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NOTE ON THE KAPITI PHONOLITES AND KENYTES OF KENYA COLONY

By W. CAMPBELL SMITH

With new chemical analyses by MAX. H. HEY

(*With Plates 1 and 2*)

SYNOPSIS

The Kapitian is the oldest series of rocks in the volcanic succession of the East African Rift Valley. Its dominant lava is a phonolite (Kapiti type). In the field it is distinct from the kenytes of the stratigraphically later (i.e. younger) Mt. Kenya Volcanic Suite. Under the microscope, however, it is found that holocrystalline examples of the kenytes are very similar to the Kapiti phonolites. Chemical analysis of a typical Kapiti phonolite shows a high water-content (3·31 per cent.), and thin sections reveal the presence of analcime in the groundmass. Otherwise there is little mineralogical difference between the two rocks. There are differences in texture, but these are not easily expressed in definitions. The name 'Kenyte' was first used by J. W. Gregory for the lavas around the central plug of Mt. Kenya, of which black glass and large anorthoclase crystals are the most conspicuous constituents in hand-specimens. These glassy types of the kenytes are quite distinct from the Kapiti phonolites.

In the volcanic succession of East Africa the oldest of the series of lavas is that named by Professor J. W. Gregory the Kapitian Series, typically developed in the Kapiti Plains of Kenya Colony. The predominant lava in this series is a dark porphyritic phonolite with large white phenocrysts of feldspar and scarcer, usually smaller, phenocrysts of nepheline in a dark base. Gregory considered that the presence of phenocrysts of these *two* minerals gave the rock a distinctive appearance unlike any other East African lava (Gregory, 1921: 193).

In a paper published in 1931 on 'A classification of some rhyolites, trachytes, and phonolites from part of Kenya Colony . . .' a detailed petrographic description was given of phonolites of the Kapitian Series, chiefly collected by J. W. Gregory in 1893, and in the same paper the kenytes of Mt. Kenya were fully described for the first time. The chief point of interest in the description of the kenytes was that, in addition to the already well-known phenocrysts of anorthoclase, they contained also phenocrysts of nepheline, the presence of which had not previously been recorded (Campbell Smith, 1931: 242). Thus both the kenytes of Mt. Kenya and the phonolites of the Kapitian Series show phenocrysts of nepheline and feldspar in a dark base, and might be very similar in appearance in hand-specimen and not always so readily distinguished as Professor Gregory had supposed.

How close this resemblance between the two types of rock may be is emphasized by the discovery that the rock selected for chemical analysis as representative of the Kapitian phonolites (Campbell Smith, 1931: 239) and taken by Gregory to belong to the Kapitian Series 'is a kenyte of the Mount Kenya Suite and has no connexion with the Kapiti phonolites . . .' (Shackleton, 1945: 16).

The rock specimen in question [GN417][1] was collected by J. W. Gregory in 1919 from north-east of the Amboni River, 7 miles north-east of Nyeri (Gregory, 1921: 142, 196). The locality is near Songari Hill on the eastern edge of the map accompanying Professor Shackleton's report quoted above. In the 1931 paper referred to above attention was drawn to the close resemblance of this rock in both hand-specimen and in sections to specimens of kenytes from Mt. Kenya and its description was kept separate from that of the rocks which represent the Kapitian phonolites collected by Gregory in 1893. It is now clear that the description of specimen GN417 and its chemical analysis apply to 'a kenyte of the Mount Kenya Suite' and not to a phonolite of the Kapitian Series, and that a new chemical analysis and additional petrographical descriptions of authentic specimens of phonolites of the Kapitian Series are required to re-establish their characters. An early opportunity was, therefore, sought to obtain fresh material of kenytes and Kapiti phonolites from the type areas, and Dr. K. P. Oakley of the Geological Department of the British Museum (Natural History) kindly undertook to collect suitable specimens in the course of his visit to Kenya Colony as a delegate to the Pan-African Congress on Prehistory in 1947.

The specimens of Kapiti phonolites collected by Dr. Oakley are from two localities: B.M. 1947, 200 (1) and (2), both from lat. 1° 40′ S., long. 36° 50′ 15″ E. on the Kapiti Plains, about 12 miles north-east of Kajiado Station; B.M. 1947, 200 (3), lat. 1° 50′ S., long. 36° 50′ E., near Cairn Hill, 6 miles east-north-east of Kajiado Station. All three specimens are good examples of the phonolite of the Kapitian Series. The first specimen [B.M. 1947, 200 (1)] was chosen for analysis as it was the largest and freshest specimen and provided plenty of material for sampling. Its petrographical description is given at the end of this paper. For the moment it will be sufficient to state that it appears to be exactly like the phonolite [GN250] collected by Gregory in 1919 at Kajiado, and this in turn corresponds exactly to the phonolite [G574] from Chanjavi (Ol Doinyo Sapuk, lat. 1° 10′ S., long. 30° 15′ E.) collected by Gregory in 1893 and described in the 1931 paper quoted above (p. 238). These rocks are recognized as typical of the predominant phonolites of the Kapitian Series.

Another phonolite very similar to the analysed specimen is one collected by Arthur Champion in 1912 from 'the pass over which runs the road from Ikutha to Kibwezi through the Yatta Plateau'. The phonolites of the Yatta Plateau form part of the Kapitian Series. They have recently been described by J. J. Schoemann (1948: 35).

For the chemical analysis 270 grammes of the rock were broken up and roughly crushed, mixed, and quartered several times, and eventually 36 grammes were ground finely for the analysis, care being taken to keep the sample thoroughly mixed during the grinding. The analysis was made by Dr. Max. H. Hey of the Department of Mineralogy, British Museum (Natural History), and I am greatly indebted to him for this important contribution to the present paper. His analysis is given in Table I, column 1, and compared with the analysis of the kenyte [GN417], referred to above, and with three previously published analyses of kenytes from Mt. Kenya.

[1] Numbers in square brackets refer to specimen numbers. G refers to J. W. Gregory's 1893 collection; GN to specimens collected by Gregory in 1919 and described by Miss A. Neilson.

TABLE I

Analyses

	1	2	3	4	5
SiO_2	55·48	52·10	53·98	53·80	54·53
TiO_2	0·70	0·30	0·57	0·31	0·98
Al_2O_3	18·70	22·29	19·43	18·46	19·48
Fe_2O_3	3·53	1·73	4·39	6·22	1·18
FeO	2·08	4·10	2·05	0·40	5·72
MnO	0·12	0·23	0·26	0·33	0·12
MgO	1·75	1·17	1·07	1·05	1·44
CaO	2·17	2·42	2·04	2·53	2·28
Na_2O	7·04	8·60	8·81	7·09	9·16
K_2O	4·85	4·66	5·27	5·46	4·80
H_2O+	3·31	0·75	1·66	3·54	0·12
H_2O-	0·19	1·00	0·13	0·85	0·06
P_2O_5	0·24	0·46	0·30	0·53	0·12
Cl′	tr.	n.d.	n.d.	n.d.	tr.
CO_2	nil	n.d.	n.d.	n.d.	nil
Totals	100·16	99·81	99·96	100·57	99·99
NORMS					
or	28·64	27·80	31·14	32·80	28·36
ab	39·82	25·68	26·46	32·49	23·53
an	5·00	8·34	—	1·95	—
ne	10·65	25·56	23·71	15·05	26·90
ac	—	—	3·70	—	3·42
di	3·24	—	6·64	5·40	8·99
ol	1·99	6·31	0·14	—	6·10
mt	5·05	2·55	4·64	1·62	—
il	1·32	0·61	1·06	0·61	1·85
ap	0·57	1·34	0·67	1·34	0·27
hm	0·05	—	—	5·12	—
ns	—	—	—	—	0·08
'NIGGLI VALUES'					
si	183	154	165	175	160
al	36	39	35	35	34
fm	23	19·5	21	22	24
c	8	7·5	7	9	7
alk	33	34	37	34	35
ti	1·8	0·7	1·3	0·8	2
k	0·31	0·26	0·28	0·33	0·27
mg	0·37	0·26	0·23	0·23	0·26
c/fm	0·35	0·38	0·32	0·39	0·31
qz	−49	−82	−77	−61	−77

1. Phonolite (Kapiti type), I(II).6.1(2).4. 12 miles NE. of Kajiado Station, Kenya Colony. M. H. Hey anal. [B.M. 1947, 200 (1).]

