . .	3·8	2·3	6·1	—
Analcite . . .	1·8	·6	1·4	4·7 ¹
Titanaugite . . .	25·1	27·6	25·9	19·7
Olivine . . .	37·8	29·5	27·9	55·4
Ilmenite . . .	2·1	4·4	4·3	2·5
Biotite . . .	2·0	1·8	1·4	—
Apatite . . .	·6	·7	·7	·7

- I. Kyllite, Benbeoch, the dominant type, analysed by Dr. Dittrich.
 II. Kyllite, a less femic facies, Benbraniachan.
 III. Kyllite, a less femic facies, Craigmark.
 IV. Kyllite-picrite, an ultra-basic facies, Chalmerston Hill, Benbeoch.

It will be noted that all these rocks are dofemic, to use a convenient term. Although the type represented by I forms at least three-quarters of the mass of Benbeoch, some distinct varieties, represented by II, III, and IV, must be recorded. II and III are satellitic outliers of the upper part of the Benbeoch sill, and are notably richer in the felspathic constituents and poorer in olivine. IV, on the other hand, forms an ultra-basic stratum at or a little below the centre of the sill. This facies consists principally of large euhedral to subhedral crystals of partially serpentinized olivine, forming 50–60 per cent of the rock. Large plates of titanaugite and fresh plagioclase form the major part of the remainder. Both minerals poikilitically enclose numerous small rounded olivines. The augite and feldspar are idiomorphic towards a turbid base, partly identifiable as analcite and partly indeterminate, which encloses flakes of biotite and large cross-fractured crystals of apatite. The feldspar plates show in unusual perfection the radiating fissures springing from enclosed olivine.

¹ This includes a little unidentified turbid matter.

This *couche* of ultra-basic rock in the centre of the Benbeoch sill appears to be susceptible of precisely the same explanation as that adopted for the similar phenomena of the Lugar complex (p. 76); and also for an olivinic ledge in the Palisade quartz-diorite sill of New Jersey.¹

C. *Rocks without conspicuous Analcite or Nepheline.*

Associated with the more alkaline types described above are a great number of less alkaline rocks, which, however, betray their affinities by the abundance of purple augite and the occasional presence of an interstitial wedge of clear analcite. Some of them accompany the analcite-syenites apparently as differentiation-facies. Others form small masses intrusive in the highest horizons in the West of Scotland—the 'Permian' red sandstones and lavas of the Mauchline district. While rather variable in their characters it does not seem possible to divide them into well-characterized groups. The following description applies particularly to the sill in the Trabboch Burn, near Stair, Ayrshire, a fresh and typical example of these rocks which may serve as a type of the whole suite. It contains a few veins and irregular patches of analcite-syenite.

Megascopically the Trabboch Burn rock is greyish in colour, medium and even-grained, consisting essentially of grey felspar and black pyroxene in approximately equal proportions. In thin section the rock consists of a coarse-grained aggregate of broad laths of zonal plagioclase in subophitic relations with large subhedral to anhedral plates of purple titanite. Fresh olivine occurs in some quantity, and also ilmenite, the large skeletal aggregates of which are intergrown poikilolithically with the pyroxene. It is associated, as usual in these rocks, with a few scraps of red biotite. A soda-bearing orthoclase may occur in some quantity, generally with analcite. The latter fills up interspaces and encloses the idiomorphic terminations of felspars, grains of augite, and needles of apatite. The proportions of orthoclase and analcite are very variable, and in some sections they are absent. The plagioclase is highly zonal, ranging in composition from Ab_1An_1 to Ab_1An_3 , and has often suffered partial analcization.

All the other rocks falling under this group have the same general aspect as the above. There is, however, considerable variation in the proportions of certain constituents. Analcite and orthoclase frequently fail, olivine often becomes an abundant constituent, whilst many of the rocks show a perfect ophitic structure.

