XXXI. *Notes on the Petrology of the Agglomerates and Hypabyssal Intrusions between Largo and St Monans.* By MRS WALLACE (Miss I. F. STEWART, M.A., B.Sc.). (With Plate XLIII.)

(Read 17th March, 1915.)

ALONG the S.E. coast of Fife from St Monans to Largo a series of volcanic necks is exposed on the shore. They rise vertically through the Carboniferous strata and are well known to geologists from the descriptions of them that have been given by Sir Archibald Geikie in his "Carboniferous Volcanic Rocks of the Basin of the Firth of Forth" (*Transactions of the Royal Society of Edinburgh*, vol. xxix., 1879), "Ancient Volcanoes of Great Britain," vol. ii., pp. 69-91 (London, 1897) and the "Memoir of the Geological Survey of Scotland on the Geology of East Fife," pp. 232-283 (1902). Some account of the petrographical characters of the rocks found in these necks has been given by Professor Seymour and Dr J. S. Flett, in the above-mentioned Survey Memoir (pp. 395-404).

In the interior of Fife many volcanic necks have also been mapped and are represented on the Geological Survey one-inch map, Sheet 41. They are believed to belong to the same series as the necks exposed on the coast. The largest and most conspicuous member of this group is Largo Law, and a few notes on the petrography of its rocks will be included in this paper.

In addition to material of volcanic origin many blocks of sedimentary rocks such as sandstone, limestone, coal and shale, occur in the necks. They agree closely in character with the Carboniferous sediments of the district, and, as they seldom exhibit contact metamorphism and, are never greatly altered, it is not intended to give a special description of them.

Volcanic rocks occur in these necks in two ways (a) as agglomerates, and (b) as intrusions. Of the latter class most of the examples are dykes, but a few may be described as sills or sheets. Figures and photographs showing their mode of occurrence may be found in Sir Archibald Geikie's books and papers mentioned in the first paragraph.

The necks that occur along the shore may be named as follows, taking them in order from East to West.

1. *St Monans.* On S.W. side of St Monans village.
2. *Newark Dovecot.* On the shore, in front of the old dove-cot of Newark.
3. *Newark Castle.* About 180 yards west from Newark Castle.

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4. *Coalyard Hill*. Shore in front of Coalyard Hill, near Ardross farm.
5. *Ardross*. About 200 yards west from the promontory on which stand the ruins of Ardross Castle.
6. *Elie Ness*. At Elie Ness. Eastern margin at Sauchar Point.
7. *Elie Harbour*. A composite neck in the neighbourhood of the promontory at Elie Harbour.
8. *Kincraig*. Shore at Kincraig Hill.
9. *Ruddon's Point*. At western side of the bay west of Kincraig Hill.
10. *Viewforth*. Shore in front of Viewforth, Lower Largo.
11. *Largo Law*.
12. *Lundin Links*. On foreshore at eastern end of Lundin Links.

Besides the necks there are intrusive sheets or sills both on the shore and a short distance inland. Some of these have evidently a connection with the necks as they consist of the same types of rock, as, for example, the sheet at Chapel Ness (Earlsferry) and the sheet that occurs in Elie Golf Course, near the Golf House. Others belong to types of rock quite distinct from those that form the necks and are to be attributed to a different period of volcanic activity. The sill at Wood Haven, east of Elie pier, is of this class.

The igneous rocks of the volcanic necks have been described by Seymour and Flett as limburgites and basalts. As many of them are, however, intrusive and rich in analcite, it will be more appropriate to describe them as monchiquites. In some of the specimens which retain the original minerals in good preservation nepheline has now been detected, so that we must recognise the presence of nepheline basalts and perhaps also nepheline basanites.

The age of these rocks is not altogether certain, but Sir A. Geikie has referred them to the Permian. They must, of course, be later than the rocks through which they rise. The neck at Lundin Links pierces the red beds which form the highest subdivision of the Scottish Carboniferous, and if we are right in assigning this neck to the same groups as the others, it is not possible to evade the conclusion that the whole series is late Carboniferous or post-Carboniferous. If they are Permian, they belong probably to the same epoch as the volcanic rocks of Central Ayrshire, and it is to be remarked that they have fairly close petrological affinities with these rocks as described by Mr Tyrrell,¹ especially in the presence in both areas of very

¹ *Geological Magazine*, Dec. 5, vol. ix., pp. 125-131 (1912).

basic types containing fresh nepheline. Limburgites, monchiquites, and nepheline basalts are also known to have been emitted in East Lothian¹ in the Lower Carboniferous along with trachytes and phonolites—but the Fife necks certainly belong to a much later period than this. Professor Heddle was at one time of the opinion that the East Fife volcanoes might be of Tertiary age, but there is no definite evidence to support this hypothesis, although monchiquites and nepheline basalts in certain parts of Scotland are regarded by many geologists as being of this date.

