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XVIII. The amount of radium present in typical rocks in the immediate neighbourhood of Montreal

A.S. Eve M.A. & D. McIntosh D.Sc.

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The amount of energy transformed per cubic centimetre of a metal into radiant energy per second is surprisingly large: nearly the whole of this is absorbed by the metal, and passes into a form other than that of radiant energy. We have seen that if E is the radiant energy per unit volume in the body when in the steady state, the amount of radiant energy produced in a cubic centimetre of the substance per second is

$$\frac{C \, . \, 4\pi V^2 \, . \, E}{K}.$$

Now VE is the stream of radiant energy passing through the substance; by Stefan's law it is equal to $\sigma\theta^4$ at the absolute temperature θ, and σ is about 10^{-12} gram calorie. For silver c, the specific conductivity, is about 1/2000; hence at the temperature 27° C. or 300 absolute the radiant energy produced per cubic centimetre of the silver per second is equal to

$$\frac{6\pi}{K} \, . \, 10^{-5} \times (300)^4 \quad \text{or} \quad \frac{1}{K} 1{\cdot}5 \times 10^6 \text{ calories.}$$

Thus if K were unity the radiant energy produced in a cubic centimetre of silver represents about 8000 horse-power. Thus, though a cubic centimetre of silver does not distribute its radiant energy well, it produces as much as a good-sized electric-lighting station.

XVIII. *The Amount of Radium present in Typical Rocks in the immediate Neighbourhood of Montreal.* *By* A. S. Eve, *M.A.*, *and* D. McIntosh, *D.Sc.**

IN 1906 Strutt made a careful and thorough investigation of the amount of radium present in specimens of rocks obtained from sources differing widely in geographical distribution and in geological time. His results, published in the Proceedings of the Royal Society (May 14th and August 18th) were most remarkable and important; and it may be convenient to reprint them in the present communication. But it is necessary to apply a correction depending on the ratio of radium associated with uranium, which in the results first published was not correctly assumed, because the value ultimately found by Rutherford and Boltwood was

* Communicated to the Royal Society of Canada. Communicated by the Authors.

not then known. The results obtained, expressed in grams of radium per gram of rock examined, are as follows :—

Igneous Rocks.

Granite	Rhodesia	$4 \cdot 78 \times 10^{-12}$
„	Cornwall	4·67 „
Zircon Syenite	Norway	4·65 „
Granite	Cornwall	4·21 „
„	Cape of Good Hope	3·57 „
„	Cornwall	3·45 „
„	Westmoreland	3·31 „
Syenite	Norway	2·44 „
Granite	Devon	1·84 „
Blue ground	Kimberley	1·68 „
Leucite basanite	Vesuvius	1·66 „
Hornblende granite	Egypt	1·22 „
Pitchstone	Isle of Eigg	1·03 „
Hornblende diorite	Heidelberg	·99 „
Augite syenite	Norway	·93 „
Peridotite	Isle of Rum	·68 „
Olivine euchrite	„ „	·64 „
Olivine basalt	Skye	·66 „
Basalt	Victoria Falls	·63 „
Hornblende granite	Leicestershire	·62 „
Dolerite	Isle of Canna	·62 „
Greenstone	Cornwall	·57 „
Basalt	Antrim	·52 „
Serpentine	Cornwall	·50 „
Granite	Isle of Rum	·36 „
Olivine rock	„ „	·33 „
Dunite	Loch Scaivig	·33 „
Basalt	Greenland	·30 „

Sedimentary Rocks.

Oolite	Bath	$2 \cdot 92 \times 10^{-12}$
„	St. Alban's Head	2·02 „
Marble	East Lothian	1·93 „
Kimmeridge clay	Ely	1·88 „
Oil-bearing sandstone	Galicia	1·52 „
Roofing slate	Wales ?	1·28 „
Gritty slate	Cornwall	1·25 „
Gault clay	Cambridge	1·01 „
Clay	Essex	·86 „
Red sandstone	East Lothian	·84 „
Fine gravel	Essex	·71 „
Red chalk	Hunstanton	·53 „
Flint	Essex	·53 „
White marble	India	·27 „
Marble	East Lothian	·26 „
Chalk, bottom of pit	Cambridge	·39 „
„ top of same pit	„	·12 „

These results show that the amount of radium in the rocks near the earth's surface is greatly in excess of that required to maintain the earth at its present temperature.

For Professor Rutherford has shown by his calculations that the heat from $\cdot 05 \times 10^{-12}$ gram of radium in every gram of the earth would be sufficient to compensate for the loss of heat from the earth by conduction and radiation. But the averages obtained from Strutt's determination are :—

Igneous rocks	$1\cdot7 \times 10^{-12}$ gram of radium.
Sedimentary rocks ...	$1\cdot1 \times 10^{-12}$ " "
Mean value	$1\cdot4 \times 10^{-12}$ " "

Hence it appears that near the earth's surface there is about 28 times as much radium present as will account for the existing temperature gradient within the earth. This result is so unexpected that it seems desirable to check all available data before embarking on speculative hypotheses. Moreover Strutt, in his work, ignored the twin continents of North and South America, for he did not select a single specimen for investigation from the New World.

