10. CONTRIBUTIONS *to the* GEOLOGY *of* BRITISH EAST AFRICA.—PART II.[1] *The* GEOLOGY *of* MOUNT KENYA.

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[PLATES X, XI, & XII (*pars*).]

CONTENTS.

I. INTRODUCTION.

MOUNT KENYA, the greatest mountain in British East Africa, was discovered by Ludwig Krapf,[2] when on December 3rd, 1849, he saw its two-horned summit from a hill above the Wakamba village of Kitui. No suggestion as to the structure of Kenya was made until 1883, when Joseph Thomson, after a view of the mountain across the Laikipia plateau, described it as the denuded remnant of an old volcano. 'The peak,' he tells us,[3] 'without a doubt represents the column of lava which closed the volcanic life of the mountain . . . . The crater has been gradually washed away.' The first definite geological information about Kenya we owe to Count S. Teleki, who was the first European to reach the mountain; in 1887 he climbed the western slopes to the height of about 13,800 feet, and brought back some rock-specimens which have been described in detail in a valuable memoir by A. Rosiwal.[4] This petrologist determined the specimens as augite-andesite, andesite-pitchstone (hyalo-andesite), and phonolite, and thus proved the volcanic nature of the mountain.

[1] Part I, 'The Glacial Geology of Mount Kenya,' was published in this Journal, vol. l (1894) pp. 515–530, with maps, etc.

[2] 'Travels, Researches, & Missionary Labours . . . in Eastern Africa' 1860, p. 544.

[3] 'Through Masai-Land' 4th ed. (1887) p. 224.

[4] 'Ueber Gesteine aus dem Gebiete zwischen Usambara u. dem Stefanie-See' Denkschr. d. k. Akad. d. Wissensch. Wien, vol. lviii (1891) pp. 496–498.

Teleki's account of the structure of Mount Kenya differed, however, from that of Thomson. The former climbed through the forest-belt from Ndoro and entered a valley, which I have named the Teleki Valley (see map, Pl. X); he followed this eastward until it suddenly bent northward and expanded into two great glacier-filled valleys, on the southern and south-western sides of the central peak. The high western wall of the Tyndall Glacier, the main western arête, the ridge which crosses the Teleki Valley, and the main peak together enclose a great depression, which Teleki regarded as the central crater of the volcano. Accordingly his companion, L. Ritter von Höhnel, in his description of the mountain, reports[1] the occurrence of a crater from 4 to 4½ kilometres in diameter and from 200 to 300 metres in depth.

A third explanation of the geological character of Kenya was added by the next visitors to the mountain. In 1891 Mr. C. W. Hobley, the geologist who accompanied the British East Africa Company's expedition to Mount Kenya, climbed through the forests on the southern slopes up to the height of about 8600 feet, whence the peaks and spurs of the Alpine zone could be seen like a ridge along the northern sky-line. Accordingly, in the report of that expedition, Kenya is described[2] as 'more properly a mountain-chain, and not a single mountain, the chain or range stretching from west to east, commencing in the high Leikipia Plateau, and rising steadily until it culminates in the great double peak. Then comes the second large peak, with five or six other smaller ones; after these again, some lower mountains, all more or less connected, and finally an isolated hill is seen rising in the Barra to the east.'

As this report was published in August 1892, three months before I left England, I was accordingly doubtful when visiting Kenya in 1893 whether the mountain were a greatly denuded volcano, an existing crater, or a mountain-range running east and west.

Unfortunately my visit to Mount Kenya occurred in the latter part of the heaviest rainy season ever recorded in British East Africa,[3] and the wide extent of newly-fallen snow that covered nearly the whole of the uppermost part of the mountain obscured the geology of the Alpine zone. My stay on the mountain was curtailed, as it would have been unjust to expose my porters to the inclement weather then prevalent longer than was absolutely necessary. I had therefore to be content with the examination of such a section of the mountain as was sufficient to determine its geological structure and history. I examined the line from Ndoro at the western foot of the mountain to the level of the upper Alpine zone, at a point south-west of the summit: and then studied more in detail the

[1] 'Ostäquatorial-Afrika zwischen Pangani u. dem neuentdeckten Rudolf-See' Peterm. Mittheil. Ergänzbd. xxi. No. 99 (1890) pp. 7–8.

[2] E. Gedge, 'A Recent Exploration up the River Tana to Mount Kenia' Proc. R. Geogr. Soc. vol. xiv (1892) p. 527.

[3] The rainfall at Mombasa in 1893 was 64·17 inches as against 26·83 inches in 1892 and 37·96 inches in 1894: see '4th Rep. Climatology Africa' Rep. Brit. Assoc. 1895 (Ipswich) p. 486.

area between the western and southern arêtes and the adjacent part of the upper Alpine zone.

As the completion of a detailed report on the geological structure of British East Africa has been delayed, it seems advisable to publish it in instalments. I gladly express my indebtedness to Mr. C. W. Hobley, who kindly gave me the rock-specimens that he collected on Mount Kenya in 1891; and to Mr. G. T. Prior for much valuable assistance in the determination of some minerals in the rock-slides, and in consulting the fine collection of foreign rock-slides in the Mineralogical Department of the Natural History Museum. I am also indebted to Mr. Prior for kindly undertaking to see these pages through the press: a task which I am unable to fulfil myself, in consequence of my somewhat hurried departure for Australia.

II. Physical Geography of Mount Kenya.[1]

Mount Kenya consists of three zones: (1) a long forest-clad slope of volcanic ash, extending to a height of about 10,000 feet; (2) the open moors and valleys of the lower Alpine zone, covered by an open scrub of *Alchemilla Johnstoni* and a previously unrecorded species of arborescent *Erica*; and (3) the upper Alpine zone, formed of grassy meadows and valleys cut in volcanic ash below bluffs of coarse agglomerate. Above this upper zone is the steep rugged central peak, where the only vegetation consists of tufts of grass and *Helichrysum cymosum* with patches of lichen.

The altitude of Mount Kenya has been variously estimated as from 17,200 feet (Smith) up to 23,000 feet (Peters). L. von Höhnel's determination by triangulation from Ndoro made the height 19,029 feet, a figure which I have accepted, as my own observations roughly agreed with it.

The three main zones of Mount Kenya are characterized by different geological features. The long slope of the forest-belt consists in the main of volcanic ash, though the remains of secondary parasitic craters probably occur on it. The Alpine zone consists of coarser ash, agglomerates, and tuffs, interbedded with lava-flows and traversed by numerous dykes, with the remains of some secondary centres of eruption. The third zone, or central peak, consists of the plug which choked the central vent, and the beds of agglomerates and thick proximal ends of the great lava-flows.

III. Petrography.

The rocks of which Mount Kenya is built may be divided into four groups: (1) the rocks of the central core, (2) the dykes of the Alpine zone, (3) the lavas, and (4) the pyroclastic rocks.

[1] For a short account of the physiography of Mount Kenya, see 'The Glacial Geology of Mount Kenya' Quart. Journ. Geol. Soc. vol. l (1894) p. 515, and 'The Great Rift Valley' 1896, pp. 166 *et seqq.*

1. The Rocks of the Central Core.

The central peak of Kenya consists of a group of rock-pyramids, formed mainly of the lava that plugged the main vent. This rock is exposed on the main southern, south-western, and western arêtes.

