Stratigraphie/*Stratigraphy*

Correlation of tephra layers from the Western Rift Valley (Uganda) to the Turkana Basin (Ethiopia/Kenya) and the Gulf of Aden

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Abstract — Four volcanic ashes have been mapped in Albertine Group strata (Warwire, Kaiso Village and Nyabusosi Formations) Western Rift Valley, Uganda. Three of these tuffs have geochemical fingerprints similar to tuffs in the Turkana Basin (Ethiopia, Kenya), in Afar (Ethiopia) and the Gulf of Aden, permitting correlation between sequences. Radioisotopic ages can be inferred for the faunas from the Albert Basin, including two of Gautier's Molluscan Associations which are the basis for fine scale biostratigraphic correlations between scattered outcrops of sediments within the Albert and Edward Basins in both the Uganda and Zaire sectors of the Western Rift Valley. The age of the Warwire Tuff, the Kyampanga Tuff and the Kagusa Tuff can be estimated at 3.6, 3.4 and 1.5 Ma.

Corrélations entre les cinérites du Rift Occidental (Ouganda) et celles du Bassin du Lac Turkana (Kenya/Éthiopie) et du Golfe d'Aden

Résumé — *Quatre niveaux de cendres volcaniques ont été cartographiés dans les couches du groupe du Lac Albert (Formations de Warwire, de Kaiso Village et de Nyabusosi) (Rift occidental ougandais). Trois de ces cinérites ont des signatures géochimiques identiques à celles du Bassin du Turkana (Kenya, Éthiopie), de l'Afar (Éthiopie) et du Golfe d'Aden qui permettent la corrélation entre les séquences. Les datations radioisotopiques ont pu être estimées pour les faunes du Bassin du Lac Albert dont deux associations de mollusques de Gautier, qui servent de bases pour les corrélations fines à l'intérieur des bassins des lacs Albert et Édouard en Ouganda et au Zaïre. Les âges estimés des cinérites de Warwire, de Kyampanga et de Kagusa sont respectivement de l'ordre de* 3,6, 3,4 *et* 1,5 *Ma.*

Version française abrégée — Les missions de l'Uganda Palaeontology Expedition effectuées entre 1986 à 1990 ont permis de réaliser la carte géologique et de définir la lithostratigraphie des terrains sédimentaires de la partie ougandaise du Lac Albert (Rift occidental) pour définir un contexte géologique précis pour les récoltes de fossiles ([1]-[5]). Lors des prospections des niveaux pliocènes et pléistocènes [réputés pour être non volcaniques ([6], [7])], ont été découvertes quatre cinérites dont l'aspect rappelle fortement celui de cendres volcaniques connues dans le bassin du Lac Turkana au Kenya ([8], [9]). Trois d'entre elles seulement ont pu être corrélées avec des cinérites provenant du bassin du Lac Turkana, de l'Afar et du Golfe d'Aden.

I. CONTEXTE GÉOLOGIQUE. — 1. *La cinérite de Warwire* (UG-1). — C'est la plus ancienne. Puissante de 5-8 cm, elle affleure en amont de la rivière Warwire (localité fossilifère NK 99) et elle présente un pendage de 7° vers le NE. On la trouve à la base de la Formation de Warwire qui a livré une faune pliocène à *Stegodon, Anancus, Nyanzachoerus jaegeri,* une variété primitive de *Notochoerus euilus* et l'association de mollusques de Gautier n° 4 ([5], [10]).

2. *La cinérite de Kyampanga* (UG90-1). — Plus haute dans la séquence et puissante partout de 45 cm, elle affleure largement le long des falaises sur le rivage entre Sebugoro au sud et Kyeoro au nord (localité fossilifère NK 135). Elle contient des empreintes d'herbe dans les 2-3 premiers centimètres de base. Au-dessous, on trouve les formes évoluées de l'association de mollusques de Gautier n° 4 ([5], [10]).

