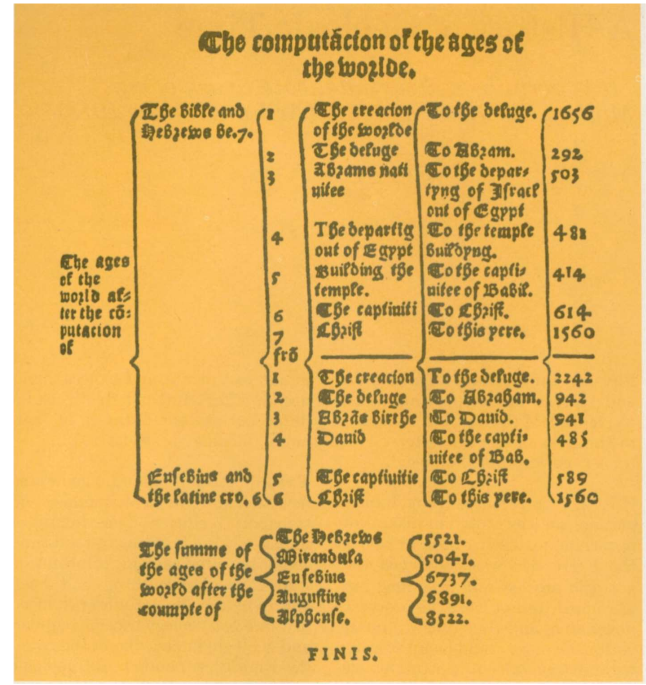
Alfred Nier and the Mid-20th Century Instrumental Revolution in Geochemistry

George Borg
Beckman Center for the History of Chemistry
Science History Institute
National Science Foundation

The Flourishing of Post-War Earth Science



The computacion of the ages of the worlde.

The ages of the world after the computacion of

The Bible and Hebrewe be. 7.

	From	To	
1	The creacion of the worlde	To the deluge.	1656
2	The deluge	To Abram.	292
3	Abrams nativitee	To the departyng of Israel out of Egypt	503
4	The departig out of Egypt	To the temple buildyng.	481
5	Building the temple.	To the captivitee of Babil.	414
6	The captiviti	To Christ.	614
7	Christ	To this yere.	1560

Eusebius and the latine cro. 6

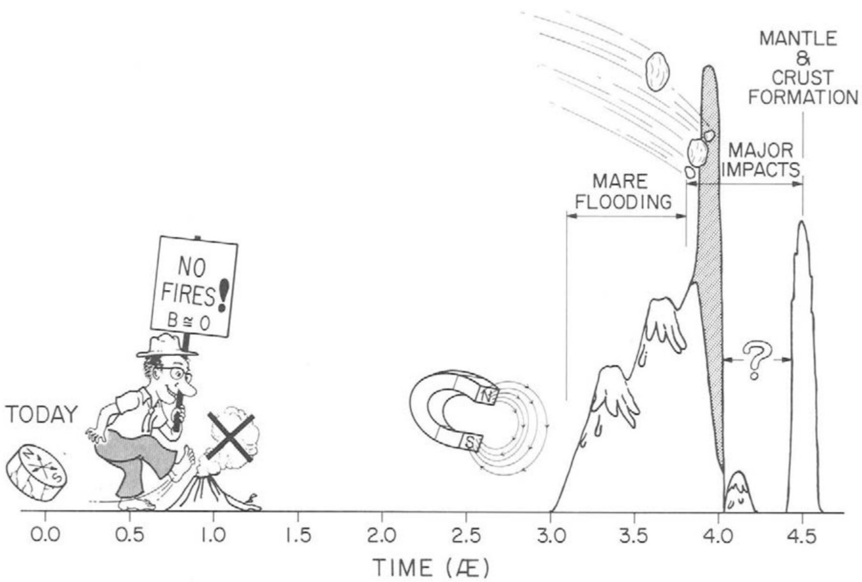
	From	To	
1	The creacion	To the deluge.	2242
2	The deluge	To Abraham.	942
3	Abrās birthe	To David.	941
4	David	To the captivitee of Bab.	485
5	The captivitie	To Christ	589
6	Christ	To this yere.	1560

The summe of the ages of the world after the coumpte of

The Hebrewe	5521.
Mirandula	5041.
Eusebius	6737.
Augustine	6891.
Alphonse.	8522.

FINIS.

The age of the Earth



The history of the solar system

The Flourishing of Post-War Earth Science

The history of the climate

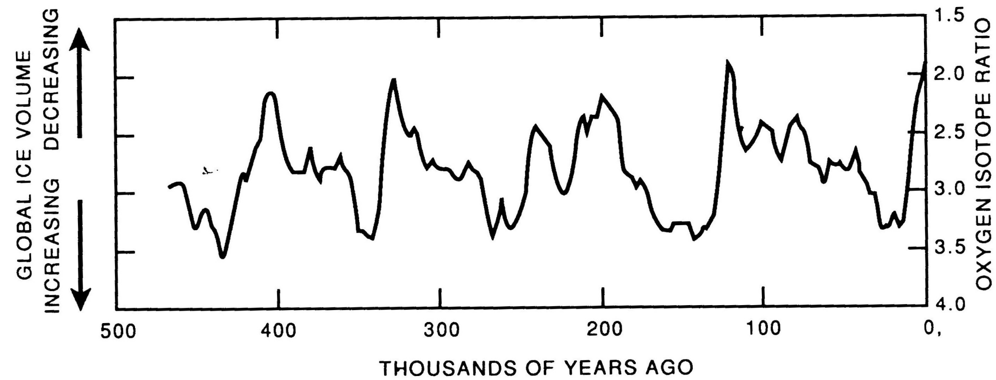
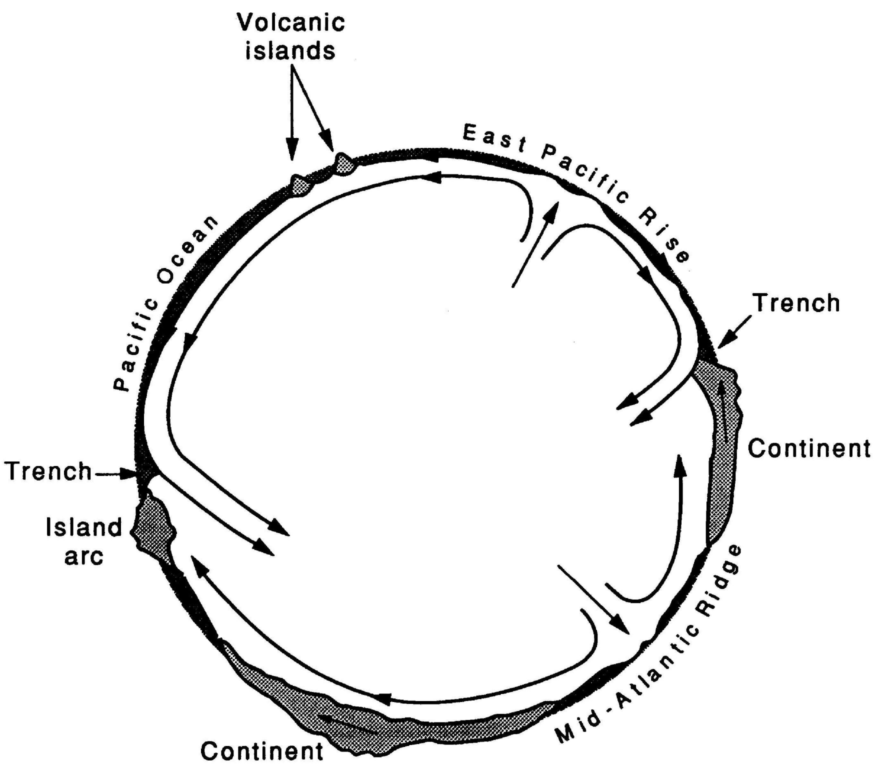
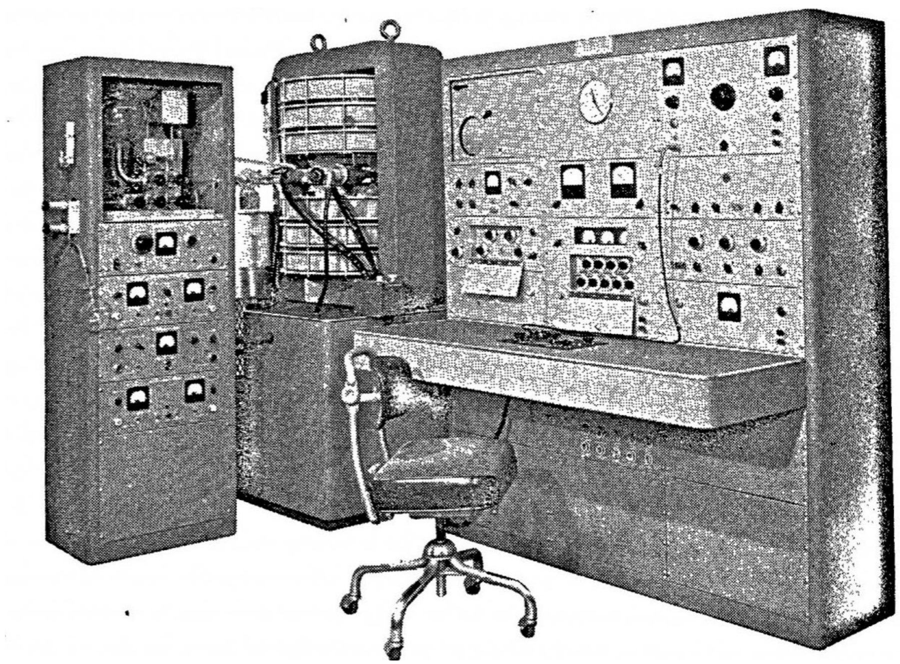


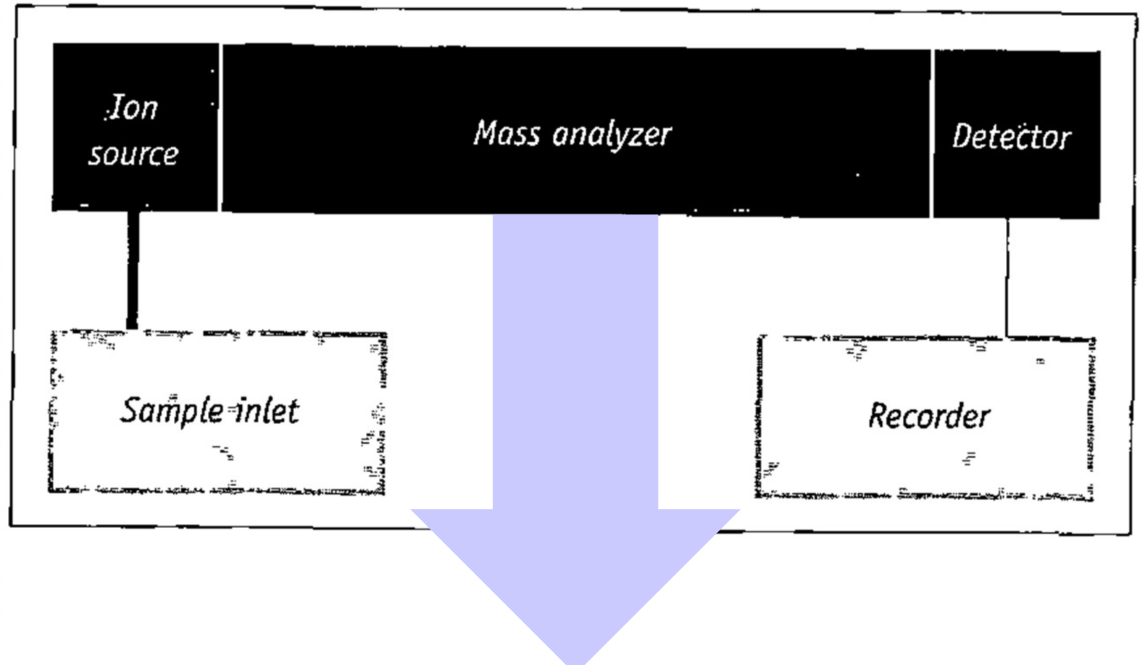
Figure 64 The variation in oxygen isotopes in seawater over the last million years, which reflects the variations in the average temperature of the surface as represented by the volume of ice in the ice cap.

