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ON THE AGE OF IRON-MANGANESE CONCRETIONS FROM THE INDIAN AND PACIFIC OCEANS

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(ABSTRACT)

Uranium, radium, thorium and ionium were determined directly on seven concretions from three stations in the Indian Ocean, and on two concretions and a manganese-rich crust from two stations in the Pacific Ocean. The uranium content averages 3 to 5 γ/g , and the thorium content varies only slightly, but the Th/U ratio in the concretions is typically 2 to 5 in the Indian Ocean and 5 to 15.5 in the Pacific. The ionium content ranges from $1.0 \cdot 10^{-9}$ to $3.6 \cdot 10^{-9}$ g/g in concretions from both oceans. Radium is more abundant in specimens from the Pacific Ocean ($Ra = 3 - 12.7 \cdot 10^{-11}$ g/g) than from the Indian Ocean ($1.5 - 5.2 \cdot 10^{-11}$ g/g). Analyses for Ca, Mn, Fe, Si, Ni, P, and ignition loss are also given.

Radioactive equilibria between uranium, ionium, and radium are strongly disturbed throughout the concretions, and the RA/U and Io/U ratios generally exceed equilibrium ratios. Migration of radium from interior layers was established, so that neither determinations of the ages of the concretions nor of their rates of growth can be considered reliable. The age of the concretions cannot exceed 800,000 years, and all grew within relatively short periods of time; there may have been "dormant" periods during growth. Estimates of growth rates are calculated from the radium and ionium contents; they show marked discordance.

Among the bottom deposits of the oceans and seas there are curious objects known as manganese concretions, objects of peculiar form and composition.

The first data on the radioactivity of manganese concretions were published by Kurbatov in 1936 [1, 2]. He investigated concretions from the Pacific Ocean and from a number of northern seas and lakes for their radium and thorium contents, and found that they differ in radium content, and that the outer layers are more radioactive than the inner layers. Kurbatov ascribed this to the decay of radium, and on this basis calculated the ages of two concretions as 5300 - 5500 years and 2000 years, respectively.

In 1943 Petterson [3] studied the rate of growth of concretions by the radioactive method, and found it to be about 1 mm per thousand years. Kröll [4] studied the distribution of radium in the manganese crusts of the Pacific Ocean. He noted that the determination of radium alone is not sufficient for accurate age measurement, and that a complete analysis of concretions for other radioactive elements, for example ionium and uranium, is necessary.

It is known [4, 5] that the thorium content in iron-manganese concretions is between $2.85 \cdot 10^{-5}$ and $3.85 \cdot 10^{-5}$ g Th/g, but there are no satisfactory data on the contents of other radioclements in these samples.

A detailed study of the radioactivity of these concretions would aid considerably in the solution of many interesting problems of oceanography, marine geology, and the geochemistry of radioactive elements. It would also throw light on the distribution, mode of occurrence, and behavior of radioactive elements, and the genesis of sedimentary deposits of these elements.

With these considerations in mind, we attempted to make a detailed study of these remarkable objects from the sea bottom.

Our investigation is not completed, but the data obtained so far are interesting enough to deserve preliminary discussion.

This communication contains only the results of investigations of a part of a collection of manganese concretions from the Indian and Pacific oceans, including seven concretions collected at three stations in the Indian Ocean (299, 287 and 255), two concretions from Station No. 3996 in the Pacific Ocean, and a peculiar iron-manganese "crust" from station No. 3782 in the Pacific Ocean.

The concretions from stations 287, 299, and 255 each have irregular spherical forms, lack layering, and are composed of a homogeneous dark-brown almost black iron-manganese layer (1 to 5 mm thick) that encloses a granitic pebble (Fig. 1), or a fragment of shale (Fig. 2). The weight of the concretions ranges from 19 to 40 g.

The concretions from station 3996 have a more regular globular form and measure about 6 by 7 cm. These concretions have well developed concentric layers, and it was possible to investigate three of these layers individually.