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3. *La cinérite de Hohwa* (UG-2, UG87-1, UG90-2). — Elle est présente sur les deux flancs de la vallée de la rivière Hohwa ainsi que dans la région-type du Membre du Village de Kaiso, dont elle forme la limite inférieure. Son épaisseur varie de 2 à 8 cm. Les faunes mammaliennes récoltées dans la formation ont suggéré une corrélation avec les faunes des membres E et G de l'Omo ([11], [13]). Les mollusques récoltés juste au-dessus et juste au-dessous de la cinérite appartiennent à l'association de Gautier X-X′ [10].

4. *La cinérite de Kagusa* (UG-17, UG-19, UG87-3). — La cinérite la plus jeune affleure au sud-ouest du Lac Albert, dans les collines de Nyabusosi (Toro). Puissante de 8 cm, elle est présente dans le Membre de Kagusa de la Formation de Nyabusosi (localités fossilifères NY 18 et NY 19) (UG-17; UG-19). Elle est intercalée dans des sédiments qui ont livré des outils oldowayens [14] et recouvre un horizon où fut découvert un crâne écrasé appartenant à *Homo sp.* [4]. L'association de mollusques de Gautier n° 6 a été récoltée dans la Formation de Behanga juste sous la cinérite.

II. Analyse géochimique. — Chacun des échantillons a été écrasé à la main et les verres séparés par des techniques magnétiques et aux liqueurs lourdes. Les isolats de verre ont été analysés par microsonde électronique, employant un cristal multi-couches à Si-W pour analyser directement l'oxygène; le contenu en eau pouvant donc alors être calculé. De nombreux fragments de verre analysés ont été susceptibles de perdre des éléments alcalins sous le rayon de la microsonde; c'est pourquoi les contenus alcalins sont ridiculement bas et ne doivent donc pas être pris en considération.

Les signatures géochimiques de trois cinérites permettent les corrélations suivantes (tableau) :

— Cinérite de Warwire avec le Lomogol Tuff [16] trouvé à la localité de Loruth Kaado (Bassin du Turkana) dont l'âge est estimé à 3,6 Ma d'après les comparaisons avec le Lokochot Tuff ([18], [20]) et le Topernawi Tuff [21].

— Cinérite de Kyampanga avec le Lokochot Tuff, trouvé dans les Formations de Koobi Fora et de Nachukui (Kenya), dans le Golfe d'Aden ([16], [22]), et avec la cinérite A de la Formation de Shungura de la basse vallée de l'Omo (Éthiopie). Son âge est estimé à $3{,}45 \pm 0{,}05$ Ma.

— Cinérite de Kagusa avec une cinérite « sans nom » de Naiyena Epul dans la région de Loruth Kaado dans le Bassin du Lac Turkana (Kenya) [17], dont l'âge peut être estimé à 1,5 Ma.

Les âges proposés ici à partir des corrélations géochimiques confirment tout à fait les dates estimées à partir de la biostratigraphie des mammifères et des mollusques.

Introduction. — During the past four field seasons of the Uganda Palaeontology Expedition, geological mapping and lithostratigraphy have been undertaken ([1]-[5]), principally in order to ensure that fossil collections were made within accurately recorded geological contexts. Although the Pliocene and Pleistocene strata in the Lake Albert region (Kaiso Formation of pre-1970 authors) have been reported to be non-volcanic ([6], [7]), we have mapped four tuffs which, in hand specimen and field occurrence, reminded us of volcanic ashes previously surveyed in the Turkana Basin, Kenya ([8], [9]). Samples of these tuffs were collected and geochemical analyses were performed at the Department of Geophysics, University of Utah, Salt Lake City. Here we provide preliminary results of this research.

I. GEOLOGICAL CONTEXT OF THE ALBERTINE TUFFS. — 1. *Warwire Tuff* (sample UG-1). — The oldest of the tuffs recognized in the Albertine Rift outcrops in the upper reaches of the Warwire drainage (fossil locality NK 99) where it is 5-8 cm thick and dips at 7° to the NE. It has sharp lower and upper boundaries, although the upper surface is weathered to a brown colour, in sharp contrast to the grey colour of the fresh tuff. It occurs near the local base of the Warwire Formation which yields a lower Pliocene fauna containing *Anancus, Stegodon, Nyanzachoerus jaegeri*, a primitive variety of *Notochoerus euilus* and Gautier Mollusc Association n° 4 ([5], [10]). Preliminary estimates of the age of the Warwire Formation based on mammalian biostratigraphic correlations with East African sites, were that it lay somewhere between 4 and 4.5 Ma ([1], [2]).

