

October 16, 1963

Mr. Haydn F. Morgan, Director
Project Research and Grants
3400 Walnut Street
Philadelphia, Pennsylvania

Dear Mr. Morgan:

Twenty-two copies of a grant proposal entitled "Studies of Remanent Magnetic Measurements" are enclosed.

If this proposal meets with your approval, I should like to submit it to Dr. Richard Baden, Program Director of the Division of Geochemistry (Department of Earth Sciences) of the National Science Foundation.

Sincerely yours,

Elizabeth K. Ralph

EKR:jtr

UNIVERSITY of PENNSYLVANIA

PHILADELPHIA 19104

OFFICE OF PROJECT RESEARCH AND GRANTS

October 28, 1963

National Science Foundation
Washington 25, D. C.

Attention: Dr. Richard Baden
Program Director
Division of Geochemistry
Department of Earth Sciences

Gentlemen:

Submitted herewith are 20 copies of a proposal for support of research entitled "Study of Remnant Magnetic Measurements" to be conducted under the direction of Elizabeth K. Ralph, Research Associate, Department of Physics, University of Pennsylvania.

The proposal has been approved by appropriate University officials and signed on behalf of the University by Dr. David R. Goddard, Provost.

In further justification for the equipment request for \$1,300 for a theodolite, Miss Ralph informs us the determination of in situ orientation of samples to an adequate accuracy requires both measurement of magnetic north and true north by shooting-the-sun. This figure was obtained from catalog prices of this type of instrument. Determination of the specific instrument to be purchased must come later.

If any further information is needed, please let us know.

Yours very truly,

James L. Malone
Contracts Administrator

JLM:md
encl.

cc: Dr. Ralph ✓
Dr. Rainey
Dr. Stephens

NATIONAL SCIENCE FOUNDATION

WASHINGTON 25, D.C.

APR 7 1964

Dr. Elizabeth K. Ralph
Department of Physics
University of Pennsylvania
Philadelphia 4, Pennsylvania

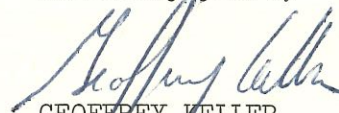
Dear Dr. Ralph:

We regret to inform you that the National Science Foundation is unable to support your proposal entitled "Study of Remanent Magnetic Measurements."

In evaluating each proposal submitted to the Foundation, a number of factors are considered. They include the following: the scientific merit of the proposal in relation to others received by the Foundation; the relation of the proposal to contemporary science; the distribution among fields of science within the program of the Foundation; the geographical distribution of support by the Foundation; and, finally, the funds available. Thus, many excellent proposals cannot be supported for reasons aside from intrinsic merit, although this is always an important consideration.

Even though we are unable to support this proposal, we will be pleased to consider other proposals which you may wish to submit.

Sincerely yours,



GEOFFREY KELLER
Division Director
Mathematical, Physical and
Engineering Sciences

Copy to:
Dr. Gaylord P. Harnwell
President

UNIVERSITY OF PENNSYLVANIA
Philadelphia 4, Pennsylvania

Submitted to: National Science Foundation,
Division of Earth Sciences

Title of Proposal: Study of Remanent Magnetic Measurements

Principal Investigator: Elizabeth K. Ralph, Research Associate,
Department of Physics

Starting Date: April, 1964

Duration: 1 year

Total Funds Requested: \$25,593

Date Submitted: October, 1963

Corporate Name of the University: The Trustees of the University of
Pennsylvania (a Pennsylvania non-profit
Corporation)

Contracting Office: The Office of Project Research and Grants,
3400 Walnut Street, Philadelphia 4, Pa.

Approvals:

David R. Goddard, Provost
University of Pennsylvania

William E. Stephens, Chairman,
Department of Physics,
University of Pennsylvania

Froelich Rainey, Director,
University Museum,
University of Pennsylvania

Elizabeth K. Ralph, Principal
Investigator, Research Associate,
Department of Physics
University of Pennsylvania

Study of Remanent Magnetic Measurements

I. Description of Proposed Research

A study of remanent magnetic measurements, primarily archaeo-magnetic, is proposed. The first objective is to determine what reliable measurements have been made and then to find out what appropriate samples are available to be collected that could be measured in order to assess the magnitude and extent of past changes in magnetic intensity and their effect upon the atmosphere C14 inventory.

This proposal has quite logically been prompted as a result of the methodological dating program (presently financed by NSF grant GP-405) of our radiocarbon laboratory. A summary of the basic C14 dating problems and what we are learning from the dating of samples of known age is given in the paper presented by E. K. Ralph at the IUGG General Assembly in Berkeley, California, August 19-31, 1963 (copies included).

Among the factors which influence the atmospheric C-14 inventory is the magnetic field of the earth. There is now more evidence that the magnetic intensity has differed in past times. The careful determinations made by the Thelliers (1959) indicated that the magnetic field of the earth was 65% stronger about 2000 years ago. The question was whether this significant change found in samples from a limited geographical region in Europe reflected a world-wide change or was a local secular effect which might be balanced by others in remote regions with no resultant effect upon the atmospheric C14 inventory. Recent measurements

reported at the same IUGG Conference made by Mme. G. N. Petrova and Mme. S. P. Burlatskaya from the cities and environs of Tbilisi and Baku (500 km apart) and by Drs. Arai and Momose (and previously by Dr. Watanabe) for sites in Japan indicate that the decrease in magnetic intensity during the past 2000 years may have been world-wide. Additionally, recent measurements by the Russians, the Japanese, and the French indicate that the magnetic intensity was greater around 600 B.C., of the order of 100%, than it is today.

It is our feeling that a study of the measurements of remanent magnetism and of C-14 dates for samples of known age go together hand-in-hand. If the change in magnetic intensity was world-wide and if we assume that other changes which affect the atmospheric C-14 inventory were minor, then the C-14 dates for samples of known age help to determine the limits of the magnetic change. For example, the effect of the change in magnetic intensity 2000 years ago, as calculated by Professors Elsasser, Ney, and Winckler (1956) upon the atmospheric C-14 inventory depends upon the starting time of the change. The maximum discrepancy in the C-14 contents for samples older than 2000 years, then, serves as a guide or limit for these calculations. Before conclusions can be made, it may be necessary to extend the time-scales for both, but it is our belief that one will assist or supplement the other.