The volcanic rocks of the necks of East Fife, so far as examined in connection with this paper, present little variety in composition. They are all very basic, and consist mainly of augite and olivine. A little felspar occurs in many of them, and in a very few nepheline has been observed. Another mineral of some importance is analcite, though it is usually secondary. The groundmass sometimes contains a colourless or brownish glassy base, which is often decomposed.

As the characters of the minerals differ little in the whole assemblage, a description of them may be given before we proceed to an account of the rocks themselves.

Augite occurs in two generations, the phenocrysts being small and idiomorphic. The mineral for the most part is a "titan-augite," lavender or purple coloured in thin sections, slightly pleochroic, and showing marked axial dispersion. Not infrequently the phenocrysts consist of an irregular corroded core of green chrome diopside, which is surrounded by a rim of purple augite. Hour-glass and other zonal structures are common, and very often the crystals are twinned. The usual product of decomposition is chlorite, but this gives place to calcite in the last stages of decay.

Olivine is present in one generation only in the form of phenocrysts, which are sometimes idiomorphic, sometimes much corroded and embayed with inclusions of the matrix or groundmass. The crystals are usually small, but often very numerous, and they are never absent. Inclusions are sparingly developed, and are chiefly magnetite and picotite.

Felspar as a normal component occurs only in the groundmass as narrow, lath-shaped prisms of plagioclase. Symmetrical extinction angles in sections cut at right angles to 010 gave a maximum value of 28°, indicating that the felspar is chiefly labradorite, somewhat more basic than Ab₁An₁. The crystals are almost free from inclusions.

Nepheline occurs as small crystals, never as phenocrysts, but

¹ "The Geology of East Lothian," *Mem. Geol. Survey* (1910), pp. 105–130.

as an ingredient of the groundmass. Its crystals are sometimes well formed short hexagonal prisms, giving characteristic longitudinal (rectangular) and transverse (hexagonal) sections. More frequently it occurs as rather irregular granules not over .01 mm. in size, enclosing magnetite, glass and augite. Its crystallisation seems to have immediately preceded, or accompanied, that of the felspar of the groundmass. Except in the freshest rocks we can hardly hope to find it, as it readily decomposes to analcite and zeolites. The mineral is most easily recognised by its low double refraction, absence of twinning, and negative character in longitudinal sections. Where the rocks are fresh staining methods may be employed, but it then must be distinguished carefully from olivine and analcite which also stain readily. Rock sections were prepared as for microscopic examination, and were treated for a few minutes with concentrated hydrochloric acid. The sections were then placed in a shallow bath, and washed by siphoning off the water. Fuchsin was then applied to the sections, and on examination it was found that the gelatinous precipitate from the action of hydrochloric acid on the nepheline had been stained a bright red.

Glass. The glassy base present in small amount in some of the rocks is generally of a brown colour, and is filled with minute prisms of augite and grains of magnetite.

Many of the rocks, particularly the blocks in the tuffs and the thinner dykes, are much decomposed. The olivine is replaced by serpentine and calcite, the augite by chlorite and calcite, and the felspar is changed to cloudy semi-opaque secondary aggregates. Nepheline alters readily to analcite and zeolites. In many slides analcite is very abundant, filling steam cavities and replacing the substance of the groundmass. There can be little doubt that this mineral is mostly secondary, as it increases in quantity as the rocks are more decomposed. It is often intimately mingled with vermicular chlorite. In the steam cavities analcite frequently occurs lining the walls and showing sharp crystalline outlines, while calcite fills the interior. In the groundmass of the rocks analcite forms a cloudy deposit, rarely isotropic, and filled with scales of secondary calcite and chlorite. White or grey are its commonest colours, but iron staining often makes it deep yellow. The zeolites that accompany the analcite are fibrous and radiate: their nature has not been specifically determined.

