LAVAS OF THE AFRICAN RIFT VALLEYS AND THEIR TECTONIC SETTING.

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ABSTRACT.

The state of knowledge and opinion as to the African Rift Valleys and their lavas was, a decade ago, such as to suggest that a definite correlation might be made between the tectonics and the chemistry of the lavas. The Western Rift Valley seemed to have been formed as a result of compressive stresses in the crust and to have associated with it lavas of potash-rich character. The Eastern Rift Valley seemed to have been formed as a result of tensional stresses and to have associated with it lavas of soda-rich character. The picture now presented is less simple. As a result of further investigation there has arisen much diversity of opinion as to the tectonic forces controlling the formation of both Rift Valleys, and there seems therefore no adequate basis for an attempt to correlate lava chemistry with contrasted tectonics. In addition, recent studies of the lavas have brought to light many exceptions to the general tendency towards preponderance of potash in the Western Rift and preponderance of soda in the Eastern Rift. Some new analyses are given which illustrate these exceptions and emphasize the fact that, as in the case of the tectonic relations, no simple picture of the chemistry of the lavas can be outlined at the present time. Indeed, when the question of the origin of the dominant lavas of the Western Rift is reviewed in the light of latest knowledge, their potash-rich character seems to be a relatively accidental circumstance. This question is discussed and the lack of any convincing relation between lava chemistry and tectony in the Rift Valleys is emphasized.

INTRODUCTION.

In 1929 the opportunity came of making a field study of the volcanic rocks of the African Rift Valleys under the auspices of the Carnegie Institution of Washington, a welcome opportunity, especially since the investigation was to be made in conjunction with structural investigations of these earth features by Professor Bailey Willis. At that time the picture of Rift Valley relations to be gained from the literature was somewhat as follows. (See Fig. I.)

In East Africa a structural trough or graben constituting, towards its southern end, the basin of Lake Nyasa, extending with more or less important interruptions and complications in a meridional direction to the basin of Lake Rudolf, turning northeastward through Abyssinia to the Gulf of Aden and having associated with it volcanic rocks uniformly of a *soda-rich* character.

In Central Africa a similar trough branching from the former near the head of Lake Nyasa, extending, again with certain complications, through the basins of Lake Tanganyika, Lake Kivu, Lake Edward and Lake Albert and having associated with it, though only locally, from Lake Kivu northward, volcanic rocks uniformly of a *potash-rich* character.

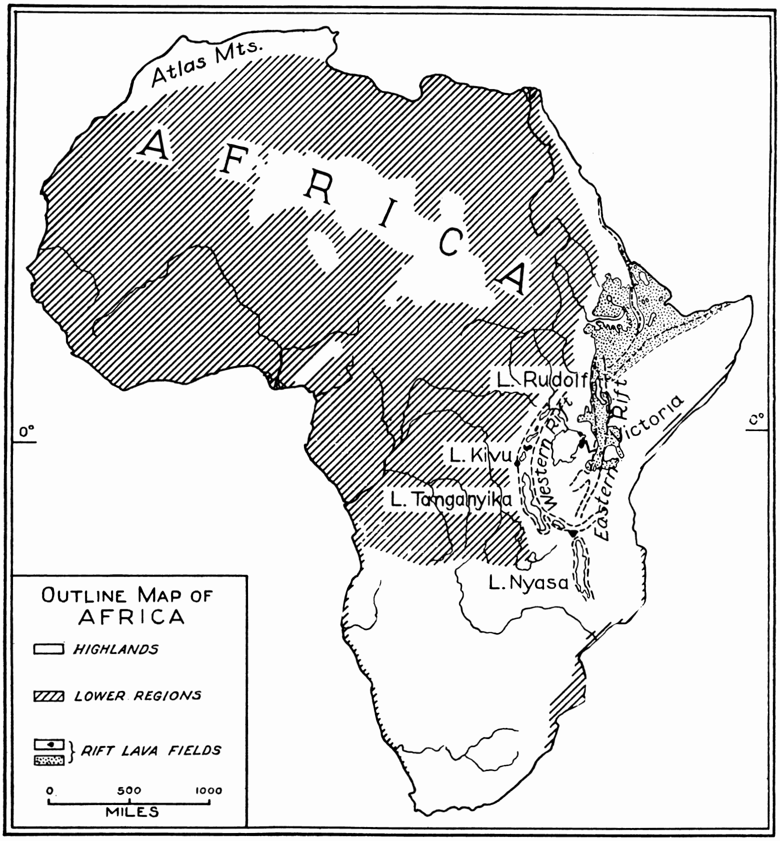

Fig. 1. Map of Africa showing position of Rift Valleys.