Since the establishment of a laboratory for measurements of remanent magnetism is, at least, as large an undertaking as that of a radiocarbon dating laboratory, this proposal is envisaged as a preliminary study to answer the following questions:

1. What pertinent measurements, both archaeomagnetic and late:

- paleomagnetic, of remanent magnetism, have been made?
2. How reliable are the measurements? The dependence here is predominantly upon the suitability and stability of the materials measured.
 3. If, as we suspect, more are needed as a start in elucidating our basic questions, what ones are important and where can they be found?
 4. Can these additional measurements be made in the existing French, English, Russian, Japanese, or USA laboratories?
 5. What is the cost of establishing a laboratory here and what equipment is most suitable?

The expeditions supported by the University Museum would be of invaluable assistance in the collection of samples. For example, during the next two years, 17 expeditions will be supported in whole or in part by the University Museum. Among the sites where appropriate samples for measurements of remanent magnetism may be found are the following:

Tel-es-Saideyeh, Dead Sea Area, Jordan, 3000-900 B.C.
Halieis, Greece, 5th, 4th C. B.C.
Kythera, Greece.
Sybaris and later Roman sites, Italy, 6th 2nd C. B.C.
Southern Pakistan (Harappa Civilization) 2500-1500 B.C.
Northern Iraq, 2000 B.C.
Northwestern Iran, 2000-800 B.C.
Gordion, Turkey, 1800-300 B.C.
Bulgaria, Greco-Roman period
Snaketown, southwestern USA, A.D. 0-300

The importance of these expeditions, in addition to the geographical and temporal variety of the sites, is the fact that samples have to be collected in situ and their orientations recorded carefully before removal. Needless to say, this procedure is greatly

facilitated when an expedition is in process. For example, first of all, the kiln, oven, or requisite fired clay has been found; digging permits, housing, and lesser items have already been arranged.

The problem, in addition to the finding of samples representative of the period of time and geographical area desired, is to collect samples that will give reliable results. As Professor Thellier has demonstrated, fired materials which have been heated above the curie point and appear to be undisturbed, such as the floors of kilns, do not always give consistent results. In many cases their magnetization has been found to be unstable. In this respect, consultations with authorities who have had experience with the collection and measurement of samples will be invaluable.

II. Facilities:

1. Space in the laboratories of the Applied Science Center for Archaeology.
2. Expeditions supported by the University Museum (as previously described) to various parts of the world.
3. Libraries and other general facilities of the University of Pennsylvania.

III. Personnel:

- a. Elizabeth K. Ralph, Principal Investigator
(Biographical sketch included)
- b. Faculty associates

Dr. William E. Stephens, Chairman of the Dept. of Physics
Dr. Froelich Rainey, Director of the University Museum
Dr. Alfred Kidder II: South America and Mesoamerica
Dr. Linton Satterthwaite: Mesoamerica
Dr. William R. Coe: Mesoamerica
Dr. Rodney S. Young: Anatolia
Dr. G. Roger Edwards: Anatolia
Dr. Ellen L. Kohler: Anatolia

Dr. Robert Dyson: Near Eastern Archaeology
Dr. James B. Pritchard: Biblical Archaeology
Mr. Bernard Wailes: European Archaeology
Dr. George F. Dales: Pakistan Archaeology
Dr. Michael H. Jameson: Classical Archaeology

c. Research Physicist

It is anticipated that Mr. Michael Tite from the Research Laboratory of Archaeology and the History of Art, Oxford University, will be available to fill this post. Mr. Tite, a graduate student in Physics, has completed most of the degree requirements at Oxford and it is hoped that he will be available in April, 1964. He has had field experience with the collection of samples, and will have the opportunity to familiarize himself with the measurement apparatus used at Oxford before his arrival here.

d. Research Assistant - part-time.

A graduate student in Archaeology or Anthropology to assist with various phases of the work as required.

IV. Budget

Salaries

Research Physicist \$8500
Research Assistant, part-time 3000

Employee benefits (8.9%)

\$11,500
1,024

Equipment

Permanent Equipment
Theodolite 1300
Trough compass 50

Expendable Equipment and supplies 1000
plaster, frames, clerical
materials, shipping costs,
etc. 1000

Equipment services - cost of 1000
sample measurement by other
institutions 3,350

Travel

Europe and Near East (2 trips or
2 people) 3200
Western USA, (2 trips or 2 people) 600
Possible additional trip to
Europe for collaboration, etc. 800

4,600

Total Direct Costs
Indirect Costs (25%)

20,474
5,119

TOTAL

\$25,593

Paper Delivered at IUGG General Assembly
Berkeley, California, August 19-31, 1963

COMPARISON OF RADIOCARBON DATES FOR
HISTORICALLY-DATED AND TREE-RING-DATED SAMPLES

by

Elizabeth K. Ralph
Department of Physics
University of Pennsylvania

There are times when the dating of samples of known age by the radiocarbon method leads one in circles, or, more precisely, cycles. First of all, there is the basic cycle of the production of C^{14} from the collisions of neutrons with N^{14} atoms and its subsequent decay back to N^{14} . The associated factors which affect the validity of C^{14} as a means of dating and also as a tool to provide basic geophysical information are well known to this group - namely,

- 1) The constancy of the cosmic ray intensity, the source of the neutrons.
- 2) The constancy of the magnetic field of the earth, which affects the numbers of cosmic rays and their associated neutrons which reach the nitrogen atoms in the earth's atmosphere.
- 3) The constancy of the equilibrium among the reservoirs, primarily the oceans which affect the atmospheric C^{14} inventory.
- 4) The rapidity of the mixing rate of the atmosphere.
- 5) The true value of the C^{14} half-life.

It is obvious that these factors are interrelated and that the determination of C^{14} date for a sample of known age will not provide

the specific reason for agreement or lack of it. Fortunately, however, the number of unknown factors has been reduced by other means.