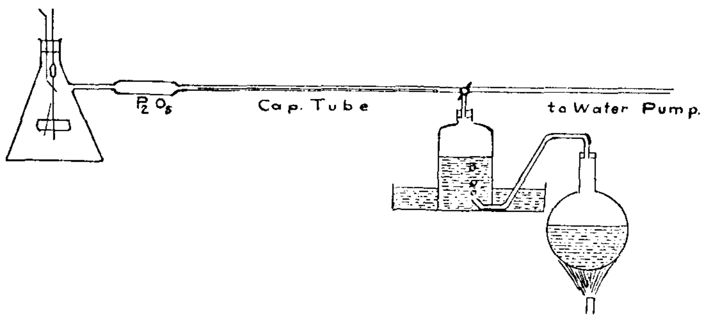
For these reasons the present writers decided to examine representative rocks obtained in the immediate neighbourhood of Montreal. Professor F. D. Adams kindly recommended a typical series, and his assistant, Mr. Bancroft, was good enough to procure specimens from the field.

Three igneous rocks were selected :—Essexite, which forms the main mass of Mount Royal; Nepheline Syenite, a subordinate part of the same mountain, and Tinguaite; which occurs as a large intrusive sheet. All these were thrust through the Ordovician plain in Devonian or later times. The sedimentary rocks selected were Trenton Limestone of the Ordovician system; and the Boulder-Clay, Leda-Clay, and Saxicava-Sands of the Quaternary or Post-Tertiary period. Thus the specimens examined cover a wide extent in point of geological time.

The rocks were chemically prepared in the following manner :—Fifteen to twenty grams of the rocks were ground so as to pass through an eighty-mesh sieve. One hundred to one hundred and fifty grams of fusion mixture (Na_2CO_3 and K_2CO_3) were added, and, the whole fused in a platinum dish for several hours in a muffle furnace. The fused mass was detached from the platinum dish, acidified with HCl, and evaporated to dryness; then taken up with dilute HCl and the silica and insoluble matter removed by filtration. This insoluble matter was treated with hydrofluoric acid, evaporated to dryness, and the small amount of residue was fused as before, and added to the soluble portion. The whole was evaporated until a reasonable amount of liquid was left, and this was stored in a tightly stoppered flask for subsequent examination.

After a definite period, usually about a week, the solution was thoroughly boiled, and the expelled air and emanation were collected over water. These were drawn into an electroscope which previously had been almost exhausted of air by a water-pump. Three hours later, when the active deposits had nearly reached maximum activity, the movement of the gold-leaf was measured by a microscope with a graduated eyepiece. Since the emanation in the flask increases to half its maximum value in about 3·8 days, it is easy to calculate the maximum from the amount measured after any definite period. It was found by experiment that the emanation was not lost to an appreciable extent by absorption when collected over water, if placed in the electroscope without delay.

The electroscope, as shown in the figure, consisted of a



filter-flask silvered inside. Strips of tinfoil moistened with phosphoric acid connected the silver coating to the earth wire. The flask was closed by a rubber stopper to which the usual gold-leaf arrangement was attached. It could be exhausted by a water-pump to a pressure of 1 or 2 cms. of mercury. Air and emanation could be admitted through a capillary-tube and a bulb of phosphorus pentoxide. The natural leak of the electroscope was 3·9 divisions an hour, and this remained remarkably constant, provided the electroscope was exhausted and refilled daily. The electroscope was not influenced by exterior electrification, nor by atmospheric conditions.

Blank tests were made involving all the chemicals and all apparatus used in the experiments. No radioactive matter could be detected by these tests.

The electroscope was standarized by inserting the air and emanation boiled from a flask containing $1{\cdot}57 \times 10^{-9}$ gram of radium, and the resulting effect was a movement of 10·3 scale-divisions per minute after 3 hours.

The standard solution was that used by Rutherford and

Boltwood in their determination of the amount of radium associated with uranium in radioactive minerals. It was prepared from some radium bromide which Rutherford and Barnes found gave per gram a heating effect of 110 gram-calories per hour.

The solutions prepared from the specimens of Montreal rocks were tested two or three times to insure accuracy. The results obtained were as follows :—

Period.	Rocks in order of age of formation.		Grams of Radium per gram of rock.
Ordovician ...	Trenton limestone, crystalline	Sedimentary.	$\cdot 92 \times 10^{-12}$
,, ...	Trent limestone, weathered.	,,	·91
*Devonian ? ...	Essexite.	Igneous.	·26
,, ...	Tinguaite.	,,	4·3
,, ...	Tinguaite (different locality).	,,	3·0
,, ...	Nepheline syenite.	,,	1·1
Quaternary ...	Boulder-Clay.	Sedimentary.	·80
,, ...	Leda-Clay.	,,	·78
,, ...	Saxicava-Sand.	,,	·16

* These igneous rocks all cut the Upper Silurian, and are of late Palæozoic age, probably Devonian.

