THE NATURE AND ORIGIN OF A SOAPSTONE FROM NEAR KISII.*

By William Pulfrey.

Visitors to Kenya soon learn of the occurrence near Kisii, in Southern Kavirondo, of rocks which are so easily carved that there has long been a native industry producing Kisiiware—ornaments and household articles which find their way into all parts of East Africa, and, as curios, abroad. In recent years other commercial outlets have been found for the stone, in a finely ground condition. The rock is the so-called Kisii-stone, or as one may prefer to call it, Kisii Soapstone. The term "soapstone" is generally applied to impure massive talc (hydrated magesium silicate) rocks, but as it is possible for rocks of similar appearance to contain little or no talc (for example a rock consisting largely of pyrophyllite—hydrated aluminium silicate), it is perhaps preferable to extend the scope of the term to cover any massive, soft, and sectile rock, though it may contain little or no talc, and to name any talc-rich soapstone, "steatite."

For many years, largely on the grounds of hearsay, the Kisii Soapstone has been called pyrophyllite, and the assumption made that it consisted mainly, if not entirely, of that mineral. This identification has been attributed to the Imperial Institute, but I have been unable to trace any published reference, though it is probable that the erroneous opinion arose from a slip made by A. W. Groves† in describing a slide of the rock, when he stated, "The report of the Imperial Institute shows it to be a pyrophyllite." The Imperial Institute Report was made on a sample of the soapstone collected by E. J. Wayland, then Director of the Geological Survey of Uganda, during a journey through Southern Kavirondo in 1930. Through the kindness of Dr. K. A. Davies, Director of the Geological Survey of Uganda, I have been able to read the report, which is dated September 25th, 1930. There is in it no suggestion that the rock is a pyrophyllite, and an analysis (carried out by a commercial firm to which the Imperial Institute sent the sample) is quoted, followed by the statement, "...........the material approximates closely in composition to kaolin, but has slightly lower content of water. It apparently belongs to the kaolin division of aluminium silicates, but is probably not a definite mineral."

Recently I visited a few outcrops of the stone near Kamagambo, and later examined thin sections and studied chemical analyses of the rock. This work indicates that soapstone from the locality examined is largely a mixture of a kaolinitic mineral and a sericitic mica, derived by the hydrothermal alteration of a lava.

This view of its composition is not new, though being supported by three recent analyses it now has more force. The mode of origin now found has not, however, so far as I am aware, been suggested previously. Wayland giving an account‡ of the soapstone at Nagichenchi (Moguranga, E. 34° 39′ 00″, S. 0° 45′ 30″) described the site as consisting largely of altered siliceous sediments of the Kisii Series (Bukoban

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The writer's thanks are due to the Directors of Messrs. Kenya Consolidated Goldfields, Ltd. for kind permission to use data from their company reports and maps : and to the Director of the Geological Survey of Uganda for allowing him to use data from a report in the files of that Survey.

†In E. J. Wayland, "Report on a Geological Reconnaissance of Southern Kavirondo, with appendices on the Petrology and Assaying by A. W. Groves," Government Printer, Nairobi, 1931. Notes on this work are also contained in the Annual Report of the Geological Survey of Uganda for 1930 (1931), p. 6 and pp. 30-38 (the latter being petrographical descriptions by Groves).

‡Loc. cit. p. 12.

System), resting on a dolerite sill and associated with intercalated contemporaneous lavas of amygdaloidal and rhyolitic types. He considered the soapstone, where quarried by natives, to lie between two sandstones, as a lenticular deposit of the nature of "a pure clay or pipe-clay," subsequently metamorphosed. From this it may be judged that Wayland believed the deposit to be sedimentary. He concluded that "it is not a true soapstone, but a pyrophyllite, or closely allied"—one gathers, on the grounds of his belief in its sedimentary origin.

Groves examined a thin section of Wayland's speciment (loc. cit. p. 54) and described it as "an extremely fine aggregate of sericite, talc or Kaolin,* or a mixture of these," continuing, "It appears to be derived from an extremely fine argillaceous rock by low grade metamorphism."

2. *Field Occurrence.*—There are several exposures of the soapstone in the Kisii District. A number were mapped by Messrs. Kenya Consolidated Goldfields some years ago,† of which twelve deposits, including at least four extensive ones, near to and south-east of Kamagambo Mission, and a large deposit at Samita Hill a little over seven miles south of Kisii (Fig. 1), are particularly notable. Several of the adjacent deposits south-east of Kamagambo Mission are the remnants of larger occurrences now divided by erosion.

