Ages of some uranium and thorium minerals from East and Central Africa.

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Summary. The following ages determined by the complete lead method have been accepted for minerals from a number of localities: uraninite, Nkana, Northern Rhodesia, 522±15 m.y.; brannerite, Kansanshi, Northern Rhodesia, 503±15 m.y.; uraninite, Shinkolobwe, Katanga, 642±20 m.y.; davidite, Mavuzi, Mozambique, 578±15 m.y.; monazite, Monkey Bay, Nyasaland, 597±25 m.y.; samarskite, north-west Kenya, 635±25 m.y. The significance of the results is briefly considered.

THIS is the second of a series of papers presenting age determinations on uranium and thorium minerals.[1] An explanation was given in the first paper (Darnley, Smith, Chandler, and Dance, 1960) of the errors taken into account in estimating the accuracy of the apparent ages provided by the different ratios. As these apparent ages seldom agree exactly it is sometimes difficult to decide what value to accept as the most probable age. No one ratio can be relied on to give the true age in all cases. Rather the evidence must be weighed for each specimen or group of specimens, and cognizance taken of the geological and mineralogical environment. Because factors causing discordance may affect different specimens from the same locality to different extents, it is a great advantage to have results from two or more specimens. In this paper certain apparent ages have been rejected either because of their discordance or because they are based on only very small amounts

[1] Preliminary accounts with slightly different ages were issued on a limited circulation by the Atomic Energy Division, Geological Survey of Great Britain, as Age Determination Reports Nos. 3, 7, 8, 9, 12, and 14.

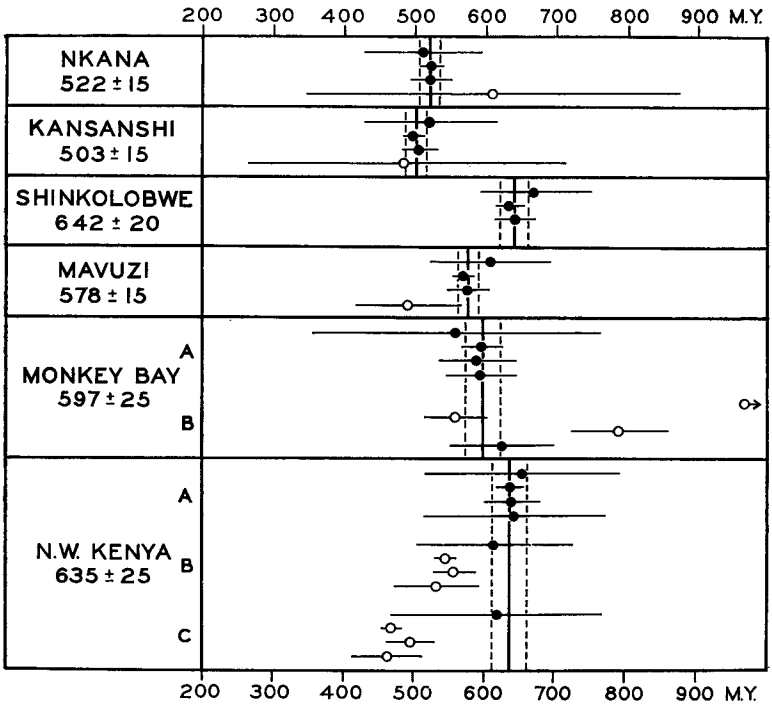

FIG. 1. Graphical summary of the results. For each specimen the apparent ages are plotted from top to bottom in the order 207/206, 206/238, 207/235, 208/232. The horizontal lines represent the estimated errors. Apparent ages shown by open circles have been rejected for the reasons stated in the text. The weighted mean of the remaining apparent ages is accepted as the age of each specimen or group of specimens. It is indicated by a vertical line. The error derived for the accepted age is shown by broken lines.

of lead-208 and thorium. The accepted age for each specimen or group is taken as the mean of the remaining apparent ages weighted in inverse proportion to their estimated errors. An approximate measure of the error of the accepted age is taken as the weighted mean of the individual estimated errors divided by the square root of the number of apparent ages involved. To facilitate appraisal of the results, they are presented graphically in fig. 1.