With scarcely a dissenting voice, opinion was that the Eastern Rift formed as a result of normal or tensional faulting.

On the other hand there appeared to be growing support for the opinion advanced by Wayland that the Western Rift, in the vicinity of Lake Albert at least, was formed as a result of overthrust or compressional faulting.

Could it be that here in Africa was offered an unequivocal demonstration of the control of tectonic forces and consequent crustal movements over the chemistry of igneous magmas?

The hypothesis that the tectonic conditions of a region exert some sort of control over the chemistry of the eruptive rocks of the region received its first impetus when Harker, in 1896, pointed out "the very general correspondence of the areas of the alkali and sub-alkali groups respectively with the areas of the Atlantic and Pacific types of coast-line as defined by Suess."[1] This led to the discrimination of an Atlantic suite of igneous rocks corresponding with those that are chemically characterized as the alkalic rocks and a Pacific suite corresponding with the sub-alkalic rocks. The merits of the concept have been much discussed, with the result that it has met with no more than partial acceptance, and in particular the wisdom of the use of terms having geographic connotations has been questioned. Yet this fact has not deterred others from introducing additional terms of like character to designate further distinctions, and thus have arisen the Arctic suite and the Mediterranean suite. The geographic-tectonic implications of the terms are now not usually stressed by those who use them. Pacific suite or branch ordinarily designates, simply, sub-alkalic rocks; Atlantic branch, alkalic rocks in which soda is the dominant alkali; and Mediterranean branch, alkalic rocks in which potash is the dominant alkali. There still adheres, albeit rather loosely, the concept that the Pacific suite is associated with folded mountains and the Atlantic suite with centripetal movement of the crust or crustal foundering. The supposed tectonic affinities of the Mediterranean suite have not been made entirely clear, but the sponsors appear to connect this suite with the early stages of folded chains in substantially the same tectonic setting as the Pacific types.[2] If, then, the lavas of the Eastern Rift were really uniformly soda-rich and the crustal movement there of a centripetal type, and if, on the other hand, the lavas of the Western Rift were uniformly potash-rich and the crustal movement there of the nature of a thrust, there would appear to be strong support for that kind of relation between tectony

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[1] Harker, Alfred: The Natural History of the Igneous Rocks, p. 93, 1909.
[2] Niggli, P.: Schweiz. Mineralog. petrog. Mitt., 2, p. 259, 1923.

and chemistry that is involved in the concept of Atlantic and Mediterranean suites. What causal connection there could be between tectony and chemistry is a question that could be attacked when and if it was verified that the conditions were really as suggested. There may, too, seem to be serious difficulty in visualizing a condition in which there could be tension on the eastern side and compression on the western side of the block enclosed between the Eastern and Western Rifts, but this difficulty is not insurmountable. We might, for example, imagine a continent which tended to drift westward but had some of its segments more firmly anchored than others. A certain segment with a more marked tendency to drag its anchor might tend to press against its neighboring segment to the west and pull away from its neighbor to the east.[3] Probably other conditions, not involving migrating continental blocks, might be imagined to explain this contrast of conditions on opposite sides of a block, were the observed facts definitely such as to encourage such speculation. Unfortunately it has proved, partly as a result of our investigation and partly as a result of later work, that the tectonic contrast suggested is not verifiable and the chemical contrast, while undeniably present in a broad sense, is nevertheless not without exceptions, and the whole picture is therefore not as clear-cut as is desirable for a test case. In the following it is proposed to set forth those findings, and opinions arising from them, that have tended to blur the simple picture.

TECTONICS.

