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The effect of leaching on the lead-uranium-thorium ratio of a crystal of uraninite

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Boston University
BOSTON UNIVERSITY
GRADUATE SCHOOL

Thesis

THE EFFECT OF LEACHING ON THE LEAD-URANIUM-THORIUM
RATIO OF A CRYSTAL OF URANINITE

by

Egbert Mason Kipp

( B.S. Iowa Wesleyan College, 1934)

submitted in partial fulfilment of
the requirements for the degree of
Master of Arts

1935
Acknowledgments

To Professor Chester M. Alter I am truly indebted for his many kind and helpful suggestions, and for his constant kindly interest in this problem and others.

I greatly value and appreciate the inspiration I have obtained at all times from Professor John Phillip Mason.

I gratefully acknowledge the kindly interest shown by Dr. E. O. Holmes in my work.

I shall be ever mindful of the fact that this year of graduate study has been made possible by the many sacrifices of my parents.
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Indexing Outline

I. Introduction

II. Material

III. Preparation and Processing

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Introduction

The question as to the probable age of the earth, has long been an engrossing and important one to mankind. Man, in addition to taking delight in forecasting the physical future of the world, has always yearned to know, as certainly as possible, the actual age of this old world.

The purpose of this piece of research is to obtain further data on the present chemical method used, in obtaining the age of the earth, that of radio-activity.

The results of this research will either lend weight to the present method, or at least indicate the weak spots existent in the present general methods used in determining the lead-uranium-thorium ratios in radio-active minerals.
Historical

There are various methods employed by means of which the age of the earth has been determined. The most important of these methods are very naturally based on physical evidence. The principle of these methods are:

a) Geochronology, or the age of the earth on the basis of sediments and life.

b) Age of the earth from the age of the ocean, which is estimated by dividing the total sodium content of the ocean, by the amount yearly poured into it by the rivers of the world.

c) Calculation of the age of minerals from radio-activity data and principles.

d) The age of the earth based on astronomical data.

One of the most accurate methods known is the one based on the age of minerals as calculated on the basis of radio-activity data and principles. The pioneer in this field is Boltwood. He originated the method of determining the age of minerals from the
Methodology

There are several methods employed to measure the age or the speed of the earth's rotation. The measurement of the earth's rotation is an important aspect of geodesy and geophysics. The technique involves the use of seismographs and other devices to monitor the earth's rotation. The results of these measurements are used to study the earth's tides and the movement of the ocean currents. This information is essential for understanding the effects of the earth's rotation on the ocean environment.
amounts of uranium and lead present in a primary mineral. This method is entirely based on the principles of radio-active disintegration theory, propounded by Rutherford and Soddy in 1903.

Boltwood, believing firmly in the disintegration theory, and observing that lead is present in all radio-active minerals, came to the conclusion that the lead in these minerals was the final disintegration product of uranium, thorium and actinium, according to the type of mineral. He found however, that the amount of lead per gram of uranium varied considerably from mineral to mineral. He therefore arranged the minerals according to the lead-uranium ratio, and drew attention to the fact that the increasing ratio corresponded in every case to the increasing age of the geological formation in which the minerals were found.

Although there are corrections which ordinarily must be made, due to the presence of various isotopes of lead, uranium and thorium, these variables lie outside of the scope of this investigation. In applying the disintegration theory to age determinations, we must assume that at the time
drawn to present a leading and lesser known conversation on the present.

The conversation was based on the principle of the nuts-and-bolts conversation, focusing on the practical aspects of the topic in question.

In the final analysis, the nuts-and-bolts conversation can be seen as a method to convey knowledge and understanding in a practical and accessible manner.
the mineral was formed, uranium, thorium and lead may have been present in any amounts. Since that time then, these elements have been disintegrating according to the law of radio-active disintegration, resulting in a cumulative deposit of radiogenic lead.

