The Radioactivity of Rocks from the Mysore State, South India.

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This investigation was started some years ago on a number of samples of the hornblendic schists of the Kolar Gold Field, selected by Mr. H. M. A. Cooke, Superintendent of the Ooregum Gold Mining Co. The samples were taken at different depths from the Kolar mines with a view to ascertaining whether the radium content varied with the depth from surface in rock of fairly uniform character and composition. These hornblendic schists and epidiorites are all ancient lava flows or sills of fairly uniform composition, notwithstanding petrological distinctions in texture and structure. An account of the method used and results obtained was published in the Philosophical Magazine (6) *28* p. 44. 1914, and the results are repeated in Table I. Nos. 1 to 15. It will be seen that the radium content is very low, remarkably constant and that there is no variation in depth down to a vertical depth of some 3,500 feet from surface.

Two of the samples – Nos. 12 and 15 – gave results considerably higher than the others, but microscopic examination showed that these samples did not represent normal types of the hornblendic schists, or "country," of the mines but had undergone considerable mineral alteration such as is common in the immediate vicinity of the quartz veins or other acid intrusives and there is no doubt that the higher values are due to the intrusion of acid material of higher radium content.

It was next decided to obtain a number of representative samples from the various components of the Archaean complex of Mysore in order to ascertain how far the various formations or groups might be distinguishable from one another by their radio-activity and what variations existed amongst the members of each group as a result of magmatic segregation. The experimental procedure was the same as before, *viz.*, 10 gms. of the finely powdered rock were fused with potassium hydroxide under reduced pressure, and the resulting gases led to an electroscope after removal of the hydrogen and drying. Towards the middle of the experiments the leaf system in the electroscope broke down, and was replaced by a smaller and more sensitive one which was subsequently carefully standardized. With this, a leak of 1 scale division an hour corresponded to $1\cdot67 \times 10^{-13}$ gm. of radium. Control experiments showed no discontinuity between the two series of values obtained. All experimental details have already been given (*loc cit*) and will not be repeated. Altogether fifty samples have been selected from specimens in the Department of Mines and Geology of Mysore and the radium determined, but each group is itself so complex and variable that a much larger number would be required before fair averages or estimates could be obtained. In spite of this, certain interesting variations appear to be indicated and the results obtained have been grouped in Table I, under the various formations taken in order of age from the oldest to the youngest.

In Table II a number of estimates of the chief constituents of these rocks is given, some of which are analyses of the actual samples on which the radium determinations were made and the rest are analyses which happen to be available of similar rocks.

The following classification is inserted for convenience of reference and shows the order of succession and relationship of the formations in Mysore as at present adopted by the Mysore Geological Survey * :—

Classification of Mysore Rocks.

	1.	Recent soils and gravels.
Possibly Tertiary.	2.	Laterite. Horizontal sheet capping archaeans.
Pre-Cambrian. (Animikean)	3.	Basic Dykes. Chiefly various dolerites.

* Outline of the Geological History of Mysore by W. F. Smeeth—Bulletin No. 6—Department of Mines and Geology, Mysore State

Great Eparchaean Interval.

Archaean.

4. Felsite and porphyry dykes.

5. Closepet granite and other massifs of corresponding age.

6. Charnockite, norite and pyrozenite dykes.

7. Charnockite massifs. (Complex.)

8. Various hornblendic and pyroxene granulite dykes.

9. Peninsular gneiss. Granite and gneissic complex.

10. Champion gneiss. Granite porphyry, micaceous gneisses, felsites and quartz porphyries; usually containing opalescent quartz and frequently associated with autoclastic conglomerates.

Eruptive unconformity.