The various opinions that have been held as to the causes of Rift Valleys and the nature of the forces involved in their formation have been summarized in a masterly manner, with apt quotations from the original sources, by Willis in his monographic treatment of these structures in Africa.[4] The early views of Suess, Gregory and others that the faults were of tensional origin had been questioned in some measure by Uhlig[5] but no important evidence to the contrary was advanced until Wayland[6] described what he regarded as reverse faults

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[3] On this suggestion see Daly: Geology of Ascension Island, Proc. Am. Acad. Arts Sci., 60, 19, 1925, and Our Mobile Earth, pp. 275-291, New York, 1926.

[4] Willis, Bailey: Carnegie Inst. of Wash. Pub. No. 470, 1936.

[5] Uhlig, Carl: Geogr. Z. Leipzig, 13, 500, 1907.

[6] Wayland, E. J.: Geogr. J., 58, 244 et seq., 1921.

in the Albertine Rift. It there had been no further development of diverse views it would have been possible to entertain a picture involving tensional faulting in the Eastern Rift and compressional faulting in the Western Rift. But Willis's own conclusion, which he regarded as applicable to all the rifts, was stated as follows, "It is clear that the causes of the vertical uplift of the plateaus and the associated effects of downward drag are the cause of the rift valleys. Horizontal forces play a subordinate part and as compressive stresses only. Horizontal tension has not been recognized."[7] To be sure, the only very cogent evidence of horizontal compressive stresses that one finds outlined is the single example of reverse faulting in the Albertine Rift, and Willis himself, setting down the first record of his opinions gained in Africa, expressed agreement with Gregory that the East African Rift (Great Rift Valley) was formed as a result of "stretching."[8]

On the other hand, since Willis's examination observations have been made, especially on the Eastern Rift, that have been regarded as indicating thrust forces. Bullard[9] has made gravity measurements in the Rift Valleys and on the adjacent plateaus. He finds the plateau as a whole compensated, but the Rift Valleys showing negative anomalies. He concludes therefore that the floor of the Rift Valley would rise were it not pressed down by the adjacent plateau, which has been thrust over it. There are in addition observations by Fuchs[10] on the Lake Rudolf portion of the Rift Valley of which he says ". . . early Miocene lavas and tuffs are folded by pressure in an east-west direction. Thus, taking the lake as a central line, we found that the folds on either side were overfolded towards it."

Whether Bullard has taken adequate count of the possible presence of very light masses of rock close to the instrument—for there are very light lavas in the valleys and therefore possibly light intrusives not far beneath them—and whether Fuchs' observations will stand, I leave for others and the future to decide. The findings and opinions listed are given merely to emphasize the complete lack of agreement upon a picture of the Rift Valleys such as that suggested on an earlier page, a tensional Eastern Rift and a compressional Western Rift, or

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[7] Willis, Bailey: op. cit., p. 71.
[8] Willis, Bailey: Living Africa, p. 304, New York, 1930.
[9] Bullard, E. C.: Phil. Trans. Roy. Soc. London, A 235, 445-531, 1936.
[10] Fuchs, V. E.: Geogr. J. London, 86, 132-133, 1935.

indeed upon any picture. There is, to be sure, a growing tendency to regard the rifts as the result of compression, yet I should be remiss in recording the facts if I omitted to state that, upon his return from a visit to the Albertine Rift, the late Dr. John W. Evans informed me that he was not convinced that this crucial area for the launching of the compression hypothesis really exhibited reverse or compression faulting.

With such lack of agreement upon tectonic relations there is naturally little encouragement to the petrologist to attempt to correlate tectony and lava chemistry.

COMPOSITION OF THE LAVAS.

Alongside this picture of the unsatisfactory state of knowledge and opinion upon the Rift structures we may place the fact that the chemical composition of the lavas is now known to show less systematic variation than had formerly been supposed to exist. The lavas of the Eastern Rift are nearly all soda-rich but a few examples were collected that show excess of potash over soda and one or two others of this character have since been recorded in the literature. The lavas of the Western Rift are dominantly potash-rich but locally there are areas showing lavas with a distinct excess of soda over potash. It is intended now to give some details regarding these exceptions to the general trend, in other words, some details of the potash-rich lavas of the Eastern Rift and of the soda-rich lavas of the Western Rift.