In regard to the mixing rate of the atmosphere, the worldwide tracing of fall-out and measurements of the increase in the atmospheric C-14 in the Southern hemisphere following the first large-scale testing in the Northern have provided data that indicate that the rate is of the order of 2 years, a rate which is sufficiently rapid in view of the average life of a C-14 atom of approximately 8,000 years.

This rapid mixing and the consequent lack of latitudinal effects has been confirmed additionally by an excellent experiment conducted recently by Dr. H. Tauber in Copenhagen. In the spring of 1961 Dr. Tauber collected grass samples along one longitude from Italy (latitude 37°N) to Scandinavia (latitude 70°N). Except for a slight decrease in Central Europe due to the Suess effect, the C-14 contents of these samples were identical. Dr. Tauber concluded, therefore, that there was negligible latitudinal effect in Europe in 1961. Since this was a year of changing atmospheric C-14 content due to previous bomb tests, the test was a stringent one.

In regard to the constancy of the magnetic field of the earth, several workers are now making measurements of the remanent magnetism of previously fired clay materials. For example, the measurements of Drs. E. and O. Thellier (1) indicated that the magnetic field of the earth was about 65% stronger in Roman times. From this Professors Elsasser, Ney, and Winckler (2) deduced that

the C-14 inventory was so much lower 2000 years ago that C-14 dates would be a minimum of 240 years too old. As Dr. Hans E. Suess has pointed out in his paper entitled "Secular Changes in the Concentration of Atmospheric Radiocarbon" (3), it is necessary to consider also the possibility of more rapid fluctuations of the earth's magnetic field and effects of such fluctuations on the C-14 activity in atmospheric CO₂ due to the slowness of isotopic exchange with the bicarbonate in the oceans. In other words, the applicability to C-14 dating of the determination of the earth's magnetic field in past times is also not independent and leads us back to our other interdependent factors. Additionally, if, by any chance, this large difference in remanent magnetism was due to local effects, this then leads us to the rapidity of the mixing rate of the atmosphere which would tend to minimize or negate the effect on a world-wide basis.

In regard to the half-life, the recent direct determinations of the half-life are in good agreement,

(by Karlen and Olsson at Uppsala, 5680 ± 40 years

by Mann, N.B.S., 5740 ± 40 years

by Wilson, Aldermasterdon, 5780 ± 50 years)

and the average value, $5730 (\pm 40)$ causes a difference in C-14 ages of 3% from that selected by Dr. W. F. Libby, 5568 years.

The measurements of samples of known age will provide an indirect means of determination of the C-14 half-life only if we assume that all of the other factors have been constant. If momentarily, we neglect the oscillations, the new value (5730) is in closer agreement with an "effective" value obtained from the

average C-14 contents of samples dated by dendrochronology.

This brings us to the cyclic path of our own making. The measurements of samples of known age have been undertaken by a number of laboratories with the hope that the results would illuminate some of the basic questions. But now, we have reached the stage at which the "knowns" themselves must be examined more critically. A "known" may be questioned for two reasons. In the first place, the chronology upon which the age of the sample is dependent may be erroneous, and secondly, the sample itself, for various reasons, may not contain a contemporaneous amount of C-14.

These factors are readily apparent in the C-14 dating of historically - and, archaeologically - dated samples.

Samples dated with reasonable reliability are available back to 2000 B.C. but beyond that even the Egyptian chronology is subject to question, and the dating of other regions is dependent upon the Egyptian. Most of the samples plotted (slide 1) in the period of present day to 1050 B.C. (3000 B.P.) are considered to be firmly dated, but it is immediately apparent that the average of these (the actual figure for 70 samples is -0.5%) falls below even the 5568 half-life line and that the peak in the range of A.D. 1700 to 1500 (as will be seen later in plots of tree-ring dated samples) is absent. The most obvious cause for this difference is non-contemporaneity of the sample itself due to the fact that the sample, whether it be wood or charcoal, originated from older parts of the tree from which the dated artifact or building was constructed.

On the graph, samples which may be subject to this "older

wood" error are plotted with arrows. If we look only at 6 samples (shown with circles) H-166, GRN-3072, GRN-1415, L-371 E, GRN-793 and Q-621 which consisted, respectively, of charred pine needles, charcoal bits from a fireplace, charred grain, carbonized bread, chaff from potsherds and shroud material - all of which represent contemporaneous materials, we see a difference. Unfortunately, these few ideal samples represent only a limited time span, but the average of the six happens to be +0.8%, a figure which, if plotted, would fall close to the 5730 half-life line.

As we examine the graph to the right of 3000 B.P. we find most of the C-14 contents diverging above the 5730 half-life line. It is now generally agreed among Egyptologists (4) that the reign of King Sesostris III of the 12th Dynasty occurred very close to 1872 B.C., and there is not much doubt that the 11th Dynasty was founded close to 2133 B.C. The uncertainty, also, is not great in the placing of the 8th Dynasty and with it, the end of the Old Kingdom at about 2160 B.C. If we accept these dates, we see from the samples in this age span that no matter which of the two half-lives we choose, the C-14 dates for samples older than 1050 B.C. are not in agreement with those in the younger time span. For reference later when we examine the tree-ring dated samples, the magnitude of this departure is approximately +5.0% (25 samples). It is likely, however, that these samples are subject also to the older growth error that this figure should be revised upward.

It is for this reason that our C-14 results for bristlecone pine sections are included in this slide. Even though, at this time, they are only "semi-knowns" (Ages have been determined by ring

counting with an average 6% correction for missing rings), they provide some material of reasonable reliability for comparison with the samples which are dependent upon the Egyptian chronology. If we accept this tentative dating of the bristlecones, we see from samples P-429 and P-415 that the departure in C-14 contents is equally as great as that for the Egyptian samples. Comments about the magnitude and duration of this upward trend in C-14 contents beyond the 8th Dynasty, I feel, should be reserved until other samples of known age or another means are found for confirmation.

To return to the problems associated with the historically dated samples, it was because of this difficulty of assessing the true age of the sample actually dated that we turned our attention to samples dated by dendrochronology. With these there is an immediate advantage in that usually enough material can be obtained so that a few growth rings may be sampled and if cross-dated by the careful techniques developed at the Laboratory of Tree-Ring Research, University of Arizona, there is little question of the true age of the sample. The next slide (#2) is a composite plot of C-14 values for tree-ring dated samples which have been determined by a number of laboratories. This includes only those results which are based either on 95% of the NBS Oxalic Standard or 100 year old wood (age corrected), the two of which have been demonstrated to be in good agreement.