Uraninite from Nkana, Northern Rhodesia.

The uraninite used for this determination was derived from a concentrate provided by Dr. T. D. Guernsey of Rhokana Corporation Ltd. The

original concentrate was taken from a mass of fractured and recemented uraninite, amounting to several cubic inches, collected from the Mindola Section of Nkana mine. This mode of occurrence is not typical of the disseminated uraninite–brannerite mineralization at Nkana.

The uraninite is fresh and entirely free from secondary uranium minerals, and from galena. In an uncrushed specimen, melonite ($NiTe_2$) is a prominent accessory mineral together with lesser amounts of bornite, chalcopyrite, digenite, and chalcocite. The opaque minerals are set in a ground-mass of calcite, quartz, biotite, chlorite, and albite. The original concentrate was purified electromagnetically to remove the small quantity of accessory minerals present.

TABLE I. Nkana uraninite.

	Lead-isotope proportions			
Chem. anal. (*wt.* %)	*Uraninite*	*Galena**	*Uraninite corrected*	*Isotopic ages* (*m.y.*)
Pb 5·79	^{204}Pb 0·0099±0·0004	1	—	207/206 512±85
U 75·82$_1$	^{206}Pb 94·02±0·05	18·25	93·84	206/238 524±15
Th 0·14$_1$	^{207}Pb 5·53±0·05	15·88	5·37	207/235 522±30
	^{208}Pb 0·446±0·004	38·47	0·065	208/232 610±265

* The isotopic proportions of common lead used throughout the paper are based on the average of 10 galena analyses from Katanga and Northern Rhodesia. Nine are taken from Holmes and Cahen (1956, 155–6) and one is a new analysis of galena from Broken Hill (204:206:207:208 = 1:18·08:15·89:39·07).

The chemical and isotopic analyses and the apparent ages derived from them are given in table I.

Discussion. There is good agreement between the ages derived from the first three ratios, on which the accepted age of 522±15 m.y. is based. The small amount of thorium present, coupled with the sensitivity of the 208/232 ratio to the common lead correction, makes the thorium age less reliable. Holmes and Cahen (1957) have reported another uraninite analysis from Nkana (mode of occurrence unknown) giving the following results: 207/206 612 m.y., 206/238 527 m.y., 207/235 540 m.y. They have accepted the 207/206 age as being most reliable, but in view of the discordance between the apparent ages, this must now be regarded as unsatisfactory. The association of melonite with uraninite is unusual, although small amounts of disseminated melonite have been seen in a few other specimens from Nkana. Melonite has also been recorded at Shinkolobwe (Derricks and Vaes, 1956).

Further work is in progress on material more typical of the disseminated mineralization at Nkana.

Brannerite from Kansanshi, Northern Rhodesia.

The specimen analysed was provided by Mr. C. J. McFarlane, manager of Kansanshi Copper Mining Co., Ltd. The mine is situated to the north-west of the Rhodesian Copper Belt at 12° 05′ S., 26° 25′ E. The specimen was collected at the point of intersection of A vein with B vein on the 290-foot level from the Main North Shaft. The mineral association of this particular specimen is not known, but in others from the

TABLE II. Kansanshi brannerite.

Chem. anal. (*wt.* %)	*Lead-isotope proportions*			*Isotopic ages* (*m.y.*)
	Brannerite	*Galena*	*Brannerite corrected*	
Pb 3·13	^{204}Pb 0·0029±0·0003	1	—	207/206 522±95
U 42·91$_0$	^{206}Pb 94·4±0·1	18·25	94·35	206/238 498±15
Th 0·072$_1$	^{207}Pb 5·47±0·04	15·88	5·42	207/235 507±25
	^{208}Pb 0·161±0·007	38·47	0·049	208/232 487±225

mine coarsely crystalline anhedral brannerite, in masses up to 5 cm. across, is associated with chalcopyrite and calcite in approximately equal proportions, and with minor pyrite.