The lowest exposure of any rock belonging to the central-core series was on the northern face of the valley below the snout of the Lewis Glacier. Unfortunately the field-relations of this rock were obscured by talus and snow. This rock (No. 496 [1]), which is somewhat gabbro-like in aspect, is coarsely crystalline, and consists of well-developed felspars, which are sometimes 15 mm. long and 3 mm. thick, separated by dark green minerals. The specific gravity is 2·6. Examined microscopically, the rock is seen to be an olivine-bearing nepheline-syenite. The rock is holocrystalline, hypidiomorphic, and coarse-grained. (Pl. XI, fig. 4.)

The main constituent is felspar, which occurs in large idiomorphic crystals twinned on the Carlsbad type, and in a mosaic of small crystals, many of which are also twinned on the Carlsbad type. The felspar is similar to that which occurs in the adjacent tuffs, and is probably in the main anorthoclase. This mineral was found in large isolated crystals in the tuffs of Mount Höhnel. The crystals are of the same character as those previously described by Mr. L. Fletcher & Prof. H. A. Miers [2]: they are described on p. 216. (See also Pl. XII, fig. 2, spec. No. 464.) The name anorthoclase is retained instead of natronmikroklin, which Brögger has shown holds priority; [3] but the latter, for English adoption, would require translation, and anorthoclase is more convenient for international use.

The second important constituent is nepheline, which occurs in very large prisms (3 to 4 mm. in diameter) and in small grains. The pyroxenes are bordered by a zone of ægyrine, which also occurs in scattered grains. The amphibole is deep brown in colour and has the pleochroism of barkevicite; but some of it, which is nearly opaque, Mr. Prior suggests may be allied to cossyrite. The rock contains a considerable amount of a bright yellow, strongly doubly-refractive, ferriferous olivine. Magnetite is scarce. Some isotropic mineral, probably sodalite, is also present.

The foregoing enumeration of the minerals shows that this rock is dominated by its high percentage of soda, and as it is the most deep-seated rock found on Mount Kenya it is natural to find the eruptive rocks characterized by soda-minerals.

Overlying this nepheline-syenite is a black glassy lava with numerous white phenocrysts of anorthoclase. The rock occurs as

[1] The numbers in parentheses are those affixed to my African rock-specimens, which will be presented to the Mineralogical Department of the Natural History Museum.

[2] Min. Mag. vol. vii (1887) pp. 10–11 & 131–132.

[3] 'Das Ganggefolge des Laurdalits' Die Eruptivgest. des Kristianiagebietes, pt. iii, in Vidensk. Skrift. pt. i (1897) No. 6, p. 12.

a massive core, which appears to have plugged the central vent of the mountain.

The rock of this plug (No. 499) consists of a black glassy groundmass with scattered phenocrysts of glassy felspar, which have rounded angles and lath-shaped sections, and range up to an inch in length. This rock occurs on the western arête above Two-Tarn Col, along the cliff that forms the right bank of the Lewis Glacier, and on the ridge rising northward from the col above the Lewis Glacier. Above these levels I could see no agglomerates, except a few unimportant patches, and these appeared to extend to the summit.

Under the microscope the large phenocrysts of felspar constitute the most striking feature of the rock; these, though seldom polysynthetically twinned, are no doubt anorthoclase.

The pyroxenic constituent is less abundant; it occurs in two forms. The sparsely scattered, small, very pale green phenocrysts, with rounded and sometimes even elliptical outlines and a high extinction-angle (over 30° from *c*) are augite. The second pyroxene is ægyrine, which occurs in small patches of green grains, while the black irregular grains which make the base appear dense are possibly altered ægyrine.

Olivine occurs in corroded crystals, often partly altered to serpentine. Apatite is present in well-developed prisms, included by all the other constituents of the rock.

The groundmass is crowded with felspar-microliths, small irregular pyroxene-granules, and innumerable small black granules which are possibly altered ægyrine. The rock does not show any pronounced fluxion-structure. (Pl. XI, fig. 1.)

The specimen (No. 499) upon which the foregoing description is based was collected on the ridge rising northward from the eastern end of the Lewis Glacier. Its specific gravity is 2·65.

To give a name to this rock is not easy. The excess of soda-minerals recalls the pantellerites, especially as Rosiwal[1] has provisionally applied that name to an allied rock from Southern Abyssinia. Mr. Prior, moreover, has called my attention to a slide of somewhat similar rock from the eastern flank of Montagna Grande (Pantelleria), which also contains porphyritic anorthoclase, a ferriferous olivine, and a pale green augite, included in a felspathic base full of minute irregular grains of pale green augite and opacite.

For the reasons, however, which are stated on pp. 213–214, it is unadvisable to include the Mount Kenya lavas among the pantellerites, and the name of kenytes is accordingly proposed for them.

[1] 'Ueber Gesteine aus Schoa u. Assab' Denkschr. k. Akad. Wissensch. Wien, vol. lviii (1891) p. 518.

2. The Dyke-rocks.

The dykes of the Alpine zone of Mount Kenya fall into two categories: a series of phonolites and one of basalts and dolerites.

(a) The Phonolites.

As an example of the phonolites, we may take a dyke 4½ feet wide which cuts vertically across the agglomerate on the western ridge of Mount Höhnel (No. 456). The rock is dark greenish, fine-grained, and somewhat fissile. The specific gravity of a specimen from the middle of the dyke is 2·6. Under the microscope the rock is seen to be composed mainly of felspar, in small lath-shaped crystals, with well-marked fluxional arrangement. The most conspicuous mineral is nepheline, which is abundant and stands out with remarkable clearness; the crystals are fresh, and the larger prisms measure from ·3 to ·4 mm. in length. The pyroxenic constituent is ægyrine, which occurs as plates with frayed ends and as crystals with regular hexagonal sections; the smaller ægyrines are often clustered like a framework around the nephelines. (Pl. XI, fig. 5.)

Mr. Prior has shown me a slide of a phonolite from Risca (Grand Canary), which is almost identical with this rock, and a second slide from Chasna (Teneriffe), in which the resemblance, though less complete, is close.

The most striking feature of this dyke is its selvage, which has the characters of a glassy basalt (No. 457). It consists of a black basic glass in which are numerous circular vesicles and small lath-shaped crystals of plagioclase: the larger crystals show twinning on the albite-type, with symmetrical extinction in alternate lamellæ of about 35°, and may consequently be referred to labradorite.[1] Olivine is abundant, occurring in small idiomorphic crystals. The glassy groundmass does not gelatinize when treated with cold hydrochloric acid. (Pl. XI, fig. 6.)

This dyke is therefore compound, being made up of a central sheet of phonolite bounded by basaltic selvages.

As this phonolite is a dyke-rock, it may seem advisable to adopt for it the name tinguaite; but in his original definition of that rock Rosenbusch[2] laid stress on the absence of fluidal structure, whereas the dyke from Mount Höhnel shows well-developed fluxion-structure, which is absent from the phonolitic flows of Kenya. In 1896, however, Rosenbusch[3] admitted fluidal structure in tinguaites, and based the distinction between them and phonolite on the aplitic instead of trachytic structure. But as the Mount Kenya dykes are as trachytic as the flows, and as the two types are microscopically indistinguishable, it seems advisable to accept the name phonolite for both.