It is now an established fact, that through the process of radio-active disintegration, uranium of atomic weight 238.14, will yield as an end product, radiogenic lead of atomic weight 206 or 207, depending upon whether it has been generated by the radium series or the actinium series. Thorium, of atomic weight 232.12, likewise yields as an end-product, a radiogenic lead of atomic weight 208.

Uranium and thorium undergo this process of radio-active disintegration, by means of a constant emission of alpha and beta particles. The beta particles, having no mass, do not affect the mass of the end product. The alpha particles possess a mass of four, consequently, each time an alpha particle is emitted, the resulting element is lower in atomic weight by four units. Let us then, follow the path of this radio-active disintegration in the case of uranium and thorium.
Uranium, in the course of its disintegration, emits a total of eight alpha particles. This can be verified by the amount of helium produced, as a helium atom is nothing more than an alpha particle which has acquired an electron. The loss of eight alpha particles results in a loss of thirty-two units in atomic weight.

\[
\text{U} \rightarrow \text{Pb} + 8 \text{He}
\]

238.14 \hspace{1cm} 206 \hspace{1cm} 32
or
207

Thorium, we find, emits a total of six alpha particles during the disintegration process, resulting in a loss of approximately 24 in atomic weight.

\[
\text{Th} \rightarrow \text{Pb} + 6 \text{He}
\]

232.12 \hspace{1cm} 208 \hspace{1cm} 24

The rates of production of helium from uranium and thorium have been rather accurately measured. From these values, the rates of production of lead from both elements have been calculated.
The data in this table shows a clear trend in the data collected. The values in the table indicate a significant increase in the measured parameter over the observed period. This trend is consistent with the hypothesis that the observed phenomenon is influenced by the conditions described in the experiment.

In the graph, the data points are plotted against time, with each point representing a data collection at a specific time interval. The trend line drawn through the data points clearly shows the upward trend, further supporting the hypothesis.

The analysis of the data suggests that the factor X has a significant impact on the outcome, as evidenced by the correlation coefficient of 0.85, which is highly statistically significant. Further experiments are recommended to explore the underlying mechanisms responsible for this trend.
Let $l/C$ represent the amount of lead produced by one gram of uranium in one million years. Then, the lead-uranium ratio of any crystal, divided by the constant $l/C$ would represent the approximate age of the mineral, or written in equation form:

$$\text{Approximate age} = \frac{\text{Pb}}{U} \times l \text{ million years}$$

where Pb, and U represent respectively the percentage of lead and uranium in the mineral.

Thorium also generates lead which accumulates with that produced by the uranium. This must also be taken into account. For a pure thorium mineral we have an identical equation:

$$\text{Approximate age} = \frac{\text{Pb}}{Th} \times l' \text{ million years}$$

Since most uraninites uranium and thorium both occur, it is necessary to convert their respective contents to a uniform basis of equivalent lead producing power. This is done by multiplying the thorium content by a constant "$k$" which is the amount of uranium equivalent to one gram of thorium in lead producing power. The equation for the approximate age is then:

$$\text{Approximate age} = \frac{\text{Pb}}{U + 0.36Th} \times l \text{ million years}$$

$C$ has been evaluated as 7600, and $k$ as .36.
Let \( y = \frac{d^2}{d^2x} \) be the moment of one million years.

Then, the expression for the age of the universe becomes:

\[
\text{Approximate age} = \frac{y}{y(d^2)}
\]

where \( y \) is the rate of expansion and \( d \) is the distance.

This means that if we assume a constant expansion, the universe is at least \( y \) years old.

\[
\text{Age of the universe} = \frac{y}{y(d^2)}
\]

Since \( y \) is constant, it is necessary to consider the rate of expansion over time. The above expression is only valid if the expansion rate is constant over time.

The expression for the age of the universe is then:

\[
\text{Age of the universe} = \frac{y}{y(d^2)}
\]

The assumption for the expansion rate is if

\[
\text{Age of the universe} = \frac{y}{y(d^2)}
\]

and we need to assume \( y = 1,000,000 \) years for...
There are a great number and variety of different radio-active minerals, which contain both uranium and lead, and in many cases also, thorium. The percentages of these elements vary considerably from mineral to mineral, although the lead-uranium ratio is fairly constant within minerals of approximately the same geological age.

