AGE OF URANINITE FROM A PEGMATITE NEAR SINGAR, GAYA DISTRICT, INDIA

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WITH AN ISOTOPIC ANALYSIS OF LEAD

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ABSTRACT

The age of an analysed specimen of uraninite from one of the pegmatites of the mica-belt of Bihar, India, is rediscussed in the light of the isotopic constitution of lead separated from the residue of the analysed powder. The data are found to be insufficient to yield an unambiguous solution and the age cannot be stated more closely than 955±40 m.y. The evidence is ample, however, to prove that the Bihar pegmatites, representing the end-stage of the Satpura orogenic cycle, are older than those of the Delhi cycle, already dated by a uraninite from Rajputana of which the age is 735 m.y. It is shown from tectonic considerations, combined with the above age estimates and tentatively supported by less reliable indications from the radioactive minerals of the Nellore district, that the sequence of the main Pre-Cambrian orogenic belts of India is: (1) Delhi; (2) Satpura; (3) Eastern Ghats; (4) Dharwar. The Aravalli belt is older than the Delhi and Satpura belts and may be a continuation of the Dhawar belt.

THE SATPURA OROGENIC BELT AND ITS RADIOACTIVE MINERALS

The mica-pegmatite swarm of Bihar, north-west of Calcutta, celebrated as the world's leading source of high-grade muscovite, extends for ninety miles from the Gaya district on the east to the Bhagalpur district on the west and has a width of up to twenty miles. A detailed account of the economic minerals of the area has recently been given by Dunn (1942). The pre-Gondwana rocks, which occupy the greater part of the region south of the Gangetic alluvium, have the following sequence:

Vindhyan System (probably Pre-Cambrian)
Newer Dolerites (probably post-Cuddapah)
Kolhan Series
Pegmatites (including those of the mica-belt)
Granites (including the Chota Nagpur and Singhbhum Granites)
Iron Ore Series (phyllites, schists, hematite-quartzites and migmatites)

To the south the Iron Ore Series is unconformably underlain by the Gangpur Series, which is correlated with similar rocks known as the Sausar Series further west. Both these older Series are characterised by marbles and gondites and, together with the Iron Ore Series and the granites and pegmatites which accompanied and followed the folding and metamorphism, they constitute a typical "Archaean" orogenic belt. The belt, of which the general trend is E.-W. or E.N.E.-W.S.W., is indicated on the accompanying map as the Satpura Belt. Following Krishnan (1943*a*, p. 140), the name is taken from the Satpura Range,