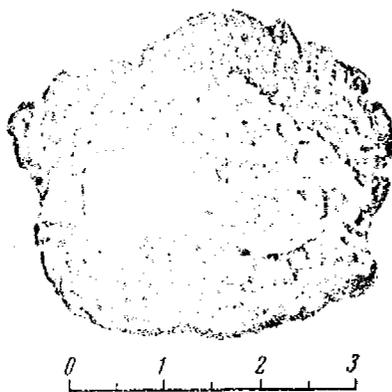


Fig. 1. Granite pebble in the core of a concretion (concretion 2, station 287, Indian Ocean)



Fig. 2. Clay in the core of a concretion (station 255, 121 cm zone, Indian Ocean)

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Finer subdivision was not possible because the thickness of the iron-manganese layer is of the order of 1 cm. The cores of the concretions are composed of unconsolidated clay impregnated with manganese oxide (Fig. 3).

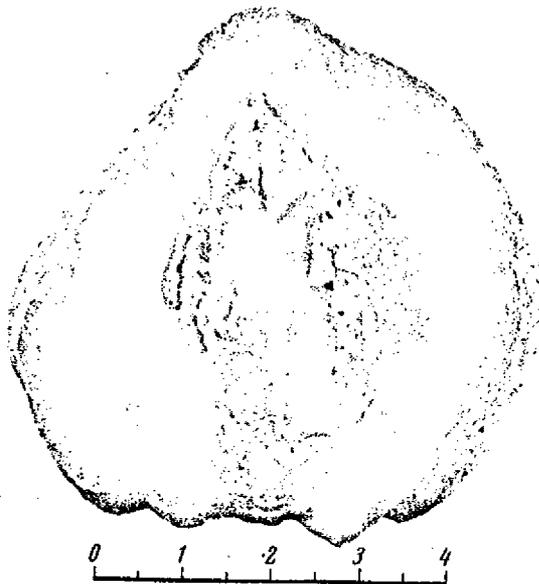


Fig. 3. Section of concretion 2 from station 3996 (Pacific Ocean)

The iron-manganese "crust" from station 3782 is composed of colloform oxides of iron and manganese deposited on argillite (Fig. 4).

The concretions were analyzed by the usual chemical methods [6], and also radiochemically as described below.

1. Uranium was determined by the luminescence method [7, 8] with an accuracy of $\pm 20\%$.

2. Radium was determined by the emanation method [9] with an accuracy of $\pm 5\%$.

3. Thorium and its isotopes were separated from the rest of the elements by chromatography with KU-2 resin [10]. We discovered that when a 30% solution of the material in hydrochloric acid is passed through the resin in H^+ form, the alpha emitters, uranium and especially polonium, are not adsorbed on the resin. This eliminates the long operation of separation of polonium by electrolysis. Thorium and ionium were determined on the same sample with control by UX1 indicator. The 1 - 2 g samples were first ignited and then were treated with concentrated sulfuric acid. After addition of UX1 indicator, the solution was evaporated to dryness, the residue was moistened with concentrated HCl, and was dissolved in hot water. The undissolved material was filtered off, washed, ignited, and was treated with a mixture of HF and H_2SO_4 . After removal of the sulfuric acid fumes, the residue was fused with soda and was leached with hot water, and after careful washing to remove traces of



Fig. 4. "Crust" of concretion No. 2, side view (station 3782, Pacific Ocean)

SO_4^{2-} , the carbonate precipitate was dissolved in 5% HCl and added to the filtrate.

The hydrochloric acid solution (30% by volume) was passed through a column of KU-2, and the resin was washed with 30% HCl until all traces of iron were completely removed. Thorium and its isotopes were eluted from the column with 10% oxalic acid, 50 mg of calcium was added to the oxalic solution, and the solution was heated to boiling. After 4 hours the solution was filtered, and the calcium oxalate precipitate was heated and dissolved in 5% HCl. The separation from the carrier, calcium, was accomplished by passing the solution through a blue ribbon filter which adsorbed the thorium isotopes quantitatively. The active precipitate on the filter was dissolved in 5% HNO_3 , the solution was evaporated, and the residue was deposited on a platinum target.

The measurement of the total alpha-activity of the thorium isotopes was made on the DA-49 instrument. After measurement of the alpha activity the precipitate was washed off the target with 5% HCl, the solution was transferred to a cuvette, and the beta-activity of UxI was measured on the B-2 instrument. The yield of thorium isotopes (in %) was measured by the content of UxI. From the cuvette the solution was transferred to a beaker, was evaporated to dryness, and the residue was dissolved in 0.1 N HCl. Thorium was then determined colorimetrically with thoron on FEK-H-57 [11, 12]. Ionium was determined by its alpha radiation, and in calculating its content a correction was made for the alpha activity of Th^{232} and RdTh . The accuracy of the determination of ionium was $\pm 20\%$. The results of analyses of manganese concretions are given in Tables 1, 2, 3, and 4.