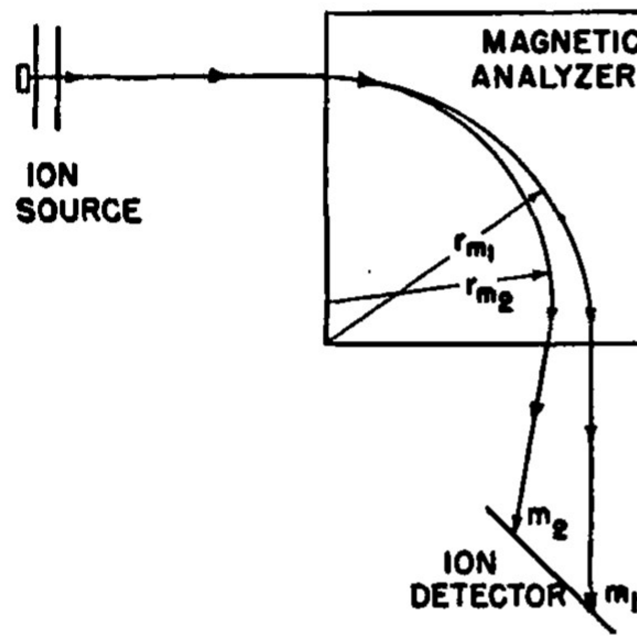


Tectonics and terrestrial evolution

Mass Spectrometry

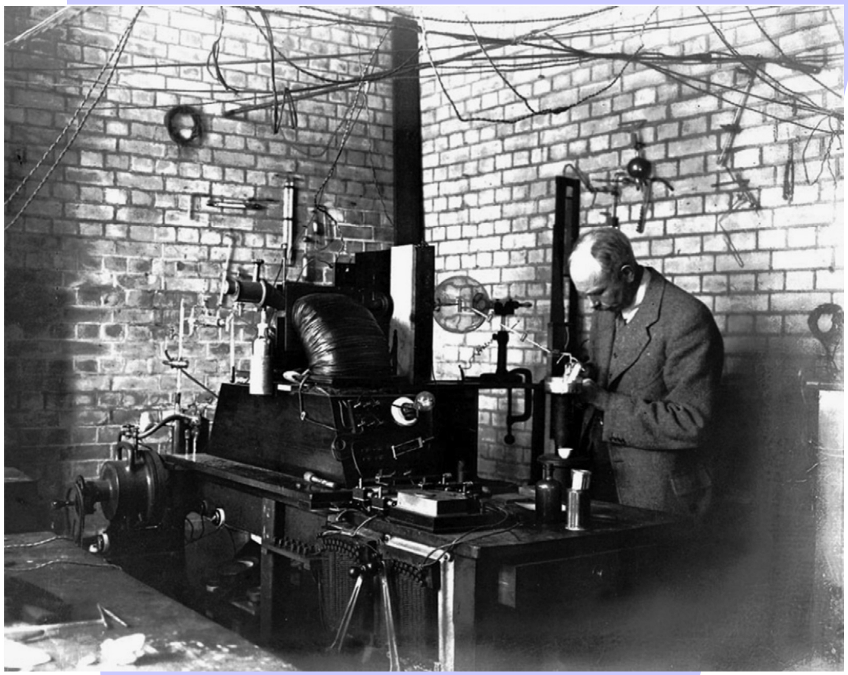






Alfred O. C. Nier
1911-1994

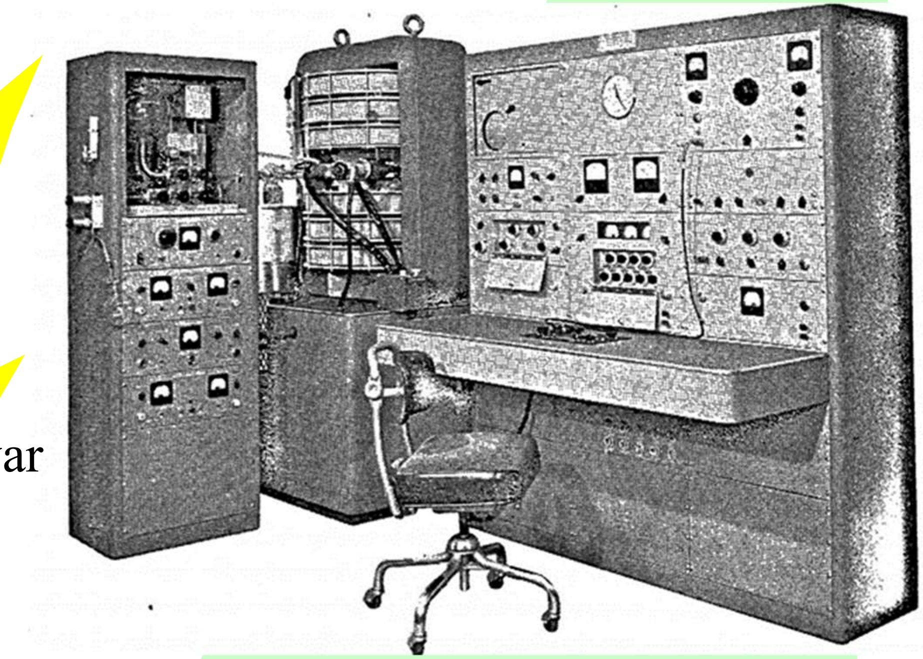
Continuity or Not?



mid-1930s

?

WW2, post-war growth



1960s

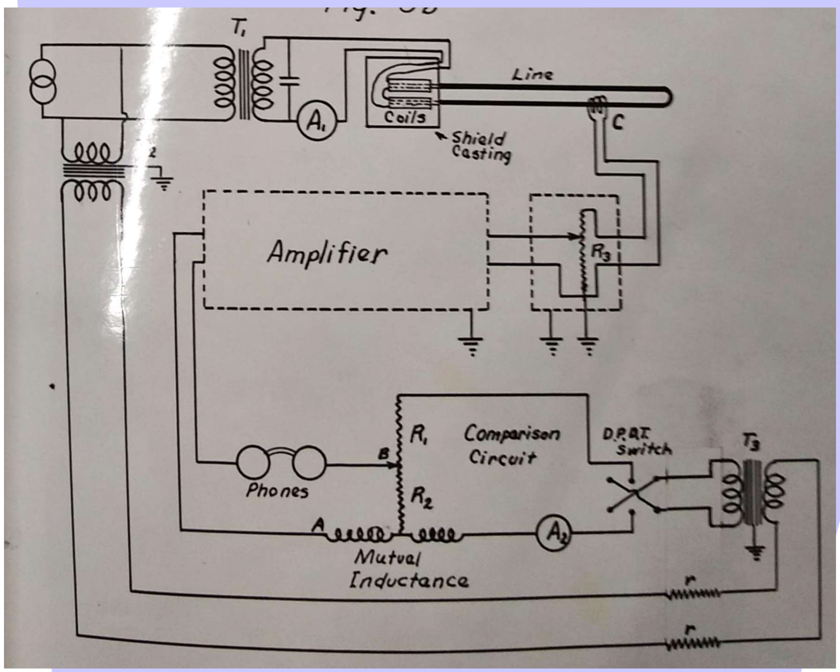
Overview

- From engineering to physics at Minnesota
- Geochronology at Harvard
- Early professorship at Minnesota and WW2
- Post-war career
- A Nierian tradition of research
- Conclusion

1927-1936
From Engineering to Physics at Minnesota

Early Years in St. Paul, MN

From Engineering to Physics



Nier's Engineering Lab ca. 1933

John Tate

AUGUST 1, 1935 PHYSICAL REVIEW VOLUME 48

LETTERS TO THE EDITOR

Prompt publication of brief reports of important discoveries in physics may be secured by addressing them to this department. Closing dates for this department are, for the first issue of the month, the twentieth of the preceding month; for the second issue, the fifth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

Evidence for the Existence of an Isotope of Potassium of Mass 40

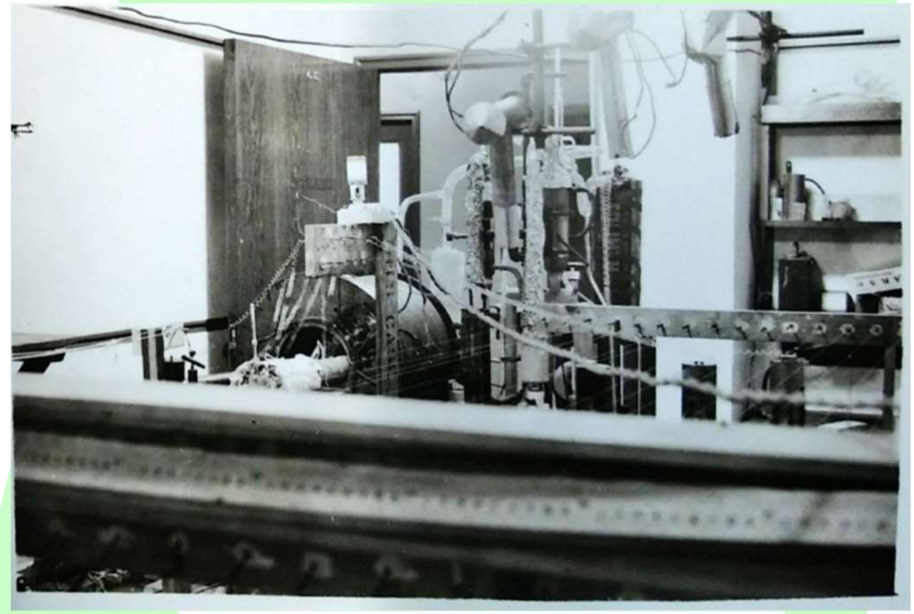
The average value of the ratio of the height of the peak due to the ion at 40 to that of the peak due to K^{39} is 1/8600

"It isn't quite clear which is which"

Larger magnet

Extremely sensitive electrical detector

Feedback control over the magnet



Nier's 1935 MS

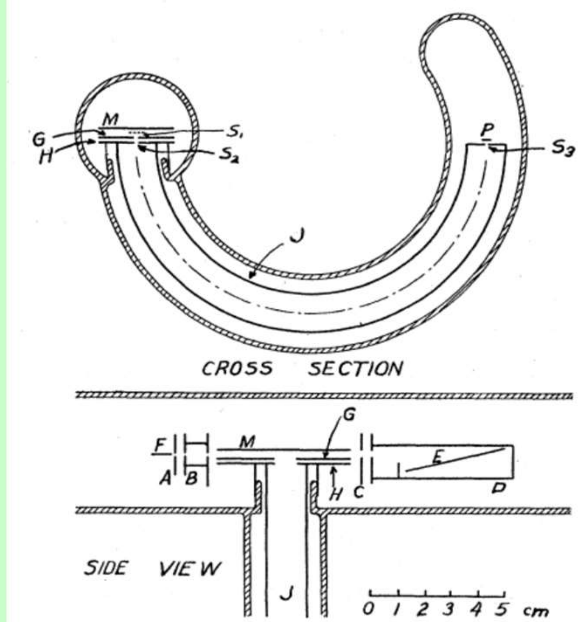


FIG. 1. Diagram of apparatus used for the study of potassium, rubidium, zinc and cadmium. Slit $S_1=0.25$ mm; Slit $S_3=0.15$ mm; Slit $S_2=0.15$ mm for K, 0.07 mm for Rb, Zn and Cd.

“If I’m going to get attention around here,
I need to be in nuclear physics”

Discovery of ^{40}K

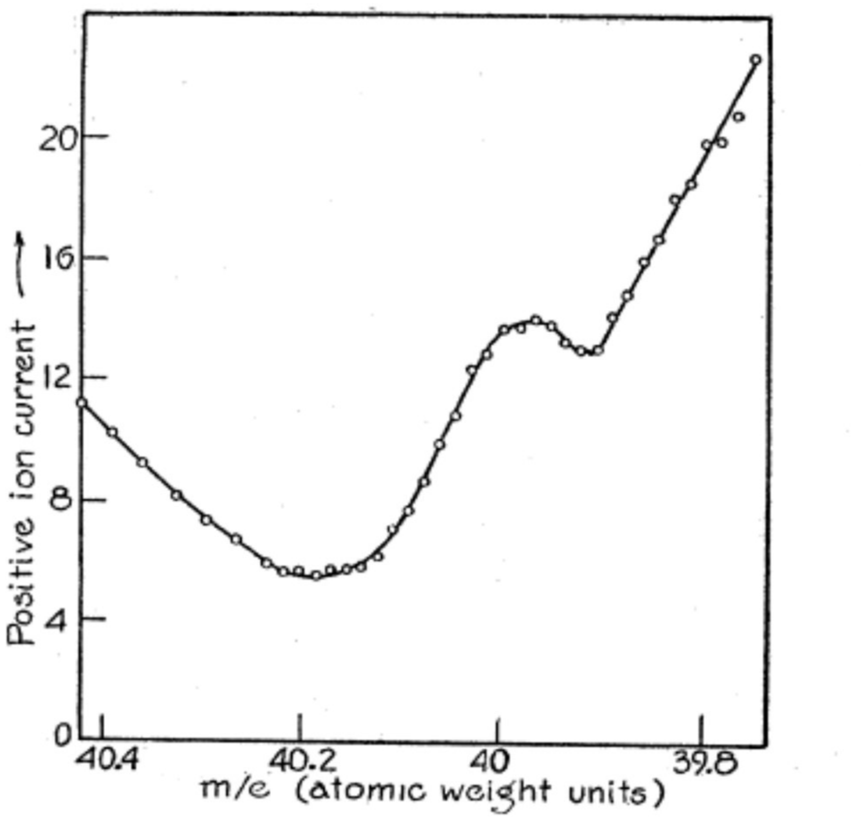
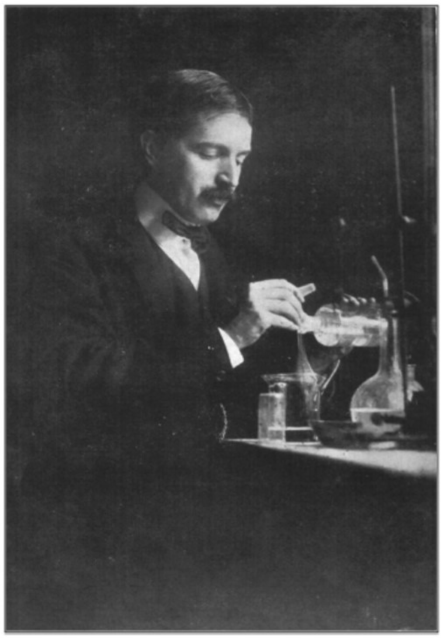


FIG. 1. Typical mass spectrographic analysis of region around mass 40. Potassium vapor in tube, 8.4 volts applied to electrons. Height of peak at 39, 44,300; at 41, 3190 units.