The brannerite is massive in habit and unaltered; it is steely-black with a submetallic lustre. A powder photograph shows it to be essentially metamict. X-ray and optical spectrographic analyses show major uranium and titanium, with subordinate lead and yttrium. Also present are minor proportions of Ca, Zr, Fe, lanthanons (particularly Dy and Er), V, Sr, Mg, and Si. Examination of a polished section of the mineral shows minor amounts of galena, chalcopyrite, and rutile, together with traces of bornite. The even distribution of the minute specks of galena suggests it is derived from radiogenic lead and therefore no attempt was made to remove any of the inclusions prior to analysis. The analyses and calculated ages are given in table II.

Discussion. All four ages are reasonably concordant, although the agreement of the 208/232 age with the others must be regarded as somewhat fortuitous in view of the very small amount of thorium present. The weighted mean of the first three ages is 503±15 m.y., which compares closely with the age obtained for Nkana. These results support the view that uranium minerals in Northern Rhodesia were formed about 100 m.y. after those in Katanga.

Uraninite from Shinkolobwe, Katanga.

This analysis, carried out for the purposes of comparison with the Nkana uraninite, was made on a specimen of massive fresh uraninite from

Shinkolobwe, presented by the Union Minière du Haut Katanga. No concentration was required. The results are given in table III.

Discussion. Because of the low thorium and lead-204 contents of the analysed material, the common lead correction is based on the amount of lead-208 present. The results are concordant within the limits of error and the weighted mean of 642±20 m.y. is taken as the true age.

TABLE III. Shinkolobwe uraninite.

	Lead-isotope proportions			
Chem. anal. (*wt.* %)	*Uraninite*	*Galena*	*Uraninite corrected*	*Isotopic ages* (*m.y.*)
Pb 7·15	^{204}Pb < 0·004	0·0259	—	207/206 671±80
U 76·73$_5$	^{206}Pb 94·03±0·04	0·4744	93·97	206/238 635±20
Th 0·014$_9$	^{207}Pb 5·83±0·03	0·4125	5·78	207/235 643±30
	^{208}Pb 0·13±0·01	1	—	

TABLE IV. Mavuzi davidite.

	Lead-isotope proportions.			
Chem. anal. (*wt.* %)	*Davidite*	*Galena*	*Davidite corrected*	*Isotopic ages* (*m.y.*)
Pb 0·65	^{204}Pb 0·024±0·001	1	—	207/206 608±85
U 7·63$_2$	^{206}Pb 92·3±0·1	18·25	91·86	206/238 569±15
Th 0·28$_1$	^{207}Pb 5·87±0·03	15·88	5·49	207/235 576±30
	^{208}Pb 1·85±0·03	38·47	0·93	208/232 492±75

Davidite from Mavuzi, Tete, Mozambique.

The davidite used for this analysis was collected by Professor C. F. Davidson and Dr. J. A. E. Bennett in 1948. The locality is 30 miles north-west of Tete at 15° 50′ S., 33° 25′ E., where the mineral occurs in shear zones filled with scapolite and carbonate in pre-Karoo norites and anorthosites. Associated minerals include rutile, sphene, magnetite, ilmenite, apatite, tourmaline, molybdenite, pyrite, and chalcopyrite. A detailed account of the deposit is given by Davidson and Bennett (1950), and of the mineral itself by Bannister and Horne (1950).

The mineral is a metamict titanate of iron and uranium. X-ray spectrographic analysis shows subordinate lanthanum, cerium, chromium, and vanadium, with minor proportions of Pb, Sr, Y, Zr, Th, and Ca. Freshly fractured surfaces are black with a bright submetallic to vitreous lustre and fragments bounded entirely by such surfaces were available for analysis (table IV).