2. Kenyte, 'Phonolite of Kapitian type'; Neilson, 1921, I(II).6.(1)2.4. North-east of Amboni River, Meru road, Kenya. W. H. Herdsman anal. [GN417.]

3. Kenyte, II.6.1.4. From the central core of Mt. Kenya, above Lewis glacier, Teleki Valley. G. T. Prior anal. [G499.] (Gregory, 1900: 209; Prior, 1903: 247; Washington, 1917: 561.)

4. Kenyte, (I)II.'6.1.'4. Lava-flow from the summit of Mt. Höhnel, Mt. Kenya. G. T. Prior anal. [G462.] (Prior, 1903: 247; Washington, 1917: 561.)

5. Phonolite-obsidian, II.6.1.4. Campi Sheitani, above the Mackinder Valley (13,000 ft.), Mt. Kenya. M. H. Hey anal. [B.M. 1948, 195.]

The kenyte represented by the analysis in column 4 [G462] has a brown, glassy, opaque groundmass and the marked preponderance of Fe_2O_3 and high content of H_2O were regarded as due to the state of alteration of the rock. If this analysis (col. 4) be left out of consideration one finds that the new analysis of the phonolite (Kapiti type) differs from the kenyte analyses only very slightly. SiO_2 is higher (1·5–3·4); MgO and TiO_2 are very slightly higher; Na_2O and Al_2O_3 are slightly lower; and so are total iron oxides and MnO. The only really notable difference is the high percentage of H_2O lost at above 105° C.: 3·31 per cent. compared with 1·66 per cent. in the kenyte (col. 3).

The higher SiO_2 and lower Al_2O_3 and Na_2O in the analysis of the Kapiti phonolite result in a lower percentage of nepheline (*ne*) in its norm than in the norms of the kenytes, but in thin sections there is more visible nepheline in the Kapiti phonolites than in the kenytes. The higher H_2O content of the Kapiti phonolite is, however, accounted for, at least in part, by conspicuous interstitial analcime and by zeolites (natrolite partly) both in the groundmass and in small amygdules. Apart from the presence of this easily visible analcime there is very little difference in the mineral composition of the two types of rock. Both contain phenocrysts of anorthoclase and of nepheline, and a few microphenocrysts of a pale green pyroxene and of olivine or its pseudomorphs. As regards the groundmass the mineral components are the same in both rocks, with the exception of the analcime mentioned above and the higher proportion of nepheline in the Kapiti phonolite.

In the Kapiti phonolites feldspar laths lie at all angles (and have been recorded up to 1 mm. in length) and tend to divide the field into small triangular areas (Pl. 1, Fig. 1). The dark minerals are katophorite, aegirine, and cossyrite, the katophorite predominating. In the less fine-grained examples the soda-amphiboles occur as allotriomorphic plates between the feldspars, and the interstices between the feldspar laths are occupied by other feldspar plates and by clear colourless analcime enclosing minute idiomorphic nephelines and grains of opaque 'ore'. There are microphenocrysts of a pale green pyroxene and of olivine which in some specimens is altered to a dark green serpentine (?). The olivine is associated with small crystals of magnetite or ilmenite and stout prisms of apatite. In finer-grained specimens the nepheline seems to be represented by brownish turbid material in the interfeldspar areas, but the texture is a small-scale equivalent of that just described (Pl. 1, Fig. 3).[1]

In the kenytes the groundmass ranges from glassy (holohyaline) to crystalline with a small proportion of a colourless isotropic base which appears to be glass and not analcime. According to Gregory (1921: 146) the kenytes with the wholly glassy base are typical of the lavas around the central nepheline-syenite of Mt. Kenya. They contain large crystals of anorthoclase and 'the dark-coloured constituents are microscopic crystals or large grains of a pale green aegirine . . . often altered to . . . opacite. The other important constituent is olivine, which is often much altered.' In the specimen of which the analysis by G. T. Prior is given in column 3 the groundmass is

[1] J. J. Schoemann has described the texture of the Kapitian phonolites of the Yatta Plateau as 'usually intergranular with the felspar laths commonly in semi-trachytic alignment', and adds: 'There is much colourless often clear isotropic material with low refractive index in the interspaces or in large patches' and 'Zeolitic material is a prominent alteration product extensively replacing both phenocrysts and groundmass'. *Rep. Geol. Surv. Kenya*, **14**, 1948: 36, fig. 6*c*.

in part microspherulitic and interstitial material is a pale brown glass (Pl. 2, Fig. 2). In the better-crystallized specimens the dark minerals are cossyrite, katophorite, aegirine, and a very pale green pyroxene. The cossyrite and katophorite occur as irregular plates up to 0·04 mm. diameter cut up by minute feldspar laths (0·05–0·1 mm. long) so that the texture is micro-ophitic. The feldspar laths lie all through the soda-amphiboles and the colourless base (Pl. 2, Fig. 4). Only rarely can one detect minute nephelines in the colourless base.[1] There are microphenocrysts of nepheline, of pale green pyroxene, and of olivine which is either fresh or altered to brown iddingsite or to an opaque material, and there are stout prisms of apatite and crystals of opaque 'ore'.

The better-crystallized specimens are represented by GN417 from near Songari Hill described in the 1931 paper (Campbell Smith, 1931: 241; Analysis, Table I, col. 2) and by specimens collected by Dr. Oakley from an outcrop below Memsahib Camp, west of Ontulili Valley at about 10,500 feet [B.M. 1947, 199 (1)] and from Liki Valley, Nanyuki, on the north-west side of Mt. Kenya. The holohyaline groundmass is seen in G519 collected by Gregory from Phonolite Cwm, east-north-east of Mt. Höhnel (Campbell Smith, 1931: 244).

Comparison of the summarized descriptions of the two types shows that, as might be expected from the analyses, there is very little difference as regards mineral composition between the holocrystalline examples of the kenytes and the Kapiti phonolites. Interstitial analcime and clearly defined nepheline in the Kapiti phonolites contrast with a colourless, isotropic, and probably glass base and few nephelines (detected with difficulty) in the kenytes. Zeolites are more in evidence in the Kapiti phonolites. In the chemical analyses the analcime and zeolites of the Kapiti phonolites are reflected by the higher water-content (Table I, col. 1). Much of the normative nepheline of the kenytes must be 'occult' and must be accounted for by the colourless base, as is indicated by the staining tests.

As regards texture, so far as the limited series of specimens examined goes, there seems to be a distinction. The Kapiti phonolites are holocrystalline with interstitial areas of analcime and small nephelines between the long feldspar laths; the kenytes, apart from those with a wholly glassy or partly glassy and sometimes microspherulitic groundmass, are commonly micro-ophitic with very short, slender feldspar laths and a colourless, apparently glassy base.

Turning now to the hand-specimens of the rocks one gets an impression that feldspar phenocrysts are more abundant and nepheline phenocrysts relatively scarce and more difficult to detect in the kenytes than in the Kapiti phonolites.[2] The groundmass colour is deep to blackish mouse-grey in the kenytes and a shade greener in the Kapiti phonolites, grading to dark olive-grey in the less fine-grained specimens.