2. *Kyampanga Tuff* (sample UG90-1). — Higher in the stratigraphic succession this tuff outcrops widely along the lake shore cliffs between Sebugoro in the south and Kyeoro in the north (fossil locality NK 135). It is consistent in thickness (45 cm) where it can be measured, and it usually contains grass leaf impressions in the lowermost 2-3 cm. Its lower and upper boundaries are sharp. Fossil molluscs found below the Kyampanga Tuff consist of evolved examples of Gautier Mollusc Association number 4. The Kyeoro Formation, which is higher in the succession contains Mollusc Association number 5 ([5], [10]).

3. *Hohwa Tuff* (samples UG-2, UG90-2). — This tuff outcrops extensively in both flanks of the Hohwa valley as well as in the type area of the Kaiso Village Member, of which it forms the lower boundary [3]. It varies in thickness from 2 to 8 cm, has sharp upper and lower boundaries, and usually outcrops in the form of a bench. Previous stratigraphic analyses of the Kaiso Village faunas have suggested ages equivalent to Omo Members E-G ([1]-[13]). Molluscs found immediately below and above the Hohwa Tuff comprise the type association of Gautier Mollusc Association X-X′ [10].

4. *Kagusa Tuff* (samples UG-17, UG-19, UG87-3). — The youngest of the tuffs found in the Albertine Rift occurs southwest of Lake Albert, in the Nyabusosi hills, Toro. It outcrops in the Kagusa Member of the Nyabusosi Formation (fossil localities NY 18, NY 19) and is intercalated in sediments yielding Oldowan stone tools [14] and overlies a horizon which yielded a crushed skull of *Homo sp.* [4]. The tuff is 8 cm thick and has sharp upper and lower boundaries. We have suggested that the age of the Kagusa Member is close to 1.5 Ma old on the basis of fossil mammals and the stone tools. This estimate is appreciably younger than previous ones made by Cooke and Coryndon [15] who thought that the Behanga suid cranium and other mammals from the same site indicated a Pliocene age between about 2.5 and 3.0 Ma. Harris and White [12] considered that the best match for the Behanga suid was with material from Omo Member G, dating from 1.9 to 2.3 Ma. The Behanga Member, which immediately underlies the Kagusa Tuff has yielded Gautier Mollusc Association number 6.

II. RESULTS OF GEOCHEMICAL ANALYSES. — Each of the samples was gently crushed by hand, and the glass separated by heavy liquid and magnetic techniques. The glass separates were analyzed by standard electron microprobe techniques, using a Si-W multilayer crystal to analyse for oxygen directly, so that the water content could be calculated. Many of the glass shards analyzed were quite susceptible to alkali loss under the microprobe beam, so the reported alkali contents are aberrantly low, and should not be relied on. For this study, all analyses were performed under the same analytical conditions using the same standards. We note that there are significant differences in

TABLE

Analyses of glass from the Warwire, Kyampanga, Hohwa and Kagusa Tuffs,
with comparative analyses from the Eastern Rift. (Major elements in %; trace elements in p.p.m.)