It should be noted that there are no qualitative differences in the chemical and radiochemical compositions of the concretions investigated, whatever the locality or depth from which they were collected.

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Fe, %

Mn/Fe

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Io · 10⁻³ g

Ra · 10⁻¹¹ g

Th · 10⁻⁵ g

Io/U · 10⁻³

Ra/U · 10⁻¹¹

Th/U

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Fe, %

Mn/Fe

U · 10⁻⁶ g

Io · 10⁻³ g

Ra · 10⁻¹¹ g

Th · 10⁻⁵ g

Io/U · 10⁻³

Ra/U · 10⁻¹¹

Th/U

Note: All

Table 1
Indian Ocean

Elements	Station 287, concretions			Station 299, concretions	
	1	2	3	1, outer layer	2*
Loss on ignition, %	18,00	17,82	16,21	—	28,38
Insoluble residue, %	45,22	46,15	49,13	—	—
Si in insoluble residue, %	13,41	—	11,03	—	—
Ca, %	0,70	0,78	2,10	1,14	1,42
Mn, %	13,97	11,52	16,82	23,76	19,83
Fe, %	7,79	8,26	6,75	15,96	10,94
Mn/Fe	1,77	1,40	2,48	1,48	1,80
U · 10 ⁻⁶ g/g	3,36	4,80	4,98	4,80	5,49
Io · 10 ⁻⁹ g/g	1,60	1,70	2,30	3,60	1,20
Ra · 10 ⁻¹¹ g/g	2,70	1,81	1,91	5,17	1,50
Th · 10 ⁻⁵ g/g	3,90	4,20	—	2,50	3,0
Io/U · 10 ⁻³ g/g	47,6	35,4	46,1	75,0	21,8
Ra/U · 10 ⁻⁷	80,0	37,7	38,4	107,0	27,3
Ra/Io · 10 ⁻²	1,7	1,1	0,82	1,44	1,25
Th/U	11,6	8,7	—	5,2	5,4

* Concretion without core. The whole specimen was powdered.
Note: All commas are equivalent to decimal points.

Table 2
Indian Ocean

Elements	Station 255				
	Concretion 1		Concre. 2	Concretion 3, zone 121	
	outer layer	core	outer layer	outer layer	inner layer
Loss on ignition, %	12,15	1,5	9,25	19,22	18,10
Insoluble residue, %	59,66	94,23	64,11	36,21	43,68
Si in insoluble residue, %	—	—	14,13	11,92	12,27
Ca, %	0,98	—	1,00	—	—
Mn, %	6,64	} 4,22	5,00	13,2	10,22
Fe, %	7,80		6,16	13,95	12,95
Mn/Fe	0,85	—	0,81	0,95	0,80
U · 10 ⁻⁶ g/g	2,13	—	1,60	2,13	3,90
Io · 10 ⁻⁹ g/g	1,33	—	1,02	2,01	2,56
Ra · 10 ⁻¹¹ g/g	2,55	0,1	1,84	2,35	2,25
Th · 10 ⁻⁵ g/g	3,10	—	1,90	3,30	2,80
Io/U · 10 ⁻³	62,4	—	63,8	94,0	65,0
Ra/U · 10 ⁻⁷	119,7	—	115	110	57,7
Ra/Io · 10 ⁻²	1,9	—	1,8	1,17	0,87
Th/U	14,5	—	11,9	15,5	6,6

Note: All commas are equivalent to decimal points.