Such differences in the macroscopic and microscopic characters as these are slight distinctions difficult to introduce in definitions of the two rock-types, nor, until a far

[1] After being treated with conc. HCl for 2 minutes much of the colourless base stains with malachite-green and is, therefore, probably nepheline. P. Marshall has given reasons for regarding the interstitial colourless material in some phonolites, called by Rosenbusch and others 'phonolite-glass', as zeolite (1947: 41).

[2] Schoemann estimates the phenocrysts and amygdules in the Yatta Plateau phonolites at 20–30 per cent. with nepheline : feldspar about 1 : 4. *Rep. Geol. Surv. Kenya*, **14**, 1948: 36.

more extensive suite of rocks has been examined, could one tell whether they ar distinctions of general application and of diagnostic value.

Already one may note that Schoemann describes the feldspar laths in the Yatt Plateau phonolites (Kapitian) as 'commonly in semi-trachytic alignment' (footnote p. 6), and Shackleton records a non-porphyritic fissile phonolite in the Mt. Keny Volcanic Suite with 'microphenocrysts of anorthoclase in a dark base of moss aegirine and cossyrite, clearer areas of alkali felspar, minute nephelines, an analcite'.[1] However, the fact remains that the kenytes of the Mt. Kenya Volcani Suite and the Kapiti phonolites are not only stratigraphically distinct but are easil distinguished in the field. Shackleton (1945: 16) writes: 'The kenytes are distin-guished in the field by their very abundant large anorthoclase crystals, usually o the rhombic habit, and fewer greenish nephelines, in a dark grey non-fissile base Weathering to very large rough masses, round rather than angular, is highly charac-teristic (and entirely different from the slabby outcrops of the fissile Kapiti phono-lite, or any of the other plateau phonolites).'

It seems as if the farther one gets from the microscope the less alike do the kenyte and Kapiti phonolites appear. The names were first given in the field and they ar names of great utility in Kenya Colony. It is not for the petrographer to attempt t destroy them, but he may be allowed to give a warning that the difference betwee them is a slender one.

If, as P. Marshall suggests, the colourless interstitial material in many phonolite is not 'phonolite-glass' but zeolite, the mineralogical difference is reduced to merel one of recognizable analcime in the Kapiti phonolites and a smaller percentage o unresolvable, possibly zeolitic, colourless material in the groundmass of the kenytes.

It would have been as well if the names had not been applied to any rocks outside Kenya Colony; indeed, Kapitian phonolite (with one exception) has not. Kenyte, however, has been applied to rocks on Kilimanjaro and on and around Mt. Erebus in South Victoria Land which resemble rather closely the kenytes of Mt. Kenya, but it has been applied also to other rocks not so like. The limits within which the names kenyte and Kapiti phonolite should be used need to be carefully considered by petro-graphers who have studied these rocks in the field as well as under the microscope.

It may be advisable to restrict the name 'kenyte' to rocks like those round the central plug of Mt. Kenya (to which Gregory first gave the name) in which large crystals of anorthoclase (and nepheline more rarely) lie in a black, glassy base. These rocks could probably be so defined as not to exclude the somewhat similar rocks from Kilimanjaro and Mt. Erebus, especially if the name is to be used mainly (or only) as a field name. Such a limitation of the name 'kenyte' to those with obviously glassy base would exclude those variations with crystalline groundmass which we have seen to resemble so closely the Kapitian phonolites. For these and for the Kapiti phonolites a single descriptive name is needed such as 'porphyritic (anorthoclase-) phonolite' followed by some distinguishing 'type' name which will not imply connexion with either the Mt. Kenya Volcanic Suite or the Kapitian Series. If the analcime so frequently observed in the Kapiti phonolites proves to be generally

[1] Other non-porphyritic phonolites on Mt. Kenya were recorded by Gregory and described by Prior as phonolite (Kenya type). (Prior, 1903: 239.)

present and to be a distinguishing feature it could be introduced in the descriptive name where appropriate.

In chemical composition the kenytes and Kapiti phonolites are not only like each other but they are also rather similar to phonolites (Kenya type) from Mt. Kenya and from Kisumu, and it appears, therefore, that there is very little difference in the composition between the lavas of the Mt. Kenya Volcanic Suite and those of the earlier Kapitian Series. May it be that more magmatic water was held by the Kapitian phonolites than by the lavas erupted at Mt. Kenya? If so, the higher water-content may have so reduced the viscosity of the Kapitian phonolites that they were able to spread over the Kapiti Plains and the Yatta Plateau, while a similar magma but with less water retained resulted in the more viscous and perhaps more quickly solidifying lavas of Mt. Kenya. Some support for the suggestion that the water content of the lavas of Mt. Kenya may have been very low is afforded by a new analysis of a phonolite-glass found by Dr. F. E. Zeuner as fragments lying among loose crystals of anorthoclase and acting as a matrix for rough agglomerations of these crystals, at Campi Sheitani, above the Mackinder Valley (13,000 ft.) on Mt. Kenya. The analysis of this glass made for me by Dr. Max. H. Hey is quoted in Table I, column 5. It shows only 0·12 per cent. of water lost at above 105° C. This, however, is at present an isolated example. Other lavas from Mt. Kenya show water contents varying from 0·98 to 1·66 per cent. The glassy lavas of the central plug and higher parts of Mt. Kenya have not been investigated in any detail. There is a field here for much further work when material is available.

It may be possible to show what relation there is between the composition of the glass collected by Dr. Zeuner and the composition of other glassy kenytes with their associated phenocrysts and of the other lavas of Mt. Kenya. Through this study also one may find the explanation of the loose crystals of anorthoclase lying around the old crater so similar in mode of occurrence to the potash-oligoclase crystals that strew the slopes of Mt. Erebus in South Victoria Land.

Description of the Analysed Specimen of Kapiti Phonolite [B.M. 1947, 200 (1)]

Megascopic characters. Holocrystalline, porphyritic with feldspar insets up to 2·5 cm. long and, less frequent, hexagonal nephelines, sometimes 1·5 cm. across. The groundmass is compact, clearly crystalline, and dark olive-grey in colour. Some microphenocrysts, up to 2 mm., of a black mineral prove to be pyroxene. There are rare, compact white patches of zeolite some of which are 0·5 mm. across, but those more generally distributed through the rock are small (1–2 mm.) amygdules. The zeolite filling them is natrolite.

The feldspar phenocrysts are simple Carlsbad twins showing in some sections rather indefinite twin lamellae resembling albite twins but not showing the very fine-scale twinning so often seen in anorthoclase. On a (010) cleavage flake, extinction with reference to a second cleavage was measured as $7\frac{1}{2}°$, and refractive indices in sodium light as α 1·527, β 1·533. These values are rather close to those given by E. D. Mountain (1925: 336) for the loose feldspar crystals collected by J. W. Gregory (1900: 216) on the slopes of the crater of Mt. Kenya in 1893, which were shown to have the composition $Or_{27}Ab_{63}An_{10}$ and to fall within anorthoclase as defined by H. L. Alling (1921: 253).

The pyroxene microphenocrysts are rather rare; only one was seen in a section 3×2 cm. The colour is very pale greyish-green in thin section and the pleochroism is very weak. $Z \wedge c$ in one section gave 48°.

The nepheline has refractive index in Na-light, $\omega = 1{\cdot}5335 \pm 0{\cdot}0005$. This is near that of the nepheline phenocrysts in the kenytes (Campbell Smith, 1931: 245).