In this slide, we see an upward trend starting beyond 500 B.C. and also the peak or peaks noted by Dr. Hl. de Vries (5) and others between A.D. 1700 and A.D. 1500. We see also, however, a scatter, which I think is greater than one would expect from this rather

careful selection of tree-ring dated samples. This leads us to some of the minor problems associated with C-14 dating. First of all there is the question of natural fractionation, which, hopefully may be corrected for by measurements of C^{13}/C^{12} ratios.

Secondly, we have indications of some unexplained variation in the intake or retention of C-14 in certain trees or portions of them. This observation became apparent last December in the course of discussions with Drs. W. F. Libby and G. J. Fergusson in regard to the Mayan calendar correlation problem. Two temples at Tikal, Guatemala with supposedly identical calendrical inscriptions have been dated carefully by both the UCLA Laboratory and ours. Our interlaboratory results are in excellent agreement, but the two temples differ by 100 years. Incidentally, this study confirmed also the 95% relationship of the NBS Oxalic wood standard with 100 year old wood (age corrected) since UCLA used the former and we, the latter. Of course, in this example, there is the big loophole due to the uncertainty of the calendrical inscriptions or to their association with the beams sampled.

However, if we look at the cross section of one of our bristlecone pines (slide #3) and then at the C-14 data, we see that even though samples P-492, 451, and 493 are in a direct path in the tree, their C-14 contents are inconsistent for some reason which is not clear. (slide #4) These trees grow on mountain slopes at 10 and 11 thousand feet and there is no reason to suspect poor circulation, bad drainage or a similar factor as the cause. In the plot of University of Pennsylvania tree-ring dated samples, this anomalous variation can be seen also for some of our sequoia samples. For

example, P-490 and P-348.

There is also the perennial problem of contamination. We had assumed that the NaOH pretreatment for humic contaminants was effective. We have recently measured a contemporaneous series from Cape Krusenstern, Alaska, collected by Dr. J. L. Giddings. The slide (#5) illustrates the large difference in age between the woods and the charcoals. Some of each material were pretreated with NaOH, which in this case, was ineffective in removing the contamination. This is an extreme example from a region, the Arctic, where contamination is most severe but shows that all is certainly not well with this wood.

In spite of these minor problems, there is no doubt, as evidenced by historically dated and tree-ring dated samples, that there is a divergence in C-14 contents beyond 1050 B.C. due to one or more of the external influences which affect natural C-14 determinations. The question remains as to whether this is cyclic and if so, what is its magnitude and duration, and of course, the cause (6).

For extension of the range of "knowns" for C-14, by dendrochronology, there is now hope from two separate approaches. Dr. C. W. Ferguson at the Laboratory of Tree-Ring Research, University of Arizona, has successfully cross-dated bristlecone pine trees back to 1100 B.C. and will soon reach 1550 B.C. Living trees are now known to be 4000 years old and older "floaters" have been found which, when cross-dated with the living trees, may extend back 5000 to 6000 years. Secondly, in cooperation with Dr. Bryant Bannister of the same laboratory, we hope to determine the feasibility of creating a master tree-ring log for woods imported into

Egypt. Our preliminary investigations indicate that cross-dating is possible for certain near Eastern trees and that sufficient material for Egypt is available.

For the moment, let's assume that the magnetic field of the earth did change around 2000 years ago and, if it decayed from that time, then the change in the period of 2000 years ago would be 240 years. On this basis, there is then this possibility, namely -- If the change in the magnetic field were world-wide, then a half-life value of 6400 is a better fit, but only if the world-wide magnetic intensity were back at its present value 4000 years ago. (Slide #6)

Or, (2) if the magnetic intensity did not change, 5730 is the optimum value, but something else affected the C-14 inventory 4000 years ago.

Or, (3) if there were no world-wide change in magnetic intensity and 6400 is the better value, then something else affected the inventory 2000 years ago.

A few arguments in favor of a change in magnetic intensity are:

(1) It is possible that the decrease in the magnetic field of the earth as measured in Europe by Thellier and Thellier is greater than the localized variations reported by Vestine, et al, (7) between A.D. 1922 and 1945. This, of course, is subject to question in the absence of measurements over a longer period of time.

(2) The recent measurements of the half-life were done by similar techniques and may be subject to the same errors, the most difficult of which to assess is adsorption. Due to this, it would be possible to obtain too high a disintegration rate in the final

dilution of the high-specific-activity with inert carbon dioxide, and, consequently, a half-life value too low (8).

It is fortunate, however, that it is now physically possible to obtain magnetic and, to a lesser extent, remanent magnetic intensity measurements on a world-wide basis, and that these combined with a different type of half-life measurement, may soon provide the answers to some of these questions.