Analyse des verres provenant des cinérites de Warwire, Kyampanga, Hohwa et Kagusa, comparée aux analyses de cinérites du Rift oriental. (Éléments majeurs en %; éléments en traces en p.p.m.)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3 ([a])	HnO	MgO	CaO	Na_2O	K_2O	Cl	(H_2O)	Sum
Warwire Tuff (*UG*-1) *and Lomogol Tuff* (*K*82-742, *Turkana Basin; EVR*-032, *Ethiopia*)												
UG-1	73.73	0.26	9.63	4.42	0.19	0.05	0.17	2.09	4.44	0.14	5.4	100.5
K82-742	73.71	0.26	9.77	4.54	0.19	0.02	0.19	1.37	2.93	0.14	7.4	100.5
ERV-032	73.97	0.27	9.73	4.38	0.19	0.05	0.18	1.03	2.75	0.13	7.2	99.9
Kyampanga Tuff (*UG*90-1) *and Lokochot Tuff* (*K*80-295, *Turkana Basin*)												
Low iron shards:												
UG90-1	74.75	0.15	10.52	3.28	0.08	0.02	0.16	2.44	4.86	0.13	3.6	100.0
K80-295	74.57	0.16	10.53	3.20	0.09	0.02	0.16	2.08	3.74	0.15	6.0	100.7
High iron shards:												
UG90-1	73.73	0.20	9.64	4.56	0.13	0.02	0.17	2.51	5.14	0.19	3.4	99.7
K80-295	74.13	0.23	9.65	4.50	0.12	0.02	0.18	1.86	3.25	0.19	6.5	100.6
Hohwa Tuff (*UG*-2, *UG*87-1, *UG*90-2) *and Ngong Obsidian* (*MER*-107, *Kenya*)												
UG-2	59.25	0.51	17.11	5.04	0.22	0.36	0.91	0.74	1.38	0.25	9.4	95.2
UG87-1	59.60	0.50	17.62	5.06	0.23	0.37	0.90	0.63	1.78	0.25	12.6	99.6
UG90-2	60.11	0.51	17.66	5.10	0.26	0.36	0.94	0.70	1.72	0.26	12.0	99.6
MER-107	58.40	0.50	16.20	5.84	0.27	0.41	0.84	9.29	4.87	0.15	n.d.	96.8
Kagusa Tuff (*UG*-17, *UG*-19, *UG*87-3) *and correlative in Nachukui Formation* (*K*89-3335, *Turkana Basin*)												
UG-17	72.25	0.28	8.92	6.13	0.29	0.01	0.21	2.82	3.74	0.16	5.0	99.8
UG-19	72.83	0.33	8.79	6.35	0.30	0.01	0.22	2.96	3.77	0.17	4.4	100.2
UG87-3	72.36	0.30	8.83	6.14	0.29	0.02	0.22	2.80	3.77	0.17	5.4	100.3
K89-3335	73.09	0.28	8.68	6.41	0.21	0.01	0.20	1.82	2.60	0.12	6.5	99.9

Trace elements	Ba	Nb	Rb	Y	Zn	Zr	Hf	Ta	Th	U	La	Ce	Nd	Sm	Eu	Vb
Warwire Tuff and correlatives																
UG-1	<25	153	112	98	202	1,115	29	9.5	17	4.	142	265	115	20.	2.55	11.
K82-742	<25	161	143	110	204	1,136	28	9.4	20	5.4	149	278	114	19.6	1.18	12.2
ERV-032	<25	152	111	103	208	1,133	26	10.	16	4.6	143	265	114	20.	2.77	10.8
Kyampanga Tuff and Lokochot Tuff																
UG90-1	100	153	137	145	281	1,442										
K80-295	123	152	132	141	239	1,403										
Hohwa Tuff and Ngong Obsidian																
UG-2	<25	280	152	60	171	1,184										
MER-107	n.d.	295	132	62	187	1,088										
Kagusa Tuff and probable correlative																
UG-17	42	159	110	111	224	1,136										
UG-19	33	157	112	113	237	1,105										
K89-3335	155	147	101	111	230	1,160										

([a]) Total iron reported as Fe_2O_3.

SiO_2, Al_2O_3, and Fe_2O_3 in the Lokochot Tuff compared to analyses reported by Brown *et al.* [16] which were made under different conditions and using different standards. X-Ray fluorescence techniques were described by Brown and Cerling [17]. For the Warwire Tuff additional compositional data were obtained by neutron activation analysis. Compositional data on these tuffs, along with comparative analyses are given in Table.