- Detected extremely low abundance ^{40}K isotope (peak magnitude 1/45,000 compared to ^{39}K)
- Explained radioactivity of K as due to decay of ^{40}K
- Would later serve as basis for important K-Ar dating method
- Also discovered isotopes of **Ar, Rb**, Zn, Cd

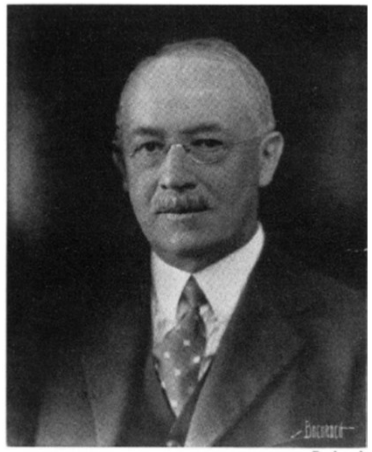
1936-1938 Geochronology at Harvard

Nier goes to Harvard



ca. 1905.

T. W. Richards
1868-1928



G. P. Baxter
1876-1953

K. T. Bainbridge
1904-1966

A. C. Lane
1863-1948

"That's what pushed the whole thing up to something that was different"

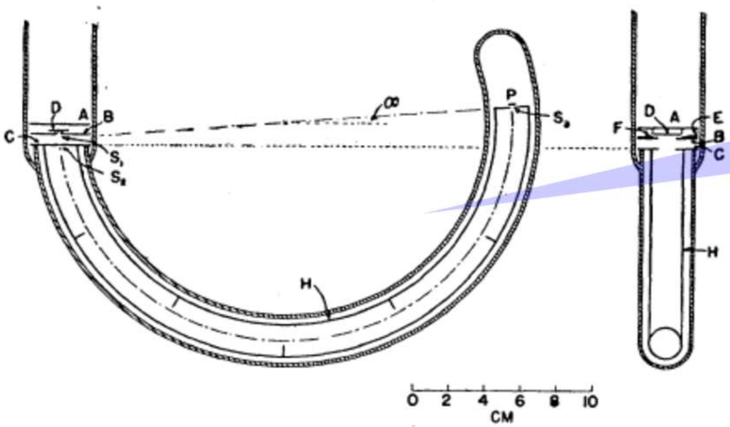


FIG. 1. Diagram of mass spectrometer. Slits S_1 and $S_2=0.2$ mm, Slit $S_3=0.3$ mm. The magnetic field is perpendicular to the paper in the cross-sectional view shown at the left.

Doubled the radius of 1935 instrument

Feedback control of power supply instead of magnet

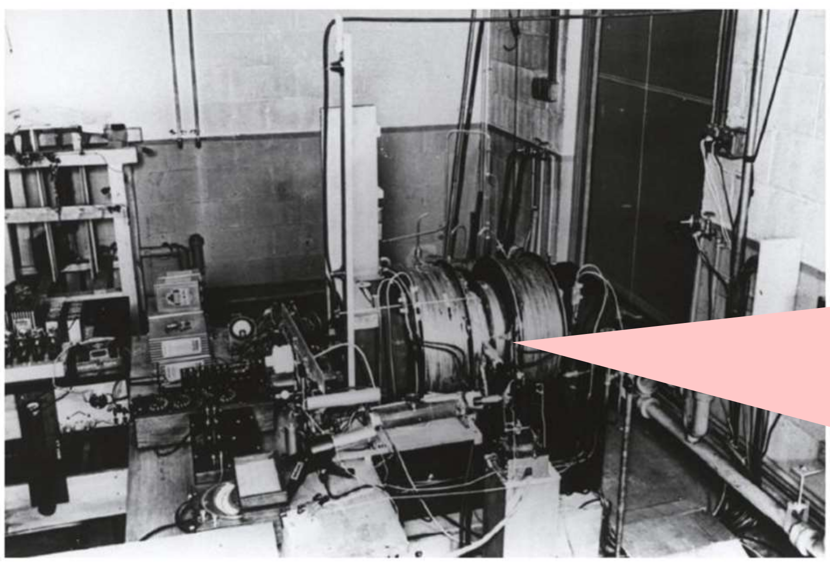
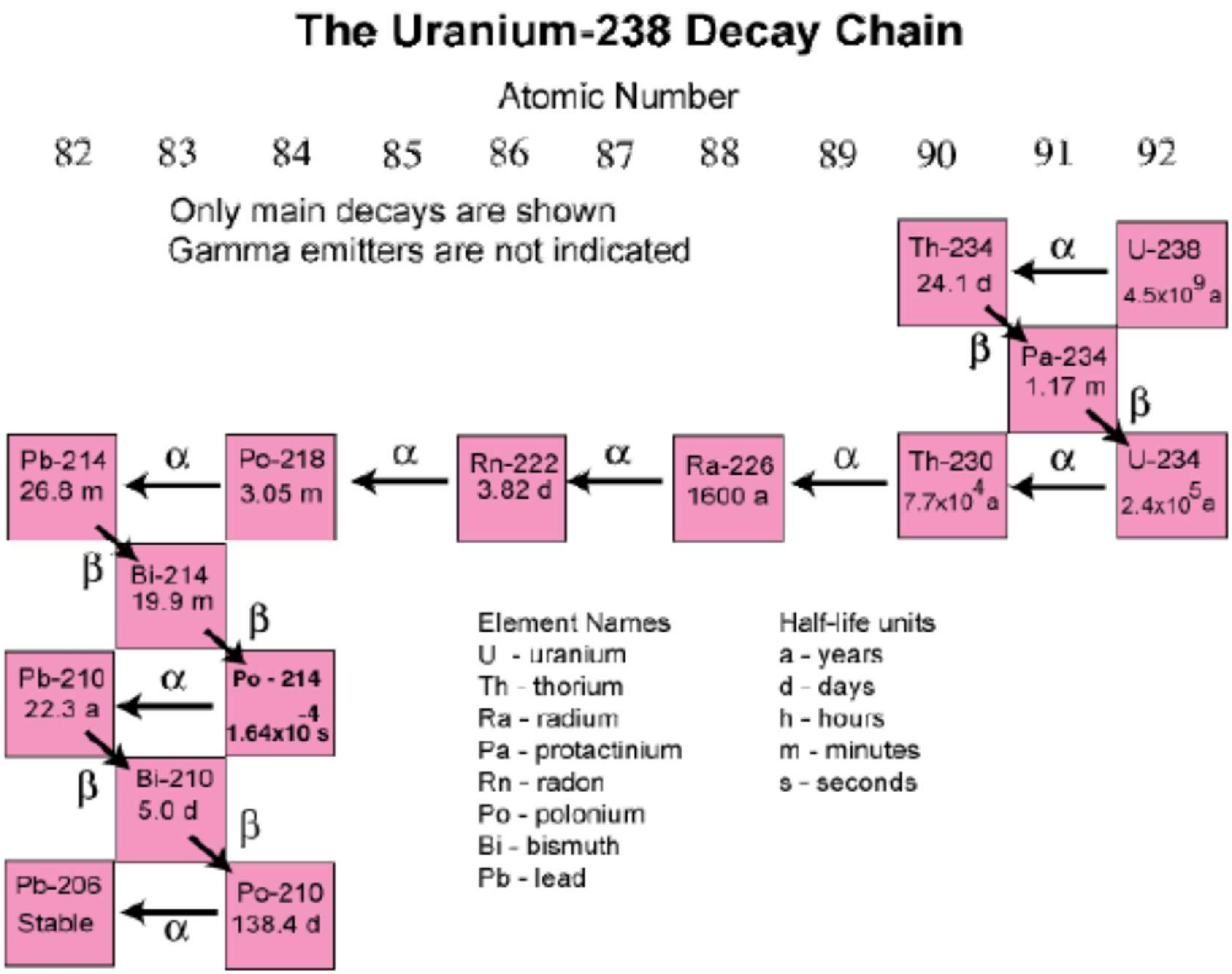


Figure 7. Photo of Harvard 180° mass spectrometer used for isotope analyses of U, Pb, Hg, Xe, Kr, etc.

Replaced earlier solenoid magnet with much larger 2-ton, 5 kW electromagnet

Uranium-Lead Dating



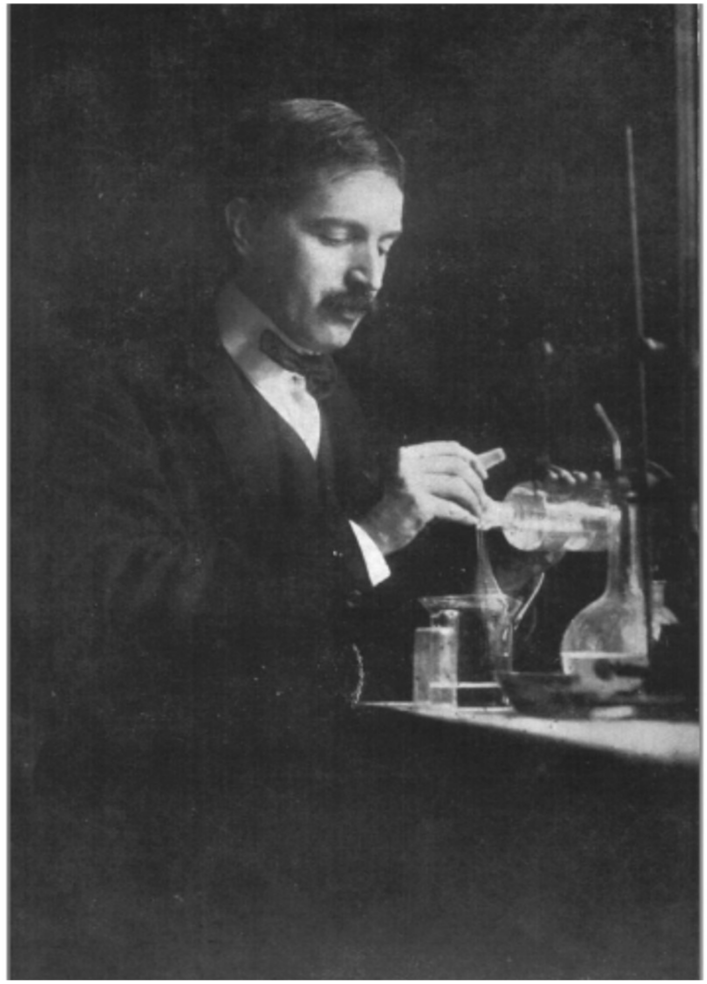
$$\boxed{D = D_0 + N(e^{\lambda t} - 1)}$$

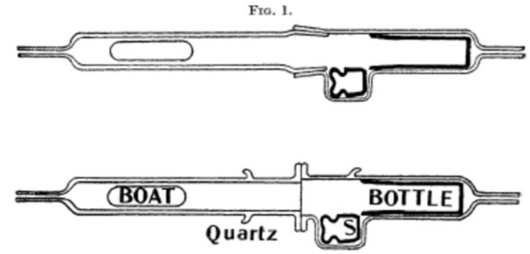
$$^{206}Pb^* = {}^{238}U(e^{\lambda_{238}t} - 1)$$