The nomenclature of the rocks gives rise to some difficulties. They have been described hitherto as basalts and limburgites. Felspar occurs in them only in exceedingly small quantity and might be regarded as a non-essential mineral. If its presence is considered to require recognition, the more felspathic types

might be called analcite basalts or basalts of the Hillhouse type, as described in the "Memoir on the Geology of the Edinburgh District" (*Mem. Geol. Surv.*) p. 320. There are no true lava flows connected with these necks, and the blocks in the tuffs might be called limburgites or monchiquites (seeing that the necks are intrusive). The dykes in the necks are monchiquites, rich in analcite. The presence of large crystals of corroded hornblende, augite, and alkali felspar is a well-known characteristic¹ of the monchiquite dykes. Traces of the ocellar structure so frequent in monchiquites are also observed in the Elie dykes, though not in perfect development.

The nepheline-bearing rocks contain little or no plagioclase felspar and are best described as nepheline basalts, rather than as nepheline basanites.

The difficulties in finding perfectly appropriate names for certain of these rocks arise partly from the fact that felspar never occurs except in very small or negligible amount: again the glassy base of many of the rocks—had it crystallised—would probably have yielded felspar: also decomposition is often so advanced that the original nature of the groundmass can no longer be ascertained. Moreover, the rock varies somewhat even in a single mass. Thus the sill at Chapel Ness, Earlsferry, contains nepheline basalt, nepheline basalt with a trace of felspar (which might be called nepheline basanite), limburgite, or monchiquite, with a glassy base but neither nepheline nor felspar, and these varieties have no sharp demarcations but seem to grade into one another. The rocks, in fact, are on the border line between basalts and monchiquites, and it seems best to neglect their less important components, and emphasise their essential features by calling them monchiquites and nepheline basalts.

XENOCRYSTS IN THE TUFFS AND DYKES.

Large crystals of hornblende, augite, and biotite, usually corroded and often broken, occur both in the tuffs and in the dykes of the necks. Their mineralogical characters have been described by Heddle.² The hornblende is found "in cleavable masses of the size of beans to that of small eggs; the cleavages give the angle $124^{\circ} 19'$. The colour is black, with a shade of green; it is highly lustrous." In thin section it is seen to be

¹ See *Mem. Geol. Survey*, "The Geology of Colonsay, etc.," 1911, p. 44; *Mem. Geol. Survey*, "The Geology of Oban and Dalmally," 1908, p. 127; and "On a Monchiquite Intrusion in the Old Red Sandstone of Monmouthshire," by Prof. Boulton, *Q.J.G.S.*, vol. lxvii., p. 460 (1911).

² *Trans. Roy. Soc. Edin.*, vols. xxviii. and xxix. (1879 and 1880), and also in "Mineralogy of Scotland," Edinburgh, 1901.

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a brown basaltic hornblende. As is evident from the following analysis by Professor Heddle of a specimen from Elie, it is a variety notably rich in alumina such as is often found in basic igneous rocks. Its specific gravity is 3.37.

SiO ₂	=	40.38
Al ₂ O ₃	=	19.01
Fe ₂ O ₃	=	2.12
FeO	=	7.28
MnO	=	.46
CaO	=	11.54
MgO	=	17.50
H ₂ O	=	1.17
		<hr/>
		99.46

Augite in pieces up to the size of a pigeon's egg has been recorded by Heddle as "augitic glass" from dykes in the Elie tuffs. He described the mineral as a dark green, brittle glass, and noted its association with pyrope. Similar "vitrified" augites have been recorded from a neck of Upper Old Red Sandstone age near John o' Groats, Caithness. The mineral is perfectly crystalline and not glassy. An analysis of the Elie material by Heddle gave the following result:—

SiO ₂	=	49.04
Al ₂ O ₃	=	9.71
Fe ₂ O ₃	=	1.25
FeO	=	5.16
MnO	=	.31
CaO	=	16.25
MgO	=	16.88
K ₂ O	=	.31
Na ₂ O	=	.79
H ₂ O	=	.3
		<hr/>
		100.01

Specific Gravity=3.33.

Professor Heddle recorded brown biotite in plates usually about 2 ins. in diameter from the agglomerates at Kincaig, Elie, and St Monans. I have found similar crystalline aggregates of biotite in the Ardross neck.