These rocks are ophitic dolerites, which, whilst not conspicuously alkaline, show considerable affinity with the alkaline series. This may be appropriately recognized by terming them *alkali-dolerites*. Those varieties which contain analcite and soda-orthoclase belong to the *essexite* family, and their doleritic aspect may be recognized by the designation *essexite-dolerite*. They closely resemble the 'crinanites' of Argyllshire. (Mem. Geol. Surv., *Geology of Colonsay*, 1911.)

¹ J. V. Lewis, *Annual Report of State Geologist for 1907*: Geol. Surv. of New Jersey, 1908, p. 129.

The alkali-dolerites and essexite-dolerites are abundantly developed in the Dalmellington district. The chief localities are Muck Burn, Dalnean Hill, Dalcainnie Hill, Grimmet Glen, Whitehill (Patna), Polnessan Burn, Rankinston, Dunaskin Glen, and Ashbeugh Glen. In the district of which Tarbolton is the centre, the chief localities are Auchincruive, Helenton, Howford Bridge, Dippol Burn, Trabboch Burn, Stair, Failford, Auchinweet, and Barskimming.

The analcite-syenite differentiate is only found in the Mauchline-Tarbolton district; it has not been recognized in the Dalmellington area. In the latter, however, the alkali-dolerites sometimes contain pink acid veins, notably at Muck Burn, Dalmellington, and the Coyle Water, Rankinston. At the latter locality the veins consist of a medium-grained plexus of zonal plagioclase margined by orthoclase, associated with an approximately equal quantity of moiré and perthitic orthoclase in broad anhedral plates. A little granular pyroxene and skeletal ilmenite is enclosed in the feldspars, also some biotite and chlorite; but the proportion of femic minerals is very small. This rock has affinities with the monzonites.

The Muck Burn variety is much finer in grain, and attains a vein-width of 5 inches. It consists of a fine-grained aggregate of well-shaped laths of orthoclase and acid oligoclase, the latter slightly predominating. The interstices are filled with quartz and cryptocrystalline matter. The only other constituent is a little leucoxene. The structure is typically orthophyric, and the rock might be termed a monzonitic orthophyre. If the orthoclase is soda-bearing, as is probably the case, the rock becomes a keratophyre.

D. *The Mauchline Lavas.*

These rocks occur in a narrow ring-shaped outcrop surrounding the 'Permian' red sandstones of the Mauchline-Tarbolton area. Their geological features have been described by Sir A. Geikie.¹ Their petrographical character is the subject of a brief note by Dr. Hatch in Sir A. Geikie's *Ancient Volcanoes*.² The picrite there described is probably one of the monchiquite or limburgite lavas. Mr. David Ferguson, who has devoted much attention to this district, estimates the thickness of the lavas at 280 feet. This thickness is made up by a number of thin flows intercalated with tuff and red sandstone. These intercalations increase in number and thickness towards the top of the lavas until they merge into the thick overlying sandstones. The lavas have been poured out from a series of small 'greenhill' vents situated mostly round the northern edge of the outcrop.³ Numerous vents also occur round the margin of the high Carboniferous plateau to the north of Dalmellington, which was doubtless once covered by a cap of lavas. The vents contain lavaform material in blocks and apparently intrusive masses, which extend our knowledge of the petrography of this late series of Palæozoic lavas.

¹ GEOL. MAG., Vol. III, p. 243, 1866.

² *Ancient Volcanoes of Great Britain*, vol. ii, p. 57, 1897.

³ Tyrrell, "The Geology of Mauchline," in *The Land of Burns*, by J. T. Gibb, of Mauchline, 1911.

Megascopically the lavas are very uniform in appearance. They are all compact, aphanitic, varying in colour from dark red to purplish, rarely grey or black. A very characteristic aspect is imparted by a universal red speckling due to the replacement of microporphyritic olivines by red iron-ores derived from the overlying sandstones. A red stain of diffused iron-oxide frequently gives the rocks an appearance of decomposition which is belied by the general freshness apparent in thin section. Porphyritic olivine is invariably present, augite rarely, but felspar never. The above characters easily distinguish these rocks from the earlier Carboniferous lavas, and have been found very useful in determining the age of some doubtful vents.