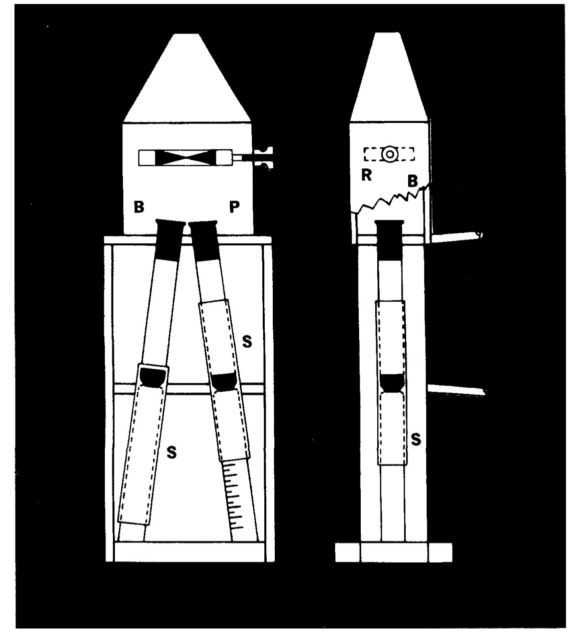
Also:

$$^{207}Pb^* = {}^{235}U(e^{\lambda_{235}t} - 1)$$

"Ordinary Lead"



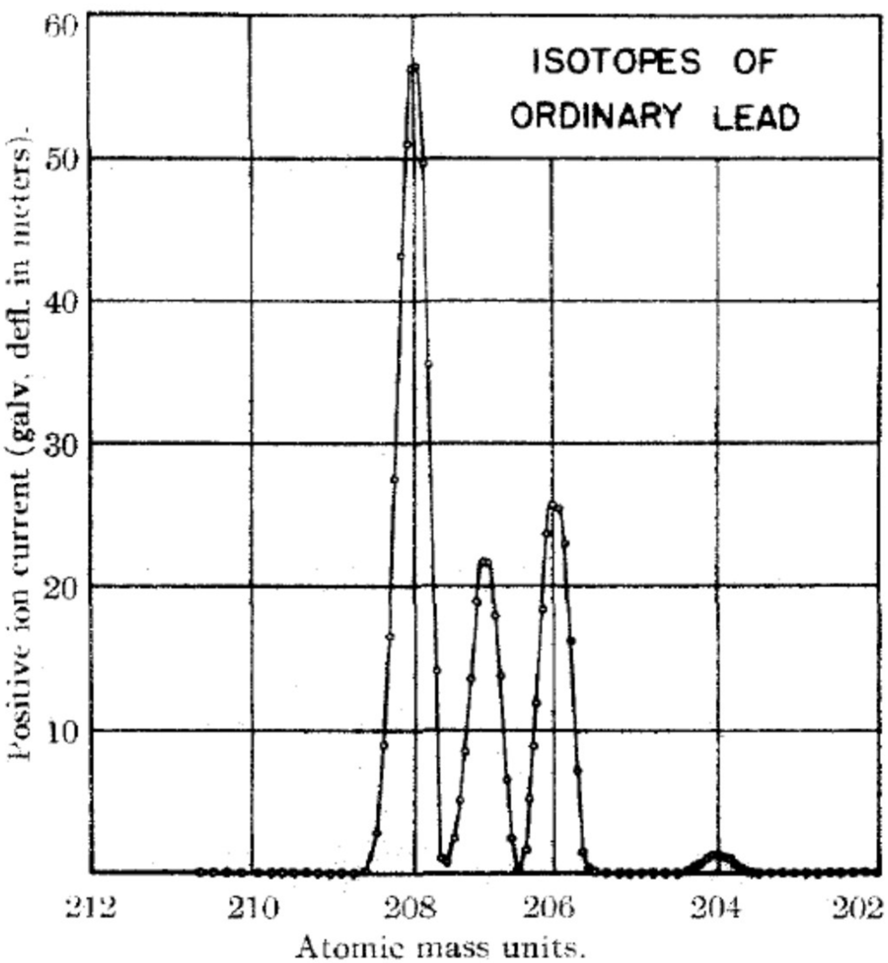




Galena ore

Atomic weight = 207.21 $\pm$ Δ

Ordinary Lead: Not So Ordinary



Many chemical measurements by Richards, Baxter and others had always returned a constant atomic weight for ordinary lead

Atomic weight = 207.21 $\pm$ Δ

Nier: ordinary lead consists of a mixture of isotopes the relative abundance of which varies by sample source!

“Lead as it existed when the earth’s crust formed”

Mixture results from addition of radiogenic to “primordial” lead

Permitted Patterson’s determination of age of Earth!

Radiogenic lead from uranium and thorium decay

added to

“primordial” lead

“ordinary” lead

“If I had followed up on that I’d have been generations ahead of other people”

TABLE I

C^{12}/C^{13} RATIO FOR VARIOUS SOURCES OF CARBON

Sample	Source	Age, 10^6 yrs.	Series 1	Series 2	Series 3
		1. Igneous C			
Graphite	Ceylon	500+	89.7	89.9	
Meteorite	Cosby's Creek, Tennessee	900 ±	89.6	89.1	
Diamond	Kimberley Mines, Africa	60?		89.0	
		2. Limestones, $CaCO_3$			
Grenville	New York	1200	87.2	88.3	88.2
Ordovician	Vermont	380	88.6	88.5	
Clam shell	Boston	Present	88.7	88.6	
		3. Plant Sources			
Anthracite coal	Tennessee	250	92.1	91.7	91.5
Wood	Mass. pine	Present	91.8	91.2	
		4. Unclassified			
Dry Ice	Virginia coal	230+	91.6	90.8	
Oil	West Texas	200+		91.2	
Air[a]	Mass. 3/14/38	Present	92.5		
Air[b]	Mass. 3/22/38	Present		89.8	89.9
Na_2CO_3	Michigan limestone	300+	88.3	88.3	
Clam flesh	Boston	Present		90.1	

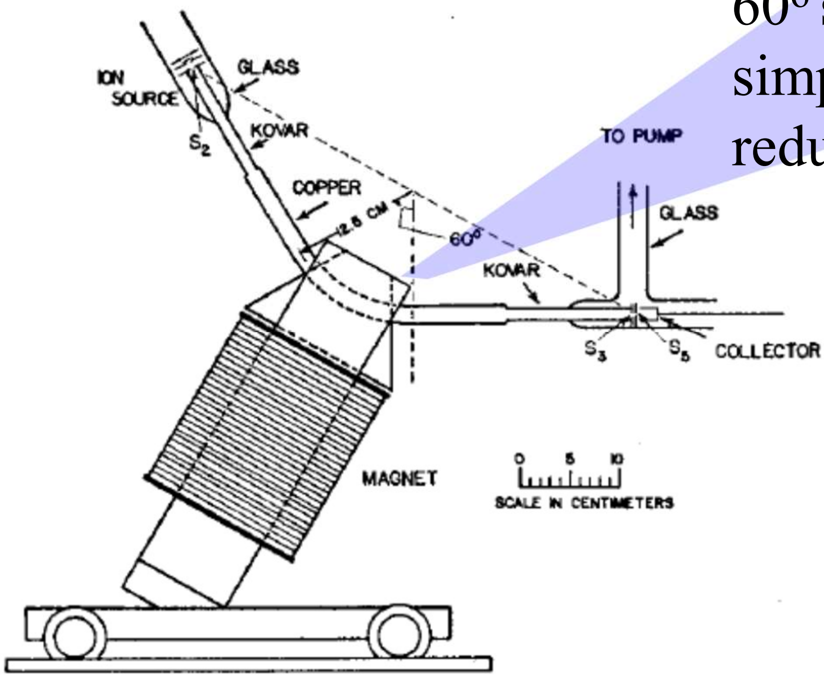
Isotope ratio variations can also occur in stable elements

Nier: $^{13}C/^{12}C$ ratios vary by up to 5% depending on the sample source, e.g. limestones v. plants

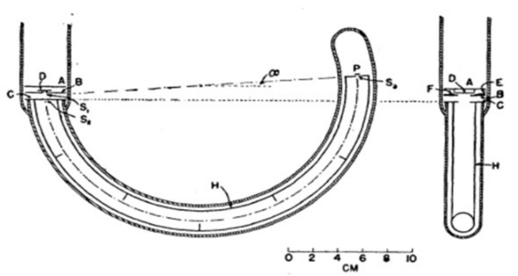
Discovery-instrument combo paved way for stable isotope geochemistry

1938-1945 Back to Minnesota and Manhattan Project

Mass Spectrometry for the Masses



60^o sector analyzer crucial for simplifying design and reducing magnet size



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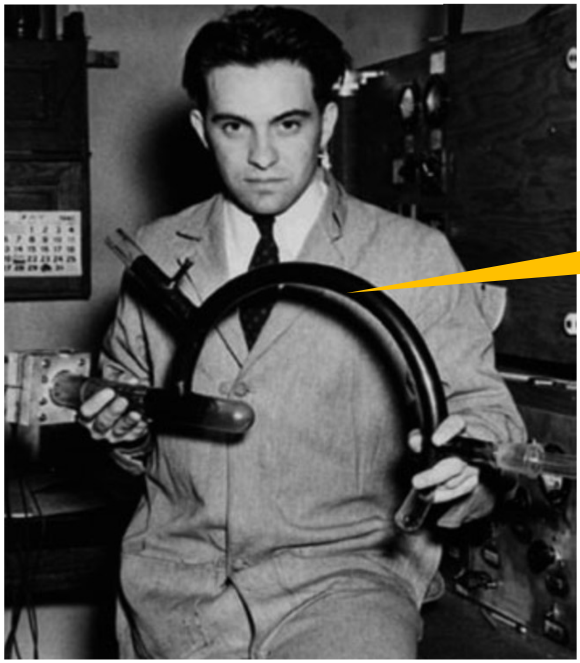
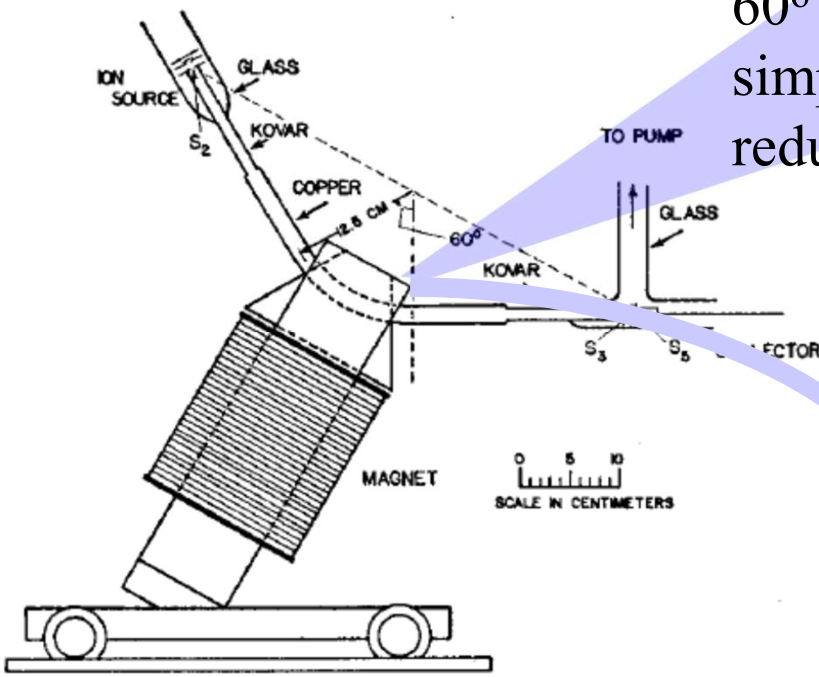
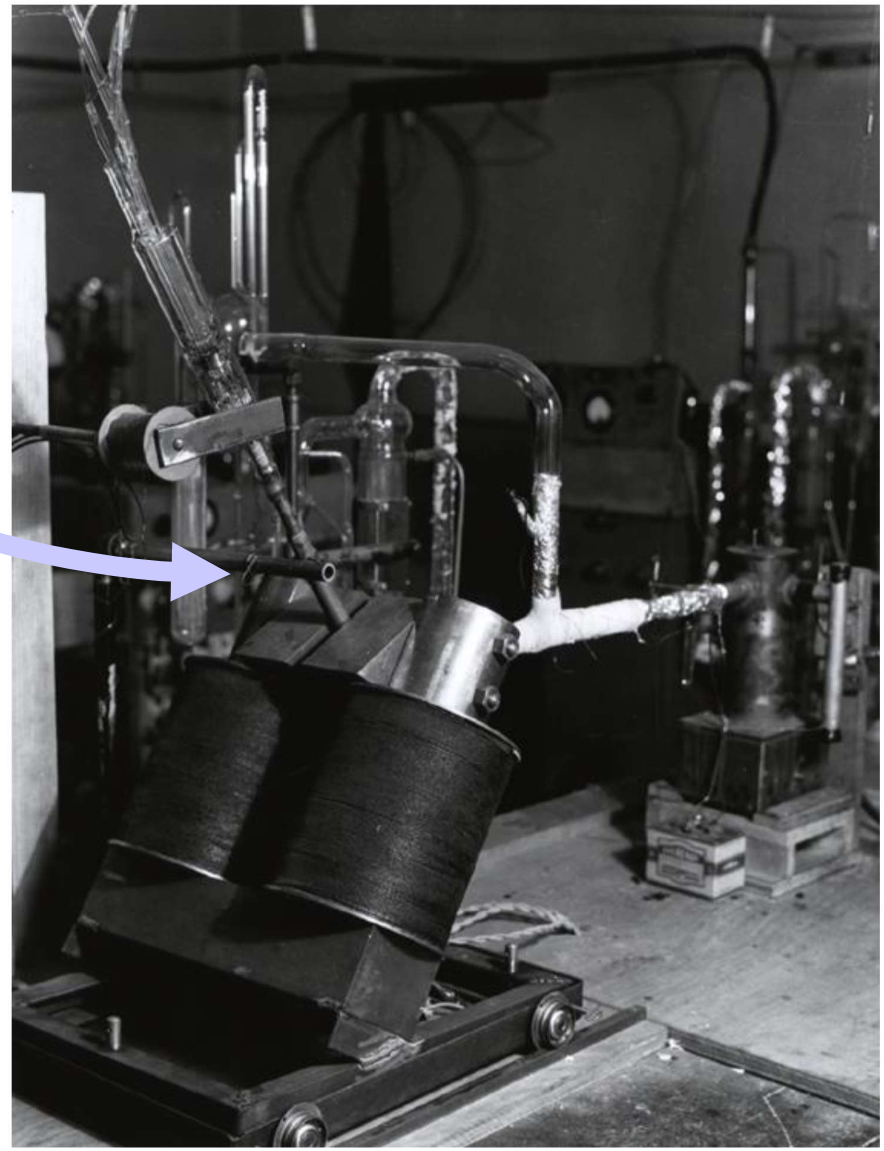