[1] The identification of this plagioclase has been kindly confirmed by Mr. Prior.

[2] 'Mikroskop. Physiogr.' 2nd ed. vol. ii (1887) p. 628.

[3] *Ibid.* 3rd ed. vol. ii (1896) pp. 479–480. Brögger has described a fluidal tinguaite from Lyseböfjord, north of Laurvik, in 'Die Gesteine der Grorudit-Tinguait Serie' Die Eruptivgest. des Kristianiagebietes, pt. i, in Vidensk. Skrift. pt. i (1894) No. 4, p. 117.

(b) The Basic Dykes.

The dykes of the second group are more basic in character, and range from a basalt with a little olivine to a coarsely crystalline dolerite rich in olivine.

The rock of this series, which, judging from its specific gravity, is the least basic, is a dark brown, compact basalt, collected by Mr. C. W. Hobley during the British East Africa Company's expedition to Mount Kenya in 1891. It was obtained in a ravine at the height of about 7000 feet on the southern slope of the mountain. The specific gravity is 2·74. Under the microscope the rock appears as a felted mass of lath-shaped plagioclases, which are cut across in all directions. Some platy felspars are also present. Granules of a pale brown to greyish pyroxene and of olivine are abundant; and numerous very thin acicular crystals, which Mr. Prior refers to apatite, traverse the plagioclases.

The basic dykes of the Teleki Valley district have a higher specific gravity, and contain more olivine and magnetite than the specimen collected by Mr. Hobley. These more basic dykes are well exposed near the snout of the Lewis Glacier, and are of considerable width; in the centre they are coarsely crystalline, and may be called olivine-dolerites. The dykes which have yielded specimens 510 & 511 may be taken as types of this group.

No. 510, from the centre of a dyke below the snout of the Lewis Glacier, consists largely of plagioclase-laths: these, from their high extinction-angle, may be referred to labradorite. Augite is abundant, in nests of small prismatic crystals and in rounded phenocrysts. Olivine in small altered crystals is also plentiful. The specific gravity of the rock is 2·8.

A larger dyke from the same locality (No. 511) is a black rock weathering dark brown; it contains numerous tabular crystals of plagioclase, roughly parallel in arrangement, and large crystals of black pyroxene which are recognizable in hand-specimens. The specific gravity is 2·97. Examined under the microscope, the plagioclase is seen to occur in two forms. The olivine is idiomorphic. The augite is titaniferous, with a pleochroic outer zone. This rock is the most basic of the Kenya dykes from which specimens have been collected so far.

3. The Lavas.

The Mount Kenya lavas belong to three groups:—

(a) The Kenytes or Lavas of the Nepheline-syenite Series.

At various points on the south-western flanks of the central peak of Mount Kenya are a series of flat-topped, massive crags, which can be recognized from Laikipia. These crags are remnants of the greatest series of lava-flows that came from the central vent of Kenya. The rocks which form these crags are well exposed, for instance, on the Lewis Col and on the Teleki Ridge, where they rest upon beds of agglomerate and tuff, which in places also cover them. The typical representatives of this lava are rhyolitic in aspect, earthy-looking, vary from light red to pale brown, and show very conspicuous fluxion-structure.

Examined microscopically the rocks of this type appear to consist of a brown, light green, and dark green glassy base, with numerous opacite-granules and felspar-microliths, and large corroded phenocrysts of anorthoclase. The matrix is indeterminable microscopically, but when treated with cold acid it becomes gelatinous and yields abundant crystals of common salt; we may, therefore, safely infer that the glassy matrix is extremely rich in soda, and would probably have yielded much nepheline had it crystallized. The rock represents the flows from the plug of solid lava that choked the main vent. The specific gravity of the variety (No. 500) nearest the lava of the central plug is 2·62, while in flows farther away from the central core, at the Lewis Col and on the Teleki Ridge, the specific gravity sinks to 2·5.

The aspect of the rock is very variable; as examples we may take the following types:—

No. 500, from north of the Lewis Col. Specific gravity 2·62. The rock has a light-green matrix and an indefinite fluxion-structure; the phenocrysts of anorthoclase are large, but not crowded; the groundmass is dense from the abundant pale green microliths, which Mr. Prior, from their optical characters, refers to ægyrine.

No. 507, from the Lewis Col itself. Specific gravity 2·5. A coarse, rhyolitic-looking, reddish lava, with well-developed fluxion-structure round the anorthoclase-phenocrysts, which contain inclusions of the glassy base.

No. 508. Dark green, almost black rock, with small anorthoclase-phenocrysts in a dense base of minute felspar-microliths, magnetite- and ægyrine-grains. The felspars are often twinned on the Carlsbad type. (Pl. XI, fig. 3.)

No. 452 is a specimen from a flow of black lava similar to the last, but including a bomb of a reddish rock. (The latter is closely allied to No. 519, the reddish base probably resulting from the alteration of a basic glass.) The black lava contains many phenocrysts of anorthoclase showing well-developed twin lamellæ. The glassy base includes ægyrine and some ill-defined mineral, which is probably ægyrine undergoing alteration into opacite. An imperfect spherulitic structure occurs in places. Mr. Prior notes that some of the phenocrysts are partly replaced by an aggregate of lath-shaped felspars and pale-green augite, similar to the pseudomorphs after felspar described by Brögger [1] in grorudite. Mr. Prior also remarks the resemblance of this rock to a specimen in the Natural History Museum from the west side of the Val di Monastero, Costa di Zichidi (Pantelleria).

No. 519. One of the most interesting rocks in this kenyte-series is a black porphyritic pitchstone, which occurs in Phonolite Cwm,

[1] 'Die Gesteine der Grorudit-Tinguait Serie' Eruptivgest. des Kristianiagebietes, pt. i, in Vidensk. Skrift. pt. i (1894) No. 4, p. 15.

east-north-east of Mount Höhnel, and in the agglomerates of that district. The rock consists of large anorthoclase-crystals embedded in a black tachylytoid glass, which is apparently more basic than in pantellerites. Examined under the microscope the glass appears deep brown, and contains some vesicles. The anorthoclase-phenocrysts are large, and zonally constructed; they include apatites and brown-glass inclusions. Some cleavage-fragments have been measured by Mr. Prior, who determined the extinction on *b* as 8° to 9°, and on *c* as nearly straight. Olivine occurs in corroded phenocrysts. The specific gravity of the rock, measured from a large block which may contain a few vesicles, is 2·5. (Pl. XI, fig. 2.)

To find a suitable name for these rocks is not easy. In the field I called them rhyolites, but they differ from ordinary rhyolites by the absence of quartz and by their great excess of soda. Accordingly, it is natural to compare them with the rich soda-bearing rhyolites of Pantelleria, especially as the porphyritic pichstone is practically identical with a rock from Shoa, in Southern Abyssinia, described by Rosiwal,[1] who named it 'vitrophyrischer augit-trachyt (pantellerit).' But this identification has been denied by Rosenbusch, who maintains that a rock composed of anorthoclase-phenocrysts in a glassy groundmass rich in soda is not necessarily a pantellerite.

