Radiocarbon Dates of Pre-Mankato Events in Eastern and Central North America

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THE discovery of natural radiocarbon by W. F. Libby and its application for age determinations has led, during the past few years, to a unique method for stratigraphic correlation and for dating many events that followed the Mankato glacial maximum (see, for example, articles by Flint and Deevy, *1* and Flint, *2*). The progress of the carbon-14 dating technique, particularly the substitution of gas counting for solid-carbon counting as developed by Suess (*3*), has extended the possible range of dates from about three half lives to more than six and has thereby opened the way for fixing in time the events of the last major glaciation preceding the Mankato in North America and its European equivalent, the Fennoscandian. A group of samples related to the earlier phases of the Wisconsin glaciation was therefore assembled by Flint with the cooperation of numerous collectors and was measured by Suess at the U.S. Geological Survey radiocarbon laboratory (*4*). Since the consistency of the results became apparent, additional related samples have been collected and measured (*5*).

This article (*6*) attempts a brief critical assessment of the stratigraphic meaning of these pre-Mankato samples. It does not pretend to be a compendium or a detailed description, for it is expected that the collectors will publish full evaluations pertaining to their respective field areas.

Primary Considerations

Most of the samples discussed consisted of wood, a substance believed to be best suited for radiocarbon dating. Each date derived from a C^{14} determination is subject to two types of error, the laboratory error and the field error. The latter embraces three possibilities: (i) erroneous stratigraphic correlation of the sample; (ii) admixture of foreign materials such as modern roots; and (iii) the results of natural isotope fractionation during growth, burial, and partial decomposition (*7*). The errors listed by experimental investigators include laboratory error only. Usually expressed as standard errors (*8*), they include statistical counting error, uncertainties in background and calibration, isotope fractionation during preparation of the sample, uncertainty in the accepted C^{14} half life of 5568 yr, and other factors.

Radiocarbon dates are derived on the probable assumption that secular production rate and diluting carbon reservoir are constant. Any actual deviation from this assumption will change the absolute time scale but not relative age. For this reason we use the term *radiocarbon years* in this paper, even though such deviation is probably insignificant.

Although the laboratory errors listed with the date of each sample can readily be considered in evaluating and correlating the dates, unrecognized field errors may occasionally lead to wrong conclusions. Therefore an adequate statistical population of dates is necessary before obviously erroneous results can be excluded. However, the consistency of the group of dates under consideration is such as to justify the assumption that all are accurate. Our discussion is based on that assumption.

General Results

From the dates of samples measured before 1 Dec. 1954, these general inferences are drawn:

1) Although some of the dates fall into a somewhat different order from that of the stratigraphic units to which they had been assigned, their order is reasonable and implies no physical improbabilities. The discrepancies are believed to result from errors in stratigraphic correlation that are inherent in any field study of successive sheets of till and loess in which no fossils are present to aid correlation.

2) A major glaciation began 25,000 or more yr ago, reached a maximum about 20,000 to 18,000 yr ago, and was in oscillating retreat between 13,000 and 12,000 yr ago. The Mankato advance, a later fluctuation, is not under discussion in this article.

3) If the C^{14} dates are accepted as a more reliable basis of correlation than that afforded by field methods in the absence of fossils, existing correlations and nomenclature will need some revision.

The samples discussed fall into three age groups, designated temporarily as *young, middle,* and *old.* We begin with the young group, in which the samples are correlated with the Cary substage of the Wisconsin stage of glaciation, either with assurance or with probability, and then turn to samples less firmly correlated.

Young Group of Samples

Lake Arkona, Cleveland, Ohio (W-33) (*9*). An event securely fixed in the late-Wisconsin stratigraphic sequence is the rise of the glacier-dammed lake in the Erie basin from the low-water Arkona phase to the

Whittlesey phase (*10*). That event resulted from a readvance of the ice-sheet margin to the Port Huron moraine, and occurred late in Cary time (*11*). It entailed a rise of the water surface of about 45 ft.

A sample of broken twigs, roots, and leaves was collected by G. W. White and J. D. Winslow from a horizon representing a Lake Arkona lagoon, exposed in the southern part of the city of Cleveland. Lying at an elevation of 690 ft, the Arkona horizon is overlain by 10 to 12 ft of sand and silt deposited in the lake as it deepened during the rise to the Whittlesey beach, well developed in the vicinity. The wood, identified as cedar, is interpreted by the collectors as having grown around the shore of the lagoon. Its date, 13,600 ± 500 yr (*12*), is reasonable in that it antedates the peat layer at Two Creeks by about 2000 yr, an interval during which the glacier margin advanced to the Port Huron moraine and then retreated to or north of the Strait of Mackinac. The implied minimum rate of displacement of the glacier margin is no greater than rates observed on existing glaciers.