All the deposits were considered by the Kenya Consolidated geologists as belonging to the middle portion of the Kisii Series, viz.:

Kisii Series	Upper	Andesites.
	Middle	(not always present) Quartzites, cherts and beds of massive soapstone.
	Lower	Basalts, often amygdaloidal.

They believed the middle division to have developed in isolated basins in the rolling upper surface of the Lower Lavas, and noted two kinds of deposits—short thick lenses of massive soapstone overlain by about 60 feet of massive clean unfossiliferous quartzites of sub-aerial origin, and cherts with concentric algal structures. It is evident that, like Wayland, they believed the soapstones (which were identified provisionally as pyrophyllite) to be of sedimentary origin. They recorded that the soapstone occurs in lenses up to 5,000 feet in length, with a maximum thickness of 50 feet.

I have had the opportunity to examine only the deposits occurring south-west of Nyamwai, on the ridge north of the R. Nyangore. A map was made of the westernmost of these occurrences (Fig. 1, inset). There is a lens-shaped outcrop of soapstone of which the margins cut markedly across the contours, so that it cannot be a sedimentary intercalation in the gently dipping Kisii Series. Closely associated with the soapstone are altered lavas, while above and below it are outcrops of the quartzitic sandstone which forms much of the western portion of the ridge.

The evidence shows that the soapstone is more closely associated with the altered lavas than with the sandstones, and the disposition in the field suggests that the lavas form an intercalation in the sandstone series, and that the soapstone is an alteration product of portions of the lavas. The latter is borne out by examination of thin sections of specimens of the soapstone.

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*In the Annual Report of the Geological Survey of Uganda for 1930 (p. 37), which presumably appeared earlier than the report published in Kenya, he considered the minerals to be "sericite or talc, or a mixture of these."

†Shown on maps, prepared by A. A. Fitch, C. D. Hallam, W. Edgeworth-Johnstone and F. d'U. Burgess, of which copies were lodged with the Mining and Geological Department, Nairobi.

3. *Petrography.*

(a) *Lavas associated with the soapstone.*—Lavas outcropping on the eastern edge of the soapstone are propylitised. There are medium grey with rare pyrite specks, and contain whitish patches up to 10 mm. across. Some of the latter are hazy, but others are clots or vesicular infillings of a quartz-like mineral, which is sometimes banded and like agate. A thin section, IV, 214,*shows that the rock is prophyritic with phenocrysts up to 2 mm. in length, entirely replaced by chlorite and quartz, with some sericite. The matrix contains a large proportion of a flaky, occasionally coarse, penninite-like chlorite associated with sericite and leucoxene, and, interstitially, quartz. Scattered pseudomorphs of small felspar laths can be seen. A vesicle shows a core of penninite with a few grains of a colourless epidote (?), set in a granular quartz base.

The rock is so altered that precise identification is not possible, but it may have been an andesite or an intermediate hypabyssal type.

On the south-west edge of the soapstone other lavas (IV, 216) are exposed. These are markedly vesicular and as before, porphyritic and propylitised. The phenocrysts are prisms up to 1 mm. long, replaced by finely granular chlorite and quartz. The matrix contains abundant lathy felspar pseudomorphs, now consisting either of a light brown, weakly birefringent mineral (probably chlorite), or of glass-clear, finely granular aggregates of quartz or secondary felspar. The remainder of the matrix is made up of a brownish chlorite and small aggregates of leucoxene. The vesicles are up to 1 mm. across and usually contain zones of granular quartz, and chlorite sieved by quartz.

Near the eastern tip of the soapstone no outcrops of lava were seen, but blocks (IV, 215) of acid lavas and an intrusive rock were found. The intrusive type is highly altered but was probably originally a dolerite, while the lavas resemble altered rhyolites in which a little biotite is developed.

On the track a little under a mile east of the soapstone there are extensive outcrops of lava (IV, 217). These are vesicular and feebly porphyritic. They are highly altered, being replaced entirely by quartz, chlorite, epidote and leucoxene. They were probably originally andesites.

(b) *The Soapstone.*—In hand specimens the soapstone is a whitish to creamy-white, or slightly iron-stained, fine-grained soft rock. In exposures it is well jointed, the joint faces being coated by iron oxide films. In spite of the generally close jointing it is possible to extract sound blocks as large as 1½ cubic feet. It can readily be cut with a knife, and in general fashioned like wood. The hardness of chips is slightly over 3 on Moh's scale. The specific gravity of the block stone is 2.66 (i.e. about 166 lbs. per cubic foot). From experiments it is known that when heated to about 1,300°C, the stone begins to soften and has a tendency to flow.