			Including also ;—
Dharwar System (probably Keewatin.	11.	Upper (chloritic) division. (Green stones and chlorite schists.)	Amphibolites, peridotites, etc., mostly intrusive. Conglomerates (autoclastic). Banded-ferruginous - quartzites; origin doubtful possibly igneous. Quartzites and quartz-schists mostly intrusive. Lime stones; probably secondary Mica schists; metamorphic igneous. Intrusive masses of dioritic and diabasic character.
	12.	Lower (hornblendic) division. (Epidiorites and hornblendic schists.)	
		(Unknown).	

We may now very briefly consider the groups of figures presented in Table I, and the following summary of the results will help to bring out such points of similarity or distinction as exist amongst them although the observations are too few in numbers to permit of final conclusions being drawn.

TABLE I.

Radioactivity of Rocks from the Mysore State.

(The rock groups are arranged in order of age from the oldest to the youngest. The radium is given in units of 10^{-12} grammes per gramme of rock.)

Serial No.	Registered No.	Description.		Radium per 10^{12} gm.	Remarks.
		Group I.—Dharwar System—Lower (hornblendic) Series.			
			ft.		
1		Balaghat Mine—depth	1000	0·21	(The first 15 samples are all hornblende schists and epidiorites from the Kolar Gold Field. The depths are measured on the dip of the lode)
2		" " "	2000	0·14	
3		" " "	3000	0·21	
4		Nundydroog " "	1000	0·17	
5		" " "	3000	0·14	
6		Ooregum " "	1000	0·18	
7		" " "	2000	0·17	
8		" " "	4000	0·21	
9		Champion Reef " "	2000	0·21	
10		" " "	3000	0·18	
11		" " "	4000	0·14	
12		Mysore " "	1000	0·34	Altered schist.
13		" " "	2000	0·21	
14		" " "	3000	0·23	
15		" " "	4000	0·96	Much altered schist; part of the lode formation; contact alteration close to quartz of lode.
16	82/377	Amphibolite—footwall of lode—Ooregum.		0·82	Contact alteration.
17	Z3/510	Fine hornblende schist, Bababudan Hills, Kadur District.		0·25	
18	J1/535	Hornblende granulite; Kolar schists.		0·19	
		Group 2—Dharwar System—Upper (chloritic) series			
19	*Z3/258	Santaveri trap; Bababudan Hills.		0·20	Chloritic trap with some hornblende.
20	Z4/757	Banded chlorite schist; Sacrebail, Shimoga.		0·27	
21	Z4/703	Calc—chlorite trap; Tarikere series.		0·51	Probably altered hornblendic trap.

Group 3—*Intrusives of Dharwar age—subsequent to the schists.*

22	S2/943	Hornblende diabase or diorite; Bababudan Hills.	0·16	
23	W3/69	Bellara trap; Tumkur District	0·05	Altered diabase intrusive into chloritic series.
24	Z4/95	Grey trap; Chitaldrug do	0·07	Chloritic trap probably related to Bellara trap.
25	J4/117	Titaniferous iron ore; Ubrani Shimoga.	0·05	Associated with ultrabasic intrusives

Group 4—*Champion Gneiss Series—intrusive into Dharwars.*

26	J1/335	Grey micro granite; Kolar ...	0·85	
27	J1/156	Fine micaceous granite-matrix of crush conglomerate. Kolar Gold Field.	1·45	
28	S3/313	Fine mica granite; Mysore mine at depth of 3000 ft.	1·34	
29		Auriferous quartz from the Mysore mine.	1·28	These are considered to be products of the Champion gneiss magma.
30	A/624	Quartz—felspar porphyry ..	1·05	
31	S/402	Massive phyrrhotite from Champion Reefs Mine.	0·07	From Gifford's shaft

Group 5—*Peninsular Gneiss Series—later than Champion Gneiss.*

32	J3/238	Dark porphyritic granite; Kolar.	0·91	These are in order of intrusion beginning with the oldest.
33	J3/278	Dark grey granite; Kolar...	0·99	
34	J3/212	Fine dark grey granite ,, ...	1·28	
35	J3/276	Fine light grey granite ,, ...	0·47	
36	J3/63	Light crushed granite; East of Kolar Field.	0·40	
37	J3/122	Uniform granite mass; Patna Kolar.	1·50	
38	S/326	Pagmatite cross-course, Balaghat mine.	1·44	These probably belong to the Peninsular gneiss.
39	S/354	Pegmatite cross-course; with tourmaline; Ooregum mine.	6·90	In No. 39 the tourmaline itself is not abnormally ligh in radium.