According to Rosenbusch's definition, 'pantellerites are characterized by the absolute predominance of the alkali-felspar, the total absence of the lime-soda felspar, the development of ænigmatite [cossyrite], diopside, ægyrine, and arfvedsonitic amphibole as the colouring constituents with the almost absolute suppression of mica; by the absence of magnetite, the rarity of quartz of the first generation, the predominance of the glassy and microcrystalline structures and the extreme rarity of microfelsitic structure; and by the abundant formation of the colouring constituents in the eruptive period.'[2] This definition certainly does not describe accurately the Mount Kenya lavas. They contain neither ænigmatite nor arfvedsonitic amphibole, nor, in fact, any other amphibole. The positive characters also are different: olivine is fairly abundant in some slides; the colour of the rock is dark sepia-brown, red, or grey, rarely green, and one variety occurs with a tachylytoid groundmass.

Rosenbusch objects that the Shoan rock described by Rosiwal should be referred to pantellerite because 'of its colour (brown to grey) and its glassy, felsitic habit.' 'The anorthoclase alone,' he continues, 'does not postulate the pantellerite character; for that are needed also the alkali-pyroxene and the alkali-amphibole, and the remaining above-stated characters.'

To include these Mount Kenya lavas in pantellerite would necessitate a complete redefinition of that term. The only definition of pantellerite that would include the type-rock and these

[1] 'Ueber Gesteine aus Schoa u. Assab' Denkschr. k. Akad. Wissensch. Wien, vol. lviii (1891) p. 518.
[2] 'Mikroskop. Physiogr.' 3rd ed. vol. ii (1896) p. 612.

lavas would be limited to the character that it is a lava with a glassy base containing phenocrysts of anorthoclase; and that statement as a definition of pantellerite Rosenbusch has emphatically repudiated. No doubt the kenytes and pantellerites are closely related, but I do not feel justified, on the evidence at present available, in radically altering Rosenbusch's diagnosis. It seems therefore advisable to give to these East African lavas the new name of kenyte, from the mountain where they reach their highest development.

The kenytes may be defined as liparitic representatives of an olivine-bearing nepheline-syenite, consisting of anorthoclase-phenocrysts, with or without some augite- and olivine-phenocrysts, and a glassy or hyalopilitic groundmass, which varies in colour from greyish-green to a deep sepia-brown. Ægyrine, if present, occurs in small granules; ænigmatite and quartz are absent.

The kenytes are most nearly allied to the pantellerites, but are probably as a rule more basic. Taking the average of the five analyses of pantellerites quoted by Prof. Lœwinson-Lessing,[1] and the formulæ which he has calculated from them, pantellerite agrees more nearly with the chemical composition of dacites than with that of nepheline-syenites:—

	RO.	R_2O_3.	SiO_2.	Acidity.
Pantellerites	2·34	1·40	11·48	3·54
Dacites	2·23	1·74	11·24	3·02
Trachytes	2·52	1·96	10·26	2·42
Nepheline-syenites	2·69	2·31	9·25	1·91

Prof. Zirkel[2] quotes an analysis of a dacite with a higher soda-percentage than is recorded for any of the five analyses of pantellerites. The rock is from Zovon, west of Teolo, in the Euganean Hills; it is described by Zirkel as having a 'light-coloured groundmass, with many large oligoclases from 3 to 4 lines long, also biotite and hornblende; much magnetite ... a little quartz in small druses; specific gravity 2·593.' From the analysis it appears not improbable that this Teolo rock should be included among the pantellerites, and that the mineral determined as oligoclase is really anorthoclase:—

	Dacite.	Pantellerite.
SiO_2 Silica	67·98	68·33
Al_2O_3 Alumina	13·05	10·94
FeO Ferrous Oxide	......	3·74
Fe_2O_3 Ferric Oxide	5·69	5·41
CaO Lime	1·63	1·36
MgO Magnesia	0·14	0·16
K_2O Potash	3·23	4·08
Na_2O Soda	7·96	7·09

But if this Teolo dacite be a pantellerite, the fact that it has been included among the dacites illustrates the chemical similarity of these rocks.

[1] 'Stud. über die Eruptivgest.' Congrès Géol. Internat. Compt. Rend. sess. vii, St. Petersb. (1897) pp. 449, 451, 453.

[2] 'Lehrbuch d. Petrogr.' 2nd ed. vol. ii (1894) pp. 575, 582.

(*b*) The Phonolites.

The lavas of the phonolite-group are less conspicuous than the kenytes, as they form the lower slopes of the upper Alpine valleys, which were obscured by moraine and snow. The phonolites may be seen on both banks of the Teleki Valley, and one of the best exposures is on the lower western slopes of Mount Höhnel.

The rock (No. 490) in hand-specimens is dark, speckled, and greyish-green, and is very fissile. In the centre of the flow it is compact, and under the microscope resembles more closely a dyke than a flow. This rock consists of much the same material as the dyke on the western ridge of Mount Höhnel. Its structure is trachytic; the groundmass includes abundant, small, lath-shaped felspars, which are irregular in arrangement, and often occur in radial groups. The pyroxenes are small, and consist of ægyrine in needles and short crystals, often arranged in moss-like aggregates. Nepheline is not very abundant, but occurs in larger crystals than the other constituents. (Pl. XII, fig. 1.)

(*c*) The Basalts.

The basalt-flows of Mount Kenya occur in two main areas. There is one series of very fissile olivine-basalts which occur in the forest-zone. Mr. Hobley collected on the southern slopes a specimen of a very vesicular basalt composed mainly of lath-shaped plagioclases, with a well-marked fluxion-structure around the empty vesicles. The groundmass is very dense, from the abundance of small crystalline granules and grains of magnetite. Olivine occurs both as granules and as small, corroded, rounded crystals.

On the western foot of Kenya a fissile olivine-basalt is one of the commonest constituents of the tuffs and gravels; and, as the pebbles appear to have travelled a shorter distance than the kenytes, it is probable that some dykes or flows of this rock occur in the forest-zone. These fissile basalts have a specific gravity of 2·7.

The second set of basaltic lavas occur in the neighbourhood of Mount Höhnel and the Teleki Valley. The best example of this rock forms crags of columnar basalt, wherein the columns are some 20 feet high and are often curved. The rock in the upper and lower surfaces of the flow is massive, and the lower belt contains a few inclusions of the kenytes.

No. 517 is a heavy, black, fine-grained basalt of specific gravity 3·09; the section shows no phenocrysts of plagioclase. Olivine is abundant, and occurs both in idiomorphic crystals and in rounded inclusions, which, though corroded, are not serpentinized; in one case the olivine forms a mere shell surrounding an included fragment of the groundmass. The groundmass consists of microliths of plagioclase and grains of pyroxene, olivine, and magnetite.

The rock in an adjacent part of this flow is coarser in grain, and there the chief minerals are olivine, plagioclase, and titaniferous augite, while magnetite occurs in large skeleton-crystals.