Another mineral long known to occur as xenocrysts in the agglomerates and dykes of East Fife is a soda-rich alkali felspar. Heddle described it as "quite unaltered, fresh-looking, of a brilliant lustre, transparent, but sometimes much fissured in the interior." He calculated the cleavage angle as 89° 50' and

the density as 2.609. His analysis of a specimen from Kinkell may be compared with an analysis quoted by Rosenbusch of the felspar in the Laurvikite of Laurvik, Norway.

I.		II.	
SiO ₂	= 63.07	SiO ₂	= 62.81
Al ₂ O ₃	= 18.69	Al ₂ O ₃	= 23.21
Fe ₂ O ₃	= 2.47	MgO	= 0.07
MnO	= .06	CaO	= 2.60
CaO	= 2.2	K ₂ O	= 7.54
K ₂ O	= 6.62	Na ₂ O	= 4.23
Na ₂ O	= 5.5		
H ₂ O	= 1.39		
			100.46
	99.99		

I. Analysis of felspar from Kinkell, Fife, by Professor Heddle.

II. Analysis of anorthoclase in Laurvikite from Laurvik, quoted by Rosenbusch in "Elemente der Gesteinslehre," p. 104.

To Heddle the systematic position of these crystals was "an enigma." Later James Bisset and Andrew G. Stenhouse¹ identified them as soda-microcline. Large specimens are abundant in a dyke in the Coalyard Hill neck. Their outlines are much corroded and embayed by the groundmass of the rock (Plate XLIII, Fig. 5). The crystals sometimes exhibit the characteristic cross-hatching of microcline (Plate XLIII, Fig. 1), and, since the soda content is high they may perhaps be termed soda-microcline. It should be remarked, however, that the analysis reveals the presence of a noteworthy percentage of lime, and this suggests comparison with the analysis of anorthoclase or cryptoperthite from Laurvik. Iddings regards the lime content of these felspars as anorthite in solid solution. Heddle suggested that the impurities were due to inclusions of the groundmass of the rock.

Another mineral of much interest is pyrope, the so-called "Elie ruby," which is remarkably abundant in the sands of a beach at Ardross. Like the xenocrysts already described, it occurs both in the tufts and in the dykes of the necks; it is not, however, an easy matter to obtain specimens *in situ*. Heddle recorded the mineral from the agglomerates of Elie Ness, from two basaltic dykes which cut the tufts about a mile east of Elie Ness in association with iserine, saponite, and sanidine, and again from a columnar basalt at Ruddon's Point where he found it along with large crystals of olivine and iserine. Two analyses by Heddle and Connell show that the mineral is a typical pyrope.

¹ Heddle's "Mineralogy of Scotland," vol. ii., p. 199.

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I.	II.
SiO ₂ = 40.92	41.80
Al ₂ O ₃ = 22.45	28.65
Fe ₂ O ₃ = 5.46	—
FeO = 8.11	8.85
MnO = .46	.25
CaO = 5.04	4.78
MgO = 17.85	10.67
H ₂ O = .10	—
100.39	96.46

Specific Gravity=4.124.

- I. By Heddle.
 II. By Connell (quoted in Heddle's "Mineralogy of Scotland," vol. ii., p. 47).

According to Connell the mineral contains also a trace of aluminium. Since pyrope is the variety of garnet characteristic of ultrabasic igneous rocks these xenocrysts, like the associated olivine nodules, may perhaps have been derived from abyssal representatives of the dykes in which they now occur.

NODULES OF OLIVINE, HORNBLLENDE, ETC.

In addition to the above xenocrysts crystalline aggregates or nodules of different minerals are also of frequent occurrence. The olivine nodules (Plate XLIII, Fig. 4) are highly decomposed; their chief constituent is olivine, now entirely replaced by serpentine, talc, and carbonates. They contain also numerous large crystals of brown chrome spinel.

Nodules in which the dominating constituent is hornblende fall readily into two groups—(1) types with felspar, (2) types without felspar. The former consist mainly of euhedral elongated crystals of brown hornblende, which, along with numerous euhedral biotites, are embedded in anhedral plates of oligoclase-andesine felspar. Apatite is abundantly developed as an accessory mineral, and in smaller amount may be noted sphene, zircon, and pyrites. In the felspar-free types the chief constituent again is a brown hornblende, which, in this case, is accompanied by subordinate green chrome diopside, and an occasional crystal of black iron oxide. The structure is the even-grained hypidiomorphic texture characteristic of plutonic rocks.