Examination of thin sections shows that the soapstone is a mixture of minerals, as Groves realised, and that even though pyrophyllite were present, it could not constitute much more than half of the bulk.

Thin sections of a specimen from the outcrop described above are particularly instructive. Viewed in ordinary light (Fig. 2a) it has the appearance of a lava—probably andesitic—which has been smeared so that outlines are a little hazy. With crossed nicols, however, there is no sign of this texture, and the whole slide appears as an aggregate of finely granular minerals and a finely flaky mineral (Fig. 2b). The texture seen in ordinary light is relict, the texture the rock had before it was completely replaced by the granular and flaky minerals of which it is now entirely constituted.

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*Numbers IV, 214, etc., refer to specimens and thin sections in the Museum of the Mining and Geological Department, Nairobi.

Minerals identified are: sericitic mica, kaolinite, leucoxene and limonite. In the field the soapstone is seen to contain also sporadic knots and streaks of quartz. Marginally, where the soapstone probably merges into the propylitised lavas, it is to be expected that some specimens will in addition contain chloritic minerals and perhaps epidote.

Sericitic mica occurs in colourless flakes up to about 0.05 mm. long, and is scattered with all orientations throughout the rock. It has refractive indices lying between 1.570 and 1.584, and birefringence about 0.017. The extinction is straight, and the elongation positive.

These properties, except for the birefringence, are indicative of a white mica with the habit of sericite. From experience of sericite in many other rocks it is known that the birefringence of sericitic micas is often much lower than that of ordinary muscovite, of which sericite is a variety. Further confirmation that the mineral is a potash-soda mica is afforded by chemical analyses of the rock, dealt with below.

Kaolinite forms the bulk of the remainder of the rock and is present as a colourless granular matrix to the sericite flakes. The refractive indices lie between 1.558 and 1.700, and the birefringence is about 0.005, though often grains appear to be almost isotropic. The optical sign is negative. The mineral absorbs ink readily and becomes stained.

These properties, while not sufficient to identify the mineral positively, are a strong indication that it is kaolinite or a closely allied mineral. Consideration of the chemical analyses lends confirmation to this suggestion.

Leucoxene, and perhaps sphene, are present as minute grains and aggregates scattered through the slides, and owing to their opacity appear much more abundant than the analyses show can be possible.

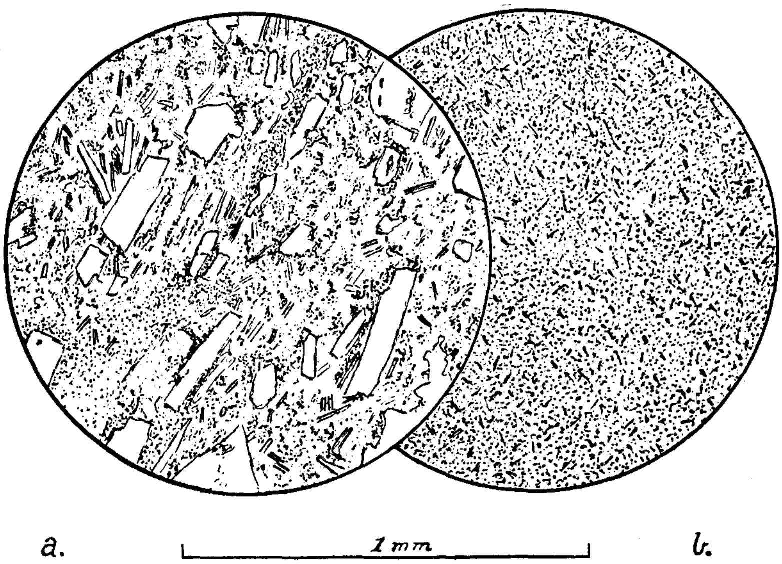


FIG. 2.

(*a*) Drawing of a thin section of soapstone (IV.213/1) as seen under the microscope using ordinary light. The texture is that of a larva.

(*b*) The same microscope field as in (*a*) seen with crossed nicols.

Limonite occurs as a cluster of small pseudomorphs in slide IV, 213/2. The original mineral was cubic, and was probably pyrite.

A slide of soapstone (B. 20) from Samita Hill (Fig. 1, south-east), presented to the Mining and Geological Department by Messrs. Kenya Consolidated Goldfields, Ltd., differs considerably from the rock described above. It is somewhat more coarse-grained, and contains abundant epidote. Sericite and kaolinite are also present but except in their larger grain size do not differ from the same minerals in slides IV, 213/1 and 2.