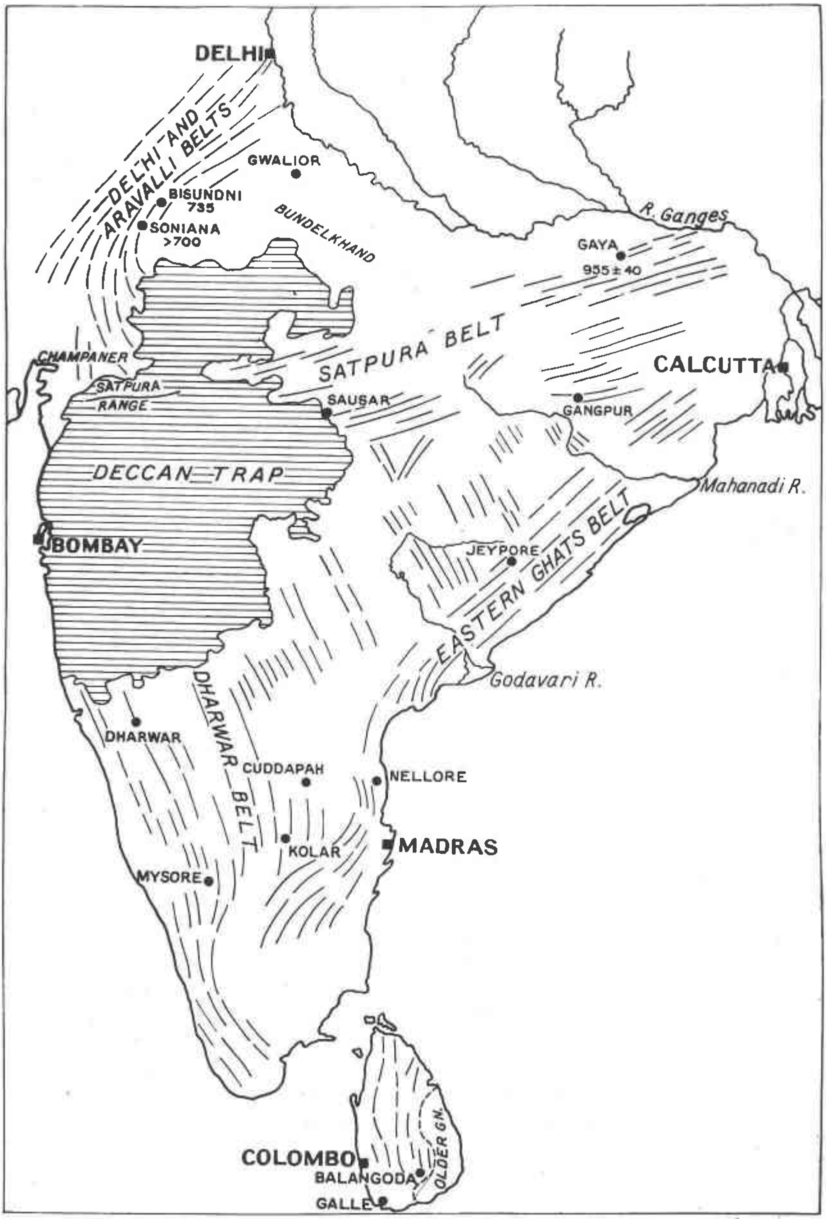

FIG. 1. Provisional tectonic map of the Pre-Cambrian orogenic belts of Peninsula India and Ceylon. The figures represent the ages of radioactive minerals in millions of years.

where schists, migmatites, granites and pegmatites have a regional trend roughly conforming to the E.N.E. direction of the range itself. Fermor (1936) regards these rocks as the geological extension, beneath the Deccan Traps, of the 'Archaean' rocks of Chota Nagpur; and Crookshank (1936, pp. 196 and 208) provisionally correlates them with the Sausar Series, apart from a group of banded hematite-quartz rocks which may be the equivalent of part of the Iron Ore Series. In the other direction the continuation of the Satpura Belt is thought to be represented by the Shillong Series of the plateau of Assam, which is separated from Bihar by the broad lowlands of the lower Ganges and Bramaputra (Krishnan, 1943*b*, p. 129).

Radioactive minerals have been found in some of the Bihar pegmatites, notably around Singar (lat. 24°34′: long. 85°30′), Pichhli (lat. 24°36′: long. 85°27′; see Tipper, 1919) and Ranchi (lat. 23°22′: long. 85°20′), and some of these have been analysed (Table 1). The apparent ages, read from the graphs prepared by Wickman (1944), in which Pb/(U+Th) is plotted against U/(U+Th) for various ages, range from ?830 to 980 m.y. Omitting A, the average value of the remaining four crude ages is 950 m.y.

TABLE 1. RADIOACTIVE MINERALS FROM PEGMATITES OF THE SATPURA BELT, INDIA

	Pb	U	Th	$\frac{Pb}{U+Th}$	$\frac{U}{U+Th}$	Apparent age in m.y.
A.	8.66	67.46	(? 7.0)	(.116)	(.90)	(830)
B.	8.92	64.30	8.12	.123	.89	885
C.	.49	.23	10.55	.0455	.02	965
D.	.013	0.00	.29	.0448	.00	980
E.	.021	0.00	.47	.0447	.00	980

A. Uraninite, Singar Mine, Gaya district. *Analyst:* W. R. Criper (T. H. Holland, *Mem. Geol. Surv. India*, **34,** 1902, p. 131). Criper did not determine ThO_2 separately, but from his analysis it is clear that ThO_2 could not have exceeded 8 per cent. Without Th the "apparent age" is 850 m.y.