Nodules in which the chief constituent is a pyroxene are less common. They are rich in green chrome diopside, and contain usually much biotite (Plate XLIII, Fig. 6), with brown hornblende in subordinate amount. Some of the nodules carry a basic soda-

lime felspar; in others felspar is absent. Apatite and iron oxides occur as accessory minerals.

PETROGRAPHY OF THE IGNEOUS ROCKS IN THE AGGLOMERATES
AND OF THE ASSOCIATED INTRUSIONS.

St Monans.

The predominant boulders in the agglomerates here are monchiquites, free from, or almost free from, felspar. The phenocrysts include olivine, augite (sometimes in glomeroporphyritic aggregates), and an occasional crystal of brown hornblende. A conspicuous feature in some of the slides is the development in the groundmass of "eyes" of radiating prisms of augite. These show in cross section as circular or elongated rings whose centres are filled with analcite, or chlorite, or sometimes with glass. Similar patches have been described by Dr Flett from a limburgite from Dunino,¹ near St Andrews. The groundmass is fine-grained and contains varying amounts of analcite and glass, but, as already remarked, never more than a trace of felspar.

A coarsely crystalline basalt of the Gallaston type was also noted among the blocks in this neck.

Although many of the dykes in the neck are highly decomposed there can be no doubt that their affinities are with the monchiquites just described. Perhaps their most striking feature is a remarkable development of the ocellar structure so characteristic of such rocks. The ocelli consist for the most part of analcite areas often crowded with minute prisms of brown hornblende. Augite "augen," too, are not infrequent. The dykes are on the whole very rich in analcite as a constituent of the groundmass; felspar is rarely present.

A few of the dykes resemble rather the nepheline basalt of the Chapel Ness intrusion. That they originally contained nepheline the nature of certain pseudomorphs leaves little reason to doubt. So far, however, fresh nepheline has not been detected in them.

The smaller branches of the dykes are very vesicular, and their rounded vesicles are infilled with analcite and chlorite.

Newark Dove-Cot.

The agglomerate of this neck consists largely of blocks of sedimentary rocks including limestones, cement-stone, ironstone, shale, and sandstone, embedded in a matrix of tuff.

¹ *Mem. Geol. Survey*, "The Geology of East Fife," 1902, p. 404.

Newark Castle.

The larger constituents of the agglomerate here again are for the most part sedimentary rocks. Olivine nodules with chrome spinels also occur.

Coalyard Hill.

Most of the blocks in the agglomerate of this neck are sedimentary rocks. Along with these, however, occur occasional boulders of decomposed monchiquite or limburgite. Scattered through the agglomerate, too, are numerous olivine and hornblende nodules, and broken, corroded plates of biotite are of frequent occurrence.

The monchiquite dykes at this locality are noteworthy for the size and abundance of their included xenocrysts of corroded soda-microcline. (Plate XLIII, Figs. 1 and 5.)

Ardross.

The igneous blocks in the agglomerate here are mostly highly decomposed monchiquites, which present no point of particular interest. Two boulders of quartz dolerite have also been detected, but they are so much weathered that the primary character of the quartz may perhaps be regarded as doubtful. In all probability, however, like the olivine-free dolerites from the necks at Lundin Links and Viewforth, they have been derived from the late Carboniferous intrusions of the quartz dolerite series.

The dykes in the Ardross neck are all of the same type—monchiquite somewhat rich in accessory plagioclase. Dark brown hornblende accompanies augite and olivine among the phenocrysts; it occurs again with analcite in ocellar patches, and it is also found in brush-like form lining the vesicles of the rock; it is also a constituent of hornblende-olivine nodules in one of the dykes.

Elie Ness.

Among the larger volcanic constituents of the agglomerate of this neck monchiquites again predominate. All are microphyritic with olivine and augite, and the fine-grained ground-mass usually contains a considerable amount of undifferentiated glassy base. A few of the rocks are rather rich in both felspar and analcite, and might be regarded as analcite basalts; others appear to be free from both felspar and analcite, and hence are decidedly limburgitic in character. Even in the latter, however,

analcite occurs in small vesicles, notably in the blocks from Sauchar Point. Augite "augen" are not infrequent. Xenocrysts of partially resorbed quartz are surrounded by rims of prismatic augite, which is accompanied in one instance by a good development of brush-like microlites of felspar. Corroded xenocrysts of alkali felspar have also been noted in several slides.