180^o sector

Mass Spectrometry for the Masses

60° sector analyzer crucial for simplifying design and reducing magnet size

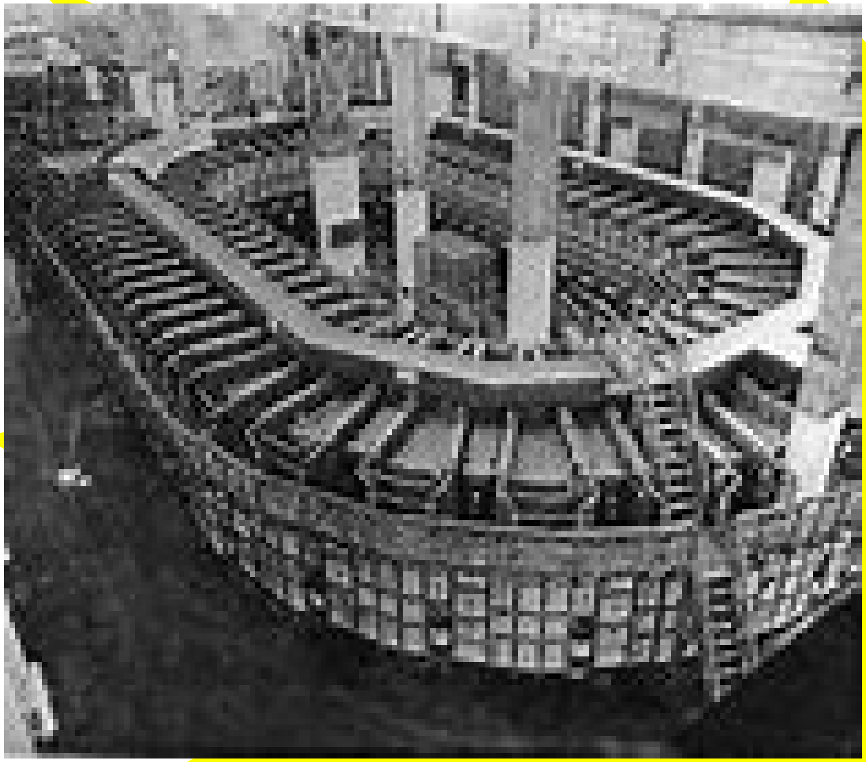


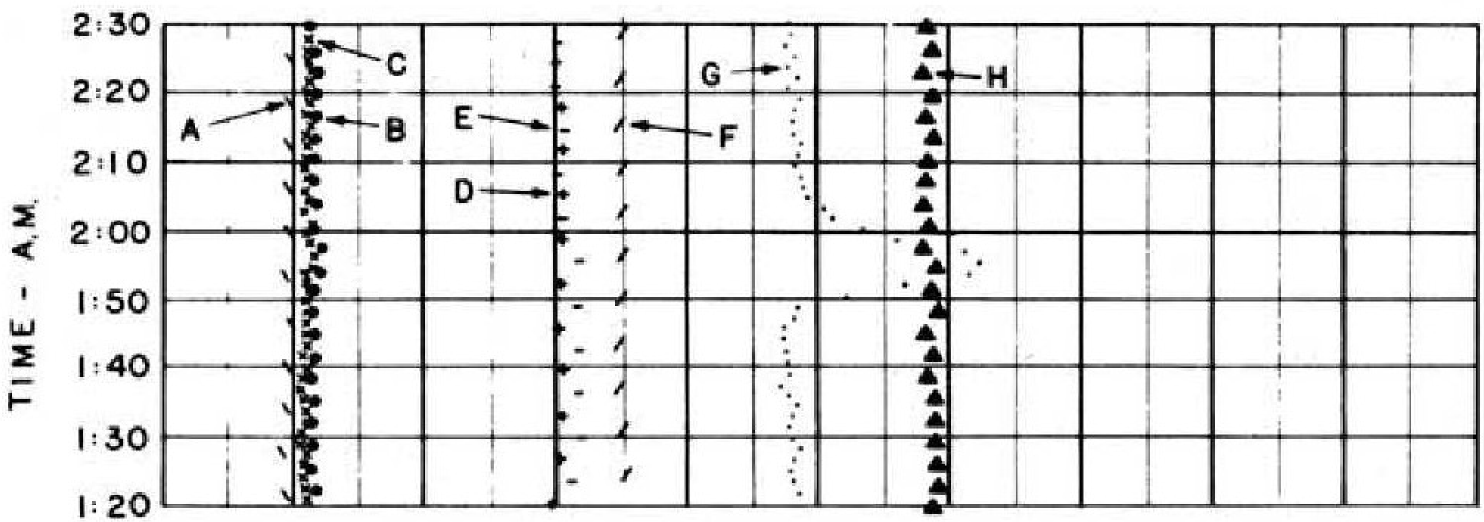


"If you could make these tools available to other people, who didn't necessarily have to know how a mass spectrometer worked, but could use it, they could apply it to problems in their fields**. I think that this is one of the very important developments of our time"**

Uranium for Bombs

Uranium for Bombs





1945-1994
Post-War Career

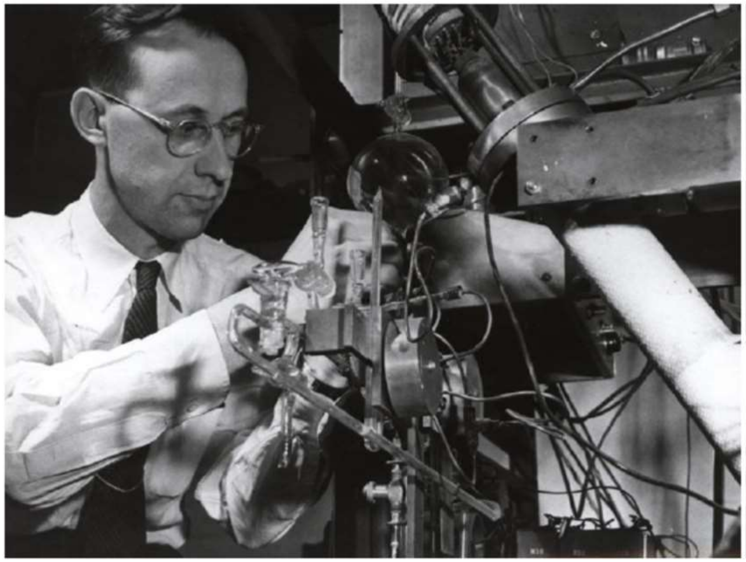
Back to Geochronology

Argon 40 in Potassium Minerals

L. T. Aldrich and Alfred O. Nier
Department of Physics, University of Minnesota, Minneapolis, Minnesota
(Received July 8, 1948)

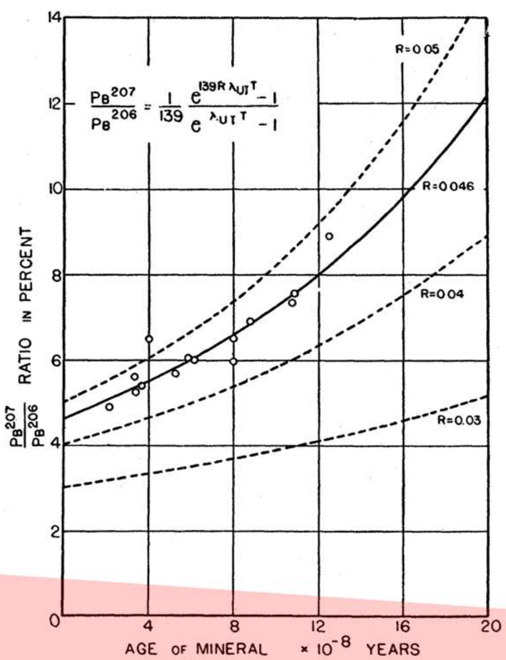
An investigation has been made of the isotopic composition of the argon from four potassium minerals. In each case a high A^{40}/A^{36} ratio compared to that of atmospheric argon is observed showing directly that K^{40} decays to both Ca^{40} and A^{40}. From the absolute amounts of radiogenic A^{40} and K^{40} in the minerals a lower limit on the branching ratio λ_K/λ_β can be made. If the half-life, 7×10^8 yrs., is assumed for $K^{40}\rightarrow Ca^{40}$, λ_K/λ_β must be at least 0.02. The possibility of using this method for measuring geological age is suggested.

The K-Ar method would become a pillar of geochronology



Back to Geochronology

Arthur Holmes
1890-1965



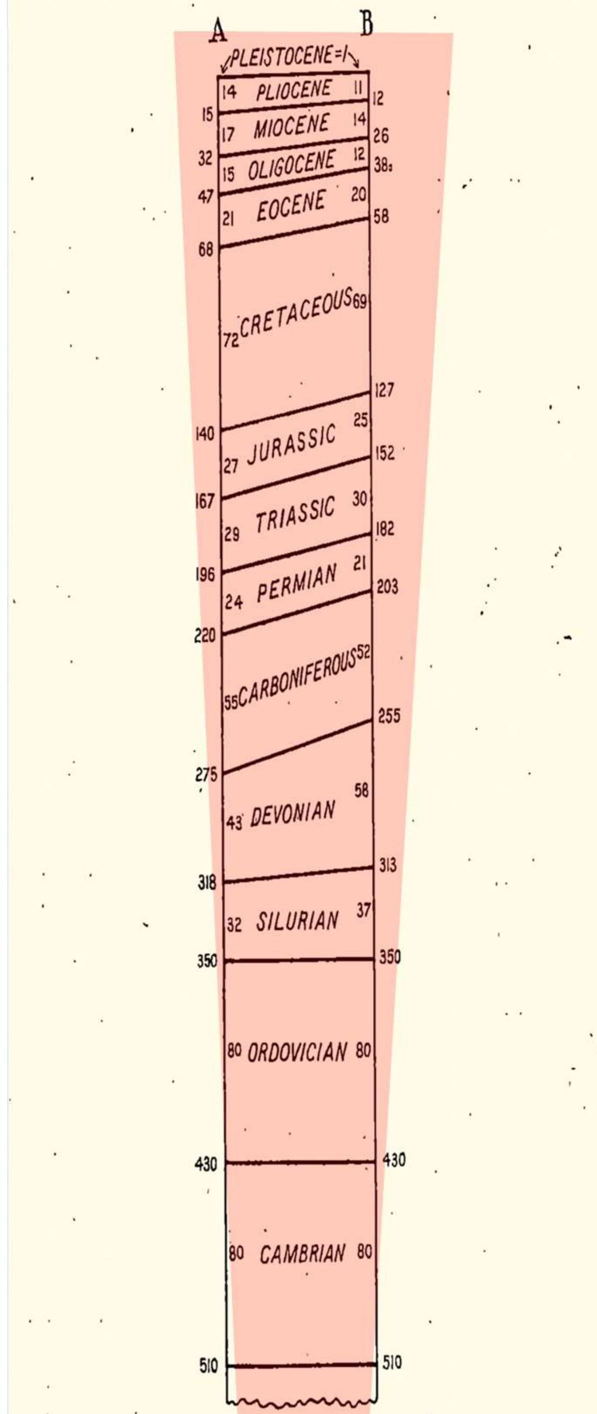
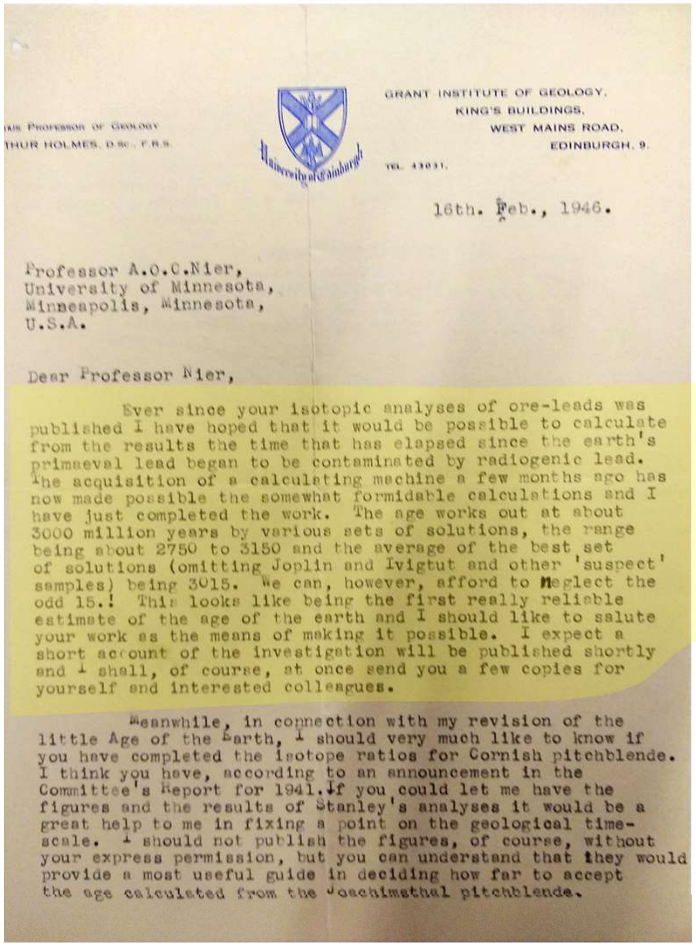