The lavas of the Eastern Rift normally contain such a marked excess of Na_2O over K_2O that any representative which contains even a small excess of K_2O over Na_2O is worthy of at least passing mention in this connection. The more salic lavas of the Rungwe volcanics, occurring at the head of Lake Nyasa, sometimes contain a slight excess of K_2O over Na_2O. Thus there is a nepheline trachyte with Na_2O 6.04 per cent and K_2O 6.39 per cent and a quartz bostonite with Na_2O 5.68 per cent and K_2O 5.74 per cent.[11] In the middle reaches of the Eastern Rift the chemistry of the lavas is best known, but from this section and the neighboring great volcanoes, Kilimanjaro and Mt. Kenya, only one example with even a moderate excess of K_2O has been recorded. This is a rhyolitic obsidian from Lake Naivasha with Na_2O 4.55 per cent and K_2O 4.69 per cent.[12]

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[11] Lehmann, E.: Z. Vulkanologie, 4, 101 and 113, 1924.

[12] Bowen, N. L.: This Journal, 33, 14-15, 1937.

Farther to the north, examples become more common both in the Rift and in the neighboring great volcano, Mt. Elgon. In the lavas of Elgon there is a general tendency towards more even balance of the two alkalis and in one leucocratic type, a phonolite, there is Na_2O 6.48 per cent and K_2O 6.52 per cent.[13] A somewhat more marked development of this relation is shown in a phonolitic trachyte pitchstone collected by Professor Willis at Lake Baringo. The analysis is given in Table I.

TABLE I.

Analyses of Potash-Rich Lavas of the Eastern Rift Valley.

	I	II		I(a)	II(a)
SiO_2	55.65	69.78	Q	...	37.1
Al_2O_3	15.97	6.68	or	37.8	30.0
Fe_2O_3	3.80	5.63	ab	34.1	6.3
FeO	2.77	2.68	ne	6.8	...
MgO	.86	.04			
CaO	1.71	.68	ac	3.2	12.5
Na_2O	5.96	2.42	di	5.3	3.2
K_2O	6.37	5.07	hy	...	1.9
H_2O+	3.93	5.43	ol	1.2	...
$H_2O—$	1.45	1.09	mt	3.9	1.9
TiO_2	.75	.56	il	1.4	1.1
P_2O_5	.16	...	ap	.3	...
Cl	.11	...	CaF_2	.2	...
F	.15	...	hl	.2	...
MnO	.29	.19			
S	.04	...			
	100.06	100.25			
	— .09				
	99.97				

I Phonolitic trachyte pitchstone, Lake Baringo. R. B. Ellestad, analyst.
II Pantellerite pitchstone, Turkana. F. Raoult, analyst. E. Jérémine, Compt. rend., 198, p. 675.
I(a) Norm of I.
II(a) Norm of II.

A very marked excess of K_2O is found in a pitchstone from Turkana, a name given to the country immediately to the west of Lake Rudolf. The analysis by Raoult[14] is here given in Table I. A volcanic plug in the same region has been described

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[13] Ödman, O.: Geol. Fören. Förh., 52, 504, 1930.

[14] In Elizabeth Jérémine, Compt. rend., 198, 673-675, 1934.

as consisting of "pure orthoclase"[15] but Campbell Smith (personal communication) does not accept this observation.

It is probable that for the more extreme cases of richness in potash feldspar a secondary origin is to be inferred, say in the potash-rich pitchstone. Terzaghi[16] suggested that lavas may be enriched in K_2O by hydrothermal after-action and Fenner has shown that this result has come from such action in Yellowstone lavas.[17] Even apart from these extreme cases it is still true that the soda-rich rocks of the Eastern Rift have associated with them types with an excess of K_2O. If tectonic forces controlled the composition of the rocks they did not produce rocks uniformly soda-rich.

The Western Rift does not display vulcanism through such a great proportion of its length as does the Eastern Rift. Towards the south there are no associated lavas; even the spectacular trough occupied by Lake Tanganyika, with its bottom locally as much as 2,200 feet below sea level, is free from lavas. Some 30 miles southwest of Lake Kivu the lava field of South Kivu begins and extends to the southern and southwestern shores of the lake. After an interval the great lava field of North Kivu (Birunga), with two volcanoes still active, comes in at the northern extremity of the lake and extends over 40 miles northward and northeastward. Beyond the limits of this field there are sporadic occurrences of volcanic activity extending northward, with wide barren intervals, for a distance of 150 miles, to the southeastern foot of Ruwenzori. The activity in this section is characterized almost exclusively by explosion craters and tuff beds, lava flows being very rare.