One of the commonest and most satisfactory minerals with which to work is uraninite, of which there are several sources, but primarily from the Katanga mines in the Belgian Congo, and from the Wilberforce regions in Ontario, Canada. The advantage of uraninite over other minerals is its relative purity and regular crystal form. The uranium and thorium and lead content is comparatively high, making an accurate analysis somewhat easier.

Uraninite occurs as crystals or large crystal masses, embedded in felspar, or as crystals attached to the felspar margin of calcite-fluorite areas, and also as irregular masses intersown with magnetite. The freshest or least altered uraninite is that which is wholly embedded in the surrounding minerals. The crystals are well formed, and predominately cubic.
The crystal of uraninite used in this research was originally obtained from the deposits on the property of Mr. W. M. Richardson, Cardiff township, east of Wilberforce, Ontario, Canada, and then obtained from Professor Alfred C. Lane of Tufts college. The uraninites from this region are generally referred to as "Wilberforce" uraninites or pitchblends.

The most recent work on Wilberforce uraninite has been done by Todd and Ellsworth. Todd has found the lead-uranium ratio, to be 0.150, corresponding to an age of 1,140 million years. Ellsworth has analyzed two uraninites, one altered and the other fresh or unaltered. He has found the altered uraninite to have a lead-uranium ratio of .171 corresponding to an age of 1,299.6 million years, and the fresh uraninite a ratio of .157, corresponding to an age of 1,193.2 million years. This last figure is in fair agreement with that obtained by Todd.
Method And Probable Value Of Analysis

The work done on the age of the earth by means of the determination of the lead-uranium ratio in radio-active minerals, has been done on the general assumption that the minerals have been altered to a very slight degree, or, if at all, that the lead, uranium and thorium have all been leached out at the same rate.

The value of the lead-uranium ratio would be quite trustworthy, if we could be assured of the fact that none of the radio-active elements have been leached out of the mineral by outside agents of nature. It would still be trustworthy if we knew that the uranium and lead have been leached out in the same proportions as they existed in the mineral.

An analysis of a perfect uraninite crystal, performed in such a manner as to make it possible to determine whether or not any leaching of either uranium, thorium, or lead has occurred, would have an important bearing on the value of this method of age
MEDITATION AND TAPROOTS VITAL TO WILDLIFE

The work done on the age at the stage

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important passing on the value of their we can to age.
calculation. There is a possibility that the effects of leaching, if any, only penetrate to a certain depth and therefore, by utilizing only the innermost core of the crystal, the leaching effects would be absent, and the data therefore, would become more trustworthy as far as its bearing on the age of the earth is concerned.

1 It has been pointed out, that certain crystals of uraninite appear altered, and the possibility of differential leaching has been admitted to be possible. There are two or three instances where the crystal of uraninite to be analyzed has been cleared and cleansed of a thin section of outer coating and some or all of the apparently altered portion of the crystal removed. However, this is not an assurance that all of the actually altered portion has been removed, for the actual extent of the leaching effect has not been determined in any of the cases. It was merely assumed that the above precaution was sufficient.

Ellsworth and Todd 2 have completed some interesting analysis of both altered and fresh Wilberforce uraninites.

2. Ibid
There is a possibility that the effective compensation to the company, in the form of bonuses or other financial incentives, may be influenced by the way in which sales figures are presented and interpreted. The accuracy of these figures can affect the overall assessment of a company's performance.

I have seen situations where the sales figures were manipulated to show a positive trend, even though the underlying business conditions were not as favorable. This practice can create a misleading perception among investors and stakeholders.

In such cases, it is important to rely on reliable data sources and to ensure that the figures are presented honestly. Transparency and integrity are key principles in maintaining the trust of all stakeholders.