Table 3

14 Pacific Ocean 12 42 14 10 16

Element	Station 3996 (Lat. 4°56' N; Long. 135°29' E)					
	Concretion 1			Concretion 2		
	layer 1	layer 2	layer 3	layer 1	layer 2	layer 3
Loss on ignition, %	20,88	22,12	22,32	23,02	23,76	23,86
Insoluble residue, %	21,06	19,50	20,70	15,32	15,42	17,50
Si in insoluble residue, %	7,40	6,38	6,34	5,41	5,56	6,77
Mn, %	26,41	19,26	14,62	26,41	19,81	17,13
Fe, %	9,70	12,28	16,30	8,93	13,84	15,68
Mn/Fe	2,72	1,57	0,90	2,94	1,43	1,1
Ni, %	0,75	0,70	0,40	0,85	0,65	0,60
P, %	0,50	0,43	0,44	0,37	0,33	0,40
U · 10 ⁻⁶ g/g	3,90	5,30	5,26	5,06	9,35	7,14
Io · 10 ⁻⁹ g/g	2,82	2,60	2,70	1,00	0,40	0,21
Ra · 10 ⁻¹¹ g/g	12,70	4,86	1,37	7,59	0,77	0,24
Th · 10 ⁻⁵ g/g	1,46	1,33	1,98	1,37	1,54	1,79
Io/U · 10 ⁻⁵	70,0	49,0	51,0	19,7	4,2	2,9
Ra/U · 10 ⁻⁷	340	92	26	150	8,0	3,3
Ra/Io · 10 ⁻²	4,50	1,86	0,5	7,59	1,92	1,17
Th/U	5,0	3,6	3,7	2,7	1,6	2,5

Note: All commas are equivalent to decimal points.

The concretions from the Indian Ocean contain a greater amount of insoluble residue and a correspondingly higher content of silica. We believe this is caused by greater contamination of these concretions with terrigenous material.

The contents of manganese and iron in the concretions and their ratio are very characteristic. The distribution of manganese is nearly the same in the concretions from the Indian and Pacific oceans. The only exceptions are concretions from station 255 in the Indian Ocean that were collected from the surface of the bottom. The manganese content is considerably lower in these concretions. In general, the manganese content diminishes from the surface layers to the core (stations 3996 and 3782).

The iron content in the concretions from the Indian and Pacific oceans is more uniform. The amount of iron increases from the outer to the inner layers, and the Mn/Fe ratio varies within relatively narrow limits from 0.8 to 2.9, but mostly from 1.2 to 1.4. Only the exceptional concretions from station 255 in the Indian Ocean have Mn/Fe beyond these limits.

The content of calcium in the Pacific Ocean concretions is very stable. The Indian Ocean concretions contain a little less calcium. The contents of phosphorus and nickel also are stable.

There is little variation in the uranium content in the concretions investigated, and it usually averages $(3 - 5) \cdot 10^{-6}$ g/g. In the layered concretions the concretion of uranium in the outer layer is somewhat lower than in the inner layers. The content of uranium in the concretions is from four to six times higher than its normal content in the other ocean bottom deposits. Evidently

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Table 4

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Element	Station 3782 (Lat. 23°55' N; Long. 173°39.9' E)				Station 3782, crust layers not separated
	Crust 1		Crust 2		
	layer 1	layer 2	layer 1	layer 2	
Loss on ignition, %	28,40	27,65	28,19	27,70	27,10
Insoluble residue, %	16,05	20,63	18,25	21,50	29,40
Si in insoluble residue, %	4,41	4,56	5,06	4,96	11,72
Mn, %	18,50	18,71	19,03	18,16	19,15
Fe, %	12,74	14,47	13,51	15,40	13,40
Mn/Fe	1,46	1,3	1,4	1,13	1,42
Ca, %	1,81	1,93	1,73	1,80	1,60
Ni, %	—	—	0,37	0,34	0,38
P, %	—	—	0,30	0,40	0,42
U · 10 ⁻⁶ g/g	4,50	6,27	5,88	6,60	6,00
Ra · 10 ⁻¹¹ g/g	4,64	2,69	5,27	4,25	5,61
Th · 10 ⁻⁵ g/g	—	—	2,90	3,40	2,35
Io · 10 ⁻⁹ g/g	2,3	1,7	1,63	1,78	2,04
Ra/Io · 10 ⁻²	2,01	1,65	3,23	2,39	2,75
Ra/U · 10 ⁻⁷	103	43	89	64	98
Th/U	—	—	5,0	5,0	4,0
Io/U · 10 ⁻⁵	51	25	27,7	27	34

Note: All commas are equivalent to decimal points.

uranium is adsorbed from the ocean water on the iron and manganese hydroxides.

The ionium content in concretions from the Indian and Pacific oceans is also rather uniform, usually varying from $1.0 \cdot 10^{-9}$ to $(2.5 - 2.9) \cdot 10^{-9}$ g/g. Only one of the Indian Ocean concretions (station 299) contains $3.6 \cdot 10^{-9}$ g/g Io.