The tuffs and other products of these northern vents are all potash-rich as are also nearly all the lavas of the North Kivu (Birunga) field. They are the best known lavas of the Central African Rift and it is this fact that has led to the acceptance of the rift as a region of potash-rich lavas.[18] The latest flows of the latter area show, however, a distinct trend towards richness in soda. These occur at the southern extremity of the area, on the northern shores of Lake Kivu, into whose waters some recent lavas have poured, prominent among them being the Katerusi flow of 1912. Analyses have been made of a

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[15] Fuchs, V. E.: Geogr. J. London, 86, 126, 1935.

[16] Terzaghi. Ruth Doggett: This Journal, 26, 377, 1935.

[17] Fenner, C. N.: Trans. Am. Geophys. Union, 15, 241-243, 1934.

[18] Holmes, A., and Harwood, H. F.: Quart. J. Geol. Soc. London, 88, 370-442, 1932, and Geol. Survey Uganda Mem. No. 3, pt. 2, 1937.

number of these flows with an excess of Na_2O over K_2O. They are given in Table II with references to the original papers. Included in the table is an analysis of the Kanamaharagi flow of 1905 which shows that the recent lavas do not all have an excess of Na_2O, though the excess of K_2O in it is quite small. This lava, which is a leucite basanite and is named for its source, a small cone on the eastern slope of Nyamlagira, flowed to the lower slopes of Mikeno, destroying the banana groves of the natives. It has been examined microscopically by all who have studied collections from the area but has not hitherto been analyzed.

TABLE II.

Analyses of Soda-Rich Lavas of North Kivu Lava Field.

	I	II	III	IV	V	VI	VII	VIII
SiO_2	47.67	44.42	48.62	46.71	44.18	44.82	37.70	44.88
Al_2O_3	14.20	14.27	17.44	12.46	14.77	18.11	13.83	14.22
Fe_2O_3	3.59	3.39	5.42	3.00	3.70	7.34	4.27	1.88
FeO	9.18	8.68	6.55	9.03	7.69	3.63	7.09	9.96
MgO	6.24	7.23	5.50	9.56	5.35	2.92	5.41	7.59
CaO	8.98	12.36	10.00	11.61	15.40	10.61	15.02	10.65
Na_2O	3.21	3.64	2.30	3.10	2.51	5.65	4.50	2.85
K_2O	2.41	2.44	1.92	1.06	1.02	4.30	4.92	3.09
H_2O+		.15					1.22	.08
	.92		.63	1.11	1.13	.78		
H_2O-		.09					.61	.03
TiO_2	2.64	3.42	1.29	1.74	2.19	.82	3.18	3.40
P_2O_5	.66	.13	.11	.33	.51	.78	1.86	.62
Cl	....	....	....	....	....	.03	....	.05
S	....	....	....	.05	....	.07	....	.05
MnO	....	....	....	....	.39	.24	.26	.19
CO_2	....	....	....	....	....	....	.12	.06
BaO	....	....	....	....	....	....	....	.05
	99.80	100.17	99.79	99.76	99.69	99.51?	99.99	99.65

I	Leucite basanite (doleritic), Mukira. L. Finckh, op. cit., p. 18.
II	Basanitoid, Bobandana. A. Lacroix, Min. de Madagascar, 3, 265, 1923.
III	Trachydoleritic leucite basanite, Kisenyi. L. Finckh, op cit., p. 18.
IV	Limburgite, Adolph Friederich Volcano. L. Finckh, op. cit., p. 22.
V	Limburgite, Adolph Friederich Volcano. L. Finckh, op. cit., p. 22.
VI	Melilite nephelinite, Ngoma. L. Finckh, op. cit., p. 26.
VII	Melilite-leucite nephelinite, Ngoma. R. B. Ellestad, analyst.
VIII	Leucite basanite, Kanamaharagi. R. B. Ellestad, analyst.