Dyer spit, Ind. (W-140; W-161). During retreat of the ice-sheet margin from the Port Huron moraine, and therefore after the Lake Arkona lagoon was covered by Lake Whittlesey sediments, the additional discharge from lakes in the Huron-Erie basin deepened the Chicago outlet, lowering Lake Chicago from its Glenwood position to its first-attained Calumet level (*11,* p. 425; *13,* p. 32). Prior to that lowering, and during Glenwood time, an eastward-growing spit near Dyer formed a bay in which driftwood and peat accumulated. Shortly thereafter a second spit grew westward over this material. Samples of wood were collected by J H. Bretz, L. Horberg, and M. Rubin from the peat horizon and from within the overlying second spit itself. The wood at the peat horizon (W-140) gave a date of 12,650 ± 350 yr, and the wood from the younger spit (W-171) gave a date of 12,200 ± 350 yr—an internally consistent sequence in general agreement with the afore-mentioned Lake Arkona date.

Durham Meadows, Conn. (W-46). An accumulation of peat and gyttja forming Durham Meadows overlies clay, sand, and gravel tentatively correlated, before dating, with late Tazewell or Cary drift by Flint (*2*). A complete section of the deposit was obtained and pollen analyzed by Estella Leopold. A sample of gyttja from 2.5 ft above the top of a gravel outwash, recording a point on a line of transition from a spruce maximum to a pine maximum, implying a change toward a warmer climate, gave a date of 12,700 ± 250 yr. When compared with the Lake Arkona (W-33) and Dyer (W-140, W-161) dates, this appears to be a reasonable late Cary date and implies that the underlying drift is probably Cary rather than Tazewell.

Poggenwisch, Holstein, Germany (W-93). A sample of gyttja was collected by Alfred Rust from a bog occupying a kettlelike basin at Poggenwisch, near Hamburg. The basin occurs in drift sheets laid down during oscillating retreat of the ice-sheet margin from the Pomeranian position. The sample, taken from a sequence firmly tied to the pollen stratigraphy by R. Schutrumpf, belongs to pollen zone I of the German sequence—tundra phase of the older Dryas zone underlying the Alleröd zone. Because the latter is the radiocarbon-dated equivalent of the forest-bed horizon at Two Creeks, which directly overlies Cary drift, the Pomeranian drift had been expected to be at least in part equivalent to the Cary. The date of the sample, 15,150 ± 350 yr, is consistent with the expectation in that, when compared with the Lake Arkona and Dyer dates, it is a reasonable Cary date. Hence it strengthens the belief that the Pomeranian glacial substange is correlative with a considerable part, if not all, of the Cary glacial substage, and that late Wisconsin climatic fluctuations in western Europe were at least broadly synchronous with those in eastern North America.

Avilla, Noble County, Ind. (W-58). A series of samples were collected in northeast Indiana by W. J. Wayne from organic deposits in or associated with glacial deposits believed to be of Cary age. Sample W-58 is wood taken from the base of a black, fossiliferous peaty clay overlying gravel outwash. Spruce cones and needles were found in abundance with the wood. The clay is overlain by 3 ft of calcareous gravel and sand topped by 3 ft of alluvial sand and silt. The organic zone is believed by Wayne to represent deposits in a lake dammed either by ice to the east, possibly at the Wabash moraine position, or by a valley train along Eel River. Wayne (*14*) considers the overlying gravel to be nonglacial alluvium rather than glacial outwash. The date of the wood is 12,380 ± 360 yr.

Laketon, Wabash County, Ind. (W-64). Another sample of gyttja from under 12 ft of marl, collected by Wayne, was determined to be 13,140 ± 400 yr old. The gyttja is the bottom deposit in a kettle lake situated in a broad outwash area along the distal edge of the Packerton moraine (*15*) in the Saginaw lobe. Wayne (*14*) considers it more likely that the large ice block responsible for the kettle constituted part of the glacier at the Packerton moraine rather than that it was floated by meltwater from the nearest moraine of the Erie lobe. A hasty pollen study of the sample layer showed that, of 56 pollen grains counted, 89 percent were spruce and fir.