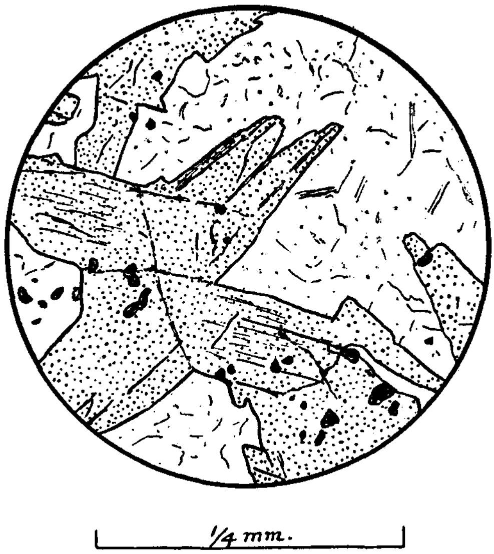


FIG. 3.

Drawing of thin section of epidotic soapstone, Samita Hill, slide B20.

The *Epidote* occurs as scattered crystals, and loose or packed aggregates. The crystals usually show long " prismatic " sections with blunt, pointed, or forked terminations, but squarish clinopinacoidal sections are also seen. Some are cruciform twins (Fig. 3). The prismatic crystals range up to about 0.25 mm. in length, and are colourless or slightly yellowish or brownish, though when coloured they exhibit little pleochroism. They are positively elongated, and of negative optical character. The refractive indices are high, probably somewhat over 1.7, while the birefringence was determined as 0.27.

These optical properties indicate that the mineral is epidote, while the birefringence shows that it is an iron-poor variety containing about 80% of the clinozoisite molecule. The general lack of colour supports the suggestion of a low iron content.

4. *Chemical Analyses.*

Three new analyses are available—all of material from the outcrop on the ridge north of the R. Nyangore. These are quoted below, together with the analyses reported to the Uganda Geological Survey by the Imperial Institute and two old analyses of somewhat similar rocks.

	1.	2.	3.	4.	A	B
SiO_2 ...	46.59	46.42	49.53	46.78	48.60	45.66
Al_2O_3 ...	36.83	37.00	35.73	39.70	32.82	35.10
Fe_2O_3 ...	0.67	0.59	0.29	0.35	—	—
FeO ...	n.d.	n.d.	n.d.	n.d.	2.76	1.11
MgO ...	0.10	0.14	0.05	n.d.	2.37	0.85
CaO ...	0.04	0.12	0.17	0.29	0.84	—
Na_2O ...	0.66	0.94	0.64	n.d.	1.32	4.39
K_2O ...	5.07	4.87	3.81	n.d.	4.08	2,30
H_2O ...	7.70	8.62	8.48	10.96*	8.83	11.68
TiO_2 ...	2.23	1.99	1.67	1.32	—	—
	99.89	100.69	100.37	99.40	101.62	101.09

*Loss on ignition.

1. Sample of ground soapstone, supplied by Messrs. Kenya Consolidated Goldfields, Ltd. Analyst: Miss A. F. R. Hitchins.
2. A second sample of ground soapstone supplied by the same Company. Analyst: Miss A. F. R. Hitchins.
3. Sample of soapstone collected by Dr. C. S. Hitchen. Analyst: Miss A. F. R. Hitchins.
4. Analysis of sample of soapstone collected by E. J. Wayland, quoted from a report supplied by the Imperial Institute to the Geological Survey of Uganda. Published by permission of the Director of the Geological Survey of Uganda.