This agglomerate contains many nodules, some rich in hornblende, others in olivine.

One of the blocks examined proved to be a much decomposed andesite or porphyrite belonging to a type common among the lavas of the Scottish Lower Old Red Sandstone.

Among the non-volcanic constituents may be mentioned fragments of plants, in some of which cellular structures have been preserved. These were submitted to Dr Kidston, who reported that none was determinable.

The associated dykes are all monchiquites; some are of the limburgite type, others contain much analcite.

Elie Harbour.

All the igneous blocks examined from this neck proved to be monchiquites rich in analcite, much of which appears to be secondary. Plagioclase occurs in varying amount in most of the slides (Plate XLIII., Fig. 3). Xenocrysts of corroded brown hornblende and soda sanidine are of frequent occurrence.

Kincraig Neck.

The igneous blocks in the agglomerate of this neck are all monchiquites, rather rich in accessory plagioclase, and resembling closely the olivine basalts of the Hillhouse type of the Scottish Carboniferous. They show considerable variations in their state of preservation. In one example the olivine is still partly fresh; in the majority the olivine is entirely replaced by serpentine, while the augite shows little or no alteration; in other specimens again both olivine and augite are represented only by decomposition products. All are microporphyritic with olivine and zoned euhedral augites. Augite occurs abundantly in the groundmass of the rock, accompanied by noteworthy amounts of analcite, basic plagioclase, and magnetite. Apatite is also a constant accessory mineral. In most of the slides a colourless glass, usually crowded with black trichites, makes up a considerable part of the groundmass. The cavities of the vesicular types are infilled, sometimes with analcite alone, sometimes with analcite and chlorite.

The associated dyke rocks are somewhat closely related to

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the above. The more decomposed examples are distinguished chiefly by the fact that analcite is confined to the vesicles. One very fresh example, however, is of particular interest since in section it is seen to contain nepheline and fibrous decomposition products after that mineral. Analcite is absent, but the ground-mass contains much colourless glass. Thin laths of plagioclase, too, are present in fair amount. If these are regarded as accessory the rock may be named nepheline basalt.

Ruddon's Point.

The igneous blocks from this agglomerate are chiefly decomposed olivine basalts showing no point of particular interest.

Viewforth.

All the blocks collected from this neck proved to be coarse-grained dolerites. Two were decomposed olivine-free quartz dolerites. The remainder were olivine dolerites in which the only unaltered minerals were the plagioclase feldspars, the olivines and augites being replaced by serpentine, chlorite, and carbonates, and the ilmenite by turbid leucoxene.

Largo Law.

Specimens were examined from the north summit, the south summit, and the tuff on the south and south-west sides.

They are mostly felspar-free, belonging to the limburgite and analcite basalt types, but the specimens from the north summit contain sparingly small prisms of felspar in the groundmass. As a rule the rocks are much decomposed, but the sill below the north summit is in an excellent state of preservation. Many crystals of olivine are found in all the slides, usually changed to serpentine. Augite of the purplish titaniferous type is also common, both as phenocrysts and as small prisms in the ground-mass. Analcite occurs filling cavities and veins, often accompanied by calcite which is obviously of later crystallisation, as it is moulded on the surface of well-formed analcite crystals. The cavities in this rock are sometimes lined with small crystals of nepheline, felspar, and augite; the centre is occupied by analcite. In one slide there is a large corroded xenocryst of alkali felspar. A specimen from the top of the south cone is perhaps an ash; it contains a large brown barkevicite crystal, which has black borders and is much corroded. A block collected from the tuff on the south side is a highly decomposed rock, nearly felspar-free, with much yellow analcite in the ground-mass.

Lundin Links.

Of considerable interest is the presence in this neck of two blocks of dolerite, one a very fresh ophitic olivine dolerite, the other a quartz dolerite free from olivine. This proves that some at least of the late carboniferous quartz dolerite sills were intruded before the formation of the Lundin Links neck.

This neck is also noteworthy for the occurrence of a remarkable dyke of basalt which contains so many rounded quartz grains that it was described and figured by Sir Archibald Geikie as a quartz porphyry. The basalt is very fine-grained, almost cryptocrystalline. It has been fully described by Dr Flett.¹

NEPHELINE BASALT OF CHAPEL NESS (EARLSFERRY).