The mean of these values is $1 \cdot 1 \times 10^{-12}$, and as this result is of the same order as that obtained by Strutt ($1 \cdot 4 \times 10^{-12}$) we did not think it necessary to examine a larger number of specimens.

It will be noted that in every case the substances examined contained much more radium than that required to account for the existing temperature gradient of the earth. It is difficult to understand how the earth can have remained at its present temperature when radium is so plentifully distributed in the constituents of the earth's mass. There appear to have been three explanations offered :—

1. Strutt has suggested that the interior of the earth is different in constitution to the earth's crust. The great density of the earth lends some weight to this suggestion. Moreover, Milne finds further support to this hypothesis in the rate of propagation of earthquake waves.

2. It has been conjectured that the disintegration of radium is retarded or stopped under the extreme pressure in the earth's interior. If that is so, the heating effect of the radium would also be diminished. This suggestion is capable of experimental test. In the meantime it may be remarked

that the disintegration of radium is not affected by large changes of temperature, and it is difficult to conceive of the radium atom so closely surrounded by other atoms that the α particle would be prevented from escaping.

3. Joly has suggested that radium may reach the earth from external sources. At present there is little experimental evidence in favour of this view, and it is not easy to reconcile it with the fact that in radioactive minerals uranium and radium exist in constant proportions.

It must be remembered that in these investigations no allowance has been made for the heating effects due to radiothorium, uranium, and actinium. There is evidence that radiothorium must be distributed in the earth, both widely and in considerable quantity, for the active deposits of thorium have been found in the atmosphere in most places where an attempt to discover them has been made. This fact is the more remarkable because the thorium emanation decays so rapidly that only a minute proportion of it can escape from the soil into the air.

As the work of obtaining rocks in a state of solution is somewhat lengthy, involving the expenditure of time and materials, some experiments were made in order to ascertain if the emanation could be driven off by simple heating. Fifty grams of each specimen investigated were powdered and passed through an 80-mesh sieve. The powder was placed in a porcelain tube and heated for an hour in a combustion-furnace. The air driven off by expansion was collected over water, and at the end of the heating the air in the tube was blown out, and all the gases thus obtained were introduced into the electroscope and tested. The results were compared with those obtained when portions of the same specimens were in a state of solution, and the emanation driven off by boiling. The amounts found by heating expressed as percentages of the amounts found by boiling are as follows :—

Trenton Limestone	27	per cent.
Tinguaite	49	„
Essexite	10	„
Nepheline Syenite	55	„
Leda Clay..........................	47	„
Saxicava Sand	81	„

It is, therefore, clear that the method does not give consistent or accurate results. But when a large number of rocks have to be examined, the extraction of the emanation by heating may serve as a valuable preliminary test, and furnish an indication of the amount of material which should be reduced to a state of solution, in order to obtain an accurate determination with the least expenditure of time and chemicals.

Some tests were also made of the effect of adding a little sulphuric acid to the solution of Tinguaite. The radium was then probably precipitated, for the emanation was not freed by boiling. In one experiment the amount obtained was only one-fifth of that measured previous to the addition of the sulphuric acid.

A special experiment was made with Tinguaite, which was finely powdered and the soluble portion was leached out with water. When tested, the insoluble gave about eight times as much emanation as the soluble. The addition of HCl made no change in the ratio nor in the total amount obtained. In the case of clay, Strutt found that the total emanation could not be obtained until HCl was added. The ratio of the emanation derived from the acid and alkaline solutions, as found by Strutt for various substances, is about the same as that found by us in Tinguaite.

In a previous paper published in this Magazine (Sept. 1906) an account was given of an attempt to measure the amount of radium in the earth from the penetrating radiation due to it. The result found was $10{\cdot}5 \times 10^{-12}$ gram of radium per gram of rock, and it depended upon Cooke's value of the penetration radiation measured on the College campus at Montreal. The subsoil consists of Saxicava sand and Leda clay; and it is clear that the value found by the penetrating radiation method, although of the right order, is too large, unless there is a large quantity of radiothorium in the ground. Or a partial explanation may be found in the value of the coefficient of absorption of the γ rays by rocks. Wigger has found that the value of λ for the most penetrating rays is considerably less than that assumed in the paper in question.

We are indebted to Professor Rutherford for his interest and advice in this work, and to Professor Adams and Mr. Bancroft for their assistance in matters geological.

McGill University, Montreal,
May 1907.