FIG. 5.—Columnar representation of the time-scales A and B of Fig. 3. The figures inside the column indicate the lengths of the respective Periods in millions of years; those outside indicate the cumulative ages. Scale B is regarded as the more probable of the two.

Towards the Age of the Earth …



…US PROFESSOR OF GEOLOGY
…THUR HOLMES, D.Sc., F.R.S.

GRANT INSTITUTE OF GEOLOGY,
KING'S BUILDINGS,
WEST MAINS ROAD,
EDINBURGH, 9.

TEL. 43031.

University of Edinburgh

16th. Feb., 1946.

Professor A.O.C.Nier,
University of Minnesota,
Minneapolis, Minnesota,
U.S.A.

Dear Professor Nier,

Ever since your isotopic analyses of ore-leads was published I have hoped that it would be possible to calculate from the results the time that has elapsed since the earth's primaeval lead began to be contaminated by radiogenic lead. The acquisition of a calculating machine a few months ago has now made possible the somewhat formidable calculations and I have just completed the work. The age works out at about 3000 million years by various sets of solutions, the range being about 2750 to 3150 and the average of the best set of solutions (omitting Joplin and Ivigtut and other 'suspect' samples) being 3015. We can, however, afford to neglect the odd 15.! This looks like being the first really reliable estimate of the age of the earth and I should like to salute your work as the means of making it possible. I expect a short account of the investigation will be published shortly and I shall, of course, at once send you a few copies for yourself and interested colleagues.

Meanwhile, in connection with my revision of the little Age of the Earth, I should very much like to know if you have completed the isotope ratios for Cornish pitchblende. I think you have, according to an announcement in the Committee's Report for 1941. If you could let me have the figures and the results of Stanley's analyses it would be a great help to me in fixing a point on the geological time-scale. I should not publish the figures, of course, without your express permission, but you can understand that they would provide a most useful guide in deciding how far to accept the age calculated from the Joachimsthal pitchblende.

"Ever since your isotopic analyses of ore-leads was published I have hoped that it would be possible to calculate from the results the time that has elapsed since the earth's primaeval lead began to be contaminated by radiogenic lead. The acquisition of a calculating machine a few months ago has now made possible the somewhat formidable calculations and I have just completed the work. The age works out at about 3000 million years by various sets of solutions, the range being about 2750 to 3150 and the average of the best set of solutions … being 3015. We can, however, afford to neglect the odd 15.! [*sic*] This looks like being the first really reliable estimate of the age of the earth and I should like to salute your work as the means of making it possible."

Towards the Age of the Earth …

June 16, 1948

Dr. J. J. Kipling
Department of Chemistry
University College
Hull, England

Dear Dr. Kipling:

I am almost embarrassed to answer your letter of May 8 at this late date but the pressure of work at the end of our school term has resulted in a great many odds and ends piling up on my desk. While I have glanced at Professor Holmes' papers, I have not considered in detail all of the figures which he uses. This much I can say, however. The ages of the common lead samples which I have analyzed are only estimates based on the usual geological evidence and I have merely accepted these ages without being greatly concerned about the absolute accuracy since I was not attempting in my paper to make any quantitative comparison between the age of the mineral and the isotopic composition of the common lead.

I have never met Professor Holmes but like yourself have become greatly interested in the geological age work and have read all of Holmes' interesting papers. While Holmes has given great stimulus to much work along this line, I know there are many people who feel that he has a tendency to sometimes attach too much significance to the figures which are given in the literature. I have a feeling in the case which you mention, he may be a bit too optimistic in employing some of the published estimates of ages.

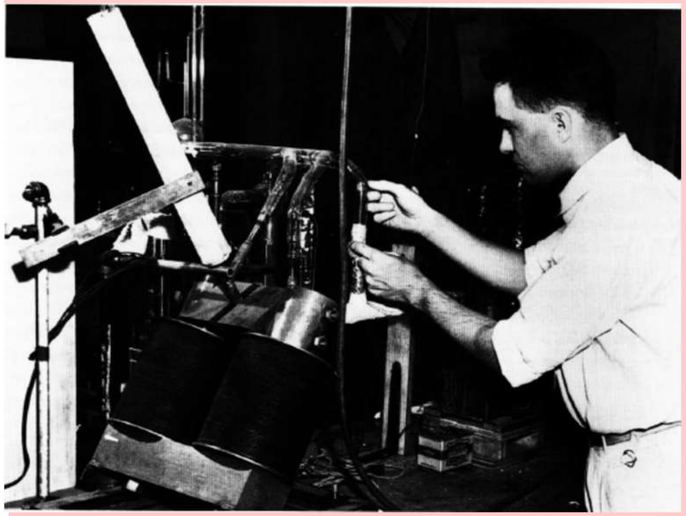
Sincerely yours,

Alfred O. C. Nier
Professor of Physics

AOCN/hew

"I have never met Professor Holmes but like yourself have become greatly interested in the geological age work and have read all of Holmes' interesting papers. While Holmes has given great stimulus to much along this line, I know there are many people who feel that he has a tendency to sometimes attach too much significance to the figures which are given in the literature. I have a feeling that in the case which you mention, he may be a bit too optimistice in employing some of the published estimates of ages."

Miniaturization for Space Exploration



Mars’ surface photographed by Viking probe (1976)

Isotopic Composition of Nitrogen: Implications for the Past History of Mars’ Atmosphere

Abstract. *Models are presented for the past history of nitrogen on Mars based on Viking measurements showing that the atmosphere is enriched in ^{15}N. The enrichment is attributed to selective escape, with fast atoms formed in the exosphere by electron impact dissociation of N_2 and by dissociative recombination of N_2^+. The initial partial pressure of N_2 should have been at least as large as several millibars and could have been as large as 30 millibars if surface processes were to represent an important sink for atmospheric HNO_2 and HNO_3.*

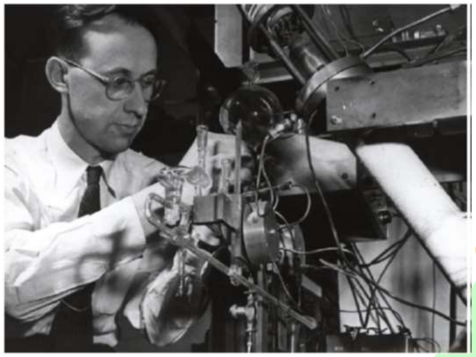
1945-present The Nierian Tradition in Isotope Geology

“The Nier pyramid”

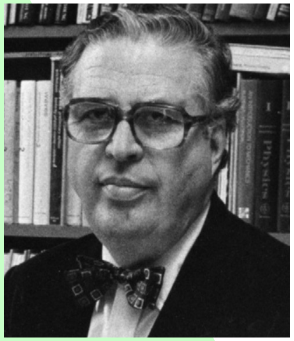
John Reynolds

“**One can categorize a large part of the worldwide geochronological effort as a pyramid of workers with Al at its apex.** The Nier pyramid would be all encompassing with respect to geochronologists, if using magnetic sector instruments were the defining category, which is much the case.”

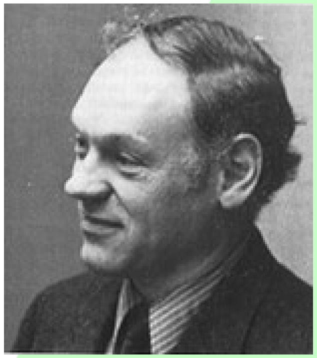
“The Nier pyramid” 1940s-1960s



L. T. Aldrich
Carnegie Institution
Washington, D.C.



Mark Inghram
U. of Chicago
Argonne National
Laboratory



Paul Gast
University of Minnesota
Columbia

Urey's clam thermometer

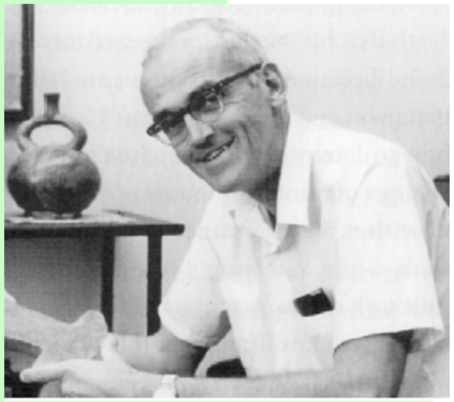
Harold Urey
U. of Chicago

Supervised Nier's work on Manhattan Project

Nier's $^{13}C/^{12}C$ ratios provided key empirical evidence for Urey's 1947 theory of stable isotope fractionation

Optimized a Nier-type spectrometer to initiate paleoclimate studies

The Age of the Earth (1956)



Harrison Brown

Clair Patterson

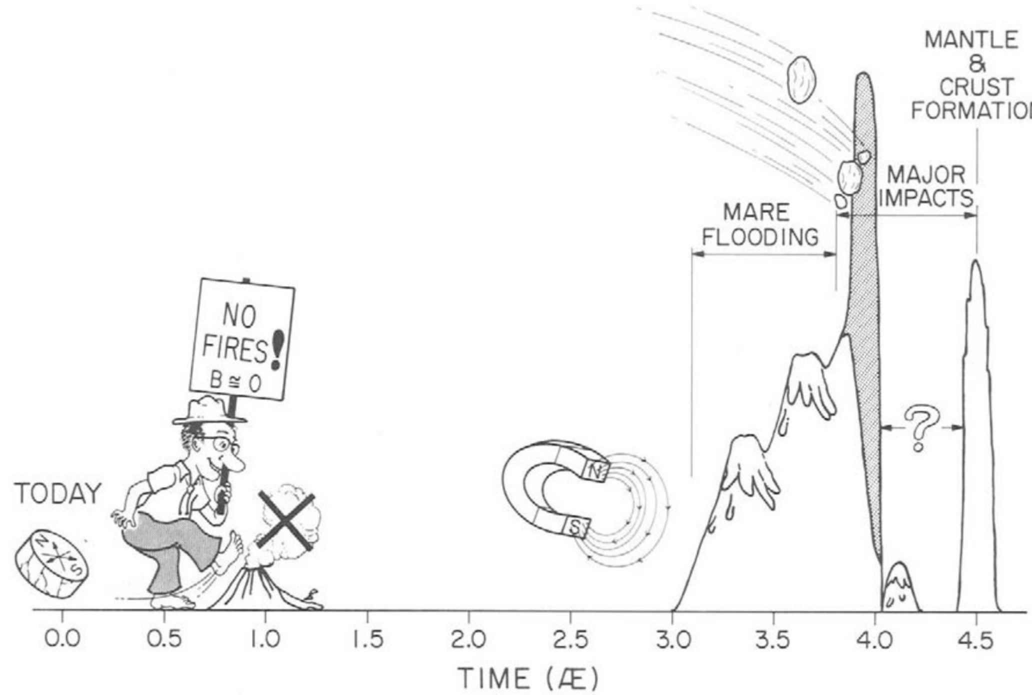
U. Chicago
Caltech

Both learned MS in 1940s

Calculated age of Earth based on Nier's equations and primordial lead in meteorites

Used one of Inghram's modified Nier-type spectrometers to measure lead isotope ratios

Gerald Wasserburg's Lunatic



Gerald Wasserburg
U. Chicago
Caltech

Student of Inghram and Urey

Invented first fully digital Nier-type spectrometer

Applied to solar system history i. a.