The following minerals have been found in thin section: olivine, almost invariably pseudomorphed by hæmatite, purple titanite, plagioclase ($Ab_1 An_1 - Ab_2 An_2$), analcite, nepheline, and sparse iron-ores.

The lavas can be broadly divided into two divisions characterized by the presence or absence of felspar. The feldspathic group is the most abundant, and includes femic types of olivine-basalt (cf. Hillhouse and Dalmeny types), analcite-basanite, and analcite-nepheline-basanite. The two latter are probably to be classed with the Kidlaw basalt of the Lothians.¹ In the Dalmellington district the vents contain blocks comparable to mugearite and Markle basalt (a non-porphyritic variety). These, however, are extremely rare. The felspar-free rocks include monchiquite, analcite- and nepheline-basalt, and limburgite, types which are also represented in the Lothians.²

The *olivine-basalts* consist of abundant micro-porphyritic olivines, pseudomorphed by hæmatite and serpentine, in a groundmass made up of granular augite and lathy plagioclase, the former usually predominating. The minute interstices are occasionally filled with analcite or with turbid material resulting from its decomposition. Transitional types connect these with the *analcite-basanites*, in which analcite occurs in sufficient quantity to rank as an essential constituent. In a rock from the Thornton vent, near Kilmaurs, the analcite occurs as a fresh pellucid, pervading base, enclosing a plexus of augite granules and plagioclase laths. Olivine and a little augite occur as phenocrysts. In another type from Sorn Hill, near Catrine, the texture is doleritic, and the analcite occupies large polygonal cavities, usually bounded by laths of felspar. It contains detached granules of deep-purple augite, and envelops projecting felspars which appear to have suffered corrosion. Olivine is abundant as phenocrysts with the usual hæmatite replacement; also augite in abundant large poly-somatic aggregates of a much paler tint than the augite of the groundmass. This rock also contains nodules of closely packed granules of augite with a little felspar, but no nucleus of analcite. These are comparable with the ocelli found in similar rocks in the Lothians.³

A few of these rocks contain nepheline. It is always associated with analcite, and both minerals may occur in a perfectly fresh

¹ *Geology of East Lothian*, 1910, pp. 106, 111.

² *Ibid.*, pp. 106-7.

³ *Ibid.*, p. 109.

condition in the same interspace. A typical example of these rocks occur in a vent exposed in the River Irvine, near Hurlford. This consists predominately of anhedral grains of purple augite with a little magnetite in an apparently continuous colourless groundmass, which, in polarized light, breaks up into laths of plagioclase, isotropic analcite, and low-polarizing nepheline. Both the latter occur in interstitial areas in which the nepheline occupies the margins, and projects with good crystal form into more or less decomposed analcite occupying the central space. The nepheline has the characters of 'nepheline x', described by Bailey, and is accompanied by a mineral of much the same appearance but lower refractive index, just as in the East Lothian occurrences.¹ These rocks may be termed *analcite-nepheline-basanite*. With increasing abundance of nepheline and a corresponding diminution of analcite and felspar, especially the latter, these rocks approach closely to the true *nepheline-basalts*. A rock from the Alton Burn, Tarbolton, is generally similar to the above, but is much richer in nepheline. The latter forms small plates poikilitically enclosing granules of augite. Small flakes of biotite occur abundantly in the groundmass, as well as apatite in large stumpy crystals, averaging one-tenth of an inch in diameter.

The true *monchiquite lavas* are well represented by a beautifully fresh rock from the burn near Stevenston, two-thirds of a mile north-east of Ochiltree. It consists of a crowded mass of small euhedral grains of titanite and sparse minute specks of magnetite embedded in a scanty base of analcite. Olivine is very abundant in small porphyritic crystals, partly fresh, partly hæmatized. A few small phenocrysts of augite also occur. The analcite tends to segregate into small rounded areas which have tangentially aligned prisms of augite around their margins. In the larger areas the mineral shows anomalous double refraction similar to that of leucite, and the cubic cleavage is well marked. Other slides from the same locality show large ocelli of augite with a nucleus of analcite carrying detached aggregates of augite grains and numerous minute crystals of ægirine. The groundmass of this rock is largely composed of fresh nepheline which forms small plates poikilitically enclosing the other constituents. We have, therefore, the rare type *nepheline-monchiquite*.