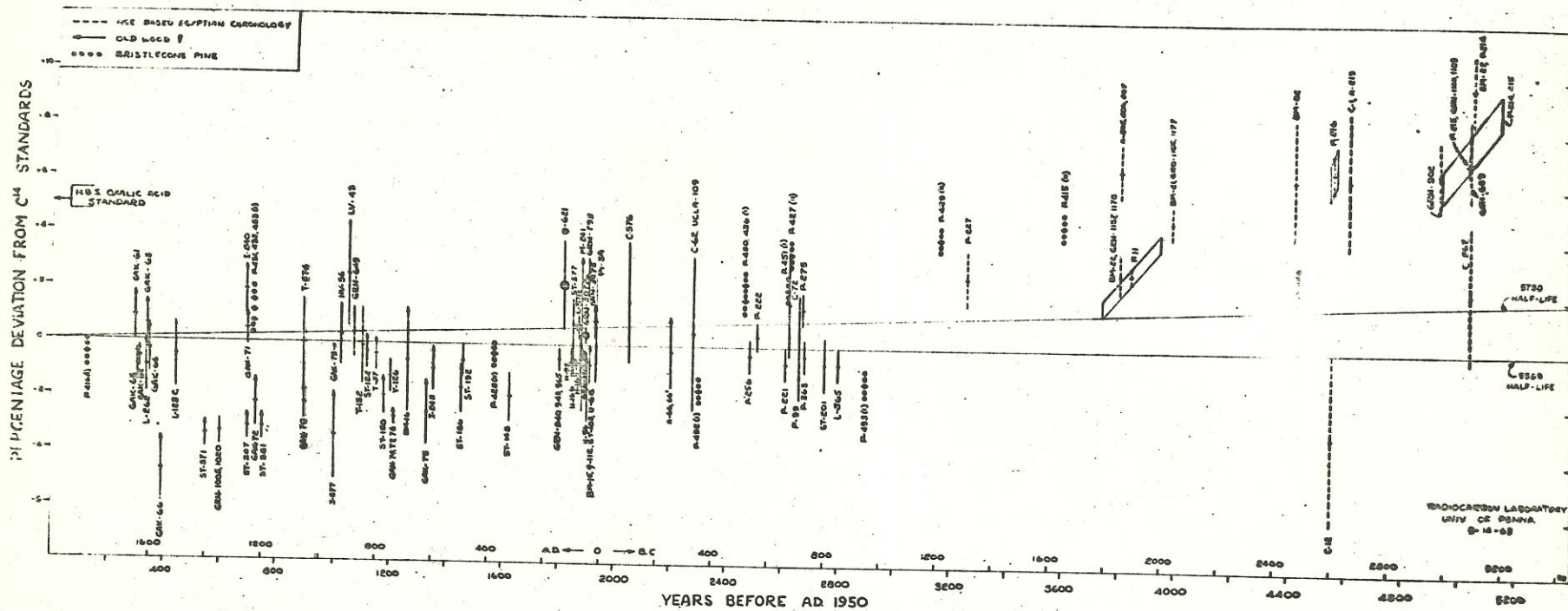
REFERENCES

- (1) Thellier, E. and Thellier, O., 1959, Sur L'Intensité du Champ Magnétique Terrestre dans le Passé Historique et Géologique: Annales de Géophysique, V.15, No. 3, p. 285-376.
- (2) Elsasser, W., Ney, E. P., and Winckler, J. R., 1956, Cosmic-Ray Intensity and Geomagnetism: Nature, V. 178, No. 4544, p. 1226-1227.
- (3) Suess, H. E., 1961, Secular Changes in the Concentration of Atmospheric Radiocarbon, Nuclear Science Series Report No. 33, Subcommittee on Nuclear Geophysics; Publication 845, National Academy of Sciences, National Research Council.
- (4) Hayes, W. C., 1962, The Middle Kingdom in Egypt: Cambridge Ancient History, revised edition, Vol. I, ch. XX.

Smith, W. S., 1962, The Old Kingdom in Egypt: Cambridge Ancient History, revised edition, Vol. I, ch. XIV.

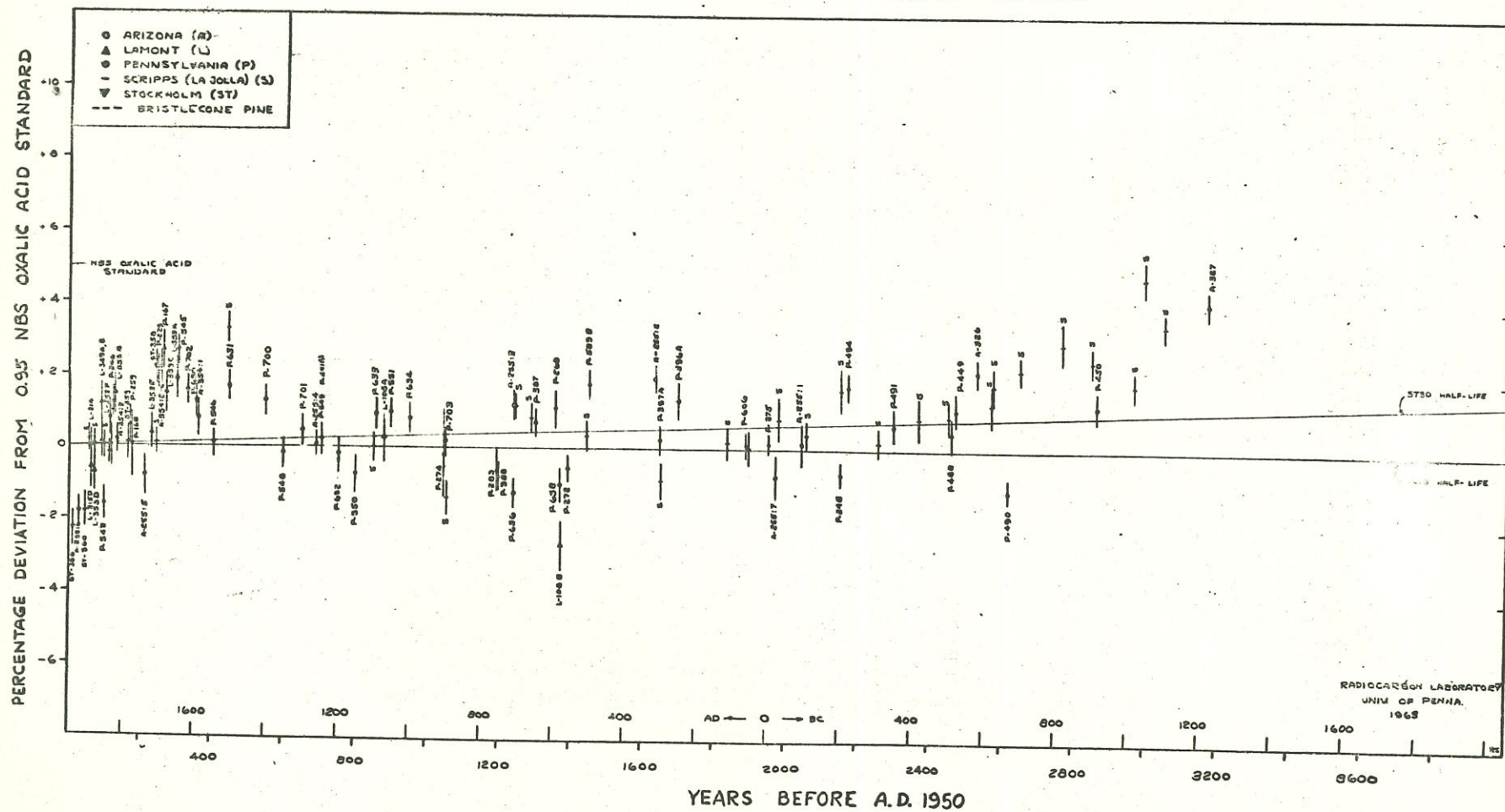
Smith, W. S., 1960, Ancient Egypt, pp. 196 ff.
- (5) deVries, H.L., 1958, Variation in Concentration of Radiocarbon with Time and Location on Earth: Proc. Amsterdam Academy of Science, Series B; V. 61, No. 2, p. 1-9.
- (6) I am grateful to the National Science Foundation for the financial support of our known age dating program; and to Robert Stuckenrath, Jr. for the preparation of the graphs.
- (7) Vestine, E. H., LaPorte, L., Lange, I., Cooper, G., and Hendrix, W. C., 1947, Description of the Earth's Main Magnetic Field and its Secular Change, 1905-1945: Carnegie Institution of Washington Publication 578.
- (8) Mann, W. B., Marlow, W. F., and Hughes, E. E., 1961, The Half-Life of Carbon-14: International Journal Applied Radiation and Isotopes, Vol. 11, p. 57-67.