Plate Tectonics and Solar System History

John Reynolds
U. Chicago
UC Berkeley

Student of Inghram's

Optimized Nier-type spectrometer for noble gas isotopic analysis

Discovered extinct radioactive nuclides

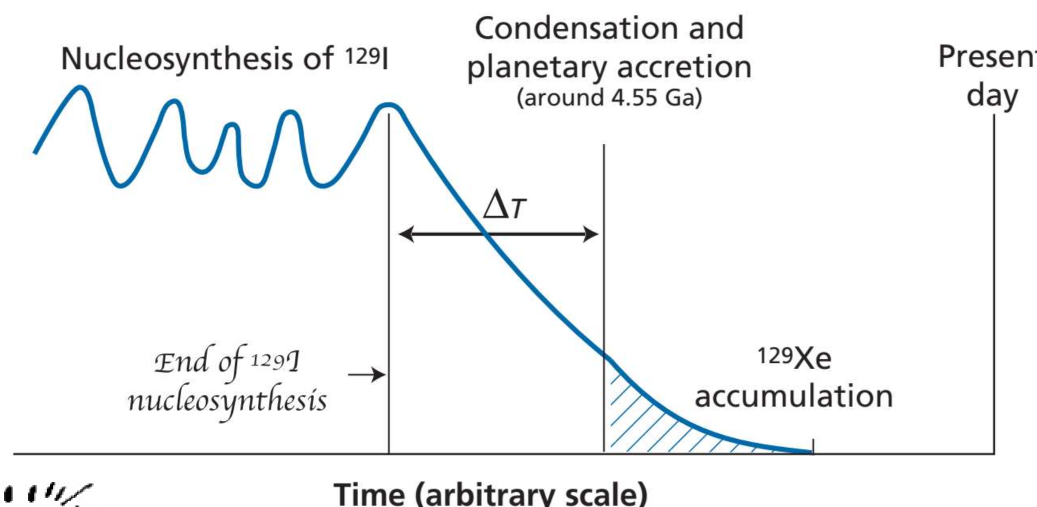
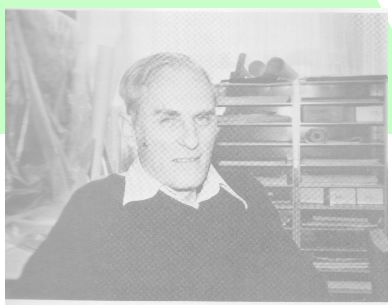


Plate Tectonics and Solar System History

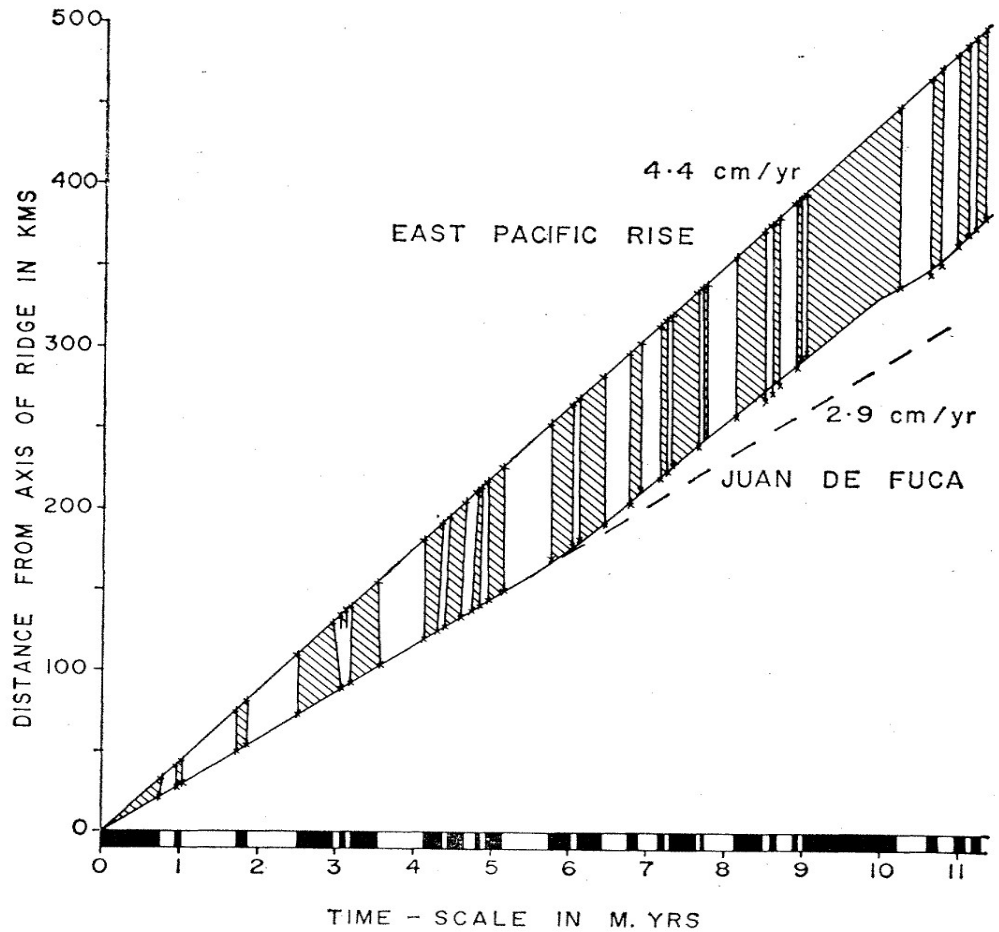
John Reynolds
U. Chicago
UC Berkeley



Garniss Curtis   Jack Evernden

UC Berkeley

Curtis, Evernden and others applied the technique to date changes in polarities of young rocks, providing key evidence for sea-floor spreading



Conclusion: An instrumental revolution in geochemistry?

The geochronology revolution

James M. Mattinson*
Department of Earth Science, University of California, Santa Barbara, California 93106-9630, USA

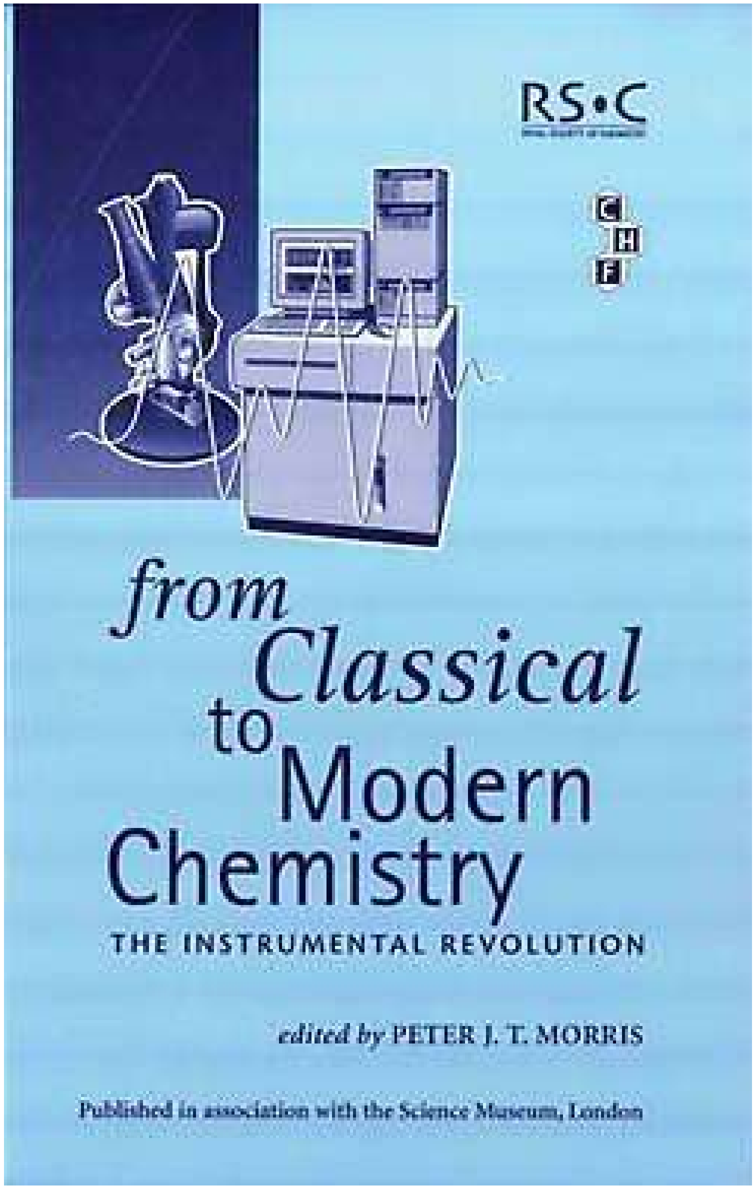
1960–1970: start of the geoanalytical revolution

Smaller, better, more: Five decades of advances in geochemistry

Evidence that geochemistry underwent a profound change in methods during post-war period

Shift from wet chemistry to electronic instruments based on physical principles

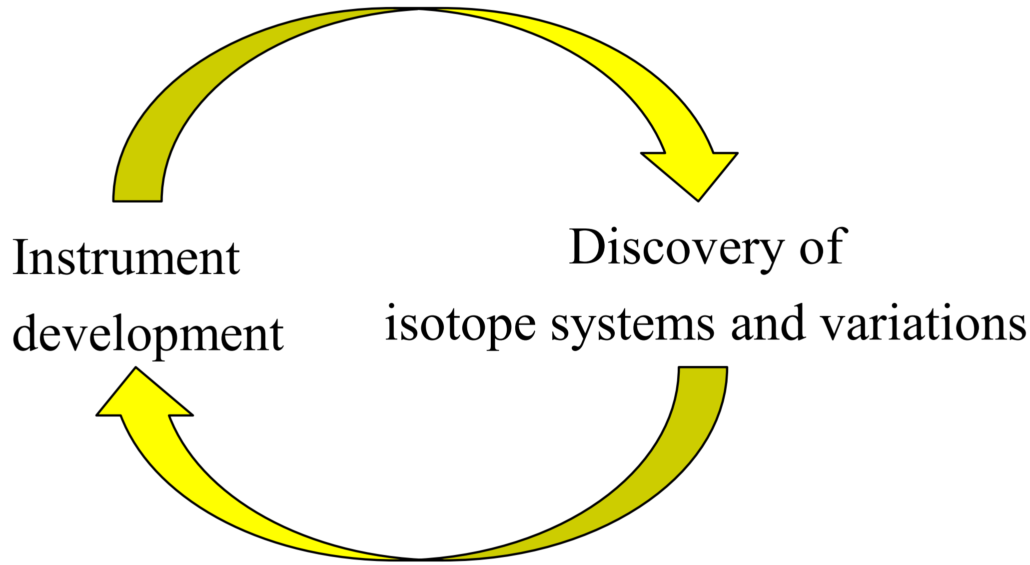
Conclusion: An instrumental revolution in geochemistry?



Shift is contemporaneous with similar transformations occurring elsewhere in chemistry at the time, dubbed "the Instrumental Revolution"

Nier's work part of a bigger trend in the chemical sciences

Conclusion: a co-evolution of instrumentation and discovery



Nier not just an instrument-maker. Opened up field of isotope geochronology.