Discussion. The first three ages are in fair agreement and give a weighted mean of 578±15 m.y., which is accepted as the most probable

age. The thorium–lead age is less satisfactory. Since approximately 50 % of the lead-208 present in the specimen is attributable to common lead, this age is particularly sensitive to the appropriateness of the lead-isotope proportions used for correction. The accepted age falls between that of the Rhodesian and the Katangan uranium occurrences. However, the age sequence suggests that there may have been some slight loss of radiogenic lead and another determination is in hand to check this possibility. It is interesting that Davidson and Bennett (1950) remark that 'the Mavuzi rocks show more widespread regional scapolitization than any other igneous complex known to the writers'. Extensive scapolitization is also characteristic of many basic and metasedimentary rocks in Northern Rhodesia, including the Copperbelt (Jackson, 1932; Darnley, 1960).

Monazite from Monkey Bay, Lake Nyasa, Nyasaland.

Monazite occurs as a minor constituent in ilmenite-rich sands that are found at the southern end of Lake Nyasa on the east side of the Cape Maclear Peninsula, 14° 15′ S., 35° 07′ E. They lie beside the road to Monkey Bay between 16 and 23 road miles north-west of Fort Johnston. The monazite-bearing sands are mostly in raised beaches approximately 30 feet above the present lake surface, but small areas have been found at intervening levels down to the present-day storm beach. The high-level beaches are consolidated by clayey material. Associated heavy minerals include magnetite, garnet, and zircon. As the source of the monazite has not been established, the geological significance of this determination is limited. It was in fact undertaken to give an indication of the possible source rocks. The results are of interest in demonstrating that detrital monazite is capable of yielding concordant ages.

Monazite was derived from two samples. One was collected by Mr. M. S. Garson of the Nyasaland Geological Survey, and the monazite subsequently concentrated by the Mineral Resources Division of the Overseas Geological Surveys using an electromagnetic separator and methylene iodide. The other was provided by Rhodesian Selection Trust Exploration Ltd. of Salisbury, Southern Rhodesia, and the monazite was concentrated electromagnetically at A.E.D. The analyses and derived ages are given in table V.

Discussion. The thorium–lead ages of both concentrates show good agreement. The lead–lead and uranium–lead ages of the first analysis agree well with the thorium–lead age, but this is not true in the case of the second. Both the 207/235 and 207/206 apparent ages are high. The

reason for this is not known. The analysed material was composed of clear, apparently unaltered grains, and the analytical results show that it was free from common-lead contamination. However, the first analysis indicates that the processes of weathering and transportation are not in themselves sufficient to produce discordant ages. The accepted age, which is the weighted mean of the four apparent ages derived from the first analysis and the 208/232 age from the second analysis, is 597 ± 25 m.y.

TABLE V. Monkey Bay monazite.

Chem. anal. (*wt.* %)	*Lead-isotope proportions* *Monazite*	*Galena*	*Monazite corrected*	*Isotopic age* (*m.y.*)
Pb 0·185	^{204}Pb 0·111 ± 0·0008	1	—	207/206 559 ± 205
U 0·15$_3$	^{206}Pb 7·13 ± 0·04	18·25	6·95	206/238 597 ± 30
Th 6·41$_6$	^{207}Pb 0·581 ± 0·008	15·88	0·405	207/235 589 ± 55
	^{208}Pb 92·3 ± 0·1	38·47	91·9	208/232 594 ± 50
Pb 0·18	^{204}Pb > 0·002			207/206 1533 ± 160
U 0·17$_0$	^{206}Pb 7·34 ± 0·09	No correction required		206/238 558 ± 45
Th 5·95$_6$	^{207}Pb 0·69 ± 0·02			207/235 792 ± 70
	^{208}Pb 92·0 ± 0·1			208/232 625 ± 75

Samarskite from north-western Kenya.