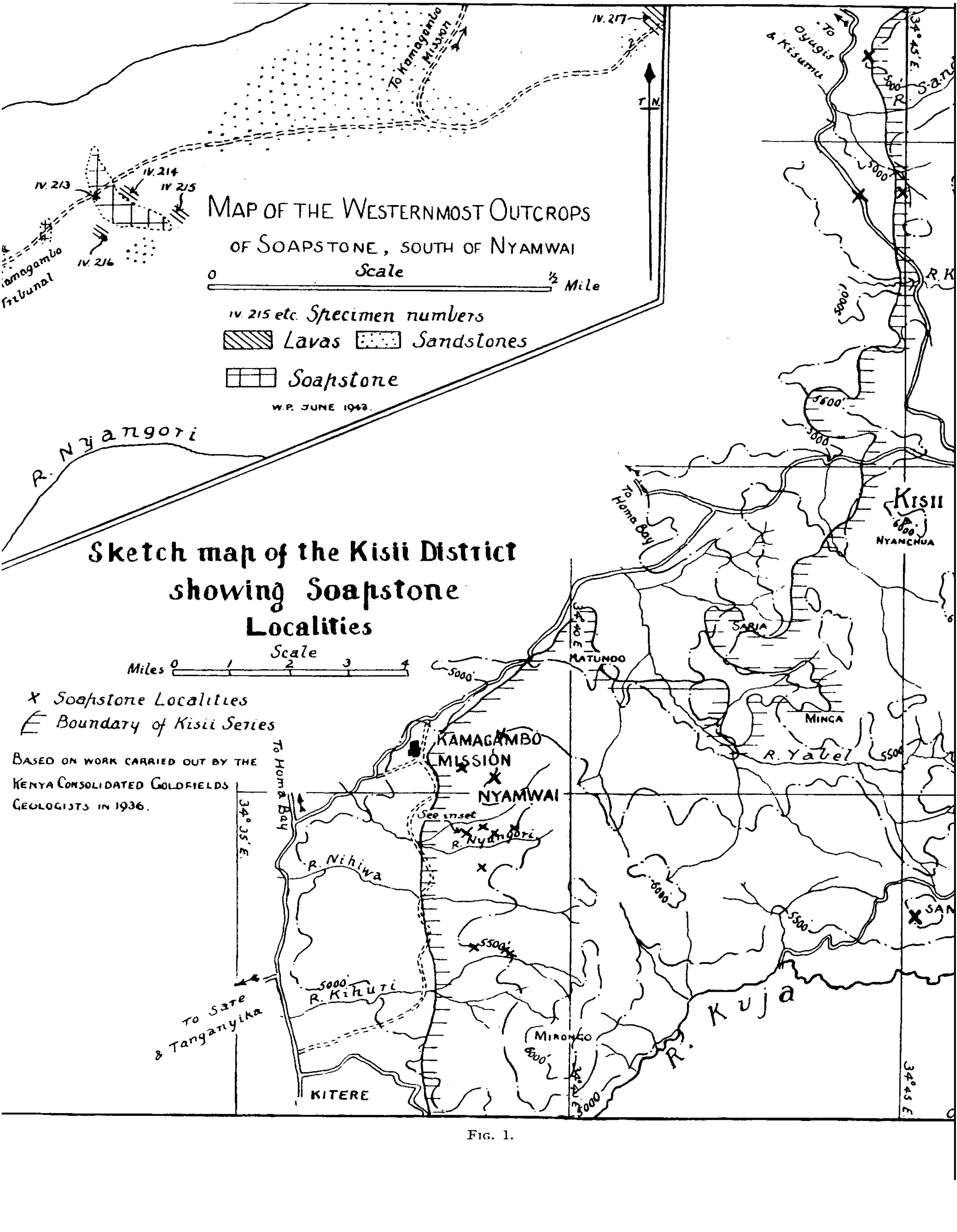
A. A pinitic alteration product from Wildschapbach (Killing, quoted by Sandberger, 1882), quoted from Dana's System of Mineralogy, 1914, p. 622.

B. Restormelite, Restormel Mine, Cornwall (Church, 1870), quoted from Dana's System of Mineralogy, 1914, p. 710, "A massive greyish-green agalmatolite-like mineral. . ."

It is obvious from the new analyses that the soapstone is a rock of variable composition—as might be expected in a replacement product. It is equally obvious that talc plays no part in it, and that pyrophyllite if present could form only a variable portion, not the whole.

The two last quoted analyses are clearly of comparable rocks, and there is a general closeness to several other analyses of pinitic "minerals" quoted by Dana. True pinite (a pseudomorph of cordierite) consists almost entirely of a potash mica but it is evident that many pinites are actually mixtures of potash mica with other minerals. Perhaps the pinitic rock most closely allied to the Kisii Soapstone is the agalmatolite of China or Nagyág in Roumania. "Agalmatolite" is, however, a sack name which has been applied to pinites, compact pyrophyllite and steatite, and has no more value than the general term "soapstone."

The analysis reported by the Imperial Institute presents difficulties. The balance required to bring the summation to 100% may perhaps be regarded as alkali, and there is a marked difference in its proportion compared with those in the three new analyses. There can be little mica in Wayland's sample. On the other hand, while silica and alumina are close to the values required for a rock composed almost entirely of kaolinite, the value for loss on ignition, presumably water, is unduly low. This might be caused by the presence of a second aluminium silicate with lower water content in association with kaolinite, or alternatively by the predominant mineral in the rock being a kaolin mineral with somewhat lower water content than normal kaolinite.