Microscopic characters. The texture of the groundmass somewhat resembles that texture of basalts described as intersertal. Laths of a feldspar up to 0·6 mm. in length and averaging 0·04 mm. in width lie at all angles and tend to divide the field into small triangular areas occupied by plates of feldspar, brown katophorite, and darker, nearly opaque cossyrite, small amounts of aegirine, minute crystals of opaque 'ore', nepheline (mostly turbid and inclusion-rich), and colourless isotropic analcime enclosing smaller nephelines (Pl. 1, Figs. 1 and 2).

Some of the nepheline, particularly that enclosed in analcime, is quite clear, but most of the material filling the inter-feldspar areas is turbid (some shows hexagonal form) and in some crystals radiating or sheaf-like fibres of zeolite have been formed. The zeolite is probably natrolite as in the amygdules. The isotropic interstitial material identified as analcime gave no reaction for Cl′. After etching with HCl it stains less readily than the nepheline.[1] A micrometric analysis of a stained section indicated about equal proportions of nepheline as recognizable crystals and isotropic base (analcime).

The feldspar laths are simple (Carlsbad) twins and mostly give straight extinction, though one as high as 7° was observed. Measurements of these crystals on the universal stage prove that the plane of the optic axes is nearly perpendicular to (010) and Z (γ) is inclined to the normal to 010 at an angle of 5° to 8°. X (α) is inclined to the *a*-axis at about 8°. $(-)2V = 42°–48°$. These properties agree with those of anorthoclase. Of the dark minerals the most abundant is a rather pale-brown amphibole referred to in previous descriptions of the East African phonolites as katophorite. The mineral is strongly pleochroic giving in thin section, X pinkish-buff (17″d), warm buff (17′d), Y russet (13′k), Z near Dresden brown.[2] The maximum extinction measured was $Z \wedge c = 34°$. At edges this amphibole grades off into a greener amphibole (Z olive-green). This olive-green amphibole forms occasional microphenocrysts. One or two were found on picking over powdered material and gave $Z' \wedge c = 10\frac{1}{2}°$ on a prismatic cleavage fragment. Refractive indices were measured by the Becke line method as α 1·651±0·001, $\beta < 1{\cdot}655$, $\gamma > 1{\cdot}664$, X′ straw-yellow (21d), Z′ olive-green (23m).

Crystals, in part very dark-brown like iddingsite, in part deep-green and serpentine-like in appearance, are thought to be altered iron-rich olivine. They are associated with good crystals of an iron 'ore' with square and triangular sections, perhaps magnetite. Apatite forms stout prisms associated with the altered olivines. Similar altered olivines are present in the specimen from the Yatta Plateau referred to above

[1] This agrees with G. W. Tyrrell's recent observation on the recognition of analcime and nepheline in rock sections. *Trans. Geol. Soc. Glasgow*, **21**, 1948: 162.

[2] Ridgway, R. 1912. *Color Standards and Color Nomenclature*, Washington.

[B.M. 1915, 193 (12)]. J. J. Schoemann observed the same kind of pseudomorphs and refers them to olivine altered to 'grass-green chlorite (? antigorite) and calcite'. These pseudomorphs occur as microphenocrysts up to 0·75 mm. diameter.

Additional Note

The specimen collected by Dr. Oakley from Cairn Hill [B.M. 1947, 200 (3)] contains some large phenocrysts of anorthoclase (up to 3 cm. long) but also many smaller feldspars (1–4 mm.) which are simple Carlsbad twins and appear to be orthoclase. One hand-specimen shows a phenocryst of nepheline 1·5 cm. across and a few small nepheline phenocrysts are seen in thin sections. The larger, feldspar phenocrysts show inclusions of, or are deeply embayed by, the groundmass. Amygdules up to 0·5 cm. across are frequent in this rock.

The groundmass is fine-grained and for the most part turbid. It consists of long, thin, and sometimes slightly curved laths of feldspar with inter-feldspar areas (dominantly triangular patches) consisting of brownish turbid material, probably altered nepheline, and isotropic analcime with scattered brown amphibole and aegirine. Where the groundmass is clear it can be seen to represent a fine-scale equivalent of the groundmass of the more coarse-grained type described above. The pale-green pyroxene appears in the groundmass and occasionally as microphenocrysts. There are stout prisms of apatite sometimes in clusters, with opaque black 'ore' and possibly also cossyrite. The feldspar laths run up to 0·4 mm. in length and average about 0·01 mm. in thickness. Fine-grained variations of this kind were also described by me (1931: 238) from specimens collected by Gregory in 1893 from Ol Doinyo Sapuk [G575] and from the plains south-east of Marungu on the north bank of the Tana near its junction with the Thika river [G552, 553, 556]. In these last the feldspar laths tend to adopt an approximately parallel alinement, and 'with minute idiomorphic nephelines, lie in a colourless isotropic base which is probably analcime' (Pl. 1, Fig. 4).

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PLATE 1

(*Photomicrographs by Mr. D. L. Williams, Dept. of Mineralogy.*)

FIG. 1. Kapiti phonolite [B.M. 1947, 200 (1)]. 12 miles NE. of Kajiado Station. ×23. (See p. 6.)

FIG. 2. The same as above. Showing hexagonal crystals of nepheline in analcime areas between feldspar laths. ×84. (See p. 10.)

FIG. 3. Kapiti phonolite [B.M. 1947, 200 (3)]. Near Cairn Hill, 6 miles ENE. of Kajiado Station. A finer grained specimen than the above. ×23. (See p. 6.)

FIG. 4. Kapiti phonolite [B.M. 1921, 536 (225) = G552]. 'Steppes of the Kiroruma, camp at "Marungu"' (1893); '(the unnamed 3,837 ft. hill, at 37° 19′ E., 0° 46′ S. on the G.S., G.S. map, sheet Kenya, 1912).' (Gregory, 1921: 157; Campbell Smith, 1931: 239). Shows trachytic alinement of feldspar laths in the groundmass of soda-amphiboles and pyroxene, and turbid, colourless minerals. The large crystal is apatite. ×60. (See p. 11.)

1

2

3

4

KAPITI PHONOLITES FROM KENYA COLONY

PLATE 2

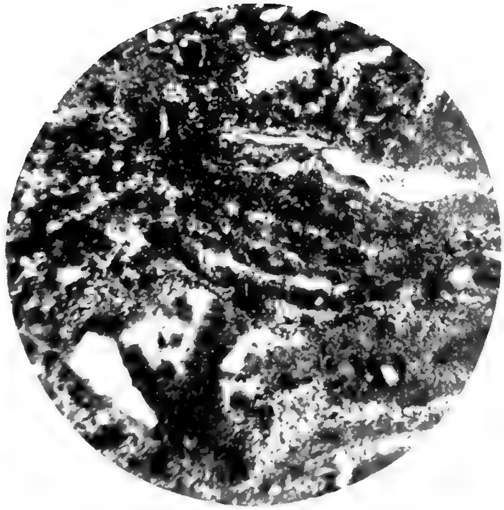
Fig. 1. Kenyte [B.M. 84757, 27 = G499]. From the central plug of Mt. Kenya, Teleki Valley. ×23. Part of the area of Gregory's original section figured by him. (1900, pl. xi, fig. 1.) The large white crystal is nepheline (*not* anorthoclase). Also shown: altered olivine, prisms of apatite, and groundmass of soda-amphiboles, &c., and feldspar laths in colourless base. (See p. 6.)

Fig. 2. Kenyte [B.M. 84757, 13 = G462]. Lava-flow, summit of Mt. Höhnel, Mt. Kenya. Elongated vesicles lined with brown glass (at the top). Texture in parts microspherulitic. The crystal (bottom left) is feldspar. ×23. (See p. 7.)

Fig. 3. Kenyte [G499]. The groundmass of the specimen figured in Fig. 1. ×60. (See p. 6.)