B. Uraninite, Singar Mine. *Analyst:* A. Holmes (1918, p. 86 for Pb and U).

C. Monazite, Gaya district. *Analyst:* T. C. Sarkar (1941, p. 247).

D. and E. Allanite (two different crystals), Ranchi. *Analyst:* P. B. Sarkar (1946).

THE AGE OF THE SINGAR URANINITE

The "Singar Mine" quoted as the locality for the uraninites referred to in Table 1 is the Abraki Pahar mica mine mentioned by Dunn (1942, p. 237) in his account of the occurrence of uranium minerals in Bihar. Dunn writes as follows:

"At the Abraki Pahar mica mine near Singar, in Gaya district, pitchblende* was found at various times early this century. It was associated with triplite and yellow uranium ochre, the latter presumably being due to alteration of the pitchblende. According to Burton [in Hayden, 1914], the mineral occurred as nodules in a pegmatite which was 40 yards wide and 350 yards in length, but most of the pitchblende was obtained from a single pit. The largest nodule weighed 36 lbs. About 6 cwt. had been found up to 1913, and a further 16 lbs. in 1914. Rare torbernite and autunite also occurred [Tipper, 1919]."

A sample of uraninite from this locality was sent to me for age determination by the Director of the Geological Survey of India about 1914, when I was engaged in a pioneer attempt to correlate the Pre-Cambrian rocks of Mozambique with those of other countries. Only Pb and U were determined in the first place, because at that time it had not been

TABLE 2. URANINITE FROM SINGAR, GAYA DISTRICT, INDIA

CHEMICAL ANALYSIS (by A. Holmes)

Pb	U	Th	$\frac{Pb}{U+Th}$	$\frac{U}{U+Th}$	Apparent age in m.y.
8.92	64.3	8.12	.123	.89	885

ISOTOPIC ANALYSIS OF LEAD (by W. T. Leland and A. O. Nier)

Isotopic Proportions of Lead (Radiogenic)	Pb^{204} *	Pb^{206} 100	Pb^{207} 7.20	Pb^{208} 4.68
Per cent of Radiogenic Lead in Uraninite	—	7.973 RaG	.574 AcD	.373 ThD
	$\frac{AcD}{RaG}$	$\frac{RaG}{U}$	$\frac{AcD}{U}$	$\frac{ThD}{Th}$
Lead Ratios	.0720	.1240	.0893	.0459
Calculated Ages (m.y.)	995	883	912	1003

* Less than 1/20,000. Original lead is therefore negligible.

realised that thorium was also a generator of lead. It was not until 1932 that an opportunity arose for determining Th. This was carried out on part of the powder originally analysed.

In the light of more recent advances it appeared highly probable that the 'age' calculated from my analysis (B, Table 1) was too low. The original analysed sample of uraninite, though free from even microscopi-

* In accordance with the distinction now generally accepted this should read "uraninite."

cally visible alteration products was penetrated by clean cracks. Some loss of radon during the lifetime of the mineral, and therefore a deficiency of RaG (Pb^{206}), would therefore seem to have been a possibility (Wickman, 1942). The consistently higher monazite and allanite "ages" (C, D and E) also suggested that my uraninite "age" was low. To attempt to clear up the doubt Professor Nier generously agreed to determine the isotopic constitution of lead separated from the residue of the analyzed sample B. I am deeply indebted to Professor Nier and Dr. Leland for their welcome collaboration and also to Mr. W. C. Hughes, Chief Analyst of the Research Department of Imperial Chemical Industries Limited at Billingham, Co. Durham, under whose supervision a sample of pure lead iodide was prepared from the mineral powder.

The results and the apparent ages calculated from them (Keevil, 1939) are given in Table 2. The 'age' corresponding to the value of AcD/RaG is read from a graph prepared by Wickman (1939).

The "spread" of the three ages calculated from the ratios involving RaG and AcD is consistent with that resulting from (*a*) gain of U; (*b*) loss of Pb; (*c*) loss of radon and consequent deficiency in RaG; or (*d*) any combination of (*a*), (*b*) and (*c*). These possibilities will be discussed in turn in the light of the following summary:

Type of alteration	Effect on "Ages" as calculated from			Correction required to bring all 'ages' into agreement with the 'unchanged age'
	$\frac{AcD}{RaG}$	$\frac{AcD}{U}$	$\frac{RaG}{U}$	
(a) Gain of U	unchanged* (995)	low	lower	−7.97U (per cent of mineral)
(b) Loss of Pb	unchanged* (995)	low	lower	+1.25Pb; +1.20Th
(c) Loss of Radon	high	unchanged (912)	low	+ .32RaG; + .83Th

* If the gain or loss occurred long ago, instead of recently, the 'age' from AcD/RaG would be just a trifle lower than the real age (see Holmes, Leland and Nier, 1950, Fig. 1).