4. The Pyroclastic Rocks.

The fragmentary volcanic rocks of Mount Kenya consist of a broad zone of volcanic ash, which forms the main foot-slope of the mountain, extending on the west from Ndoro (at an altitude of 7100 feet) to the lower edge of the Alpine zone (alt. 10,100 feet). In the lower part of this foot-slope occur beds of tuff and lava-gravel, in which pebbles of fissile basalt predominate.

In the Alpine zone the most prominent fragmentary rocks are beds of coarse agglomerate, well exposed as rough crags and pinnacles. The materials of these agglomerates are mainly coarse blocks of kenyte and phonolite.

The tuffs are best developed in the upper Alpine zone, where they are well exposed on the cliffs of Mount Höhnel, a section of which shows them interbedded with ash and flows of kenyte overlying the main phonolitic beds at the base (fig. 1, p. 217). The tuffs are often vesicular, with the cavities lined by zeolites. The most interesting feature of these tuffs is the occurrence of large crystals of anorthoclase, which have been kindly examined by Mr. Prior, who reports as follows:—'The crystals are apparently simple, with the faces *b* (010), *m* (110), M $(1\bar{1}0)$, *c* (001), with *x* $(\bar{1}01)$, or in some crystals *y* $(\bar{2}01)$, all well developed. The cleavage-angle *b c*, measured by the reflecting goniometer, did not differ more than 2′ from 90°. The extinctions measured on cleavage-flakes are

on *b*, 7° to 8°, obtuse positive bisectrix;
on *c*, 1° to 2°, very fine twin lamellæ.

The material gives a strong sodium-flame.'

IV. The Stratigraphy of Mount Kenya.

Turning from the petrography of the rocks to their stratigraphical arrangement, we find that this is simple. The nepheline-syenite to the north-west of the snout of the Lewis Glacier is the most deep-seated holocrystalline rock on the mountain, and doubtless represents the original magma of the volcanic series. This rock probably passes upward into the massive core of porphyritic kenyte which forms the central peak of the mountain; but no actual passage could be traced, and it is conceivable that the nepheline-syenite may be an intrusion into the kenyte-plug. (See fig. 2, p. 217.)

The upper Alpine zone, with its coarse agglomerates and radial dykes, no doubt occupies the site of the crater-walls of the old volcano, though the crater-edges must have been some thousands of feet above the present height of this zone. The Alpine agglomerates are traversed by numerous vertical dykes of olivine-basalt and olivine-dolerite, and some flows of olivine-basalt also occur in it.

The main lava-flows of Kenya are best exposed in the upper Alpine zone. They slope at a dip of usually 8° to 15° from the central plug. So far as my observations extended, the dip of

Fig 1.—*Diagrammatic section from the summit of Mount Kenya to the south of Mount Höhnel.*

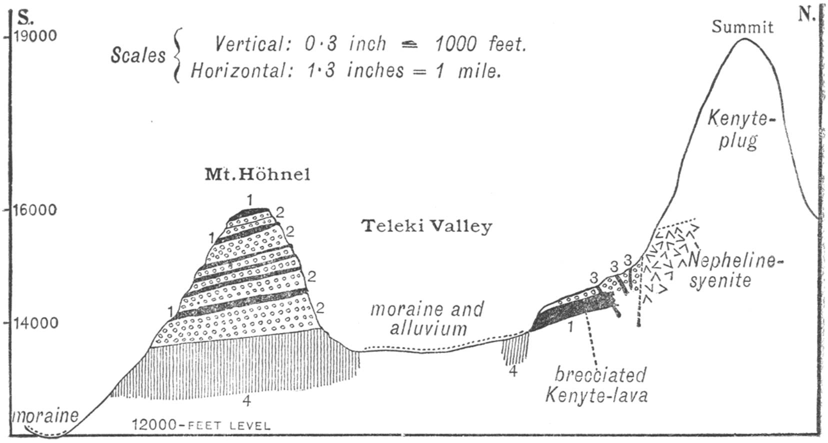
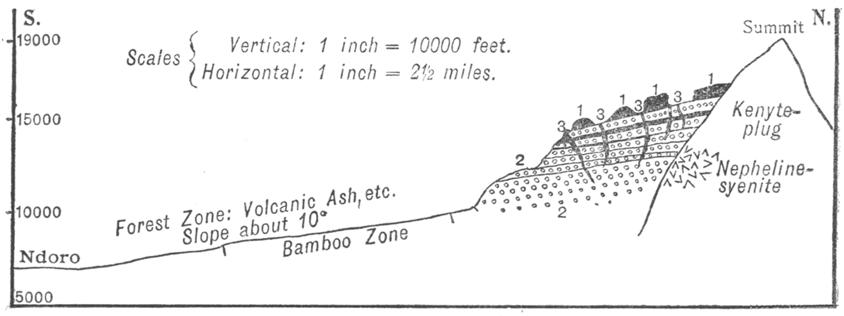


Fig. 2.—*Diagrammatic section through the south-western part of Mount Kenya.*



1 = Kenyte-flows (in some cases with agglomerates).
2 = Kenyte-agglomerates and ash.
3 = Basaltic dykes.
4 = Phonolite lava-flows.

these lavas is quaquaversal; thus on the eastern ridge of the Hobley Valley the rocks dip south-eastward; on the Lewis Col and its main southern ridge they dip southward; on the flanks of the Teleki Valley they dip south-westward; and on the north of the Thomson Valley (the second valley northward from the Teleki Valley) they dip north-westward.

As an illustration of the arrangement of the lava-series in the Teleki Valley area, we may consider the section exposed on the western arête and face of Mount Höhnel. At the base are greenish fissile phonolites, which form the slopes around Lake Höhnel, the lower part of both flanks of the Teleki Valley and of Phonolite Cwm, and the floor of the col at the lower end of the western ridge of Mount Höhnel. This phonolite is not well exposed, for the rock is easily denuded and weathers into smooth slopes, which are mostly covered by talus, snow, and moraine-débris. Ascending Mount Höhnel by the western ridge we find the following sequence. Next above the phonolite comes:

2. A thick flow of porphyritic kenyte wherein the anorthoclase-phenocrysts are smaller and more crowded, and the groundmass is of a brighter red than in the usual variety;
3. A thick bed of tuff, partly vesicular, and enclosing large crystals of anorthoclase;
4. A flow of kenyte;
5. Coarse kenyte-agglomerate (no basalt-pebbles could be found in it);
6 (in 5). A vertical compound dyke of phonolite with basic selvages; the dyke is 4½ feet wide, and stands out as a wall 3 feet high;
7. Brown and buff volcanic ash over the agglomerate (5), dipping 8° south-westward;
8. Flow of black kenyte, including red porphyritic bombs;
9. Alternations of coarse ash and agglomerate, weathering into crags (including the 'Janda Pinnacle');
10. Porphyritic kenyte, with a dull pinkish groundmass;
11. Thin kenyte-flows interstratified with tuff; and
12. A coarse flow of porphyritic kenyte capping the summit.

The total thickness of the foregoing series (2 to 12 inclusive) is about 1600 feet.