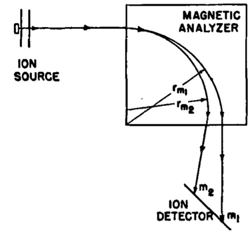
Uniquely positioned to combine multiple lines of research and kinds of knowledge

Getting the synergy off the ground

$$D = D_0 + N(e^{\lambda t} - 1)$$

Radiometric dating

Chemical analysis



Mass spectroscopy

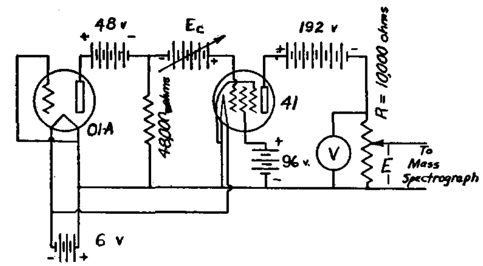
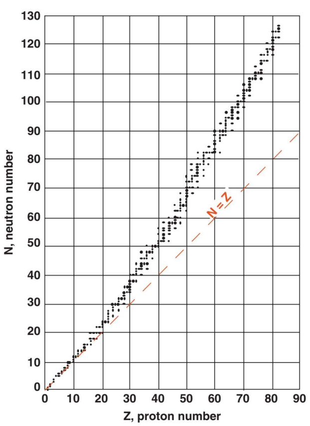
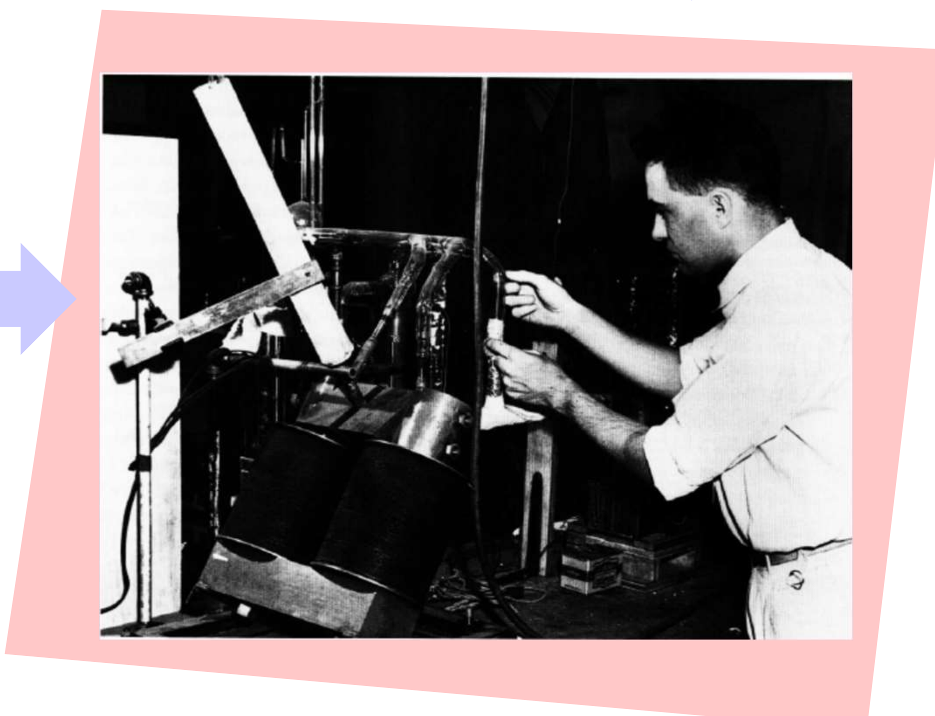


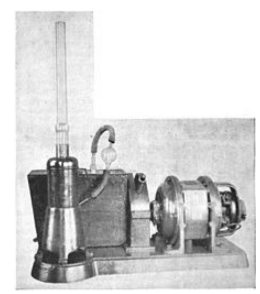
FIG. 1. Circuit diagram for compensator.

Electrical engineering



Atomic and nuclear physics





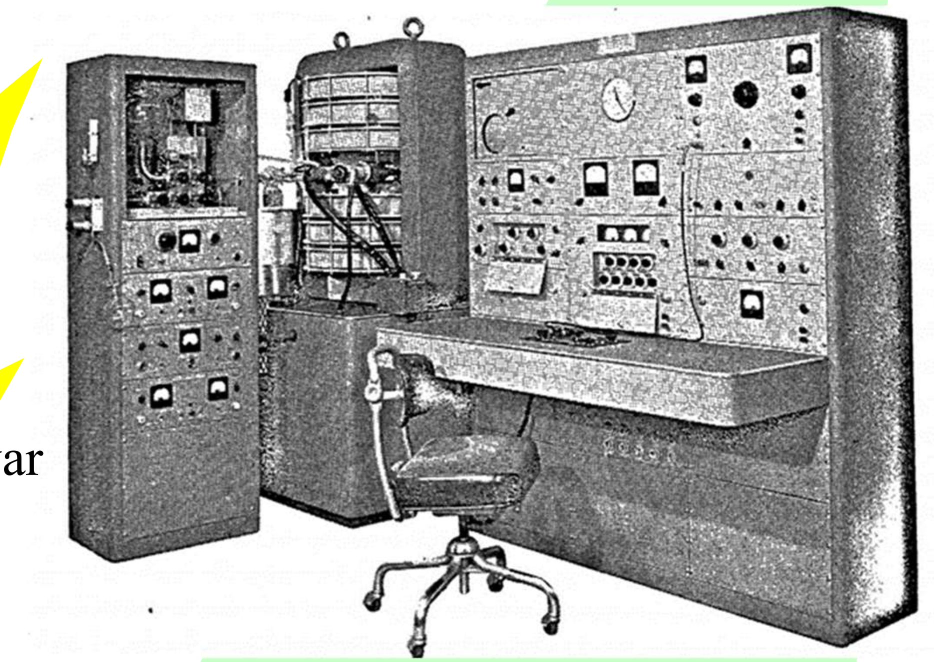
Vacuum technology

Continuity or Not?

1938-1941

?

WW2, post-war growth



1960s

Nier's career suggests that there were important continuities in pre- and post-war geochronology. Nier developed the fundamentals of the instrumentation central to isotope geochronology before direct US involvement in the war.

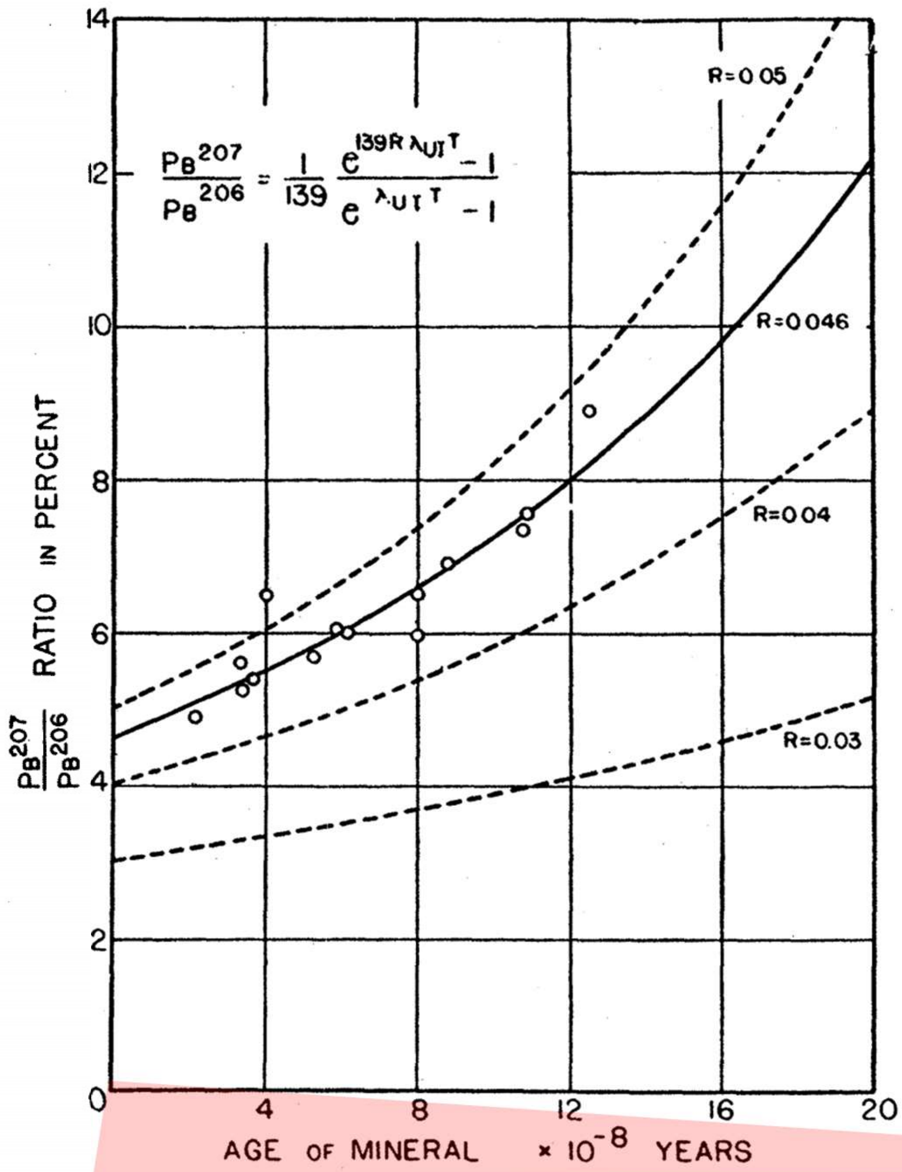
End

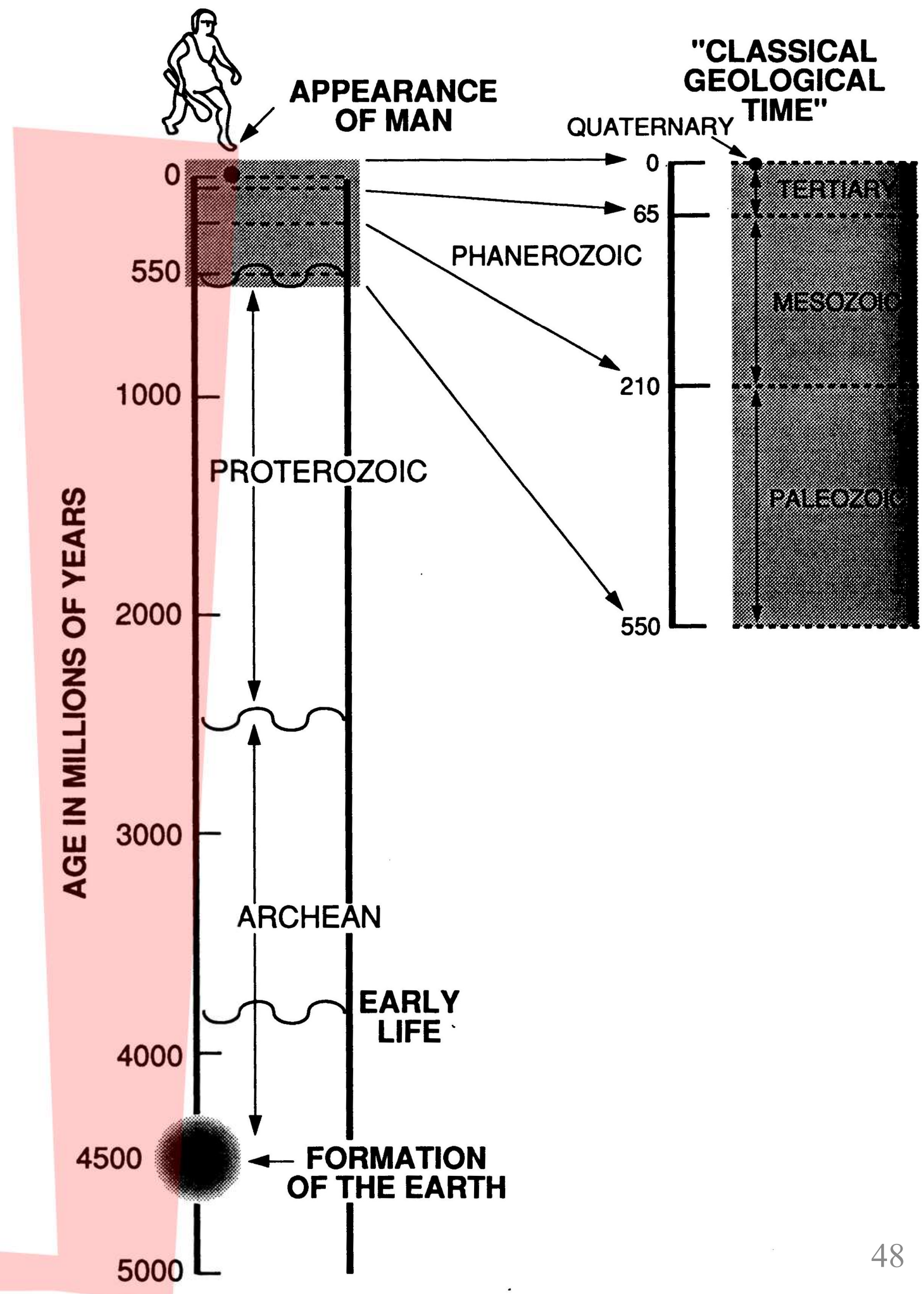
gborg@sciencehistory.org

Acknowledgements:
Dr. Roger Turner
Beckman Center Members
National Science Foundation

Out-takes

Geochronology





“If I had followed up on that I’d have been generations ahead of other people”