The distribution of ionium in the 2nd concretion from station 2996 is worthy of note: In the outer layer (layer 1) the ionium content is somewhat lower ($1.0 \cdot 10^{-9}$ g/g) than in the outer layers of other concretions, and decreases regularly towards the core ($0.4 \cdot 10^{-9}$ in layer 2 to $0.21 \cdot 10^{-9}$ in layer 3). This decrease evidently reflects the process of decay of the excess of ionium with time. In concretion 1 from station 3996, the ionium content is the same in the outer and inner layers and is in excess of equilibrium with uranium. This is true also of concretions from station 3782 and station 255, horizon 121.

Somewhat greater variations are observed in the distribution of radium. In the Pacific Ocean concretions, the radium content ranges from $3 \cdot 10^{-11}$ g/g to $7 \cdot 10^{-11}$ g/g, and in one case rises to $12.7 \cdot 10^{-11}$ g/g (station 3996, concretion 1). In concretions from the Indian Ocean the radium content is slightly lower, ranging from $1.5 \cdot 10^{-11}$ to $2.7 \cdot 10^{-11}$ g/g, but in concretions from station 299 it reaches a value common in the Pacific Ocean concretions of $5.17 \cdot 10^{-11}$ g/g.

In all concretions separated into several layers for analysis, the radium content decreases sharply from the outer to the inner shells, but the radium-uranium ratio is always higher ($150 \cdot 10^{-7}$ to $310 \cdot 10^{-7}$) than the equilibrium ratio ($3.4 \cdot 10^{-7}$).

The radium-ionium ratio in concretions is very characteristic; it varies from $0.5 \cdot 10^{-2}$ (concretion 1, station 3996) to $7.59 \cdot 10^{-2}$ (concretion 2, station 3996), and in some cases approaches the equilibrium ratio ($1.9 \cdot 10^{-2}$).

A comparison of the Ra/Io ratios in different layers of a concretion shows that they decrease regularly from the outer to the inner layers. Very interesting are the extremely low Ra/Io ratios in the inner layers of some concretions (Pacific Ocean, station 3996, concretion 1; station 3996, concretion 2, layer 3; Indian Ocean, station 255, horizon 121, layer 2). It is probable that this is caused by selective migration of radium from the inner into the outer layers and into the pore solutions of bottom mud. It is probable that the migration of radium obeys dynamic equilibrium and that some of it remains in the inner layers and is replenished by the decay of ionium. This, however, does not explain why the migration of radium does not affect the outer layers of the concretions, which usually have higher and sometimes much higher Ra:Io ratios ($4 \cdot 10^{-2}$ to $7.5 \cdot 10^{-2}$) than the equilibrium ratio. Additional experimental data are needed to answer this question.

At present we can only suppose that the rate of introduction (precipitation) of radium from water to oceanic sediments compensates the removal of radium from the outer layer of concretions into the bottom or near-bottom waters, insuring high absolute radium concentration in the outer layer and a high value of the Ra/Io ratio.

The Io/U ratio in concretions should be examined next. The equilibrium ratio is $1.85 \cdot 10^{-5}$, but in all concretions investigated it is considerably higher, ranging from $25 \cdot 10^{-5}$ to $50 \cdot 10^{-5}$, and occasionally rising to $70 \cdot 10^{-5}$ or even $75 \cdot 10^{-5}$. It is notable that the Io/U ratio is much higher than the equilibrium value, even in the inner layers of concretions (Pacific Ocean, station 3996, concretions 1 and 2; station 3782). What causes this relative enrichment of both the outer and inner layers of concretions in ionium? This question is especially interesting because the uranium content in concretions is considerably higher than in the normal bottom sediments of the ocean. Evidently the excess of ionium (relative to uranium) precipitated during the existence of all layers of the concretion does not have time to decay and to reach equilibrium with uranium. It should be noted that a similar excess of ionium relative to uranium was recently found in the bottom sediments of the Indian Ocean [13].