Group 6—Charnockite Series—later than the Peninsular Gneiss.

40	J2/824	cid Charnockite, Chamrajnagar, Mysore District.	0·01	Order of intrusion doubtful.
41	J2/822	Intermediate charnockite, Chamrajnagar, Mysore Dt.	0·10	
42	J2/722	Basic Charnockite, Heggaddevankotte, Mysore District.	0·12	
43	J3/631	Hypersthenite; Nanjangud ...	0·06	These are considered to be derived from the Charnockite magma
44	J3/713	Quartz—magnetite ore: Heggaddevankotte.	0·08	

Group 7—Closepet Granite—later than Charnockite.

45	J3/434	Coarse grey porphyritic granite; Closepet, Bangalore District.	0·27	In order of intrusion beginning with the oldest.
46	J3/430	Grey granite; Closepet ...	0·63	
47	J3/429	Red granite " ...	2·14	
48	Z2/621	Dark quartz—felspar porphyry, Yelwal, Mysore District.	2·42	These porphyries are subsequent to the Closepet granite and may belong to the same magma
49	Z2/648	Pink felspar—porphyry; Kirangur, Mysore District.	1·37	

Group 8—Post Archaean Dykes.

50	J1/333	Normal dolerite dyke; Kolar Gold Field.	0·45	Typical of a large series of post—Archaean dykes which may be of Cuddapah age (Animikean)

GROUP.		Radium gm. per 10^{-12} gm. Limits.
Dharwar System.	Hornblendic series	0·14 to 0·25
	" " altered types ...	0·34 " 0·96
	Chloritic series	0·20 " 0·54
	Basic intrusives	0·05 " 0·16
	Champion gneiss	0·65 to 1·45
	" " auriferous quartz ...	1·28
	Peninsular gneiss	0·40 to 1·50
	" " pegmatites ...	1·44 " 6·90
	Charnockites	0·04 to 0·12
	" hypersthenite	0·06
	" quartz-magnetite ore ...	0·08
	Closepet granite	0·27 to 2·14
	" " porphyries... ...	1·37 " 2·42
	Dolerite dykes (post archaean) ...	0·30

The hornblendic rocks of the Dharwar system are low in radium and exhibit no great variation from the mean though many petrological types are included—such as hornblende schists, hornblende diabases, amphibolite and hornblende granulite. When however these rocks are altered in contact with intrusions of the Champion gneiss and of the related quartz veins of the Kolar Field both of which contain much more radium than the normal schists—the radioactivity of the altered types is considerably increased to a point intermediate between the radioactivities of the two reacting masses.

The rocks of the chloritic series do not appear to differ much in radium from those of the hornblendic series. The higher value in No. 21 may possibly be the result of alteration due to a neighbouring granitic intrusion. The basic intrusives of Dharwar age that is to say intrusives into the general body of the Dharwar schists prior to the period of the Peninsular gneiss contain much less radium than even the schists them elves. This is particularly noticeable in the Bellara trap and the grey trap of Chitaldrug.