Fig. 4. Kenyte (previously described as phonolite of Kapiti type) [B.M. 1930, 380 (9) = GN417]. NE. of Amboni River, 7 miles NNE. of Nyeri. Showing groundmass. Cossyrite, katophorite, and pyroxene as irregular plates, with feldspar laths, in colourless base. ×60. (See p. 7.)

1



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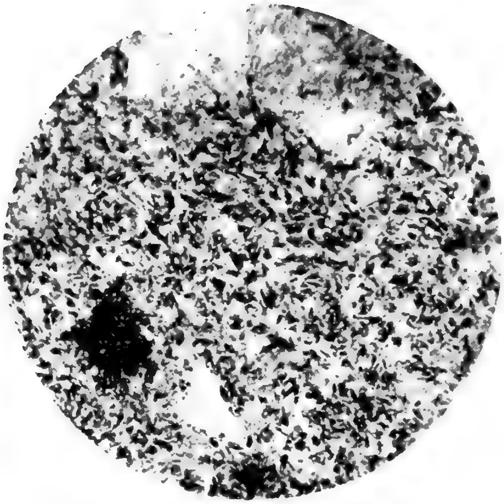

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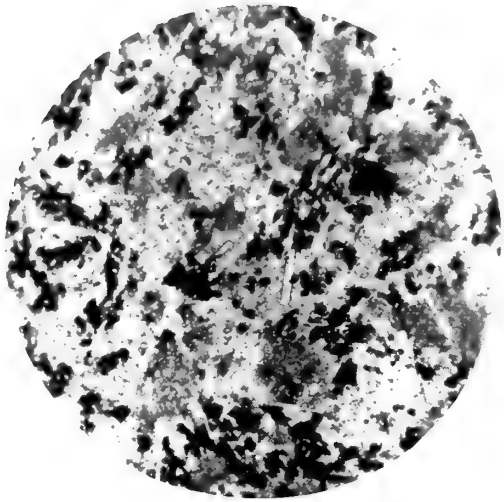


4

KENYTES FROM KENYA COLONY

ROCKS COLLECTED BY W. THESIGER IN OMAN, ARABIA, IN 1946–7

By P. M. GAME

(*With Plate 3*)

SYNOPSIS

Rock specimens collected by Mr. W. Thesiger on the south-west flank of the Hajar range, Oman, Arabia, are the first obtained from this area. They are described and compared with rocks collected by G. M. Lees from the eastern side of the Oman range and with those collected by H. St. J. B. Philby in the west central area of Arabia, 900 miles to the west.

THE purpose of this note is to list the rocks collected by Mr. W. Thesiger during his journey in Oman in 1946–7, to describe the more interesting types, and to compare them, where possible, with the specimens brought back by previous explorers from other Arabian localities.

That portion of Mr. Thesiger's route on which the collection was obtained is shown in the sketch-map (Fig. 1). The specimens are the first recorded from the landward (south-west) flank of the Oman mountain chain, known as the Hajar range, and for this reason considerable interest attaches to them. Since the majority of the specimens could not be obtained *in situ* (access to the range itself being impossible) they do not permit any conclusions on structure and mutual relations; but they provide valuable evidence as to the composition of some of the rock-types of which this most interesting orogenic belt is composed.

For descriptive purposes the collection will be considered in two groups—a southern and a northern. The southern group comprises rocks which do not belong to the Hajar range proper, but which were obtained, mainly *in situ*, along and near the south-east coast in the region of Batin el Mahai. The northern group consists of pebbles collected in the wadis draining the western flank of the Hajar range, 100 to 120 miles west of its crest.

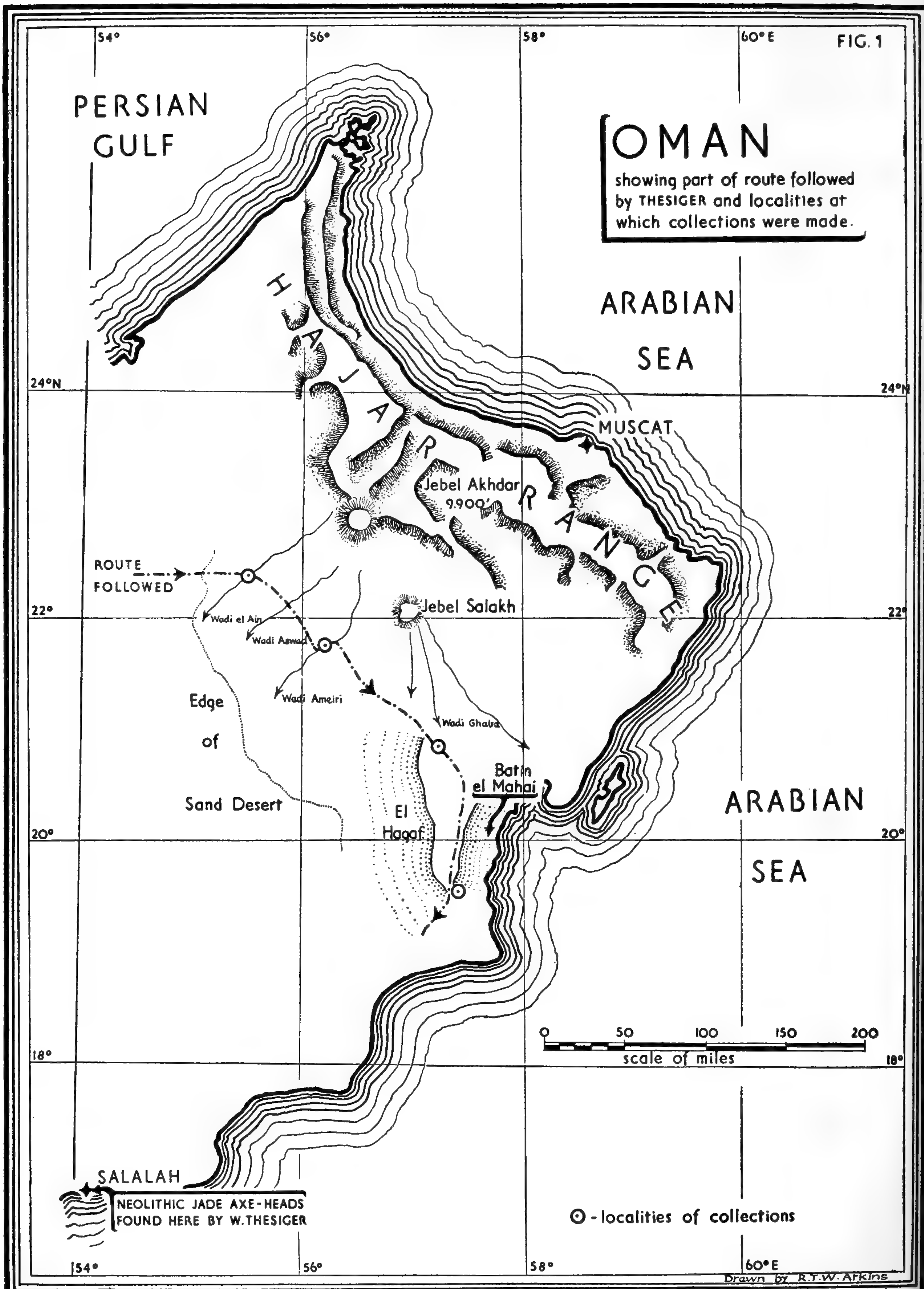
SOUTHERN REGION

The most interesting rocks from the Batin region are the granites, porphyries, acid tuffs, and rhyolites which appear to form a well-marked acid igneous suite in this area.

Granites

In its non-marginal phase the freshest granite [1][1] is a pink, medium- and even-grained, non-porphyritic granophyric variety with very small ferromagnesian content and a dominant proportion of pink orthoclase, the crystals of which attain a maximum diameter of 0·5 cm. The average grain-size is slightly lower.