The Th/U ratio in the concretions ranges from 1.6 or, more commonly, from 4 or 5 to 11 and up to 15.5. The higher values (5 - 15.5) are characteristic of concretions from the Indian Ocean concretions, and the lower (2 - 5) are characteristic of concretions from the Pacific Ocean. This can be explained, evidently, by the greater participation of terrigenous suspensions in the formation of the concretions from the Indian Ocean investigated by us. One of the Indian Ocean stations (255) is not too far from shore, and the other (257) lies within the iceberg area.

The data presented in the tables and in the text show clearly enough that the ratios of the radioelements in the concretions are complex, and this is particularly true of the Ra/Io and Io/U ratios. The determinations of ages of the concretions and the rates of their growth from their radium content (Table 5) cannot be considered reliable because migration of radium from the inner layers destroys the normal (exponential) distribution of the radium content, decreasing it below equilibrium with ionium (layers 2 - 3).

The use of ionium in the determination of ages of concretions requires a more detailed discussion (Table 5). The fact is that most of the concretions investigated are not separable into layers, and the few concretions which it was possible to separate into two layers (station 255, concretion 3; station 3782, crusts 1 and 2) or three layers (station 3996, concretion 1) have practically the same ionium content in the inner and outer layers.

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Station 3996
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Station 3782

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Table 5

	Layers	"Age" of concretions		Rate of sedimentation	
		Radium age in years	Ionium age in years	calculated from Ra content, mm/1000 yrs.	calculated from Io content, mm/1000 yrs.
<u>Pacific Ocean</u>					
Station 3996	1-2	2205	Negative	1.6	Negative
Concretion 1	2-3	2890	value	1.2	value
	1-3	5100		1.4	
Station 3996	1-2	5240	110260	0.62	0.029
Concretion 2	2-3	2670	77260	1.12	0.039
	1-3	7910	187710	0.79	0.033
Station 3782		1240	36000	1.2	0.04
<u>Indian Ocean</u>					
Station 255		100	Negative	30	Negative
Concretion 3			value		value
Zone 121 cm					

The constancy of the ionium content indicates that the concretions were formed so recently that ionium in the inner layers has not had time to decay to a noticeable degree. The age of these concretions is evidently less than 400,000 years (5 T Io). This conclusion is confirmed to some extent by concretion 2 from the outer to the inner layer. It would seem that the age of this concretion might be determined from the distribution of the ionium. Its calculated age (188,000 years, Table 5) is less than the established limit (< 400,000 years), and therefore the two calculated ages are not contradictory. However, several questions arise. Why is the distribution of ionium so different in two concretions (1 and 2) from the same station? Is ionium uniformly distributed among the layers of concretion 1, while in concretion 2 its content diminishes gradually from the outer to the inner layers, and the outer layer contains only a quarter of the amount of Io present in the outer layer of concretion 1? Evidently the age of concretion 1 (station 3996) is not only less than 400,000 years, but less than 188,000 years; i.e., concretion 1 is younger than concretion 2. Another question arises now: Might not concretion 2 be older than 188,000 years? In accepting the age of 188,000 for it, are we not making a mistake by neglecting possible decay of ionium in the outer layer?

Here we must consider the basic question: What do we mean by the age of a concretion? In geochronological investigations the age of a mineral or rock is the interval of time elapsed between the moment of its formation and the time of investigation ("absolute age"). In the case of concretions, however, this definition is not acceptable, because the methods used in their investigation do not guarantee the determination of the "absolute age" in the generally accepted sense.

In using the radium or ionium methods, we determine the time required for the formation of individual layers and of the whole concretion ("time of growth" but not the time elapsed since its inception. The "absolute age" of the concretions remains unknown. It can be established only if the concretion is extracted from the parent medium (sea bottom) while it was still growing at a sufficiently slow rate so that its growth is recorded by the decrease of ionium and radium content in the inner layers.

Here we come upon the still unsolved problem of the origin of the iron-manganese concretions [1], and of the causes initiating and ending their growth. Evidently after a concretion ceases to grow it may continue to exist on the ocean bottom for an indefinite period of time. Concretions with absolute ages of 600 to 800 thousand years should not contain excess ionium, but all concretions investigated so far do contain excess ionium, and this means that none of them is older than 800,000 years. All these concretions are relatively young and were formed ("grew") within a relatively short period of time. This is indicated by the constancy of the concretion of ionium in the different layers of all but one concretion (station 3996, concretion 2). This concretion differs from the rest because in it the concretion of ionium decreases from the outer to the inner layers and, migration excluded, this must mean a long period of growth interrupted by periods of "dormancy". If it were possible to determine the difference in the concretion of ionium in the monomolecular surface of the inner layer and the adjacent outside layer, the lengths of the periods of dormancy could be estimated.