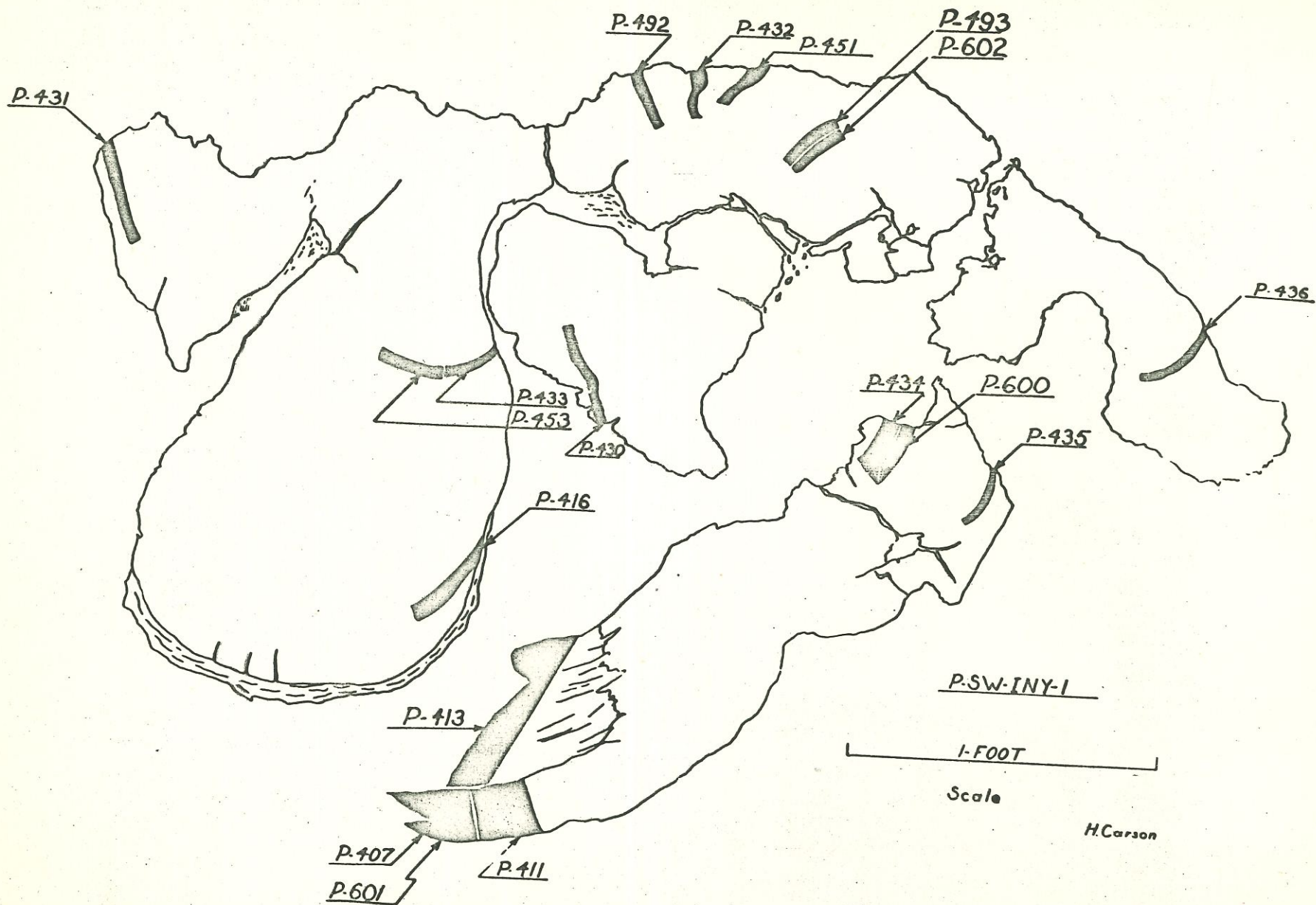
C¹⁴ CONTENTS OF 'HISTORICALLY' DATED AND RING-COUNTED BRISTLECONE PINE SAMPLES



SLIDE 1

C¹⁴ CONTENT OF TREE-RING DATED SAMPLES