Map of the Westernmost Outcrops of Soapstone, south of Nyamwai
Scale
0
½ Mile
IV. 215 etc. Specimen numbers
Lavas
Sandstones
Soapstone
W.P. June 1943.
IV. 213
IV. 214
IV. 215
IV. 216
IV. 217
To Kamagambo Mission
T.N.
R. Nyangori
Sketch map of the Kisii District showing Soapstone Localities
Scale
Miles 0 1 2 3 4
X Soapstone Localities
Boundary of Kisii Series
Based on work carried out by the Kenya Consolidated Goldfields Geologists in 1936.
To Oyugis & Kisumu
To Homa Bay
Kisii
Nyanchua
Saria
Matundo
Minga
R. Yabel
Kamagambo Mission
Nyamwai
See inset
R. Nyangori
R. Nihiwa
R. Kihuri
R. Kuja
To Sare & Tanganyika
Kitere
Mirongo
34° 35′ E.
34° 40′ E.
34° 45′ E.

Fig. 1.

5. *Calculation of Possible Mineral Constitutions.*

If it is assumed that the microscope determinations of the minerals are correct, mineral constitutions can readily be calculated from the new chemical analyses.* The results are:

	1.	2.	2.
Ilmenite $FeO.TiO_2$	1.27	1.12	0.55
Sphene $CaO.TiO_2.SiO_2$	0.14	0.42	0.59
Rutile TiO_2	1.50	1.23	1.14
Potash mica $K_2O.3Al_2O_3.6SiO_2.2H_2O$	42.95	41.27	32.28
Soda mica $Na_2O.3Al_2O_3.6SiO_2.2H_2O$	8.15	11.67	7.90
Kaolinite $Al_2O_3.2SiO_2.2H_2O$	43.12	41.47	50.95
Quartz SiO_2	3.24	2.90	7.35
MgO	0.10	0.14	0.05
Water	—	0.41	—
	100.47	100.63	100.81
Less water added for kaolinite	0.65		0.47
	99.82		100.34

The supposed titanium minerals are probably all contained in the leucoxene of the rock, while the potash and soda micas should be understood as contained in the sericitic mica.

The fact that the analyses can be so reasonably calculated to mainly micas and kaolinite is some confirmation of the identifications of the minerals in the thin sections. If the calculation is carried as far as the micas (in analysis No. 1 for example) and then it is assumed that the remaining alumina is in pyrophyllite, it is found that there is a deficiency of 16.84% of SiO_2 and an excess of 2.38% H_2O. Attempts to extract pyrophyllite first, before dealing with the alkalis, are similarly foiled, there being immediately a deficiency of silica.

Re-calculation of the analysis reported by the Imperial Institute is more difficult. If alkali is assumed to be 0.6% K_2O and the calculation is made on the lines indicated above, after the abstraction of titanium minerals and mica, amounts of silica, alumina and loss on ignition (assumed to represent water) remain which cannot be combined to give kaolinite or any other standard hydrated aluminium silicate, owing to a deficiency of water. A few calculations also show that though a mixture of kaolinite and pyrophyllite can be found which contains the amount of water available, the

*The method of calculation is as follows:—standard molecules are assumed, and magnesia is neglected; Fe_2O_3 is recalculated as FeO and combined with a portion of the TiO_2 to form ilmenite; more TiO_2 is absorbed in combination with the total CaO and part of the SiO_2 to give sphene; the balance of the TiO_2 is then expressed as rutile; the total K_2O is combined with opposite amounts of Al_2O_3, SiO_2 and H_2O to give potash mica, and Na_2O treated similarly for soda mica; the balance of the Al_2O_3 is then combined with SiO_2 and H_2O for kaolinite, after which only SiO_2 (quartz) and a small amount of water is left (or a small amount of water must be added to satisfy the kaolinite).

silica and alumina are widely in disagreement, and it may be considered as unlikely that pyrophyllite appears in the rock. The results of a calculation using a " kaolin " deficient in water is reported below :

	4.
Ilmenite $FeO.TiO_2$	0.66
Sphene $CaO.TiO_2.SiO_2$	1.01
Rutile TiO_2	0.56
Potash Mica $K_2O.3Al_2O_3.6SiO_2.2H_2O$	5.09
" Kaolin mineral " $Al_2O_3.2SiO_2.1.61H_2O$	92.86
Water	0.04
	100.22
Less SiO_2 added to form "kaolin mineral"	0.26
	99.96

No mineral, so far as I am aware, has the composition of the " kaolin mineral " quoted, and as the analysis varies so widely from the three recent analyses of similar rocks, it is perhaps preferable at present not to place emphasis on it. In the discussion below only the modern analyses are considered.