The samarskite specimens were provided by Mr. H. Wreford Smith of Kitale, Kenya. They came from three separate pegmatites (Kokusan, Kenailmet, and Morukong) situated within a mile of each other at approximately 1° 59′ N., 35° 04′ E., in the Turkana Province. The pegmatites belong to a swarm striking approximately north–south, and cutting folded plagioclase amphibolites and limestones of the Basement System. Dr. G. J. H. McCall, formerly of the Kenya Geological Survey, reports in a personal communication that the feldspar present is often perthitic and is associated with pale green muscovite and occasionally biotite with vermiculite. Samarskite, columbite, garnet, and tourmaline are present together with some corundum.

The samarskite shows fresh black conchoidally fractured surfaces with a bright vitreous lustre. X-ray and optical spectrographic analyses of each specimen show them to be essentially niobates of uranium, yttrium, and iron, with subordinate tantalum, thorium, and lanthanons (particularly gadolinium, dysprosium, and samarium). Minor proportions of Ti, Pb, Mn, Zr, Ca, Si, and Al are also present. X-ray photographs of unheated specimens show they are metamict, but samarskite patterns are obtained on heating in nitrogen at 1 000° C.

Discussion. Results on material from Morukong are very satisfactory,

but there is internal discordance in the ages obtained on the specimens from Kenailmet and Kokusan. However, the 207/206 ages of all three specimens are similar. The pattern of discordance with 207/206 > 207/235 > 206/238 indicates that lead loss is the most likely cause of the

TABLE VI. Kenya samarskite.

Chem. anal. (*wt.* %)	*Lead-isotope proportions*			
	Samarskite	*Galena*	*Samarskite corrected*	*Isotopic age* (*m.y.*)
		Morukong.		
Pb 1·18	^{204}Pb 0·008±0·002	1	—	207/206 654±140
U 12·12$_7$	^{206}Pb 90·5±0·1	18·25	90·25	206/238 636±20
Th 1·49$_4$	^{207}Pb 5·64±0·13	15·88	5·51	207/235 639±40
	^{208}Pb 3·88±0·08	38·47	3·57	208/232 642±130
		Kenailmet.		
Pb 1·08	^{204}Pb 0·053±0·002		—	207/206 613±110
U 12·46$_6$	^{206}Pb 87·1±0·1	As above	86·13	206/238 544±15
Th 2·24$_1$	^{207}Pb 6·00±0·07		5·16	207/235 557±30
	^{208}Pb 6·86±0·06		4·82	208/232 531±60
		Kokusan.		
Pb 0·77	^{204}Pb 0·075±0·002		—	207/206 618±150
U 10·13$_4$	^{206}Pb 85·5±0·1	As above	84·13	206/238 468±15
Th 2·02$_1$	^{207}Pb 6·24±0·13		5·05	207/235 495±35
	^{208}Pb 8·18±0·08		5·29	208/232 462±50

discordances and the validity of this assumption can be demonstrated by calculating the percentage of radiogenic lead which must be added to the mineral to bring the 206/238 age into agreement with the 207/206. The 207/235 result will then automatically fall into line, as the three ratios are interdependent, but the 208/232 age will only agree if lead loss is in fact the predominant cause of the discordance.

The results tabulated below show that there is good agreement between the adjusted 206/238 and 208/232 ages:

	207/206	206/238 *adjusted*	% Pb *added*	208/232 *adjusted*
Kenailmet	613	613	13·4	601
Kokusan	618	618	33·4	614

It is concluded from the geological evidence that the three pegmatites are of the same age, and that the discordance in the Kenailmet and Kokusan results is due to lead loss. The weighted mean of the four Morukong ages and the 207/206 ages of Kenailmet and Kokusan is 635 m.y., which is taken as the most probable age with an error of ±25 m.y. The determination demonstrates the value of analysing at east two specimens if this is at all possible, as the Kenailmet or Kokusan

results alone might have been misleading or their correct interpretation lacking in conviction. Mica specimens collected from the Kenailmet pegmatite by Dr. McCall have been submitted to the Department of Geology and Mineralogy at Oxford for age determination by the potassium–argon and rubidium–strontium methods. These results will be of interest for comparison with the lead age accepted here.

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