There is included in the table also an analysis by Hauser of a melilite nephelinite from the crater, Ngoma, a small crater on the north shore of Lake Kivu. The analysis[19] shows a considerable excess of soda over potash but there are in this case reasons for regarding the analysis as unacceptable. The rock is described as containing phenocrysts of melilite and nepheline in a groundmass consisting essentially of melilite and nepheline, with leucite, augite, magnetite and small amounts of other constituents. Yet the analysis of this rock, so rich in melilite, shows nearly 45 per cent SiO_2 (No. VI, Table II) and when the norm is calculated no calcium orthosilicate and no olivine is found. On the contrary there is over 25 per cent normative orthoclase and even some normative albite.[20] An analysis of a melilite-leucite nephelinite from Ngoma is now available (No. VII, Table II) which shows that the actual mineral composition of the rocks of this general type from the crater is not so notably abnormative. The norm, calculated from this analysis, shows no orthoclase or albite but much leucite and nepheline and more than 20 per cent calcium orthosilicate and olivine represented in the rock largely as melilite.[21] It is clear that the Hauser analysis is not acceptable, indeed it may be noted that the summation of the analysis is given as 99.51 whereas the figures actually add up to 100.18, so that there is perhaps a printer's error involved. It is most unfortunate therefore that Holmes and Harwood should have used this analysis as representative of an actual rock corresponding with their hypothetical "Magma X" to which they attach fundamental importance in the genesis of rock types in the North Kivu area.[22]

In contrast with the North Kivu lavas which show only in some instances a departure from the prevailing dominance of K_2O over Na_2O in the region of the Western Rift, the lavas of South Kivu, the southernmost area of vulcanism of this Rift, appear to trend towards a dominance of Na_2O, though there are marked exceptions to this condition. Unfortunately, not enough is known of their chemistry to permit a more definite statement.

At the time of our visit, little was known of the extent and general relations of the South Kivu field and we saw it for the

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[19] Finckh, L.: Wiss. Ergebn. Deut. Zentral-Afrika-Exped. 1907-8, 1 (1), 26, 1912.

[20] Washington, H. S.: U. S. Geol. Survey, Professional Paper 99, 583, 1917.

[21] Bowen, N. L., and Ellestad, R. B.: Am. Mineral., 21, 365, 1936.

[22] Holmes, A., and Harwood, H. F.: Geol. Survey Uganda Mem. No. 3, pt. 2, 82, 1936.

most part only en route from Lake Tanganyika to Lake Kivu and on the shores of Lake Kivu itself. Since that time it has been discovered by Boutakoff[23] that the lavas of the South Kivu field came principally from two great composite volcanoes, Biega and Kahusi, to the southwest of Lake Kivu. From these centres flows spread as much as 40 miles to the south and southeast and 20 miles to the west. The most extensive flows are basaltic, though trachytes are rather wide-spread also. Of limited distribution and closely associated with the centres of eruption are masses of quartz porphyry and rhyolite which have emphasized explosive phases and the formation of Pelée-like domes. Of these various types only the basalts and trachytes were seen in our traverse.

The basaltic lavas have been described as ordinary olivine basalts but in specimens of adequately coarse crystallization it can be made out that there is a feldspar of index lower than balsam in the groundmass (anorthoclase) and the rocks would be more adequately described as trachydolerites, indeed their general microscopic aspect is trachydoleritic. A specimen collected at the rapids at the outlet of Lake Kivu appears to be typical. It has phenocrysts of augite and olivine in a groundmass containing the same minerals with labradorite. This is zoned and passes to anorthoclase which is not abundant but forms a sort of mesostasis. Specimens of columnar lava from the shores of Lake Kivu about a mile northwest of Bukavu (Costermansville) are not significantly different. By reason of a mislaying of the specimens after chips had been sent off for thin sections it has not been possible to get an analysis of these trachydoleritic basalts. They show no significant microscopic differences from the trachydolerites of the North Kivu field but whether they would prove to be potash-rich or, on the other hand, soda-rich, like the basaltoid rocks of the Eastern Rift is a question that has not been decided.