[1] Figures in square brackets refer to entries in the rock register of the Department of Mineralogy under B.M. 1947, 369.


OMAN
showing part of route followed by THESIGER and localities at which collections were made.
PERSIAN GULF
ARABIAN SEA
ARABIAN SEA
HAJAR RANGE
MUSCAT
Jebel Akhdar 9,900′
Jebel Salakh
ROUTE FOLLOWED
Wadi el Ain
Wadi Aswad
Wadi Ameiri
Wadi Ghaba
Edge of Sand Desert
El Haqaf
Batin el Mahai
SALALAH
NEOLITHIC JADE AXE-HEADS FOUND HERE BY W. THESIGER
⊙ - localities of collections
0 50 100 150 200
scale of miles
54° 56° 58° 60° E
24°N 22° 20° 18°
Drawn by R.T.W. Atkins
FIG. 1

A thin section of this rock (Pl. 3, Fig. 1) shows a beautifully developed micrographic intergrowth of quartz and orthoclase, which makes up probably 80 per cent. of the whole rock. Very little quartz or feldspar occurs not intergrown. There is a small proportion of acid plagioclase and some patches of decomposed biotite. An aplitic phase of this granite contains a considerable plagioclase content and the quartz shows marked undulose extinction.

A somewhat decomposed variety [2] from the southern edge of el Hagaf has a pale brownish-cream colour and a considerable plagioclase content. This specimen does not show a quartz-feldspar intergrowth. Microcline is subordinate to orthoclase, but forms relatively large grains. Biotite is sparse, but mostly unaltered. Several small, decomposed specimens from the same region resemble the pink variety described above, but show a considerable biotite content.

Microgranites

The first specimen [4] is brick-red to purplish in colour, compact, fine-grained with small sparse phenocrysts of pink feldspar. The thin section shows rare phenocrysts of acid plagioclase and orthoclase—both kaolinized—in a microcrystalline base of quartz and feldspar—the latter kaolinized and haematite-stained. Ferromagnesian minerals are absent. Iron-ore granules show a fairly even distribution. This may be a marginal phase of the granite represented by [1].

The second microgranite [3] is salmon-coloured and contains quartz phenocrysts in addition to those of feldspar (sodic plagioclase and orthoclase). The proportion of phenocrysts is much greater than in the first type.

Feldspar-porphyry [7]

This is a dull olive-green rock with conspicuous white idiomorphic feldspar phenocrysts.

The thin section shows that these phenocrysts are extensively altered and corroded. Some, however, can be still recognized as sodic plagioclase; the more altered crystals are probably potash-feldspar. Biotite also forms sparse phenocrysts, one of which is 2·5 cm. long. The microcrystalline base consists of quartz and feldspar with a considerable development of hornblende.

Acid tuff [6]

In hand-specimen this resembles a porphyry with abundant phenocrysts of orthoclase and quartz averaging 2 mm. in diameter in a dull-purplish groundmass. The thin section (Pl. 3, Fig. 2) shows, however, a well-developed vitroclastic structure in the dominantly glassy base. Most of the orthoclase crystals are heavily impregnated with haematite. The crystals have undergone some corrosion before ejection.

Rhyolite [8]

The typical variety is a highly siliceous brownish-grey rock showing, megascopically, well-developed banding. The section (Pl. 3, Fig. 3) shows this type to be devoid of phenocrysts and to be composed of a microcrystalline quartz-feldspar aggregate. The flow-structure is expressed by dusty, semi-opaque shreds of secondary, kaolinized material. This same material also occurs as a replacement product in the form of sporadic spherules 0·5 mm. in diameter with radiating, fibrous structure. A second rhyolite is black in colour and shows very fine bands. A third type varies from dove-grey to purple, is exceedingly hard and dense, and has undergone secondary silicification.

In addition to the above types, the igneous rocks from this region include a uralitized gabbro [19], which appears to have suffered mechanical deformation, and an epidiorite [21] possibly derived from a basic dyke-rock.

The sedimentary rocks from this southern area consist of sandstones and limestones, for which a Lower Miocene age is suggested by Mr. Thesiger's discovery in the same district of an oyster bed containing the species *Ostrea latimarginata* Vredenburg. The remainder of the sedimentary rocks, however, contain no fossils.

The sandstones comprise a white fissile variety [25], cemented by salt (halite) and calcium carbonate, a pale-pink type [24], and a soft friable species [16] containing glauconite.

Most of the limestones are sandy, in greater or lesser degree; they vary in colour from fawn, through drab to dark grey, and show no features of special interest.

Northern Region

The most interesting find in this area is a fragment of black jade (nephrite) [41] collected from the bed of the Wadi el Ain; this fragment has the form of a flat, water-worn pebble, roughly trapezium-shaped, measuring 5 cm. along the longest edge. It is a tough, dense, greenish-black, finely crystalline rock with somewhat hackly fracture. Microscopic examination (Pl. 3, Fig. 4) shows it to consist of a felted mass of randomly oriented, faintly pleochroic tremolite-actinolite fibres, averaging 0·1 mm. in length, with more coarsely crystalline areas in which the length of the fibres ranges from 0·2 to 0·5 mm. A few porphyroblasts of the same amphibole (some twinned) attain a length of 1 mm. The only other constituent is magnetite, which is confined to the coarser grained patches, where it occurs as well-formed crystals, 0·1 mm. in diameter.

The occurrence of this specimen in the Wadi el Ain is clear evidence of its derivation from some source in the Hajar range, though the precise location remains to be found. In view of the discovery by Thesiger in 1946 of two neolithic green jade axe-heads near Salalah, on the Arabian sea coast, this subsequent find of a similar rock type is of particular interest. In order to examine the degree of similarity between the Oman nephrite and the nephrite used for the artifacts, specific gravity determinations and optical tests were made and thin sections examined (the two axe-heads having been kindly lent by the Trustees of the British Museum for this purpose). The results obtained are shown in the table on p. 19.

These differences and the colour difference are too great to postulate identity of origin. It is more than likely that the two axe-heads were imported. The occurrence of another variety of nephrite in the same region is certainly a strange coincidence.

In the bed of the Wadi Ameiri, south of Wadi el Ain, Mr. Thesiger collected a pebble of a gabbro [30] of an interesting and somewhat unusual type (Pl. 3, Fig. 5). It consists solely of plagioclase (bytownite-anorthite) and diopside with schiller inclusions. The grain-size is very even, averaging about 1 mm. The simple mosaic texture (reminiscent of that of some allivalites from Rum [B.M. 47575, 47576]) indicates simultaneous crystallization of the two constituent minerals. The proportion of feldspar is slightly greater than that of pyroxene.

Specimen	*Locality*	*Sp. gr.*	*R.I.*	*Extinction angle*	*Other components (additional to nephrite)*
Axe-head B.M. 1947, 10.3.1	Ummdhul Spring NE. of Salalah, SE. Arabia	2·990	1·632	14½°	Small equi-dimensional grains of an unidentified colourless mineral; sporadically distributed.
Axe-head B.M. 1947, 10.3.2	Coastal plain of Jerbib, 6 miles W. of Salalah	2·981	1·630	16°	Nil.
Nephrite pebble B.M. (Nat. Hist.) 1947, 369, 41	Wadi el Ain, Oman	3·049*	1·651	19°	Small grains of magnetite (confined to patches of coarser crystallinity).

* Relatively higher sp. gr. due, in part, to the magnetite content.

A further find in the same wadi (Wadi Ameiri) was a small pebble of anorthosite [28], coarsely crystalline, consisting essentially of bytownite-anorthite, with a subordinate proportion of hypersthene. Anorthosites are often associated with pre-Cambrian 'shields' but have not so far been recorded from the ancient crystalline rocks of Arabia.