Limburgite, characterized by a glassy base, is known from one locality only, the hardened rim of the little vent at the Earthwork, Barnweill, near Tarbolton. This mode of occurrence suggests that the glass in the rock is due to the refusal of original analcite in a monchiquite lava. The glass is distinguished from analcite by the lack of cleavage, its dark-brown colour, and by the abundance of microlites of magnetite. The presence of glass in place of analcite is the only difference between this rock and the monchiquite described above.

PETROLOGY.

It is not possible here fully to discuss the petrology of these rocks considered as a homogeneous suite or province possessing certain characters in common, and otherwise bearing indications of a common

¹ *Geology of East Lothian*, 1910, p. 110.

origin. The material is deficient especially as regards the chemical analyses which are so vital to such a discussion. Nevertheless it is possible to indicate broadly the salient characters of the suite.

Geological occurrence.—The rocks occur as sills, small lenticular intrusive masses, volcanic plugs, and as a series of lava-flows. No occurrence of true abyssal habit is known. The intrusions are on a comparatively small scale, and range from occurrences, the outcrops of which cover only a few hundred square yards, to some, such as those of Craigie and Dundonald, which cover several square miles, and have a thickness of over 100 feet. Many are lenticular in form; others, however, are stratiform, and have a horizontal extension which is very great as compared with their thickness. This form frequently characterizes the sills rich in analcite, the original magma of which must have possessed unusual liquidity. A concomitant effect is a marked differentiation, which is usually best developed in sills, such as that of Lugar, having a wide horizontal extension.

The volcanic plugs may consist merely of lavaform material; but kyllite, teschenite, and other rocks have also been found with this mode of occurrence. At Carskeoch Hill, near Patna, the agglomerate is pierced by a very heterogeneous complex (p. 120). The lavas occur in thin impersistent flows. The 280 feet of thickness estimated by Mr. Ferguson includes a large number of intercalations of tuff and sandstone. The lavas have been poured out from several 'greenhill' vents, characterized by their bright-green vegetation and sharply conical form. A thin skin of lava is occasionally found adhering to the walls of an agglomerate vent.

The sieve-like perforation of the sedimentary rocks by these vents is reminiscent of the Mid-Miocene vulcanicity of the Suabian Alb, as remarked by Daly. It is noteworthy that Daly has adduced the Ayrshire and Fifeshire districts as examples of secondary vulcanism, due to the opening of vents above satellitic intrusions. He remarks: "The steady association of tuff-neck and sill in the Scottish shires scarcely looks accidental."¹

A remarkable absence of dykes belonging to this suite is to be noted. The only one known to the writer is a thick dyke-like mass of thetalite (Bellow type) crossing the Lugar Water just below the Lugar sill. This is probably connected underground with the thetalite of the Lugar sill. The Crawfordjohn dyke is a doubtful example and requires further investigation.

Chemical and Mineralogical Characters.—The chemical characters of the suite cannot as yet be adequately discussed. The chief points to be noted are that the magmas generally are poor in silica and rich in alkalies, especially soda, which is always in excess of potash.

The characteristic mineral of the suite is analcite. It occurs in almost every member, sometimes in large quantity, and in such relations to the other constituents as to establish indubitably its primary character. Indeed, this suite should go far to demonstrate the existence of an analcite series of igneous rocks parallel to those

¹ R. A. Daly, "Nature of Volcanic Action": Proc. Amer. Acad. Arts and Sciences, vol. xlvii, pp. 117-18, 1911.

characterized respectively by nepheline and leucite. Nepheline is of comparatively rare occurrence. There is abundant evidence in these rocks that it can be formed along with primary analcite. The dominant feldspar is labradorite of the composition Ab_1An_1 ; orthoclase (a soda-bearing variety or sometimes anorthoclase) occurs in very subordinate quantity.