The trachytes are light-colored rocks and have not been described in detail hitherto. Two specimens of somewhat different character have therefore been selected for analysis and special description. One of these was collected by Professor Willis one mile west of the road at a point 3 miles south of Costermansville and at an elevation of 600 feet above the lake. It is a highly vesicular lava of a light, ash-grey color, with rare phenocrysts of feldspar. Microscopic examination shows

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[23] Boutakoff, N.: Bull. soc. belge géol., 43, 42, 1933.

that these are of andesine, about Ab_1An_1 ($\gamma = 1.550$), mantled by alkali feldspar, and reveals other smaller phenocrysts of basaltic hornblende and more rarely of alkali feldspar. The hornblende is pleochroic from amber to deep brown. It has the refractive indices $\gamma = 1.719$, $\beta = 1.700$ and $\alpha = 1.686$. The extinction angle $c \wedge \gamma = 3.5°$. These hornblendes have been changed peripherally, and sometimes through and through, to a fine-grained aggregate rich in magnetite, a change which attests the instability of the hornblende in contact with magma under surface or near-surface conditions. The groundmass is made up principally of laths of alkali feldspar with prisms of the same brown hornblende, of aegirine-augite, apatite and grains of magnetite.

The chemical composition of the rock is given in Table III. It is that of a trachyte. The norm shows some 11 per cent of anorthite from which fact, together with the presence of phenocrysts of andesine, the rock may be regarded as transitional toward trachy-andesite.

TABLE III.

Analyses of Soda-Rich Lavas of South Kivu Lava Field.

	I	II	III		I(a)	II(a)
SiO_2	57.45	60.29	58.89	Q	3.2	5.8
Al_2O_3	19.46	19.55	17.61	or	24.5	31.1
Fe_2O_3	4.65	3.60	2.44	ab	46.1	48.2
FeO	.91	.60	3.47	an	11.4	1.1
MgO	1.18	.50	.65	C	1.8	4.0
CaO	2.99	.61	2.11			
Na_2O	5.47	5.68	4.57	hy	3.0	1.2
K_2O	4.11	5.33	7.86	il	2.1	1.5
H_2O+	1.21	1.77	1.80	hm	4.6	3.7
H_2O-	.42	.50		ap	1.3	.7
TiO_2	1.26	.84	.58	rutile	.2	.2
P_2O_5	.55	.27	.11			
MnO	.12	.16	...			
	99.78	99.70	100.09			

I	Trachyte, 3 miles south of Costermansville. R. B. Ellestad, analyst.
II	Trachyte, at outlet of Lake Kivu. A. Willman, analyst.
III	Trachyte Karisimbi (North Kivu) for contrast. L. Finckh, op. cit., p. 4.
I(a)	Norm of I.
II(a)	Norm of II.

The other trachyte was collected near the outlet of Lake Kivu. It is a compact ash-grey type, free from gas pores and showing rare, small phenocrysts of feldspar. Under the microscope these phenocrysts prove to be albite-oligoclase ($\gamma=1.542$) and the groundmass is found to be very rich in laths of alkali feldspar with some aegirine-augite passing to aegirine, an alkali hornblende, pleochroic from yellow to brown that may be called barkevikite, apatite needles, magnetite grains and probably quartz. The chemical composition of the rock is given in Table III. It is typically trachytic. The normative anorthite is only 1 per cent. It should be mentioned that the exact field relations could not be made out. The compact, non-vesicular character suggests that the mass may be a dike or neck rather than a flow, a possibility that is further indicated by an ill-defined vertical sheeting. If it is a dike it would be appropriately named bostonite.

These rocks contain a significant excess of Na_2O over K_2O and are thus strongly contrasted with trachytic types from North Kivu. The analysis of a trachyte from Karisimbi is given for comparison. The South Kivu trachytes are more closely related to rocks of the Eastern Rift. It is true that rocks of the Eastern Rift usually contain an excess of alkalis over Al_2O_3, whereas the rocks just described exhibit the opposite relation, having some corundum in the norm. But this condition is not unknown in rocks of the Eastern Rift especially among the more salic types. Thus the quartz bostonite described by Lehmann[24] from the Rungwe area has some normative corundum, and one of the obsidians of the Naivashan area has also a small amount.[25]

It is especially to be noted that the sodic trachytes of the South Kivu area are not contemporaneous with the very late lavas of similar alkali trend in the North Kivu area. On the contrary the former are deeply weathered, erosion has imposed upon them mature land forms, and they are probably among the oldest products of vulcanism in the Western Rift.