V. The Geological History of Mount Kenya.

Mount Kenya accordingly consists of a very ancient, denuded volcano, which is built up of rocks belonging to three petrographical types: (1) an olivine-bearing nepheline-syenite, with its kenytes; (2) the phonolite-series of dykes and flows; and (3) the olivine-basalt series.

At first, I was inclined to believe that the basalts were the oldest members of the series: for Mr. C. W. Hobley had given me in Mombasa a specimen of a vesicular basalt from the edge of the forest-zone of the southern slopes of Kenya; and, on the day after we reached the Alpine zone, I found blocks of an apparently tachylytic lava in the agglomerates. It accordingly seemed probable that

Kenya had begun with the ejection of basic materials, and that the phonolitic series was the more recent. This arrangement would have been in accordance with the general rule of ejection in order of decreasing basicity. In Bohemia, that classic land of phonolites, the sequence of the Aquitanian (Upper Oligocene) volcanic series, as determined by Hibsch, begins with nepheline- and plagioclase-basalts, which are followed by tephrites, and these in turn by phonolites, and finally come the trachytes.[1]

But further field-evidence refuted the idea that the basalts were earlier than the more acid kenytes. The supposed tachylyte in the agglomerates, in spite of its basic aspect both in hand-specimens and under the microscope, proved to be of too low a specific gravity, and must be regarded as a pitchstone; and the field-evidence in the Teleki Valley showed that the olivine-basalt dykes are intrusive into the kenyte-series, while the olivine-basalt flows must be later, as they include some fragments of the kenytes.

The oldest lavas found on Mount Kenya are the phonolites, flows of which occur below the great kenyte-series of Mount Höhnel and in the Teleki Valley. But there does not appear to be any sharp separation in age between the phonolites and the kenytes, since the former in the Mount Höhnel sequence are immediately covered by the kenyte-tuffs, which are themselves traversed by phonolite-dykes. These phonolite-dykes are darker and more basic than the phonolite-flows, but the differences are slight.

The phonolites and kenytes appear, therefore, to have overlapped, and they probably represent two closely-allied types produced by differentiation from the same rich soda-bearing magma.

The last stage in the volcanic history of the Teleki Valley quadrant of Mount Kenya is represented by the olivine-basalts. The basalt- and dolerite-dykes cut across the kenytes, and are in no place, so far as I saw, cut by the nepheline-bearing dykes. The basalts do not seem to reach the surface higher than the upper Alpine zone; Mr. Hobley found them on the edge of the southern forest-zone, at the height of 8600 feet, and the basalts probably reached the surface from a belt of secondary craters in the Alpine zone on the margins of the kenyte-plug which choked up the original vent. Such a centre of eruption probably occurred near Mount Höhnel, for flows of fissile and columnar olivine-basalts occur around that peak.

It cannot be affirmed, however, that the whole of the Kenya basalts are later than the phonolite-kenyte series, for the fissile

[1] See his 'Geologie' (1885) p. 319, for the age of the series; for the sequence, see his 'Ueber die Eruptionsfolge im böhmischen Mittelgebirge' Sitzber. deutsch. Naturw. Med. Ver. Böhm. Lotos (1897) No. 1. It is just possible that the phonolite at the western foot of Mount Höhnel may be an intrusive sheet. In the field I regarded it as a contemporaneous lava-flow, and only collected one specimen from the middle; but microscopically the rock has rather the aspect of a dyke, and it is possible that the apparently vesicular upper surface may have been due to the incorporation of tuffs.

basalts of the lower slopes, which form so large a proportion of the gravels near Ndoro, may possibly be older than the basalts of the upper Alpine zone. Petrographically the two basalts agree, but the dense jungles of the forest-zone prevent any definite correlation by stratigraphical evidence. It might be suggested, therefore, that the basalts of the lower forest-zone belong to an earlier series of basic eruptions, which were pierced by the core of nepheline-syenite, and covered by the central pile of the kenyte-series; after which a minor basaltic series closed the volcanic history of the mountain. Cases of such subsidiary recurrence of basalt are known; thus among the Kainozoic volcanoes of Scotland Sir Archibald Geikie[1] has remarked that 'in the case of the Tertiary volcanic series [of Scotland] there is evidence that after the acid protrusions a final uprise of basic material occurred.' The basalts of Pantelleria may be another illustration of this tendency. But, other than the general rule of eruptive sequence, I know of nothing to suggest the occurrence on Mount Kenya of a double series of basalts; and at present there is no evidence of any basalts on the mountain earlier than the kenyte-series. Though the basalts whose relative age is known are younger than the phonolites and kenytes, it does not seem necessary to assume any great lapse of age between them; for it is possible that all the lavas represented in the Teleki Valley quadrant may belong to one series. They may all have resulted by differentiation from the olivine-anorthoclase-nepheline-syenite magma, from which were erupted first phonolites, then kenytes, and finally olivine-basalts.

In Pantelleria, though no definite passage has been described from the pantellerites to the basalts, the sequence as determined by E. Fœrstner[2] agrees with that of Mount Kenya; for it began with phonolites, which were followed by pantellerites, and it closed with basalts. In the nepheline-syenite area of Christiania, as described by Brögger, the passage in the dyke-series from tinguaites rich in nepheline to sölvsbergites free from nepheline, and the similar passage in the deep-seated rocks from the nepheline-bearing foyaites to the nephelineless hedrumite are comparable to the passage from the nepheline-syenites and phonolites of Mount Kenya to the kenytes in which nepheline has not been developed.

VI. Kenya and Kilima Njaro.

The position of Mount Kenya in the East African volcanic series can be more conveniently considered after a description of the adjacent volcanic areas; but it is advisable to include some comparison of the mountain with the other great extinct East African volcano, Kilima Njaro. Unfortunately, however, the exact geological history of Kilima Njaro has not yet been determined. Extensive rock-collections have been made there and carefully

[1] 'Ancient Volcanoes of Great Britain' vol. ii (1897) p. 477.

[2] 'Nota preliminare sulla Geologia dell' Isola di Pantelleria' Boll. Com. Geol. Ital. vol. xii (1881) pp. 539–544.

studied, ranging from Gustav Rose [1] and J. Roth's [2] descriptions of the collection of von der Decken, and Prof. Bonney's [3] account of the specimens obtained by Sir H. H. Johnston, down to the more recent and detailed descriptions of J. S. Hyland,[4] A. C. Tenne,[5] and A. Rosiwal,[6] but the stratigraphical relations of the rocks are uncertain. Thus, as Baron E. Stromer von Reichenbach [7] has remarked, 'we are not yet able to decide further as to the character of the rocks of Kilima Njaro, for the positions of its separate points of eruption, its lava-streams, etc., have not yet been systematically investigated.'

So far as concerns the evidence of the Teleki Valley quadrant, Mount Kenya has had a shorter geological history and is built up of a narrower range of rock-types than Kilima Njaro. The rocks of the latter range from limburgites to obsidians, from peridotites to trachytes.[8] On Mount Kenya I found nothing so basic as a limburgite, or so acid as a trachyte: that mountain probably represents, therefore, only a small part of the long volcanic history of Kilima Njaro. In point of structure Mount Kenya is now in the condition of the Mawenzi peak of Kilima Njaro; and, according to Mr. Prior, the two peaks probably correspond petrographically, for he finds that rock-specimens from Mawenzi in the Natural History Museum present characters, both macroscopic and microscopic, very similar to those of the kenyte-lavas.