Performance metrics are crucial in assessing a company's success, but they must be based on accurate and reliable information.
Todd, analyzed some crystalline material, which was very fresh, that is, apparently unaltered, and obtained a lead-uranium ratio of 0.150.

Ellsworth, analyzed two different crystalline masses of Wilberforce uraninite, one altered, and the other fresh. For the altered material, he obtained a ratio of 0.171, which is considerably higher than Todd's result for the unaltered. For the fresh or unaltered crystals, he obtained a ratio of 0.157, which is comparatively close to Todd's corresponding result.

The comparatively high ratio of Ellsworth's altered uraninite would seem to indicate several possibilities.

One such possibility is that the uranium has been preferentially leached out, diminishing the uranium content relatively to the lead and thorium, resulting in a higher ratio, and therefore greater age. It is also possible, that the lead has been preferentially leached out, resulting in an abnormally low ratio. What is probably the case is that both the lead and uranium, and also the thorium are all leached out, some to a greater extent than the others. It is

2. Ibid. p.3
The compatibility gap leads to difficulties.

Efforts at harmonization may seem to improve matters but:

difficulties
don some possibilities to first the mechanics
have been demonstrated faceted and differentiated the
measures constitute a vital to the like and important
association in a physical level and purpose.

If the face is comparable, the face and the case
compatibility remains an obstacle to its compatibility
I have invested much to accommodate the case to that date, the
face and mechanism, may also be the result of the knowledge
and some components cannot play the identical.
important that some quantitative data be brought to bear on the subject, and that is what is proposed by a special method of analysis of a crystal of Wilberforce uraninite.
Experimental Procedure

A variation in the lead-uranium ratio of outer and inner portions of a crystal, would indicate leaching. The absence of any variation might indicate freedom from the effects of leaching. The crystal of uraninite was therefore dissolved in three stages. The first portion represented the outermost layer of the crystal, the third, the innermost core, while the second represented an intermediate layer.

The crystal itself was an excellent specimen of Wilberforce uraninite. It was a single crystal, possessing definite cleavage faces, and was cubic in form. It was apparently unaltered, although it was a medium buff brown to black in color. The crystal weighed approximately twenty-four grams, and was about a quarter of an inch in each dimension.

Division of Crystal Into Layers

The carefully dried and weighed crystal was placed in a 500 ml. erlenmeyer flask, and enough water added to just cover the crystal. Sufficient 1:1 HNO₃
Experimental Engineering

In an attempt to find a feasible solution, many inferior designs were tested. The process involved checking the validity of theoretical analyses and experimenting with different parameters to find the optimal solution. The final model, after several iterations, was deemed the most effective. The analysis included comprehensive testing and refinement, leading to the creation of a highly efficient prototype.
to start the solution process was then added. The flask was warmed on a hot-plate, and reaction set in with a vigorous evolution of He. After one third of the crystal had apparently gone into solution, the crystal was removed with a pair of glass tongs, carefully rinsed into the solution, dried and weighed.

Within a short time after the crystal began dissolving, it was apparent that it was not a homogeneous crystal, as was supposed. Some parts of the crystal showed evidence of greatly increased reaction with the acid, indicating that the acid was leaching out some parts preferentially. The erstwhile smooth buff brown surface of the crystal was becoming pitted in spots. It soon became evident that the crystal consisted of a pure black central core, surrounded by a fairly thick outer layer of the buff brown substance. By the time the arbitrary first third had been dissolved, most of the outer crust, which reminded one of the bark of a tree around the core, had been dissolved.

The acid solution, together with the rinsings from the remainder of the crystal, was heated for an hour, decanted into an evaporating dish, the residue being treated several times with portions of hot concentrated nitric acid. The combined solutions
were evaporated to dryness, and dissolved in enough 1:1 nitric acid to make the final diluted solution about 4% in acid concentration. The acid solution was filtered, and transferred to a calibrated 250 ml. volumetric flask, and diluted to volume. This solution represented the approximate outer third of the crystal. Aliquot portions of 25 mls. were pipetted out with a calibrated pipette into small erlenmeyer flasks. These then, represented aliquot samples of the first layer of the uraninite, ready to be analyzed.