The collections from both Wadi Ameiri and Wadi el Ain include several rhyolite pebbles [32]. These vary greatly in colour, from very dark-grey, through dull-purple, light-brown, and light-grey to cream-coloured. They mostly show fairly conspicuous banding and an absence of phenocrysts.

The most interesting sedimentary rock from this area is a dull, olive-green, siliceous radiolarian chert [31] which, in thin section (Pl. 3, Fig. 6), is seen to be cryptocrystalline and to show evidence by banding of original bedding. The tests of the original radiolaria have been replaced by radiating, fibrous chalcedony, which forms mutually interfering aggregates. These are packed together to form spherulites averaging 0·2 mm. in diameter (largest 0·3 mm.). A fairly close match for this rock is a radiolarian chert from the Oligocene 'green beds' of the Elburz mountains, north-east of Tehran. This rock [B.M. 1947, 406, 7] shows in thin section similar, though slightly smaller, spherulites (average diameter 0·15 mm.) also infilled by fibrous, radiate aggregates of chalcedony. It has been described by Sir Edward Bailey[1] as a 'rather dirty, cryptocrystalline siliceous chert including many radiolaria'. The latter have been identified by Mr. A. G. Davis as a species of *Cenosphaera*.

Other representatives of the sediments of the northern region are mainly calcareous; there are no true sandstones. The limestones include a characteristic black variety [33] with some calcite veining and traces of organic structures. Other varieties are pale-grey, cream-coloured, and yellowish-brown. The majority show etched surfaces (Rillensteine). The collection also includes a small pebble of a straw-coloured oolitic limestone [43]. The nearest possible 'match' for this is a pink oolitic Miocene lime-

[1] Bailey, E. B., Jones, R. C. B., and Asfia, S. 1948. Notes on the geology of the Elburz Mountains, north-east of Tehran, Iran, *Quart. J. Geol. Soc. London*, **104:** 13–14.

stone with small shells and foraminifera, brought back by Mr. H. St. J. B. Philby from Jaub Anbak, at the base of the Qatar peninsula [B.M. 1932, 1175, 24]; the oolites in the latter are three to four times as large as those in the Oman specimen.

The collection of pebbles from Wadi Ameiri also includes some calcareous breccias and conglomerates. One type [35] contains subangular pebbles of a pink, calcareous sandstone, 6 mm. or less in diameter. In the other main type the pebbles are mainly dark-coloured, hard, silicified rocks such as cherts and rhyolites; they are subangular and the largest are about 2·5 cm. in diameter.

It is of interest to compare briefly the rocks collected by Thesiger with those brought back by previous Arabian explorers. On the eastern (i.e. coastal) side of the Oman range Dr. G. M. Lees[1] found a variety of igneous rocks (mainly serpentine, gabbros, diorites, and alkali-basalts) which he grouped under the heading of the Semail igneous series; these, he considered, formed a great thrust-sheet, overriding an intensely crushed and contorted incompetent sedimentary series (the Hawasina series) containing massive lavas and minor intrusives (mainly keratophyres, sheared tuffs, and melaphyric basalts). It is difficult to match these types with those collected by Thesiger; the latter, moreover, do not show evidence of the strong shearing movements characteristically developed in the Semail igneous series. However, the pale-grey and blue-grey limestone pebbles from the Wadis Ameiri and el Ain may possibly be correlated with Lees's Musandam limestone (Jurassic to Lower Cretaceous) in which massive beds of this colour were recorded in a measured section. In the absence of palaeontological evidence, no more precise statement can be made.

The acid igneous rocks collected by Thesiger in the southern part of the province show general similarity to corresponding types encountered by H. St. J. B. Philby in the west central area of Arabia, 900 miles to the west. The correspondence is closest in the granites. In both regions the characteristic type is a pink to cream-coloured, leucocratic, fine- to medium-grained, non-porphyritic type with or without biotite and devoid of any gneissic banding. Thesiger's pink granophyric type from Batin el Mahai [1] finds its counterpart in a red graphic granite collected by Philby from Bani Shauhata [B.M. 1932, 1175, 97]. The rhyolites from both regions also show general similarities. The banded varieties found near Wadi Ranya and Raudhat ibn Ghannam in the west resemble rhyolites from Batin el Mahai in southern Oman, though the spherulitic structure seen in some of the latter is absent in the former.

The porphyries, which are fairly plentiful in the collections from the two separate localities, show some differences in detail. The west Arabian types are conspicuous for a noteworthy content of sphene, a mineral not observed in the Oman porphyries. The latter, moreover, contain quartz as phenocrysts, whereas in the corresponding western types quartz is in general only a constituent of the groundmass.

There is nothing in the Oman collection to match the gneisses, schists, and amphibolites which apparently occupy a considerable area in the Najran region, on the south-west fringe of the Rub al Khali. But in view of the necessarily localized character of the Oman collection and the derived nature of much of its material, this evidence of dissimilarity is inconclusive.

[1] Lees, G. M. 1928. The Geology and Tectonics of Oman and of parts of South-Eastern Arabia, *Quart. J. Geol. Soc. London*, **84**: 585–670.

Derivation of the Gravels of Jafura and Rub al Khali

The gravels collected by Philby and Major R. E. Cheesman have been described by W. Campbell Smith.[1,2] Mr. Bertram Thomas has also collected samples of pebbles from these extensive plains.

The commonest type of pebble is rhyolite—usually a dark-coloured, highly siliceous variety, generally banded, but without phenocrysts; an olive-green, dense aphanitic variety with no visible flow-structure is also abundant. After rhyolites, the pebbles most commonly found are porphyries, limestones, and pink or red granites—all types occurring in Oman as well as in the central west zone. From the correspondence with the rocks of the latter area Campbell Smith was led to infer a westerly origin for the gravels; at that time (1932) there was no opportunity for study of the rock types from west Oman. Those now brought back by Thesiger show that an easterly origin is also a possibility, and one which receives some support from the trend of the present drainage from the Oman mountain range which is to the south-west. It may well be that both east and west have contributed their quota of hard resistant rocks to these great gravel plains of the interior.

I wish to thank Dr. W. Campbell Smith for much helpful advice and criticism. I am also grateful to Mr. R. T. W. Atkins for preparing the map and to Mr. D. L. Williams for taking the photomicrographs.

APPENDIX

Catalogue of Specimens of Rocks from Oman collected by Mr. W. Thesiger, topographically arranged

Locality	*See page*	*Entry in Mineral Department Register*	*Specimens collected*
SOUTHERN AREA			
Batin el Mahai	15	1947, 369 (1)	Granite; pink; medium-grained, non-porphyritic; fresh.
	17	,, ,, (2)	Granite; weathered; biotite-rich type.
	17	,, ,, (3) & (4)	Micrograntes; purple (4) and salmon-coloured (3).
	17	,, ,, (5)	Aplite.
	17	,, ,, (6)	Acid tuff; dull purple.
	17	,, ,, (7)	Feldspar-porphyry; dull olive-green.
	17	,, ,, (8)	Rhyolite; grey; banded.
	—	,, ,, (9)	Limestone; grey-brown.
	—	,, ,, (11)	Grey marl.
	—	,, ,, (12)	Quartzite; pale grey.
	—	,, ,, (13)	Calcite rhomb.
	—	,, ,, (14)	Calcite, coarsely fibrous.
	—	,, ,, (15)	Chalcedony.
	18	,, ,, (16)	Sandstone; grey to brick-red; soft, loosely cemented; contains glauconite.
	—	,, ,, (17)	Iron pan crusts.

[1] Philby, H. St. J. B. 1933. *The Empty Quarter*, London, Appendix B: 376–379.
[2] Cheesman, R. E. 1926. *In Unknown Arabia*, London, Appendix 7: 422–426.