(*a*) The assumption that the dominant effect of alteration has been a gain of U has the advantage that 995 m.y., the age that would then be the correct one, or very nearly so, is in close agreement with the age from ThD/Th and not far from the crude ages C, D and E of Table 1. However, in view of the freshness of the analysed uraninite such a large gain of U (nearly 8%) is inherently improbable and, moreover, would be unlikely to occur without concomitant changes in Th and Pb. This solution is therefore considered to be unsatisfactory.

(*b*) The assumption of loss of lead implies that there has been loss of thorium-lead as well as of the uranium-leads, and when lead is arithmetically restored to bring the 'ages' based on RaG and AcD into agreement with 995 m.y. (again the correct or almost correct age) the 'age' based on ThD goes up to 1140 m.y. To reduce this to 995 m.y. involves the further assumption that 1.2% of Th has also been lost. Even so, the total losses are very much smaller than the gain required in (*a*) and are to that extent less improbable. The lack of visible alteration suggests the possibility that there may have been an exchange of atoms of Pb and Th for atoms of U, in which case smaller losses of Pb and Th would have been accompanied by a small gain of U. Such a combination of (*a*) and (*b*) still leaves 995 m.y. as the correct age, or nearly so.

(*c*) The assumption of loss of radon is not unreasonable, because such leakage is known to occur (Wickman, 1942) and would be favoured in this particular case by the physical condition of the uraninite. The maximum loss required is 4% of all the radon generated in the mineral throughout its history, corresponding to a present deficiency of .32% RaG expressed as a percentage of the mineral. In this case 912 m.y., the age from AcD/U, a ratio which is unaffected by loss of radon, becomes the correct one. There is then, however, the discrepancy of the "thorium-age" to be accounted for. To reduce 1003 m.y. to 912 m.y. implies that there was a loss of Th amounting to .83%. However, any such loss would almost certainly have been accompanied by small changes in Pb and U which would in turn have the effect of raising the correct age from 912 m.y. to something nearer 995 m.y. This would reduce the discrepancy of the "thorium age" and so reduce the amount of Th to be regarded as having been "lost."

(*d*) If loss of radon were the only factor concerned, then 912 m.y. could be adopted as the most probable age, whereas if no loss of radon had occurred the probable age would be 995 m.y. In the light of the above discussion it would appear that any loss of radon would also, in this case, have involved some loss of Th, accompanied, presumably, by small changes in Pb and U. The minimum total change would be one involving all the critical elements, but since there is no means of ascertaining how each one has behaved—or in what relative proportions—the evidence remains insufficient to yield an unambiguous solution.

All that can be said in conclusion is that the age of the mineral is likely to be less than 995 m.y. and more than 912 m.y. Under these circumstances the age can perhaps most fairly be stated as 955 ± 40 m.y. It had been hoped that a closer estimate would have been possible, but for this it will be necessary to await the results of similar studies on other radioactive minerals from the Bihar pegmatites.

The Position of the Satpura Belt in the Indian Pre-Cambrian Sequence

Although the present investigation leaves the age of the post-Satpura pegmatites still unsettled except between limits, even the lower limit of 912 m.y. suffices to indicate that the Satpura Belt represents the orogenic cycle immediately preceding that of the Delhi Belt, which extends from the neighbourhood of Delhi towards Gujerat in a general N.E.-S.W. direction (see map). Mica-pegmatites of post-Delhi age are distributed along the belt and uraninite from one of these, recently discovered by Dr. H. Crookshank, has been investigated in the same way as the Singar uraninite (Holmes, Smales, Leland and Nier, 1949).