The crystal was now ready to have the second layer removed. It was now almost uniformly black in color. The same procedure was employed as in the case of the first layer. Preferential leaching by the acid was still evident, and by the time that the second third had been dissolved, the crystal was so badly pitted in one section, that it was almost severed into two portions. The crystal was again taken out, rinsed, dried and weighed. By this time it was uniform in color, being an intense black all over. The second layer was separated into aliquot portions as described above.

The remainder of the crystal represented the last third. Due to the leaching action of the acid
it had become practically divided into two smaller crystals, it was therefore broken into two parts, and these parts dissolved. The final portion dissolved homogeneously, and showed no preferential leaching by the acid. It was divided into aliquot portions in the same manner as were the others.

Analysis for Lead, Uranium, Thorium

In general, the method reported by Dr. J. P. Marble in a private communication, was used in the determination of lead and Uranium. The thorium was precipitated as thorium sebacate.

The sample is evaporated to dryness, dissolved in warm dilute nitric acid, and the SiO₂ filtered off. This is repeated until no more SiO₂ is present. The filtered solution is then evaporated to dryness and dissolved to about 400 mls in 4% nitric acid. The concentration of the acid should not exceed 4% as uranium will not precipitate as the sulfide in this concentration, and at a higher concentration, some lead may be lost.

The lead is precipitated as the sulfide, by passing in a moderate stream of washed hydrogen sulfide, for about an hour. Without stopping the flow
The bond is completely dissolved when placed into two separate cells.

Liege, at a dozen of a mile of Lavaux, is a town situated on the

strike. For some years now, different authors have
of hydrogen sulfide, the solution is then heated to boiling, kept at that temperature for about fifteen minutes, and then allowed to cool very slowly to room temperature. If the precipitation has been completely satisfactory, the precipitated lead sulfide will tend to coagulate and settle, as the mixture cools. The lead sulfide is then filtered, the filtrate containing the thorium and uranium. The lead sulfide is then washed as completely as possible from the filter paper into an evaporating dish, to which is added the nitric acid solution of the residual lead sulfide in the flask. The filter paper is then ignited, dissolved in concentrated nitric acid, and added to the previous solution. The whole is then digested for several hours with concentrated nitric acid, baked almost to dryness, dissolved in water, and the reduced sulphur filtered off. It is well to ignite this sulphur, dissolve in nitric acid, filter and add to the main portion of lead nitrate. The nitrate solution is then evaporated to dryness, two or three mls nitric added to keep other salts in solution, and dissolved in 50 mls. water. To this is added, in excess, dilute sulphuric acid. This solution is then evaporated to 303 fumes, 30 to 40 mls. water added, and allowed to stand overnight. The lead sulphate separates in fine white
of the phenomena. The solution to these problems was to develop new methods of data analysis. These methods required a deep understanding of statistical techniques and the ability to apply them effectively. The development of these methods was a significant milestone in the field of data analysis. The results of these efforts have had a profound impact on various fields, including economics, psychology, and engineering.

The new methods allowed researchers to analyze complex data sets and to draw meaningful conclusions. This has led to a greater understanding of the world and to improved decision-making. The impact of these methods has been far-reaching, and they continue to be a cornerstone of modern data analysis. The work of the researchers who developed these methods has been recognized with numerous awards and honors. Their contributions have been instrumental in advancing the field of data analysis and have had a lasting impact on society.
crystals. The solution and crystals are then transferred to a weighed platinum crucible, the acid fumed off, and the sulfate heated to constant weight. In case the sulfate is discolored, it may be purified by dissolving in hot two normal ammonium acetate. This solution is then evaporated to dryness, and the acetate driven off by repeated evaporation with dilute nitric acid. The final acid solution is evaporated to dryness, dissolved in water, excess dilute sulphuric acid added, evaporated to SO3 fumes, and dissolved in water. The lead sulfate is then weighed as above.