The characteristic ferro-magnesian mineral is a pleochroic augite of a peculiar deep purple-madder tint, which is generally held to indicate a high titanium and soda content. Olivine is very abundant, and a peculiar red barkevicitic hornblende is occasionally present in some quantity. Ægirine and arfvedsonite appear in the more acid rocks.

The suite has a general basic character. Amongst the intrusive rocks teschenite is by far the most abundant. It shows a decided tendency to pass over to ultra-basic modifications. Subacid rocks are very rare in comparison, and acid rocks are unknown. The lavas are basic, with a large number of types verging on the ultra-basic. The abundance of analcite indicates a parent-magma rich in water and alkalis. Other volatile substances were probably present which are not now represented among the constituents of the rocks. Apatite, however, is very abundant, and seems always to be associated with analcite or alkali-feldspars. Hence it is probable that fluxes like fluorine or chlorine were present in the magma. Whatever fluxes were present, there is evidence to show that the magmas were usually very liquid; and to that liquidity must be ascribed the very complete differentiation seen in some of the intrusions. The liquidity in some cases was so great that differentiation was controlled more by simple gravity-stratification than by differences of temperature set up during intrusion. This remark applies to differentiation after intrusion; but assuming a single original magma-reservoir, there can be little doubt that some differentiation took place before intrusion, as is evidenced by the variety of rocks which constitute the suite.

DISTRIBUTION AND AGE.

The areal distribution of the various types seems to have some significance. The teschenites are the most widely spread types. They are mostly intrusive in the Carboniferous Limestone Series in the areas remote from the central volcanic districts of Mauchline and Dalmellington. Thus they are common in North Ayrshire and in the Cumnock districts. The Glasgow teschenites are separated from the nearest Ayrshire occurrences by a wide interval, which is mainly occupied by a great mass of calciferous sandstone volcanics. If they are connected with the Ayrshire centre it is remarkable that no teschenites are to be found in the intervening area; unless it is that these rocks found the calciferous sandstone lavas difficult of penetration.

The principal teschenite-picrite masses are ranged on the margin of the Coal-measure area surrounding the central volcanic district, as at Cumnock, Lugar, and Patna. The kyllites penetrate the Coal-measures in the zone immediately surrounding the 'Permian' lavas of Mauchline, and are mostly concentrated in the southern part of that zone. The essexite-dolerites and analcite-syenites intrude the lavas and overlying sandstones of the Mauchline area; and a zone of

alkali-dolerite also occurs around the margin of the Coal-measure area of Dalmellington.

Despite minor irregularities, therefore, there appears to be a well-marked concentric distribution of the various types, in interrupted zones, with reference to the central volcanic area of Mauchline. Although the point needs confirmation by chemical analysis, it is probable that the Mauchline lavas are the effusive equivalent of the kylites rather than any other group.

This distribution provides a clue, not only to the relative ages of the main types, but also to the age of the suite considered as a whole. It is obviously distributed in relation to the lavas of the Mauchline tract, which overlie the Upper Red Sandstones of the Carboniferous, and are believed to be of Permian age. The widespread teschenites may represent the assumed parent-magma or one of the first differentiates from that magma. They were intruded into the lower levels of the adjacent strata, and were probably prior to the effusive phase. The highest horizon cut by them is the Coal-measures in the east of Glasgow. Here they are much faulted, and are without doubt of Late Carboniferous age.¹ The kylites, alkali-dolerites, and analcite-syenites may then be secondary or tertiary differentiates derived from subsidiary magma-basins intruded into the higher sedimentary levels at a later date, and accompanied by an effusive phase which gave rise to the Mauchline lavas.