VII. Summary of Conclusions.

(i) Mount Kenya is an ancient, much-eroded volcano; the highest peak is formed of the rocks of the central plug; the site of the crater-walls is marked by the agglomerates, ashes, and tuffs of the Alpine zone.

(ii) The main lava-series is formed of kenytes, rocks allied to pantellerites, but of a somewhat more basic type.

(iii) The lowest exposure of the central core is an olivine-bearing nepheline-syenite.

(iv) The lava-sequence is: firstly, phonolite; secondly, kenytes; and finally, olivine-basalts.

[1] 'Beschreibung der von Herrn von der Decken gesandten Gebirgsarten aus Ost-Afrika, grösstentheils vom Fusse des Kilimandjaro' Zeitschr. Allgem. Erdk. Berlin, n. s. vol. xiv (1863) p. 245.

[2] 'Beschreibung der zweiten Reihe der von Herrn von der Decken aus der Gegend des Kilimandjaro mitgebrachten Gebirgsarten' *ibid.* n. s. vol. xv (1863) pp. 543–45.

[3] 'Report on the Rocks collected by H. H. Johnston from the upper part of the Kilima-Ndjaro Massif' Rep. Brit. Assoc. 1885 (Aberdeen) pp. 682–85.

[4] 'Ueber die Gesteine des Kilimandscharo u. dessen Umgebung' Tscherm. Min. Petr. Mitth. vol. x (1889) pp. 203–70 & pl. vii.

[5] 'Die Gesteine des Kilimandscharo-Gebietes' in H. Meyer's 'Ostafrikanische Gletscherfahrten' (1890) pp. 305–10; see also Calder's transl. London 1891, pp. 346–51.

[6] 'Ueber Gesteine aus dem Gebiete zwischen Usambara u. dem Stefanie-See' Denkschr. k. Akad. Wissensch. Wien, vol. lviii (1891) pp. 483–87.

[7] 'Geol. deutsch. Schutzgeb. in Afrika' Munich 1896, p. 55.

[8] F. H. Hatch, 'On a Hornblende-Hypersthene-Peridotite from Losilwa, a low hill in Taveta District, at the S. foot of Kilimandjaro, E. Africa' Geol Mag. 1888, pp. 257–60.

EXPLANATION OF PLATES X, XI, & XII (*pars*).

PLATE X.

Geological sketch-map of the south-western quadrant of the Central Peak and Upper Alpine Zone of Mount Kenya, on the scale of 1 inch to the mile.

PLATE XI.

Microscope-sections of igneous rocks from Mount Kenya.

Fig. 1. Kenyte of the plug (No. 499, p. 209). The section shows large corroded anorthoclase-phenocrysts on the right, an altered olivine in the centre, a rounded broken crystal of pale green augite on the left, with one or two prisms of apatite and dark patches of ægyrine-grains. × 12.

2. Kenyte with tachylytic base (No. 519, p. 213). The large corroded crystal at the top is anorthoclase; the rounded crystal below it is yellow olivine. × 10.

3. Kenyte-lava (No. 508, p. 212). The dense base is crowded with ægyrine-grains and minute felspar-microliths showing flow-structure: throughout the slide are rounded patches of a coarser-grained aggregate of felspar-laths and ægyrine: the felspar-phenocrysts are small (one is shown in the section to the left of the central patch), and in many cases have suffered almost total reabsorption. × 12.

4. Nepheline-syenite of the Central Core (No. 496, p. 208). In the centre of the section is an irregular crystal of barkevicitic hornblende: the colourless mineral with a dark inclusion above the hornblende is nepheline, forming part of a mosaic of felspars and nepheline, finer-grained than the rest of the section. Below the hornblende-phenocryst are large felspars in Carlsbad twins. On the left, and surrounded by opacite, are crystals of pale purplish augite fringed by a zone of ægyrine. × 20.

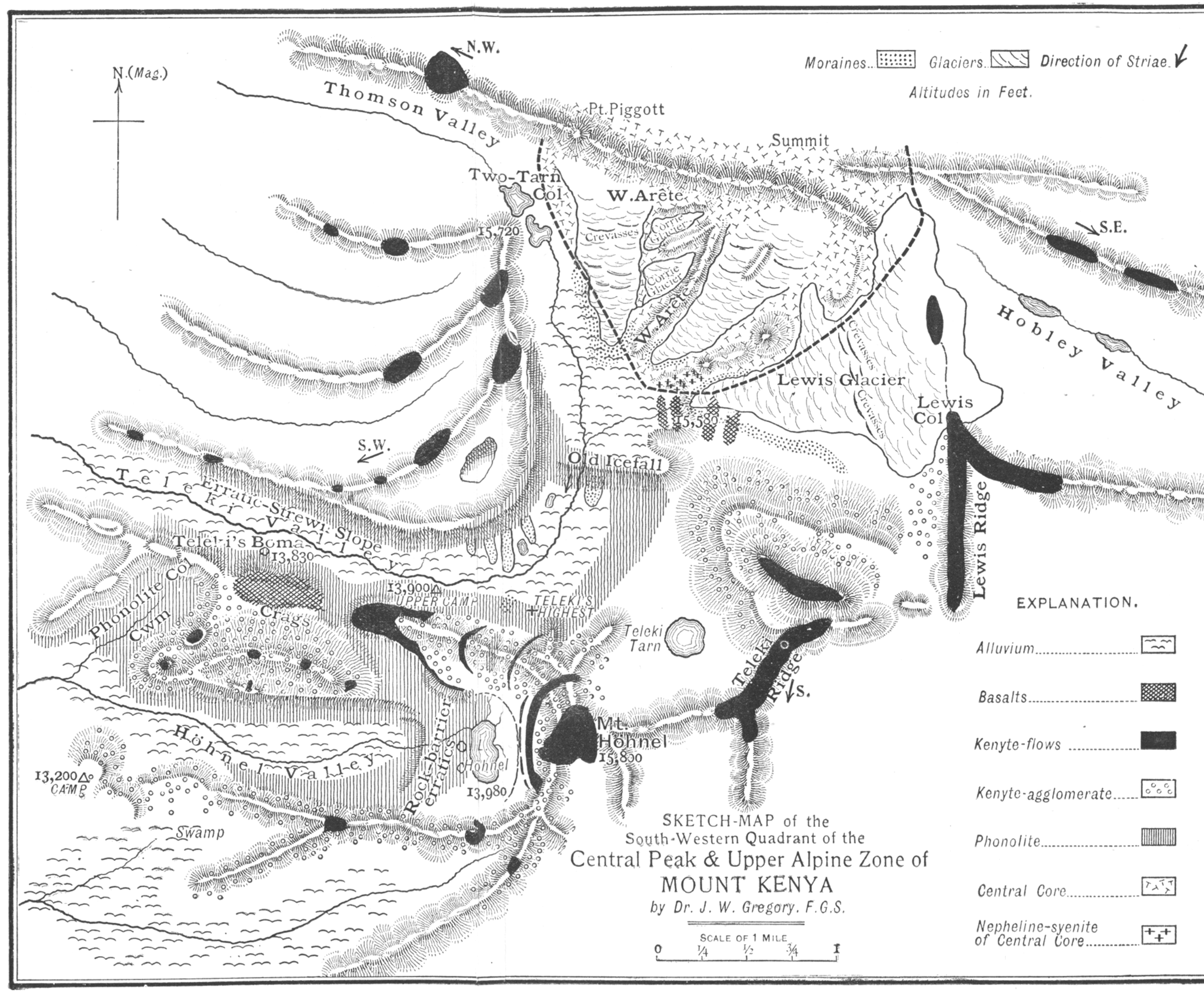
5. Phonolite dyke-rock (No. 456, p. 210). The dark phenocrysts are ægyrine, which also occurs in needles interspersed between the felspar-laths and in dense patches round the clear hexagonal and rectangular sections of nepheline. × 20.