6. *Origin of the Soapstone*.—The Kenya Consolidated Goldfields geologists could devote little time and attention to the soapstone, but it seems clear that they considered it a sediment with sedimentary associates. The present work indicates however that the soapstone occurrence described is more closely associated with lavas than with the sandstones, and that it is in fact itself a highly altered lava. The Samita stone, though not exhibiting relict volcanic textures, may from its mineral constitution be inferred to have a similar origin. It is not suggested that all the soapstones are necessarily altered lavas, but it is evident that all should be examined before a sedimentary origin is ascribed to them.

The soapstone described occurs in association with lavas which are highly altered or propylitised, a hydrothermal change which is usually ascribed to the action of hot carbonated waters rising from volcanic foci, altering already consolidated lavas or shallow intrusives as it passes through them. There is no direct evidence that the waters which altered these lavas were carbonated, or at least, no carbonates were precipitated, but the alteration may be ascribed to hot ascending aqueous solutions, while the presence of carbonic acid would afford an agent which it is known could produce the leaching effects required. The soapstone, appears to form a core to the normally propylitised lavas and may be considered as a zone or pipe in the lavas in which the alteration was either more prolonged or more intense.

The production of sericite and kaolinitic minerals by hydrothermal action is well known in ore deposits. (Ore deposit kaolinites are usually identified as dickite or nacrite, but the mineral of the present rock is optically negative and so cannot be dickite, while the ease with which it absorbs ink suggests that it is not nacrite. It is not impossible however that original nacrite or dickite may have been converted to kaolinite by weathering). Many years ago Lindgren* found that supposed talcose material in veins and in rhyolites associated with them consisted of mixtures of mica and kaolinite varying from almost pure potash mica to almost pure kaolinite. Later,† from a locality where alteration by hot uprising fluids could be proved, he showed that alteration patches in a granite consisted of sericite, kaolinite, fibrous

*" The Gold and Silver Veins of Silver City, De Lamar and other Mining Districts in Idaho." *U.S. Geol. Surv.* 20th Ann. Rep., 1898-9, Pt. III, p. 65 (p. 171).

†In W. H. Weed, " Mineral Vein Formation at Boulder Hot Springs, Montana," *U.S. Geol. Surv.* 21st Ann. Rep., Pt. II, 1899-1900, p. 227 (pp. 252-3).

silica and rutile. Many other occurrences are known where the sericite-kaolin association occurs, particularly in connection with ore deposits formed at shallow depths.

Without porosity determinations and analyses of fresh rocks similar to that from which the soapstone was formed, it is not possible to gain much information of the nature of the fluids which caused the alteration, or of the materials which were removed from the fresh lava. Comparison, however, of a soapstone analysis and computed average analyses for andesites and basalts are instructive:

	1.	C.	D.	1a.	Da.
SiO_2	46.59	59.59	48.80	124.1	142.0
Al_2O_3	36.83	17.31	13.98	98.1	40.7
Fe_2O_3	0.67	3.33	3.59	1.8	10.5
FeO	n.d.	3.13	9.78	—	28.5
MgO	0.10	2.75	6.70	0.3	19.5
MnO	n.d.	0.18	0.17	—	0.5
CaO	0.04	5.80	9.38	0.1	27.3
Na_2O	0.66	3.58	2.59	1.7	7.5
K_2O	5.07	2.04	0.69	13.5	1.8
H_2O	7.70	1.26	1.80	20.5	5.2
TiO_2	2.23	0.77	2.19	6.0	6.4
P_2O_5	n.d.	0.26	0.33	—	1.0
	99.89	100.00	100.00	266.1	290.9

1. Soapstone repeated from above.

C. Average andesite, quoted from R. A. Daly " Igneous Rocks and the Depths of the Earth," 1933, p.16.

D. Average plateau basalt, quoted from Daly, op. cit. p. 17.

1a. Calculated proportions of oxides of analysis 1 contained in 100 cc. of the rock.

Da. Calculated proportions of oxides of analysis D contained in 100 cc. of the rock.

Assume first for convenience that the parent rock was an andesite, as appears most likely from the associated rock types. As the specific gravity of the soapstone is 2.66 and the average specific gravity of andesites is about 2.65, and as no marked porosity changes accompanied the formation of the soapstone, the figures of analyses 1 and C can for present purposes be discussed as they stand. Thus the change andesite—soapstone was probably accompanied by considerable losses of iron, magnesia, lime and soda, and by a moderate loss of silica, but on the other hand by considerable gains of alumina, potash and water, with a moderate gain of titania. The gain in alumina is of particular interest as in many cases of hydrothermal alteration, except where intense silicification or impregnation by sulphides occurs, alumina remains a more or less stable factor. Cases are known however where alumina has been added.* In many cases of hydrothermal alteration gains in silica are evident, but several cases where losses occur are known and are quoted by Schwartz,† though often an apparent silica loss is caused by the introduction of large volumes of carbonates, a factor which does not operate in the case of the

*" Hydrothermal Alteration of Igneous Rocks." G. M. Schwartz. *Bull. Geol. Soc. Amer.* Vol. L, 1939, p. 181 (p. 217).