Separation of Thorium, Uranium

The filtrate from the hydrogen sulfide precipitation is diluted to about 600 mls, and the excess hydrogen sulfide driven off by boiling. After addition of fifteen mls. of 1:1 nitric acid, it is again boiled in order to remove all traces of carbon dioxide. An excess of freshly distilled ammonium hydroxide solution is added, and the precipitated uranium and thorium hydroxides allowed to settle. The solution is kept near the boiling point, and filtered hot, in order to prevent absorption of carbon dioxide, which would combine
Section of the Text:

The influence from the hydrogen molecule is such that the bonds to the 000 bands of the molecule are in a rather high proportion. While the hydrogen molecule is held highly in the large bands, the lines of the hydrogen molecule are of a much smaller size than the bands of the hydrogen molecule.
with the ammonia, forming ammonium carbonate, in which the uranium and thorium hydroxides are soluble. The precipitate is then dissolved in concentrated nitric acid, diluted to 600 mls. volume, reprecipitated with freshly distilled ammonium hydroxide, filtered and washed with two percent ammonium hydroxide. Uranium and traces of the other rare earths may be recovered from the combined filtrates by evaporating to dryness several times with an excess of aqua regia, driving off the ammonia salts. The residue is then dissolved in concentrated nitric acid, and any uranium or thorium precipitated again, as before. The uranium and thorium hydroxides are dissolved in nitric acid, evaporated to dryness, and dissolved in nitric acid of about four percent in concentration. This solution is then poured into one fourth of its volume of 10% oxalic acid. The white crystalline precipitate of thorium oxalate should stand for three or four days. This precipitation should be made in about four hundred mls volume in order to avoid precipitation of uranium, which is detectable by the yellow tinge it lends to the thorium oxalate.
Determination of Uranium

The thorium and other rare earth oxalates are filtered, and set aside for further analysis. The filtrate contains the uranium. In may more or less impure uraninite minerals, iron and aluminum exist as impurities, but in the case of this mineral, which was supposed to be comparatively very pure, it was thought that the amount of impurity from this source would be negligible, and this was found to be the fact of the matter in the case of the two inner portions of the crystal, as the uranium precipitate was a clear canary yellow, indicating an absence of iron and aluminum impurities. The first third was tinged with brown however, indicating a slight trace of iron. So it was thought safe not to precipitate the iron out separately, as it actually proved to be.

The filtrate from the oxalic acid precipitation is evaporated to dryness on the hot plate. I found it best, in order to avoid the malicious spattering which occurs, not to evaporate down to the formation of crystals, but only to a small volume. An excess of concen-
treated nitric acid is then added, and the solution evaporated to a small volume several times, until the absence of red fumes indicates that the oxalic acid has been completely driven off. The final solution of uranium should be a clear light golden yellow in color, since sometimes the red fumes will cease to evolve, while the solution is still colored a light red due to traces of oxalic acid. After the removal of the oxalic acid, the solution is diluted to about 500 mls, and the carbon dioxide driven off. The uranium is then precipitated with a slight excess of freshly distilled ammonium hydroxide, and filtered. Traces are recovered from the filtrate as before. The precipitate is then dissolved in concentrated nitric acid, diluted and reprecipitated. The precipitate is then charred and ignited to constant weight in a platinum crucible. This is most effectively done, by placing the crucible in a slanting position, with the cover tipped across the mouth. The paper is charred, and then with the cover removed, is smoked off. The crucible is then placed in an upright position, and in the full flame of the bunsen burner, is roasted to U3O8. No traces of yellow should be present.
not possible to determine the content of this page from the provided image.
Determination of Thorium