In the South Kivu lava field there are in addition to the types above described some lavas of salic character which have a very unusual chemical composition. These have been described by Sorotchinsky.[26] They comprise rhyolites of excessively high SiO_2 content (84 per cent), quartz porphyries high in K_2O (7.58 per cent) and poor in Na_2O (.32 per cent), other remarkable rhyolites with upwards of 30 per cent mag-

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[24] Lehmann, E.: Z. Vulkanologie, 4, 113, 1924.

[25] Bowen, N. L.: This Journal, 33, 15, 1937.

[26] Sorotchinsky, C.: Mém. inst. géol. univ. Louvain, 9 (vi), 98, 1934.

netite and yet others with notable amounts of graphite. Sorotchinsky interprets these as the result of fusion of subjacent formations but the extraordinary chemical characters noted are strongly suggestive of hydrothermally altered lavas. Numerous thermal-mineral springs are shown on the map of the area.

It is clear from the above discussion that the rocks of the Western Rift, while they in general show a moderate dominance of K_2O over Na_2O, nevertheless depart from that relation in many instances and thus render it impossible to accept any simple chemical picture of the Western Rift which one might hope to connect with tectonic influences. Indeed when we come to examine the detailed studies of the petrogenesis of these potash-rich African rocks we find that much evidence has been adduced pointing to a relatively accidental origin of this chemical character. Finckh[27] in his early studies of the North Kivu rocks pointed to inclusions of biotite pyroxenite in some of them, which inclusions had been partly converted to glass. To this glass biotite made the principal contribution and it is, therefore, rich in K_2O. Holmes and Harwood[28] in their recent study of the rocks of the same area have also attached great importance to the reaction of magmas with biotite pyroxenite inclusions (transfusion) and have decided that the original magma or magmas of the area showed a dominance of Na_2O over K_2O typified in their "Magma X." Their choice of an actual rock representative of "Magma X" has, as we have seen, not been fortunate, nevertheless my own studies of the rocks of the North Kivu area have led me to the conclusion that the contamination of a soda-rich magma by selective reaction with biotite pyroxenite is one possible explanation of the origin of potash-rich types in that area.

It may be suggested that the old sodic trachytes of South Kivu, and the associated trachydolerites, are representative of the original characters of the early magmas; that in later activity, especially in the northern areas, these magmas suffered contamination of the kind described and that this effect is now waning and the magmas, as represented in current activity in North Kivu, are reverting to their original sodic character. In this view there is no reason for connecting the potash-rich

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[27] Finckh, L.: op. cit., p. 31.

[28] Holmes, A., and Harwood, H. F.: Geol. Survey Uganda Memoir No. 3, pt. 2, p. 82.

lavas with any particular kind of crustal movement. If there is any connection between magma chemistry and tectonics it would appear that the control has on the whole been such as to make the lavas *normally* soda-rich throughout the Rift systems.

CONCLUSIONS.

As we have pointed out, many investigators have believed that sodic rocks are connected with crustal foundering. Such connection cannot, however, always be substantiated though the tendency toward frequent occurrence of soda-rich rocks in regions of foundering, or what has all the appearance of foundering, seems reasonably clear. One might, then, be tempted to urge that the *normally* soda-rich character of the Rift lavas indicates that the Rift Valleys are formed as a result of foundering, foundering which has followed an uplift, of course, for presumably no one doubts the general uplift of the African continent. It is, however, a temptation easy to resist. When we are still uncertain that there is any connection between tectonics and magma chemistry, when we are still uncertain as to whether what is called foundering is anywhere due to lack of adequate support, as the word implies, or whether it is only apparently so and is really a down-pressing, or again is neither, but rather a lagging behind in a general uplift—when we are uncertain of all these things it is easy to refrain from drawing the conclusion that the chemistry of African lavas favors any particular concept of the mechanism of Rift formation. In addition there is little encouragement to consider the relations observed in the African continent as an unequivocal demonstration of the control of tectonic forces over the composition of igneous magmas.