Fremont, Steuben County, Ind. (W-65). A third Indiana sample comes from an outwash plain extending west and north from the Wabash moraine, in a section exposed in a drainage ditch 3 mi southeast of Fremont. Tough lacustrine clay overlies a few feet of gravel and sand in an exposure about 1000 ft northwest of the road. Beneath these deposits, nearer the road, a thin unit of marl and peat overlies unweathered till. The peaty layer seems fairly continuous. Wood fragments from the peat were dated at 13,020 ± 400 yr. The origin of the gravel above the organic material is not certain. Inasmuch as no stream existed in this broad flat area until a ditch was dug a few years ago, Wayne concluded (*14*) that the gravel was either outwash deposited at the time the ice constructed the Wabash moraine, less than 1 mi to the east, or a deposit from melting residual, stagnant ice

masses. Of 200 pollen grains counted from the sample, 79 percent were spruce and fir.

Edon, Ohio (W-198). A date of 14,300 ± 450 yr was determined for a sample from the Wabash moraine near Edon. Sample W-198 was collected from a thin zone of organic litter 3 ft above the base of a 10-ft silt section along the crest of the Wabash moraine. The topography is such that the silt must have been deposited in a pond or lake dammed either by a large mass of stagnant ice or by the glacier itself. The section was exposed during excavation for the Ohio Turnpike a few miles east of the Indiana border; the sample was collected by W. J. Wayne, R. P. Goldthwait, J. Zumberge, D. Eschman, and M. Rubin.

The dates of the Wabash moraine (14,300 ± 450 yr) and Lake Arkona (13,600 ± 500 yr) samples are in correct relationship to each other even though many lake stages and minor glacial advances are crowded between them. However, the younger dates of 12,380 ± 360 and 13,020 ± 400 yr obtained from samples W-58 and W-65 (Avilla and Fremont), respectively, suggest that these Indiana samples do not record a time when the ice front stood at the Wabash moraine position, but represent the first deposits laid down shortly after the main body of ice left the immediate area. As such, the Indiana sample dates are in good agreement with the Ohio pair.

Middle Group of Samples from Ohio, Ontario, and Pennsylvania

Ohio samples. Seven samples from Ohio, furnished by R. P. Goldthwait, are alike in that they consist of spruce wood from logs and branches imbedded in till or, in one instance, lacustrine silt. Evidently they record forest trees destroyed and dispersed by advancing glacier ice. Their numbers, locations, and dates are assembled in Table 1. The map, Fig. 1, shows the positions of these samples in relation to the boundaries of the Cary and Tazewell drift sheets as they were tentatively drawn before the samples were dated. It is probably significant that the oldest sample, W-71 (Cleveland), lies farthest upstream measured in terms of the direction of flow of the ice sheet, whereas the next oldest, W-188 (Sidney), lies in an intermediate position, and the remaining five samples lie near the outer limits of the related drift sheets. It must be assumed that each piece of wood was carried only a short distance by the ice, for if this had not been true, the dates would not agree with the geographic occurrences of the samples. From the positions of these samples and from their dates it can be reasonably inferred that in an advance of major proportions the ice sheet invaded Ohio beginning about 25,000 yr ago, overwhelming spruce forests successively during its southward advance, which culminated about 18,000 yr ago. During the advance, apparently 7000 yr in duration, and during the subsequent deglaciation, the ice margin oscillated, as can be inferred from the several end moraines it built.

Special interest attaches to sample W-188 (23,000 ± 800 yr), the only sample from a locality in which the till with fossil logs directly overlies a soil developed in an older till. The soil does not resemble a gumbotil; hence the older till is probably not Illinoian. This relationship establishes the inference that the glacial advance that overwhelmed the forests was not the earliest post-Illinoian glacial invasion of Ohio, but was separated from an earlier post-Illinoian glaciation by an interval of soil development. This earlier glaciation probably postdates the Sangamon interglacial stage and is older than what has been recognized as Wisconsin. We believe that the Wisconsin stage might have to be adapted to include it.

The exposure from which sample W-188 was taken is a railroad cut a few miles south of Sidney, Shelby County. The exposure was examined and sampled by

Table 1. List, brief description, and C^{14} dates of the middle group of samples from Ohio. All samples consisted of spruce wood. For description and discussion of Chicago samples see Libby (*8, 25, 26*) and Flint and Deevey (*1*).