Locality	*See page*	*Entry in Mineral Department Register*	*Specimens collected*
SOUTHERN AREA (*cont.*)			
el Hagaf (southern edge)	—	1947, 369 (18)	Biotite-granite; pale-brown to cream-coloured; medium-grained.
	18	,, ,, (19)	Gabbro; uralitized.
	—	,, ,, (20)	Rhyolite; black; banded.
	18	,, ,, (21)	Epidiorite.
	—	,, ,, (22)	Rhyolite; pale-green to chocolate-brown; dense silicified type; subconchoidal fracture.
	—	,, ,, (23)	Limestones; grey-brown and cream-coloured.
	—	,, ,, (24)	Sandstone; pale-pink; friable.
	18	,, ,, (25)	Sandstone; cream-coloured; fissile; cemented by a calcareous matrix containing salt (halite).
	—	,, ,, (26)	Jasperoid quartz.
	—	,, ,, (27)	Iron pan.
NORTHERN AREA			
Wadi Ameiri	19	,, ,, (28)	Anorthosite.
	—	,, ,, (29)	Gabbro (?) fine-grained; partly decomposed.
	18–19	,, ,, (30)	Gabbro, consisting of plagioclase and diopside.
	19	,, ,, (31)	Radiolarian chert; dull olive-green; very dense; subconchoidal fracture; silicified; banded.
	19	,, ,, (32)	Rhyolites; cream-coloured; pale-grey and dark-grey; banded; silicified types.
	19	,, ,, (33)	Limestones; blue-grey; 'Rillensteine'.
	—	,, ,, (34)	Limestone; pale grey-green variety.
	20	,, ,, (35)	Sandstones; conglomeratic, with pink, sandy limestone pebbles up to 6 mm. diameter; calcareous cement; also gritty sandstones.
	—	,, ,, (36)	Quartz and jasper.
	—	,, ,, (37)	Gypsum (selenite).
Wadi el Ain	—	,, ,, (38)	Altered olivine-gabbro (?).
	—	,, ,, (39)	Quartz-porphyry; purple, with conspicuous white feldspars.
	—	,, ,, (40)	Rhyolites; dark brownish-grey; light brown; dull purple and cream-coloured; silicified.
	18–19	,, ,, (41)	Nephrite; black; dense; fine-grained.
	—	,, ,, (42)	Limestones; dark-coloured; buff-coloured; very pale-grey and white; 'Rillensteine'.
	19–20	,, ,, (43)	Oolitic limestone; straw-coloured.
	—	,, ,, (45)	Jasper.
Wadi Ghaba	—	,, ,, (46)	Sandstone; ferruginous.
	—	,, ,, (47)	Rhyolites; grey; pale-green and dark-green; silicified; banded.

PLATE 3

Fig. 1. Granophyric granite [1] showing well-developed micrographic intergrowth of quartz and orthoclase. From Batin el Mahai. Crossed nicols. ×30. (See p. 17.)

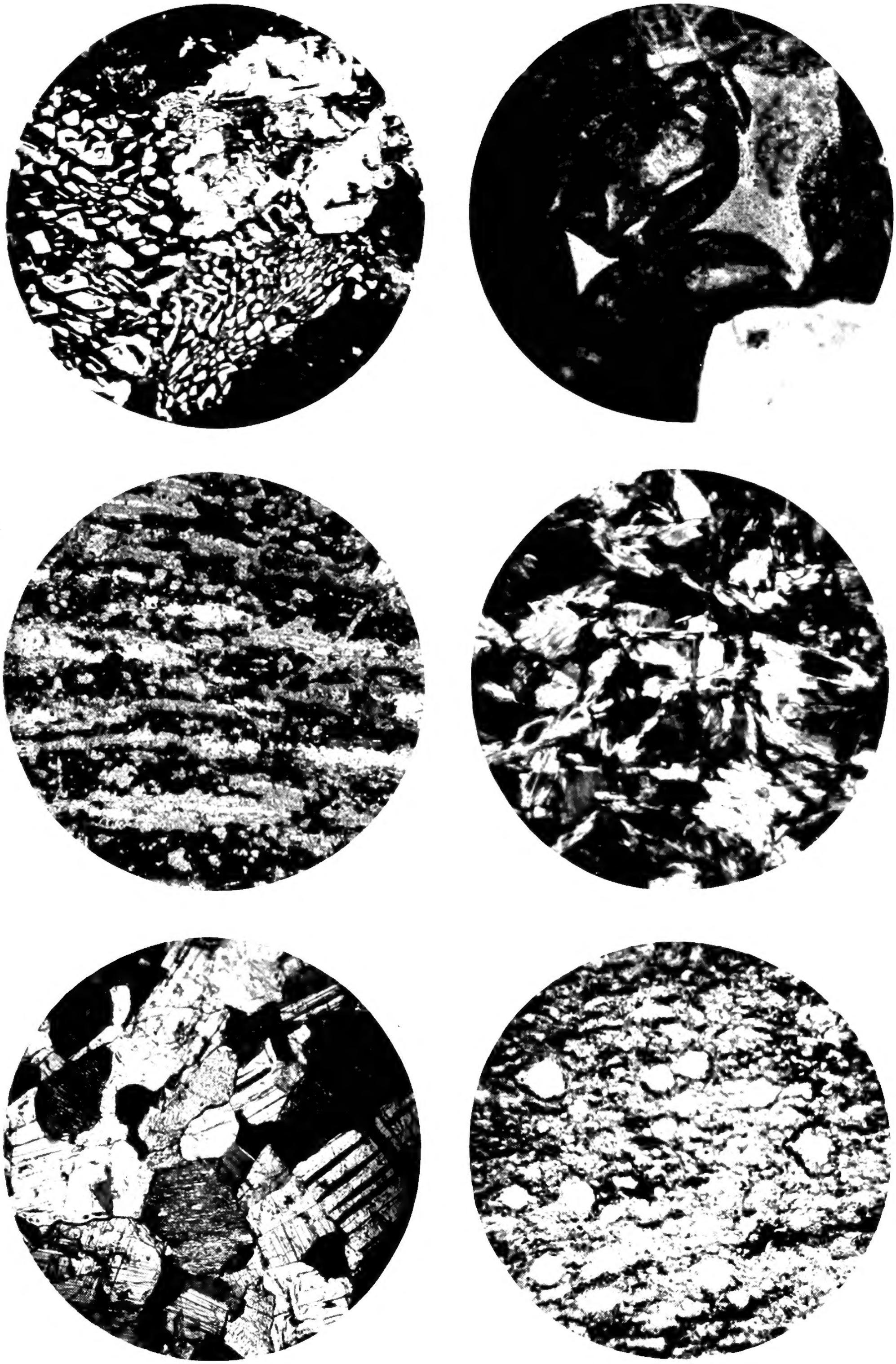
Fig. 2. Acid tuff [6] showing vitroclastic structure and a crystal of quartz at the margin. From Batin el Mahai. Ordinary light. ×90. (See p. 17.)

Fig. 3. Rhyolite [8]. From Batin el Mahai. Ordinary light. ×20. (See p. 17.)

Fig. 4. Nephrite [41] showing randomly oriented tremolite-actinolite fibres. From Wadi el Ain. Crossed nicols. ×160. (See pp. 18–19.)

Fig. 5. Gabbro [30] consisting of plagioclase and diopside showing schiller inclusions. From Wadi Ameiri. Crossed nicols. ×20. (See pp. 18–19.)

Fig. 6. Siliceous chert [31] showing sections of spherules containing radiating, fibrous chalcedony replacing original radiolaria. From Wadi Ameiri. Ordinary light. ×20. (See p. 19.)



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