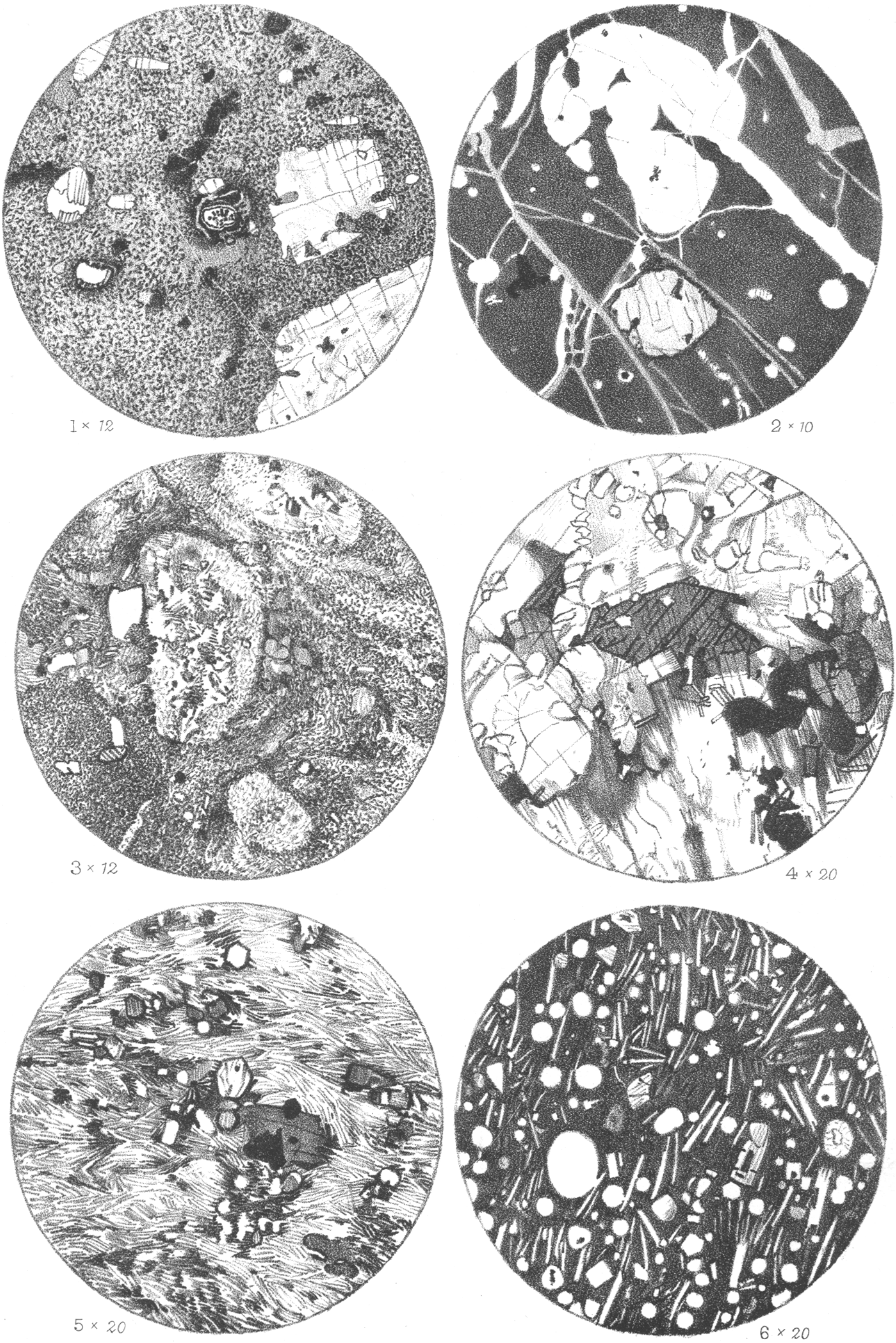
6. Glassy basalt forming a composite dyke with phonolite (No. 457, p. 210). The section shows clear, sharply-defined laths of labradorite, and numerous small rhombic and hexagonal sections of olivine, with a few augite-prisms, in a dense glassy base crowded with magnetite-grains. × 20.

PLATE XII (*pars*).

Fig. 1. Phonolite-flow (No. 490, p. 215). The section shows the same mineral constituents as Pl. XI, fig. 5, but the felspar-laths of the base do not exhibit any well-marked flow-structure. × 12.

2. Kenyte from Mount Höhnel (No. 464, p. 217). The section shows the least glassy specimen of kenyte, as seen between crossed nicols. The large phenocrysts exhibiting very fine twin striations are anorthoclase. The clear-cut octagonal section showing a nearly rectangular cleavage is almost colourless augite (diopside). The small, sharply-defined hexagonal sections are apatite. The base, which is rather dense with opacite-grains, contains numerous lath-shaped felspars. × 12.


N.(Mag.)
N.W.
Thomson Valley
Pt. Piggott
Summit
Moraines
Glaciers
Direction of Striae
Altitudes in Feet.
Two-Tarn Col
15,720
W. Arête
Crevasses
Corrie Glacier
S.E.
Hobley Valley
Lewis Glacier
Lewis Col
15,53?
Old Icefall
S.W.
Teleki Valley
Erratic-Strewn Slope
Teleki's Boma
13,830
Lewis Ridge
Phonolite Col
Cwm
Crags
13,900
UPPER CAMP
TELEKI'S HIGHEST
Teleki Tarn
Teleki Ridge
S.
EXPLANATION.
Alluvium
Basalts
Kenyte-flows
Kenyte-agglomerate
Phonolite
Central Core
Nepheline-syenite of Central Core
Rock-barrier erratics
Mt. Höhnel
15,830
Höhnel Valley
Höhnel
13,980
13,200
CAMP
Swamp
SKETCH-MAP of the South-Western Quadrant of the Central Peak & Upper Alpine Zone of MOUNT KENYA
by Dr. J. W. Gregory, F.G.S.
SCALE OF 1 MILE
0
¼
½
¾
1



1 × 12 2 × 10

3 × 12 4 × 20

5 × 20 6 × 20

E. Drake del. et lith. West, Newman imp.

ROCKS FROM BRITISH EAST AFRICA.