The carbon from the precipitated thorium and other rare earth oxalates is charred and burned off at a low temperature. The residue is then roasted in a slanted crucible, brought to constant weight with a meker burner. The oxides are then fumed to dryness with ten ml. portions of concentrated sulphuric acid until pure white in color. This is then dissolved in concentrated nitric acid, and diluted to a hundred mls. in volume. The solution is then neutralized with freshly distilled ammonium hydroxide. The thorium is precipitated and separated from the other rare earths, with a slightly less than saturated solution of sebacic acid. Both the sebacic acid, and thorium solutions must be near the boiling points. Precipitated sebacic acid is washed from the thorium sebacate with hot water. The thorium may be dissolved in nitric acid, and reprecipitated with sebacic acid, until pure white in color. The thorium sebacate is then charred and ignited to ThO₂, and constant weight, in the flame of the meker burner.
Deposition of Tannin

The tannin from the acorns is separated from the sap by a process of filtration. The tannin is then treated with a water-permeable material to convert it into a solution of tannin which is then filtered to obtain a clear extract. The extract is then concentrated and further purified to obtain a pure tannin.
A Typical Calculation

The following is the general method used in determining the percentage composition of an element or compound in a sample:

Weight of sample:

<table>
<thead>
<tr>
<th>Weight of section</th>
<th>8.5192 gms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diluted volume of dissolved section</td>
<td>250 mls</td>
</tr>
<tr>
<td>Volume of aliquot sample</td>
<td>25 mls</td>
</tr>
</tbody>
</table>

Weight of sample: 0.85192 gms

Weight of element (thorium):

| Final constant weight of ThO₂ | 0.08091 gms |
| Corresponding weight of Th | 0.07107 gms |

Weight of element (ThO₂ x conv. factor), 0.07107 gms

Percentage of element in sample:

| Weight of Th | 0.07107 gms |
| Weight of sample (aliquot) | 0.85192 gms |
| Quotient of Th by sample | 0.08380 |

Percentage of element Th: 8.38%

The same method is employed in computing the percentage compositions of lead and uranium in each section.

Computation of the age from composition data:

Average percentage composition of lead 9.63%
Average percentage composition of uranium 37.86%
Average percentage composition of thorium 8.36%
Lead-uranium ratio: \[ \frac{76}{4\times36+76}\frac{76.63}{37.86+(36X8.36)} = 0.235 \]

Age of this section is the product of the ratio by the constant 7600 million years, or 0.235x7600 million years.
A Chapter on Computation

The following is theATTERN method used in the

Remark the percentages computation of an element in commutation

<table>
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<tr>
<th>Water of Sample</th>
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<th>Water of Sample</th>
</tr>
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<tbody>
<tr>
<td>80.6%</td>
<td>80.6%</td>
<td>80.6%</td>
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</table>

Net result of water of sample

Net result of water of sample

Net result of water of sample

Sample of element as a percentage

<table>
<thead>
<tr>
<th>Sample of element</th>
<th>Sample of element</th>
<th>Sample of element</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

The same method is applied in computations.

As a result of the computations, the statement was made:

```
water-percentage-composition = \frac{\text{Water of Sample}}{\text{Total Water}}
```

The output of the statement is the percent of the element in the sample.
Experimental Results

The following is a table of the percentages of lead, uranium, and thorium in each of the three sections of the crystal, and of the crystal as a whole.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Lead</th>
<th>Uranium</th>
<th>Thorium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.92%</td>
<td>38.11%</td>
<td>8.38%</td>
<td></td>
</tr>
<tr>
<td>9.32%</td>
<td>37.73%</td>
<td>8.34%</td>
<td></td>
</tr>
<tr>
<td>37.74%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>9.63%</td>
<td>37.86%</td>
<td>8.36%</td>
</tr>
<tr>
<td>Group 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.91%</td>
<td>58.51%</td>
<td>14.13%</td>
<td></td>
</tr>
<tr>
<td>11.97%</td>
<td>58.57%</td>
<td>14.07%</td>
<td></td>
</tr>
<tr>
<td>11.95%</td>
<td>58.48%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>11.94%</td>
<td>58.52%</td>
<td>14.10%</td>
</tr>
<tr>
<td>Group 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.89%</td>
<td>60.71%</td>
<td>8.10%</td>
<td></td>
</tr>
<tr>
<td>11.87%</td>
<td>60.62%</td>
<td>8.02%</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>11.88%</td>
<td>60.67%</td>
<td>8.06%</td>
</tr>
<tr>
<td>Entire Crystal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.09%</td>
<td>51.89%</td>
<td>9.97%</td>
<td></td>
</tr>
</tbody>
</table>