Some years ago the grey trap was considered to be a modification of the less altered Bellara trap and subsequent work showed that the Santaveri trap of the Kadur District possessed a considerable resemblance to the grey trap of Chitaldrug, so much so, that it had almost been decided to class these two formations together, and separate them from the Bellara trap. The radium determinations, however, show that the grey trap and the Bellara trap have practically the same radioactivity (vide Nos. 23 and 24), which is much below that of any of the schists proper, while the Santaveri trap (No. 19) contains about three times as much radium and falls within the limits so far ascertained for the schists. This appears to confirm the original clssification which, consequently, has been allowed to stand. The case affords an illustration of the possible use of radium determinations as an aid to correlation of the highly metamorphosed members of the Archaean complex amongst which it may often happen that the chemical and mineral composition and the field relationship do not afford sufficiently definite points of similarity or distinction. The value of such determinations will depend on the possibility of ascertaining fairly definite limits for the radium contents of the various rock groups or of the various members of such groups.

Amongst the various gneisses and granites, which have been divided into four great groups of distinctly different ages, it will be noted that the Charnockites stand apart from the others in virtue of their excessively low radioactivity, which is much lower even than that of the Dharwar schists

The Champion gneiss, Peninsular gneiss and Closepet granite—which latter is also a variable complex—all contain from 12 to 15 times as much radium as the Charnockites and 4 to 5 times as much as the Dharwar schists. The Charnockites have been shown by Holland to form a distinct petrographical province amongst the gneisses of Southern India and vary, as the result of magmatic segregation, from highly acid granites to norites and hypersthenites—all characterized by the presence of hypersthene and certain physical features—and the radium determinations fully confirm the distinct individuality of the parent magma. The varieties of Charnockite which have been examined show an increase of radium with increasing basicity but the hypersthenite and quartz-magnetite ore—which are considered to be end products of the segregative process—show a relapse towards the mean value.

The other gneisses and granites are very complex and the determinations are not sufficiently numerous to permit of very definite conclusicns. It may be noted that the members of the Champion gneiss series show least variation, those of the Peninsular gneiss rather more and these of the Closepet granites the greatest variation.

The auriferous quartz of the Kolar Field (No. 29) is interesting as falling into line with the members of the Champion gneiss series with which it has been correlated on other grounds and, as already pointed out, the altered schists in contact with, or in continuation of, the auriferous quartz viens show values intermediate between those of the normal schists and of the quartz.

It is interesting also to note that the matrix of the conglomerate (No. 27) has the same radioactivity as the clearly intrusive granite (No. 28) and this helps to confirm the view that the conglomerate is autoclastic and due to crushing of portions of the Champion gneiss series.

The pegmatite cross-course (No. 39) is remarkable as yielding the highest result so far obtained. The pegmatite contains a certain amount of tourmaline and it was thought that this mineral might account for the high value. A small quantity of the tourmaline was separated and, though a definite determination was not made, the test was sufficient to show that it was not abnormally high and that the high result of the rock as a whole was not due to this mineral.

A single determination (No. 50) has been made of one of the very numerous dolerite dykes which are considered to be of pre-Cambrian age but subsequent to the formation and folding of the Archaean complex This rock is very similar in composition to the old hornblendic schists which were probably originally diabasic flows and sills of a very much earlier period. The result shows that the later rock contains rather more radium but no further inference can be drawn from a single observation.

Summary.

1. All of these very ancient rocks, all of which are considered to be of igneous origin, contain remarkably little radium.

2. Amongst the various groups which have been differentiated on geological grounds, there are some striking differences in the radium contents of some of them.

3. In the case of a fairly uniform group of rocks the radium contents do not appear to vary with the depth from surface.

4. Igneous magmas appear to contain very different amounts of radium and the latter, or the minerals which carry it, is subject to magmatic segregation. The amount of radium in the segregated portions of a magma sometimes increases and sometimes decreases with increase of basicity.

5. Amongst magmas the more basic appear to be lower in radium than the more acid and in the products of granitic magmas the pegmatities appear to carry more radium than the corresponding granites. The Charnockite magma, which was probably of intermediate composition, forms a striking exception.

6. In the case of rocks of somewhat similar character and composition and in which other means of distinction or identification are lacking, a marked difference in the radium contents may afford a means of correlating them with known groups or formations for which the radium limits have been sufficiently determined.