The time of growth calculated from the decrease in the concentration of ionium from the first ($1 \cdot 10^{-3}$ g/g) to the third ($0.21 \cdot 10^{-3}$ g/g) layers is 188 thousand years. But in all layers of the concretion the Io/U ratio is higher than the equilibrium ratio; i. e., there is an excess of ionium with respect to uranium. Therefore there is reason to deny the assumption that the first layer, considered as modern in the calculations, is actually modern at all; instead it is rather old, so that the concretion stopped growing some time ago. If it is assumed that at the moment of its formation the first layer contained as much ionium as layers 1 to 3 of concretion 1 (station 3996) contain now ($2.6 \cdot 10^{-3}$ to $2.8 \cdot 10^{-3}$ g/g), then the decay of ionium to the level of concretion observed now in layer 1 of concretion 2 from the same station must have required 120,000 years! To this must be added the time of growth of the concretion, or 188 thousand years, and then the absolute age of the concretion is actually 300,000 years (188 + 120). Therefore, in the case of concretions, we must distinguish between time of growth and "absolute age".

It is difficult to say at present how closely the calculated absolute age of concretions approximates their true age. We hope that investigation of more concretions will help to answer this question.

The ages and the rates of sedimentation given in Table 5 are obviously discordant, and show very clearly that the determinations of these time intervals either from the radium or ionium contents are inadmissible without complete radiochemical analysis, which gives the ratios of the radioelements used in the age determinations. Therefore, as pointed out in reference [4], the calculation of the ages of concretions must be based on direct determinations of uranium, radium, and ionium.

Summary

1. For the first time uranium and ionium were determined directly on iron-manganese concretions from the Indian and Pacific oceans. Radium and

thorium and
the first two ele-
ments, U, Th, and
Ra, and

2. The
concretions is cor-
related

3. It was
radium are
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concretions, a

4. The
(5 - 14) tha

5. In the
"age", i. e.,
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The time de-
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cretions are

6. The
the absolute
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The auth-
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A. P. Lisitz
concretions; an
for radium.

1. Kurbatov

2. Kurbatov

3. Pettersen

4. Kröll, G.

5. Goldberger

6. Analiz

7. Hernege

8. Starik, G.

9. Starik, G.

10. Kapatskiy

11. Kuznetsov

12. Starik, G.

thorium also were determined in these concretions. Determinations of the last two elements in manganese concretions had been made earlier by Kurbatov, Kröll, and Petterson.

2. The contents of uranium, ionium, radium, and thorium in most concretions is considerably higher than in other bottom deposits of the ocean.

3. It was found that radioactive equilibria between uranium, ionium, and radium are strongly disturbed both in the concretions as a whole and in their individual layers. The Ra/U and Io/U ratios, even in the inner layers of concretions, are in most cases higher than the equilibrium ratios.

4. The Th/U ratios in the iron-manganese concretions are usually higher (5 - 14) than the average ratio in rocks (3 - 4).

5. In the case of concretions, it is necessary to distinguish between "absolute age", i. e., the interval of time from the time of beginning of growth of a concretion to the time of investigation, and the "time of growth", i. e., the time required for the formation of an individual layer or the concretion as a whole. The time determined by the ionium and radium methods is the time of growth of the concretions, but their absolute age is indeterminable unless the concretions are collected from the sea bottom while they are still growing.

6. The ratios of the radioactive elements make it impossible to determine the absolute age of the concretions. The data obtained show that it is not permissible to calculate the ages of concretions on the basis of determinations of radium and uranium only. The minimum requirement, although not always sufficient, is direct determination of uranium, ionium, and radium.

The authors express their gratitude to I. E. Starik for suggesting the subject of this research; to P. L. Bezrukov, T. V. Gorshkova, P. V. Vinogradova, A. P. Lisitzin, V. P. Petelin, and N. S. Skornyakova for the samples of concretions; and to N. A. Gordeyeva for emanation measurements in the analyses for radium.

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Geokhimiya No. 7, 1963
pp. 678 - 688

Received for publication
July 23, 1963

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