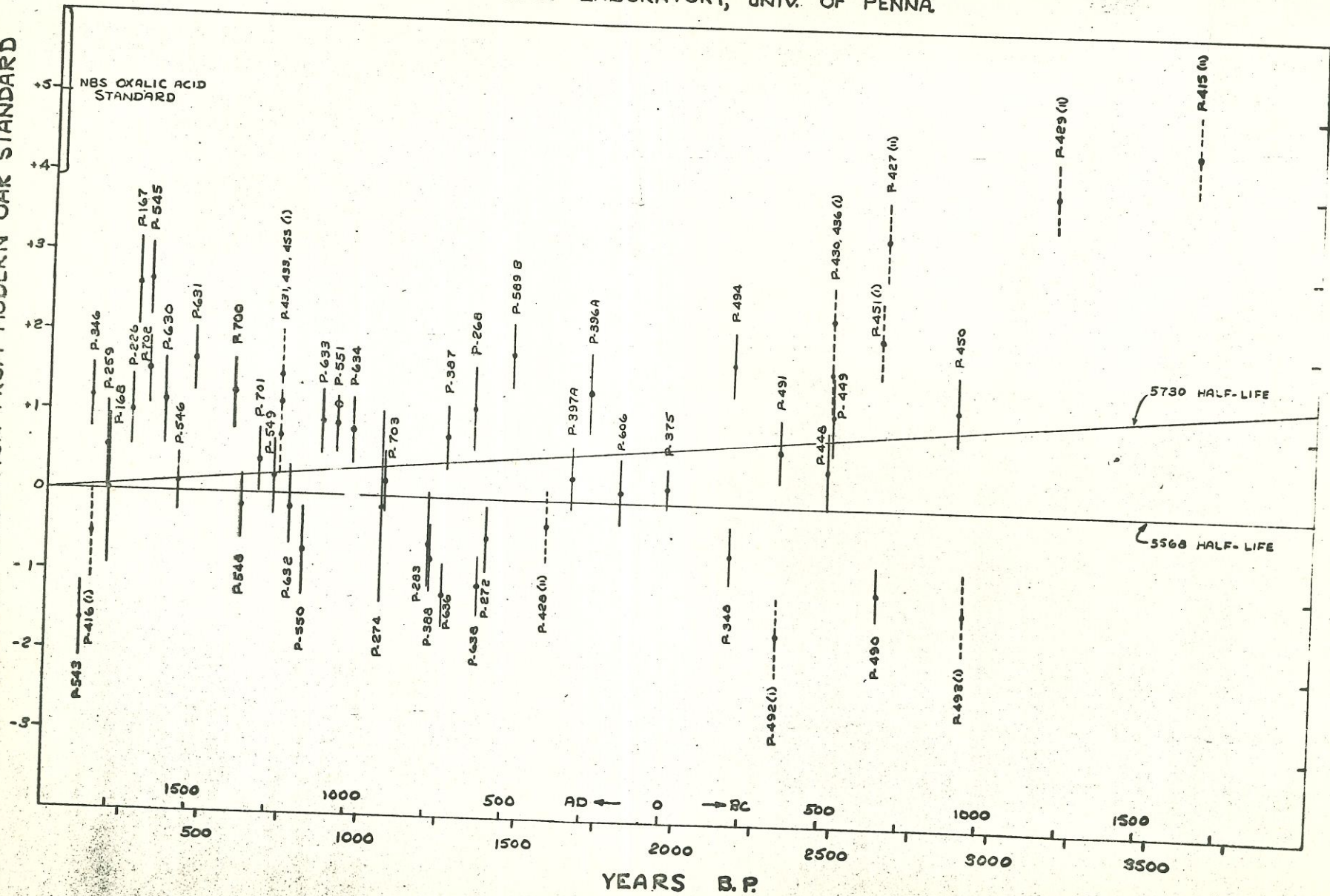




SLIDE 3

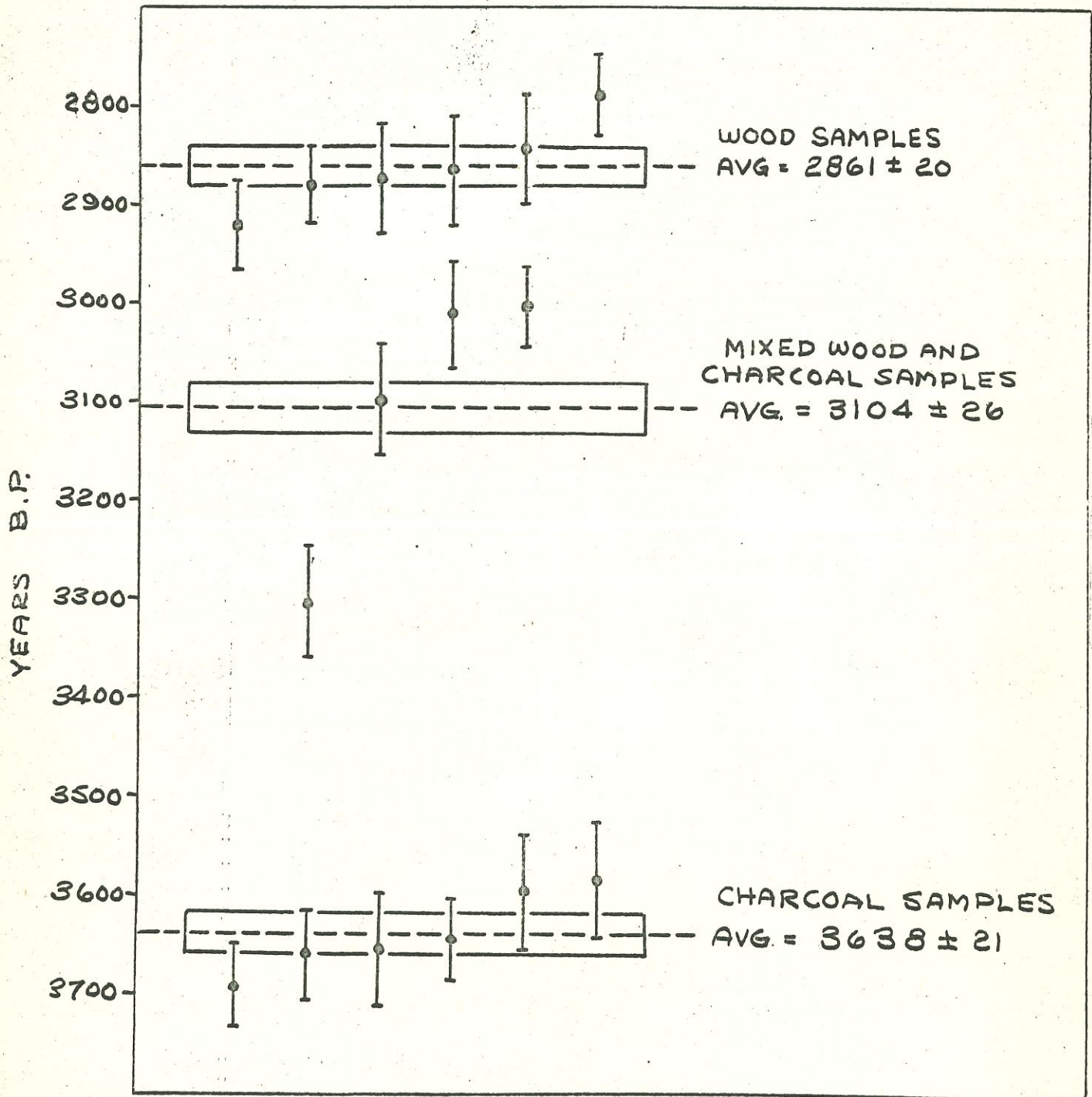
¹⁴C CONTENTS OF TREE-RING SAMPLES
 RADIOCARBON LABORATORY, UNIV. OF PENNA.