1. *Warwire Tuff* (UG-1). — It matches the composition of the Lomogol Tuff from the Turkana Basin [16] and an unnamed tuff from the Ethiopian Rift Valley very well, and we correlate these units. Our sample of the Warwire Tuff (UG-1) consists dominantly of bubble wall shards, with minor pumice shards with stretched vesicles. The sample is well sorted, and the largest shards have a mean diameter of about 250 µm. The Lomogol Tuff (K82-742) is known in the Turkana Basin only from the locality of Loruth Kaado,

at the north end of the Labur Range. There it lies about 10 m below the Lokochot Tuff within the Kataboi Member of the Nachukui Formation [18]. It has not been recognized in the Koobi Fora or Shungura Formations. The unnamed tuff (ERV-032) from the Ethiopian Rift Valley was collected near Asaberi, in the middle Awash Valley, where it lies within the Sagantole Formation [19]. The Lokochot Tuff is situated very near the Gilbert-Gauss Chron boundary, which is assigned an age of 3.42 Ma ([18], [20]), and is probably only slightly older than this. It is likely that the Lomogol Tuff postdates the Topernawi Tuff dated at 3.72 Ma [21], and thus probably is 3.6 ± 0.1 Ma old.

2. *Kyampanga Tuff* (UG-1). — It matches the Lokochot Tuff in composition very well, and we believe that these units also correlate. Both the Lokochot Tuff and the Kyampanga Tuff are composed of shards of two different compositions [16] [this paper], easily separated on their iron content. This bimodality makes the correlation virtually certain, and consequently, the Kyampanga Tuff is about 3.45 ± 0.05 Ma in age. The largest glass shards in the Kyampanga Tuff are 250 μm in mean diameter; most are bubble wall shards, but a few are stretched pumice. The Lokochot Tuff of the Koobi Fora and Nachukui Formations is equivalent to Tuff A of the Shungura Formation, and has also been identified in the Gulf of Aden ([16], [22]).

3. *Hohwa Tuff* (UG-2, UG90-2, UG87-1). — Microprobe analyses were performed for three samples of this Tuff (UG2, UG90-2, UG87-1). Pumice shards with stretched vesicles dominate this unit; bubble wall shards are present, but in low abundance. The maximum shard size is about 230 μm. Compositionally this unit is very distinctive, particularly in its high alumina and low silica content. No known, Pliocene or Pleistocene tephra unit in the Turkana Basin is even remotely similar to this tuff in composition. With the exception of the alkalis, which are known to be aberrantly low, it is reasonably similar to a syenite from Menengai (Kenya) [23] and was probably originally trachytic in composition. It is also compositionally similar to an obsidian nodule collected at the top of the rift escarpment south of the Ngong Hills in Kenya (sample MER-107), an analysis of which is given for comparison in Table. Although we cannot suggest a correlation, it seems likely that this tuff was erupted from one of the trachytic volcanoes in the Kenya Rift.

4. *Kagusa Tuff* (UG-17, UG-19, UG87-3). — An unnamed tuff (K89-3335) collected from the Naiyena Epul in the Loruth Kaado region in the Turkana Basin probably correlates with the Kagusa Tuff (UG-17, UG-19, UG87-3). Shards less than 250 μm are a mixture of stretched pumices and bubble walls in roughly equal proportion. Sample K89-3335 was collected from a tuff that lies ~ 7 m above another unnamed tuff (K89-3333) known elsewhere in the lower part of the Natoo Member of the Nachukui Formation [17]. The Natoo Member ranges in age from about 1.65 to 1.33 Ma [17]. Assuming the correlation is correct, the Kagusa Tuff is about 1.5 Ma old.

V. Conclusions. — Three of the four tuffs from the Western Rift have been dated by correlations with Eastern Rift tuffs. The oldest tuff, the Warwire tuff is correlated with the Lomogol Tuff from the Turkana Basin and one unnamed tuff from the Ethiopian Rift Valley. Its age is estimated at 3.6 ± 0.1 Ma. The Kyampanga Tuff is correlated with the Lokochot Tuff from the Turkana Basin (Kenya), Tuff A from the Shungura Formation (Omo, Ethiopia) and with a tuff from the Gulf of Aden. Its age is estimated at 3.45 ± 0.05 Ma. The Kagusa Tuff is probably correlated with an unnamed tuff from the Nachukui Formation in the Turkana Basin (Kenya) and its age is estimated at about 1.5 Ma. The Hohwa Tuff has not yet been correlated. These dates confirm the ages estimated on the basis of the biostratigraphical data.