The results, listed in Table 3, are in this case much easier to interpret. The three ages based on RaG and AcD agree as perfectly as could be expected within the limits of experimental accuracy. An age of 735 ± 5 m.y. can therefore be assigned to the mineral with confidence. The 'thorium-age' is discrepant as usual, but in this case it can only mean that there has been a trifling loss of Th (.4%). Any accompanying changes

Table 3. Uraninite, Bisundni, Ajmer-Merwara, Rajputana, India

Chemical Analysis (by A. A. Smales)

Pb	U	Th	$\frac{Pb}{U+Th}$	$\frac{U}{U+Th}$	Apparent age in m.y.
7.95	72.9	1.4	.107	.98	730

Isotopic Analysis of Lead (by W. T. Leland and A. O. Nier)

Isotopic Proportions of Lead (Radiogenic)	Pb^{204} <.001*	Pb^{206} 100.00	Pb^{207} 6.39	Pb^{208} .806
Per cent of Radiogenic Lead in Uraninite	—	7.416 RaG	.474 AcD	.06 ThD
	$\frac{AcD}{RaG}$	$\frac{RaG}{U}$	$\frac{AcD}{U}$	$\frac{ThD}{Th}$
Lead Ratios	.0639	.1017	.0065	.0429
Apparent Ages (m.y.)	740	733	733	935

* Original lead is therefore negligible.

in U and/or Pb would not affect the age calculated from AcD/RaG, i.e. 740 m.y.

The sedimentary and metamorphic formations of the Delhi cycle rest unconformably on those of the very much older Aravalli cycle. In some localities the Raialo Series intervenes between the two, this Series being provisionally correlated with the Kolhan Series, which succeeds the rocks of the Satpura Belt (Krishnan, 1943*b*, p. 135). So far as it goes this geological evidence is in accord with the geochronological proof that the Satpura Belt is older than the Delhi belt.

Inspection of the map indicates that the trend of the rocks of the Satpura Range cuts sharply across the trend of the Aravallis where the latter swing round to the S.S.E. as they approach the Deccan Traps. On this structural evidence the Satpuras appear to be younger than the Aravallis. Where the Aravallis are last seen before they disappear beneath the Deccan Traps they have a trend which is continued further south, beyond the cover of the Deccan Traps, in the rocks of the Dharwar Belt. For this reason it is provisionally supposed that the Aravallis and the Dharwars constitute parts of a single orogenic belt. This is an example of a tentative correlation that remains to be proved by the dating of radioactive minerals. It should be added that the Aravallis are underlain unconformably by a "Gneissic Complex" which represents a still older orogenic belt.

The relative positions of the Satpura and Dharwar rocks can be arrived at by another route. The map shows that the Eastern Ghats Belt, celebrated for its khondalites, kodurites and charnockites, cuts across the Dharwar Belt and therefore represents a younger orogenic cycle. The Satpura Belt, however, appears to be younger still, judging from observations made in Orissa by Krishnan (1943*a*, p. 141). Minerals suitable for dating the late pegmatites of the Eastern Ghats Belt* occur in the mica-pegmatites of the Nellore district, and already a few analyses of samarskite have been made for the purpose (Sarkar and Sen Sarma, 1946; Karunakaran and Neelakantam, 1948). The crude ages so far available (including one from a hitherto unpublished analysis by Professor Sarkar which he has kindly communicated to me) are 830, 1550 and 1760 m.y. On balance these also suggest that the Eastern Ghats Belt is older than the Satpura Belt. It is hoped that an isotopic analysis of lead prepared by Professor Sarkar from the "oldest" of these minerals will soon

* It is possible that the western margin of the Eastern Ghats Belt swings out to sea near Nellore, returning to the mainland north of Madras (*cf*. Fig. 1). If this be so, the pegmatites referred to are more likely to belong to the Dharwar Belt. It is hoped that investigation—now in progress—of an undoubted Dharwar mineral, together with further work on the Nellore minerals, will settle this question.

make possible a closer dating. There is also a possibility of dating the pegmatites from the Dharwar Belt. Ramaswamy (1943) has recorded the occurrence of monazite and samarskite from a beryl-bearing pegmatite at Yediyoor, near Bangalore. So far, however, no radioactive minerals have been recorded from the pegmatites of the Aravalli cycle.

From the evidence briefly reviewed above it appears that most of the Pre-Cambrian rocks of India fall into the following sequence. It should, however, be remembered that the supposed correlation of Aravalli and Dharwar is, as yet, no more than a plausible speculation. Moreover, it is improbable that this sequence is complete.

Vindhyan

735 m.y.
DELHI CYCLE (=? Cuddapah)

955±40 m.y.
SATPURA CYCLE

EASTERN GHATS CYCLE

(ARAVALLI CYCLE?=?) DHARWAR CYCLE

OLDER GNEISSIC COMPLEX (=? Bundelkhand Gneiss)

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