Sample No.	Locality and collector	Stratigraphy	C^{14} age (yr)
W- 37	Dayton (R. P. Goldthwait)	Imbedded in till believed, before dating, to be of Cary age. Identical with C-508, which dated > 17,000 yr.	20,700 ± 600
W- 71	Cleveland (R. P. Goldthwait)	Imbedded in lake silt overlain by till believed, before dating, to be late Cary in age, and underlain by loess (*44*, p. 366, unit 6).	24,600 ± 800
W- 88	Newark (R. M. Mahard)	Imbedded in till believed, before dating, to be of Tazewell age. Overlain by outwash believed to be Cary in age. Similar to sample C-893,* which dated 16,100 yr.	21,400 ± 600
W- 91	Chillicothe (R. P. Goldthwait)	Imbedded in till believed to be of Tazewell age.	18,050 ± 400
W- 92	Oxford (R. P. Goldthwait)	Imbedded in till believed, before dating, to be Cary in age. Underlain by lake sediments. Identical with sample C-465, which dated > 15,000 yr.	19,980 ± 500
W-127	Harrisburg (P. F. Mooney)	Imbedded in sand lens in till believed, before dating, to be Cary in age.	21,600 ± 1000
W-188	Sidney (J. Forsyth)	Imbedded in till believed, before dating, to be of Cary age. Underlain by an older till in the surface of which a well-zoned soil of the Fox series is developed.	23,000 ± 800

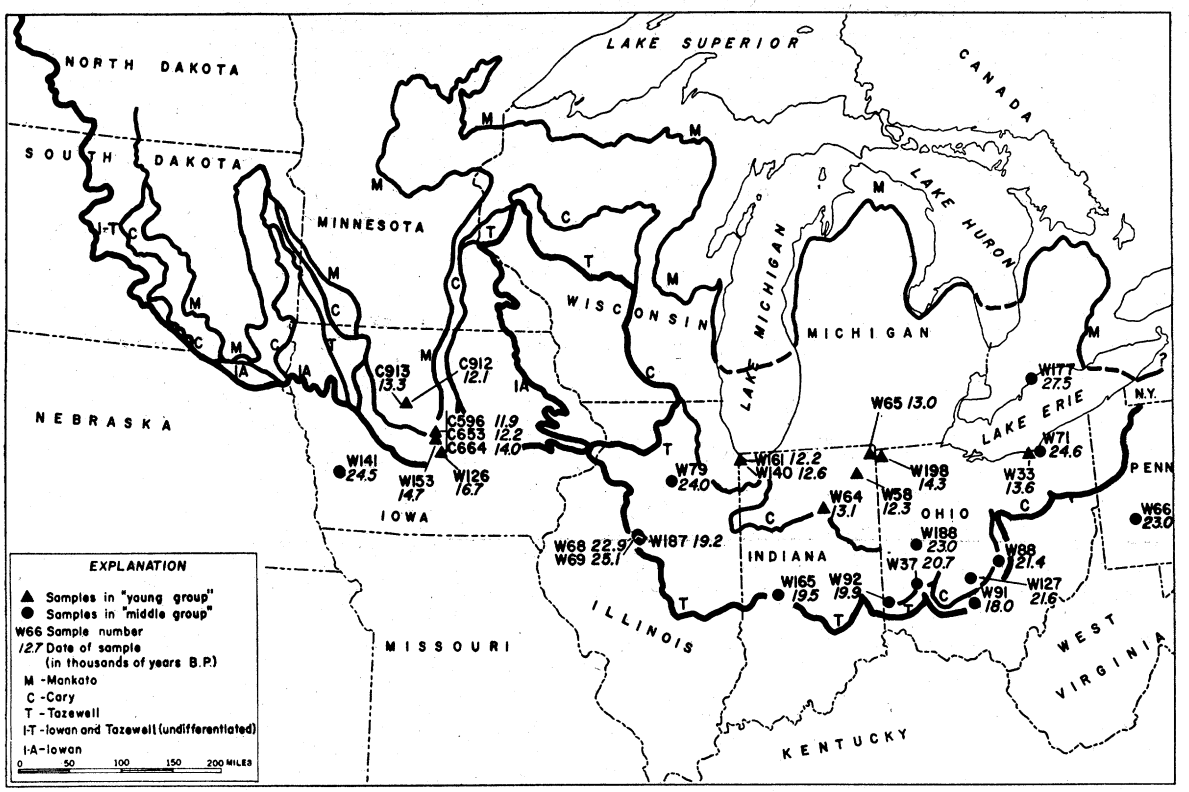

Fig. 1. Sketch map showing localities, accession numbers, and dates of significant samples. Drift borders, diagrammatic only, are compiled from the Glacial Map of North America and other sources.

Jane Forsyth. The logs are overlain by more than 20 ft of till and mark the upper contact of a well-zoned soil developed in an older till at least 30 ft thick. The soil is completely leached to a depth of at least 48 in. and is partly leached to a depth of 6 ft. The tills above and below the soil are calcareous.