PERCENTAGE DEVIATION FROM MODERN OAK STANDARD

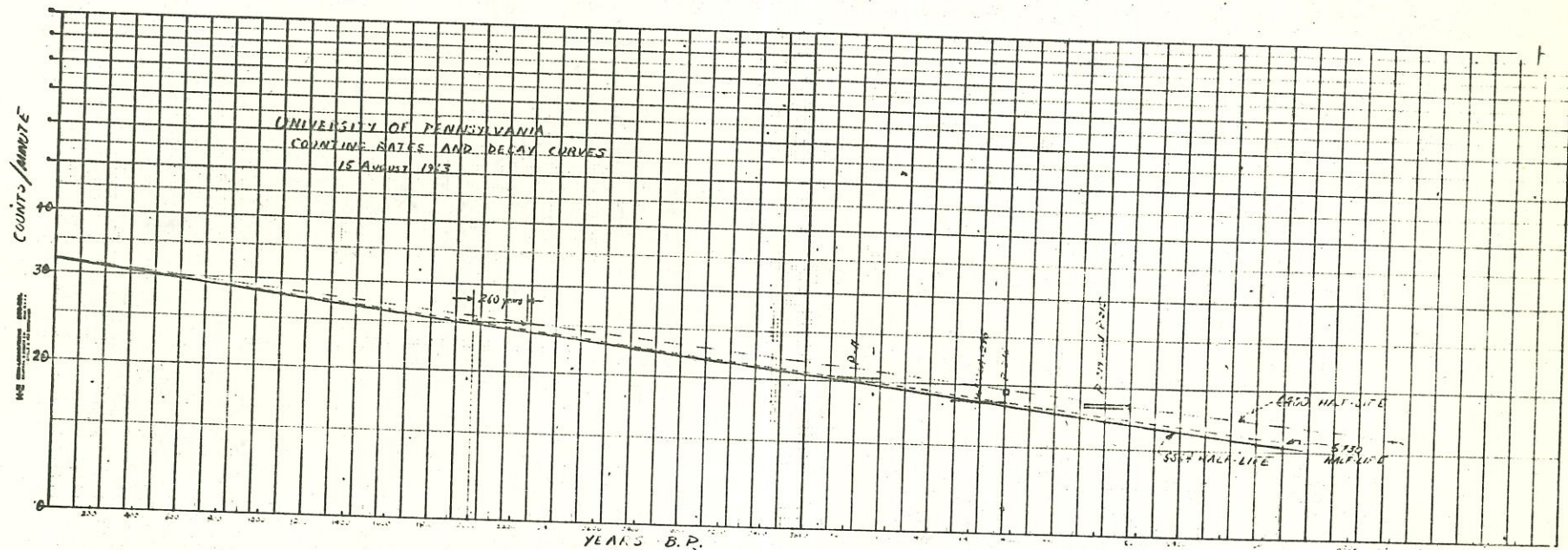


SLIDE 4

COMPARISON OF WOOD, MIXED WOOD AND CHARCOAL,
AND CHARCOAL SAMPLES OF "OLD WHALING CULTURE",
CAPE KRUSENSTERN, ALASKA
1963



RADIOCARBON LABORATORY
UNIV. OF PENNA.



SLIDE 6

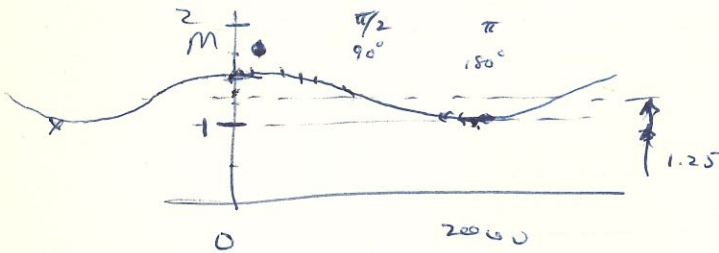
$$1.5 = M_0 + 1 + 1.25$$

$$m = M_0 \cos \omega t + C$$

t	m
0	1.5
2000	1

$$C = 1.25$$

$$M_0 = 0.25$$



$$m = \left[\frac{31}{4} \cos\left(\frac{\pi t}{2000}\right) + \frac{5}{4} \right] m_0$$

today's value

$$\omega t = 2000 \quad \cos = -1$$

$$t = 1000 \quad \cos = 0$$

$$\omega t = \frac{\pi}{2}$$

$$\omega = \frac{\pi}{2 \cdot 1000} = \frac{\pi}{2000}$$

$$P(t) = \frac{C_2}{\sqrt{m}} = \frac{2 C_2}{\sqrt{M_0} \sqrt{\cos\left(\frac{\pi t}{2000}\right) + 5}}$$

$$\frac{dI}{dt} = P(t) - \lambda I =$$

$$\frac{dI}{dt} + \lambda I = P(t) = \frac{2 C_2}{\sqrt{M_0} \sqrt{\cos\left(\frac{\pi t}{2000}\right) + 5}}$$