The field relations of the intrusive sheet of Chapel Ness have been described fully in the *Memoir of the Geological Survey* on "The Geology of East Fife," p. 246. It is there described as a "fresh, black, compact, porphyritic and somewhat amygdaloidal olivine basalt of limburgite type, resembling the prevailing rock of the Elie dykes, with which it has a further connection in containing xenocrysts of orthoclase." The present research has shown that the intrusion resembles the dykes and sheets in the necks of the Elie district in carrying analcite, and in places nepheline. As already stated, the rock has a somewhat variable mineral composition. Parts rather rich in felspar and carrying nepheline might be termed nepheline basanite; in places again the rock contains little or no felspar and no nepheline but much analcite, or sometimes glassy base, so that in part it might be called monchiquite or limburgite. The various types, however, grade into one another with no sharp demarcation, and, since this intrusion is distinguished from the local monchiquites by the occurrence in most of the slides of notable amounts of nepheline, it will be termed here nepheline basalt.

The specimens from different parts of the intrusion are all compact fine-grained basaltic rocks, porphyritic with small phenocrysts of olivine and augite. Olivine is always abundantly developed in the first generation of crystals; it sometimes shows partial or even complete alteration to serpentine and iron oxides, but in the freshest specimens shows very little trace of decomposition. It is usually free from inclusions, but in a few crystals small included crystals of iron oxide and perovskite have been noted. The euhedral and subhedral phenocrysts of titanite frequently show a corroded core of green chrome diopside.

¹ *Mem. Geol. Survey*, "The Geology of East Fife" (1902), pp. 400-403.

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The compact fine-grained groundmass is less uniform in character. It always consists in great part of small prisms and granules of purple titanite and minute crystals of black iron oxides; along with these occur in varying amounts basic plagioclase feldspar, nepheline, analcite, and brown glassy base. Specimens from the west of Chapel Ness have a considerable development of brown glass, feldspar is sometimes wanting, sometimes rather abundant, and a rather doubtful occurrence of nepheline has been noted in only one slide. The columnar portion of the sheet on the west side is rich in nepheline, which occurs sometimes in small hexagonal prisms, as in feldspar-free slides from the lowest portions of the columns, sometimes, as in a specimen from near the middle of a column, in anhedral crystals enclosing small laths of plagioclase in micropoikilitic fashion. In another slide, which contained very little feldspar, the nepheline (Plate XLIII, Fig. 2) is partly euhedral, partly anhedral, enclosing the augites of the groundmass; this section contains also much glassy base, and a few small cavities infilled with analcite. In a feldspar-rich variety from the east of Chapel Ness the occurrence of nepheline is rather doubtful. Many of the slides show numerous "augen" of augite, and apatite is a common accessory mineral.

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EXPLANATION OF PLATE XLIII.

Photomicrographs.

- Fig. 1. *Soda microcline*—xenocryst from monchiquite dyke at Coalyard Hill neck. Crossed nicols, magnified 25 diameters.
- Fig. 2. *Nepheline basalt*—from western part of Chapel Ness intrusion. The colourless crystals are nepheline with enclosures of augite and iron oxide; the photograph shows also the granular augite and black iron oxides which are the predominating constituents of the groundmass of the rock. Magnified 100 diameters.
- Fig. 3. *Analcite basalt* from agglomerate at Elie Harbour. On the right is a vesicle infilled with analcite, chlorite, and calcite; on the left a small phenocryst of serpentinised olivine with rim of iron oxide. The groundmass consists of labradorite, augite, iron oxides, and interstitial analcite. Magnified 22 diameters.
- Fig. 4. *Olivine nodule* from agglomerate at seaward edge of neck at Ardross. The black crystals are chrome spinels; all the remaining portion of the field of view is occupied by alteration products of olivine. Crossed nicols, magnified 22 diameters.
- Fig. 5. *Monchiquite* from dyke at Coalyard Hill neck. The fine-grained groundmass of the rock is seen embaying a corroded xenocryst of colourless soda-microcline. Magnified 15 diameters.
- Fig. 6. *Nodule* from agglomerate at Elie Ness. The pale-coloured mineral is green chrome diopside; the darker well-cleaved mineral is brown biotite. The two occur partly in micrographic intergrowth. Magnified 18 diameters.

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

FIG. 5.

FIG. 6.

Photomicrographs.