Groups one, two, and three, represent the three sections into which the crystal was divided. These sections are only approximate thirds, by weight, of the crystal.
The following is a table of the percentages of leaf rust and fungus infections for each line of the cultivary of a sample.

<table>
<thead>
<tr>
<th>Culture Category</th>
<th>Treatment</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>82.5</td>
<td>80.4</td>
<td>82.0</td>
<td>82.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>84.6</td>
<td>84.6</td>
<td>83.6</td>
<td>84.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>85.6</td>
<td>85.6</td>
<td>85.6</td>
<td>85.6</td>
<td></td>
</tr>
</tbody>
</table>

Average: 84.4%
The following is a table of the lead, uranium-thorium ratios of each section of the crystal, and of the entire crystal.

Table 2

<table>
<thead>
<tr>
<th>Section</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer section</td>
<td>0.235</td>
</tr>
<tr>
<td>Second section</td>
<td>0.188</td>
</tr>
<tr>
<td>Third section</td>
<td>0.187</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Section</th>
<th>Resultant age value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer section</td>
<td>1,846 million years</td>
</tr>
<tr>
<td>Second section</td>
<td>1,426 million years</td>
</tr>
<tr>
<td>Third section</td>
<td>1,420 million years</td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>Section</th>
<th>Ratio</th>
<th>Resultant age value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire crystal</td>
<td>0.199</td>
<td>1,512 million years</td>
</tr>
</tbody>
</table>
The following is a table of the results obtained:

<table>
<thead>
<tr>
<th>Section</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>First section</td>
<td>0.85</td>
</tr>
<tr>
<td>Second section</td>
<td>0.19</td>
</tr>
<tr>
<td>Third section</td>
<td>0.30</td>
</tr>
</tbody>
</table>

From these results, it can be concluded that the first section contributed the most to the overall performance, followed by the second and third sections.
Conclusions

1. The lead, uranium-thorium ratios of the two inner sections of the crystal are practically identical, and yet vary considerably from the ratio of the outer section, indicating that:
   a) the crystal has been affected by leaching agents of nature;
   b) the leaching effect has penetrated only to some point within the first section, and has not affected either the second or inner third of the crystal.

2. The effects of leaching may be removed, by cleansing the crystal of the outer third, or more, before analysis.

3. It is interesting to note, that, the percentage of lead in the second and innermost sections is practically the same, while the percentage of uranium in the second section is lower than the percentage of uranium in the innermost section. The percentage of thorium in the second section, however, is enough greater than that in the innermost section, to make up for the deficiency of uranium in the second section. The fact that this is so, and that the ratios of the two sections are the same, lends support to the accuracy of the value of the
Conclusions

...
constant "k" in the age formula, whereby the thorium is placed on a basis of equal lead producing rate as the uranium.

4. The section of the crystal which has been affected by leaching, has a higher ratio, and consequently higher age value than the inner or unaltered sections. This would seem to indicate that, in cases where the ratio has been determined for the crystal as a whole, the ratio is higher than it should be, and the corresponding age of the crystal therefore, too high.

5. Other factors being corrected for, it seems to be safe to assume, on the basis of the analysis of this single crystal, that, if the innermost portion of a crystal be used for an age determination, we have an accurate method for determining the age of the earth.
Bibliography

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3. Report of the Committee on the Measurement of
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