The suite may therefore be assigned with much probability to the close of the Carboniferous period. Possibly the later members belong to the succeeding Permian. The Mauchline lavas have been assigned to the Permian by Sir A. Geikie.² Some doubt, however, attaches to the correlation, and there is some probability for the view that the red sandstones which overlie the Mauchline lavas are merely the upper part of the barren red sandstones of the Coal-measures, the two portions being separated by a volcanic episode.³

An allied suite of alkaline rocks has recently been described from the Lothians. These are intruded into the sediments above the Calciferous Sandstone lavas, and are thus clearly subsequent to this effusive period. The great majority intrude the Carboniferous Limestone Series. These later basic analcite-bearing rocks are said to bear a great resemblance to some of the lavas of Burntisland and Bathgate, belonging to the Carboniferous Limestone Series.⁴

It still seems questionable, however, whether some of the alkaline intrusions of the Lothians and Fife may not be linked on ultimately with a later volcanic episode than that of the Calciferous Sandstone or the Carboniferous Limestone. The famous 'Permian' volcanic vents of the Fifeshire coast, so well described by Sir A. Geikie,⁵ are doubtless contemporaneous with the volcanic episode of the Mauchline district. The lavaform products have a striking similarity, although so far as is yet known, nepheline-bearing rocks have not been met with in the

¹ Mem. Geol. Surv., *The Geology of the Glasgow District*, 1911, p. 112.

² *Ancient Volcanoes of Great Britain*, vol. ii, p. 55, 1897.

³ Tyrrell, Trans. Glasgow Geol. Soc., vol. xiii, pt. iii, p. 314, 1909.

⁴ Mem. Geol. Surv., *Geology of East Lothian*, 1910, p. 104.

⁵ *Ibid.*, *Geology of East Fife*, 1902.

Fifeshire vents. It may well be, however, that on a thorough examination of material in these vents, a fuller correspondence may be established, in both intrusive and extrusive types, with the Ayrshire district. It is possible, therefore, that just as the intrusive alkaline rocks of the west are related to the Mauchline volcanic episode, so the similar rocks of Fife and the Lothians may be related to the latest ('Permian') volcanic episode of that district.

The fact emerges that the distinctively alkaline phase, at least as regards the intrusive types, began earlier in the Lothians than in the West of Scotland. In the former area the alkaline intrusions date from the Carboniferous Limestone; in the latter from the Coal-measures. The western suite as a whole was a little later than the eastern, and links itself definitely with a late Carboniferous or Permian volcanic episode; whilst the eastern suite appears to bridge the gap between the Calciferous Sandstone lavas and the 'Permian' volcanic episode of Fife.

Considered in relation to the homogeneous mass of alkaline types erupted during the Carboniferous period in the Midland Valley of Scotland, the western suite falls into place—recognizing the time element in petrographical provinces—as a sub-province and sub-period of the Carboniferous period-province of Central Scotland. Excluding the Glasgow teschenites, the boundaries of the sub-province are well defined to the north by the great mass of Calciferous Sandstone volcanics occupying North Ayrshire and Renfrewshire. These rocks, with Old Red Sandstone, also bound the area to the east. On the south and south-west the great Southern Upland marginal fault forms the natural boundary. To the west, however, the extension of the sub-province is indefinite. Some part may be faulted down beneath the Firth of Clyde. It extends at least as far as the Lady Isle, a teschenite mass in the Firth, 3 miles west of Troon; and may also include Arran and Bute. The Glasgow teschenites, as before stated, are remote from the Ayrshire district, and are possibly outlying members of the Lothians sub-province. It may be said that the western sub-province is approximately co-extensive with the county of Ayrshire, and that its time-boundaries are Coal-measures to Early Permian.

REVIEWS.

I.—GEOLOGICAL SURVEY MEMOIRS.

ON THE MESOZOIC ROCKS IN SOME OF THE COAL EXPLORATIONS IN KENT. By G. W. LAMPLUGH, F.R.S., and F. L. KITCHIN, M.A., Ph.D. 8vo; pp. vi, 212, with 5 plates and 5 text-illustrations. 1911. Price 3s. 6d.

IT is well that the Geological Survey has been able to rescue from oblivion a most important series of data, stratigraphical and palæontological, that have been disclosed by some of the coal explorations in Kent, and in particular by those at Dover, Brabourne, Pluckley, and Penshurst. The researches, of which the results are embodied in this memoir, were indeed commenced so long ago as 1897,