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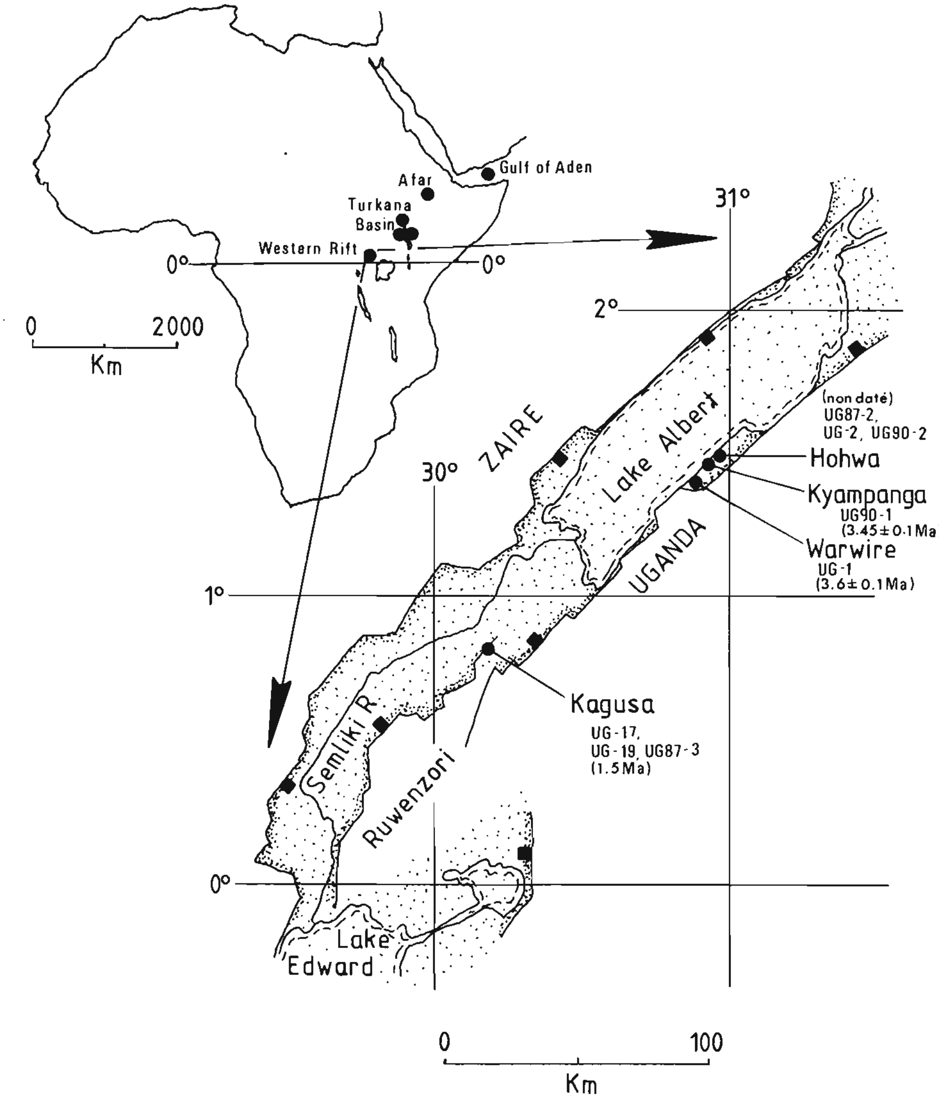

Fig. 1. – Location of tuffs in the Western Rift Valley in relation to other sites in Eastern Africa which have yielded correlative tuffs.

Fig. 1. – Distribution des cinérites dans le Rift occidental et répartition des gisements est-africains ayant livré des cendres volcaniques probablement issues des mêmes éruptions.