†Loc. Cit. pp. 215-217.

soapstone. On the whole the changes described are such as agree well with evidences of world-wide nature which are accepted as indications of hydrothermal alteration. The gain in titania is perhaps an exception, titania being more usually lost in hydrothermal alteration, though it is frequently " gained " in rocks produced by weathering processes, *e.g.*, lateritic deposits.

In the case of the Samita Hill rock the changes may have been different, *e.g.*, there may have been a gain in lime, while the accession of alumina was certainly much less, or it may even have been substracted. The propylitised lavas again show different changes viz., possible enrichment in magnesia and ferrous iron. These varying changes are probably attributable to differences in temperature and the chemical nature of the reacting fluids during the period or periods during which hydrothermal action continued.

If it is assumed that the parent rock was basaltic, an idea of the changes during alteration can be gained from the results of calculations (made to neutralise the effect of differences of specific gravity, the average specific gravity of basalt being taken as 2.91) reported in columns 1a and Da above. Quantitatively the gains and losses, with the exception of titania which remains almost constant, are those found for the andesite—soapstone change. There are, however, quantitative differences, viz., the basalt—soapstone change implies, as would be expected, much greater accessions of potash, while there is a slightly greater gain of alumina but considerably less gain in water. On the losses side there is little difference except in the iron, where naturally the basalt would have to lose a considerable proportion of its original content.

It is possible that the silica removed during alteration was later redeposited as the cherts which occur locally in the Middle Kisii Series. In addition some of the iron may have been precipitated and concentrated as oxides in the overlying sandstones. Such concentrations were first observed many years ago in Kisii sandstones.*

The nature of the acids or bases combined with the migrant radicles is not known, but it is usually considered that acid conditions are required for the formation of kaolinite, while weakly acid or alkaline conditions are required for the precipitation of sericite. The latter are known in epithermal ore deposits to follow primary acidic stages and it is perhaps admissible to consider that in the soapstone the order of formation was first kaolinite and then sericite, the formation of the latter being overlapped by the propylitisation of the non-kaolinised lavas. This sequence implies a primary removal of alkalies (mainly soda) during the acidic kaolinite-forming phase, followed by the introduction of alkalies (mainly potash) during the sericite-forming phase. In addition the propylitic alteration of the external lavas may have been in part caused by the reception of the magnesia and lime displaced from the lavas altered to soapstone.

The formation of sericite perhaps indicates the presence of fluorides in the attacking fluids.†

The fact that kaolinite was formed in the lavas yields some idea of the temperature at which the reactions took place. It has been found experimentally that with appropriate mixtures kaolinite forms under moderate pressures at temperatures

*F. Oswald, " The Miocene Beds of the Victoria Nyanza and the Geology of the Country between the Lake and the Kisii Highlands." *Quart. Journ. Geol. Soc.*, LXX, 1914, pp. 128-198 (p. 152).

†A. J. Leonard, " The Hydrothermal Alteration of certain Silicate Minerals," *Econ. Geol.*, XXII, 1927, p. 18.

between 400°C and 200°C. With similar systems pyrophyllite forms at temperatures above 400°C.* Temperatures between 400 and 200°C would be amply sufficient for the formation of sericite.†

No evidence has been obtained of the depth at which the alteration took place, but it was probably shallow and may even have been near surface. Consideration of the pressures used by Noll indicates that burial at depths of about 200 to 400 feet would have been sufficient to allow the formation of kaolinite and sericite.

7. *Summary.*

A soapstone from the Kisii district is shown to consist mainly of sericite and kaolinite. It is associated with highly altered lavas and was itself originally a lava, converted to its present state by hydrothermal action. A second soapstone from Samita Hill, is, by analogy and on its mineral constitution, similarly considered to be a hydrothermally altered rock, though not necessarily a lava.

*W. Noll. "Ueber die Bildungsbedingungen von Kaolin, Montmorillonit, Sericit, Pyrophyllit, und Analcim," quoted in G. W. Morey and E. Ingerson, "The Pneumatolytic and Hydrothermal Alteration and Synthesis of Silicates," *Econ. Geol.*, XXXII, Supplement, Aug. 1937, p. 746.

†Noll, quoted by Morey & Ingerson, loc. cit. pp. 721-2.