This soil is believed by R. P. Goldthwait (*16*) to be similar to a soil of the Fox series developed extensively throughout south-central Ohio on gravel bodies sandwiched between two tills. Within a few miles in many directions from the Sidney locality, the buried soil occurs on the gravel body that separates the two tills at Sidney. This fact lends weight to the supposition that the soil on the till is of the same age as that on the gravel. If the supposition is correct, the glaciation recorded by the lower till and the gravel was extensive.

The soil, as well as the till and gravel in which it is developed, is believed to be post-Sangamon and pre-Wisconsin of existing terminology. The alternative possibility, that the soil is Sangamon and the drift beneath it Illinoian, is unlikely because weathering of the till is not comparable to that developed on drift of known Illinoian age. Using Kay's familiar depth-of-leaching value of 2.5 ft on Mankato drift, and modifying the related time to 10,000 C^{14} yr, we have a buried soil at Sidney whose 48-in. leached zone represents roughly 16,000 yr. The predominant surface till in the area, presumably deposited a short time prior to the formation of the Wabash moraine, developed a soil with a depth of leaching of about 43 in. (*17*); this implies a weathering interval of a little more than 14,000 yr. Because this figure should represent the length of time the area has been free of ice, the date of 14,300 yr for the Wabash moraine, the southern arc of which swings just north of this area, is in fair agreement.

Samples from Ohio that record the time between the maximum of the inferred glacial advance (18,000 yr) and the time of Lake Arkona (W-33, 13,600 yr) are scarce. This could result from the likelihood that trees would not occupy the periglacial zone soon enough to be destroyed by minor readvances, or it may be purely artificial. At any rate, on the basis of the Ohio evidence alone, there is no reason to doubt that the elapsed time, about 4500 yr, represents the irregular waning of the glaciation recorded by the fossil logs. In that case the middle group of samples is related to the expanding phase, and the young group is related to the later phases of shrinkage of the ice sheet during a major glacial event. The whole event, then, as measured in Ohio, embraced at least 7000 yr plus 4500 yr, or 11,500 yr. It will be shown that evidence from other states is consistent with this interpretation.

At five of the seven sample localities in Ohio the enclosing sediment had been assigned with varying certainty to the Cary substage; at the remaining two

it had been assigned to the Tazewell (*18*). The possibility exists that the logs from Cleveland (W-71) found at the base of pro-Tazewell (?) lake silts are derived from an underlying loess that has been correlated with Farmdale loess (*19*) by A. B. Leonard (*20*) on faunal evidence.

In Illinois, the material deposited contemporaneously with this advance, as will be shown by dates from additional samples, has been named Farmdale, Iowan, and Tazewell, whereas the till deposited around the lake border during the pre-Mankato retreat phase has been termed Cary.

Plum Point, Ontario (W-177). From the north shore of Lake Erie comes a sample that fits reasonably into the reconstruction of events in Ohio. At Plum Point, 2 mi southwest of Port Talbot the modern Lake Erie cliff exposes two different till sheets separated by a few feet of lacustrine clay. Within the lower till, 12 ft below its top, are fragments of larch wood. Because the locality lies outside the supposed Mankato drift border and because the upper till antedates a strandline believed to be that of glacial Lake Maumee, a Cary lake, the upper till is considered to be pre-Mankato. Wood from the lower till, collected by Aleksis Dreimanis, yielded a date of 27,500 ± 1200 yr. The date, of course, is consistent with the pre-Maumee correlation of the overlying till, for Lake Maumee should have existed more than 13,600 yr ago (W-33, Lake Arkona) and considerably less than 18,000 yr ago (W-91, Chillicothe). But it is consistent also with the Ohio reconstruction, for the glacial advance that overwhelmed a forest near Cleveland about 24,600 yr ago (W-71, Cleveland) and reached southern Ohio 7000 yr later can reasonably be expected to have been responsible for the lower till at Plum Point, 60 mi north of Cleveland, some 3000 years earlier. The upper till and underlying clay at Plum Point may well date from a much later time, shortly before the creation of Lake Maumee or even during the existence of that lake.

Bridgeville, Pa. (W-66). Also consistent with the group of dated samples from Ohio is a peat sample furnished by E. R. Eller from a section near Bridgeville, well described by Schopf and Cross (*21*). The peat lies conformably between two lake deposits 8 mi south of the Ohio River in the valley of one of its tributaries, Chartiers Creek, and 25 to 30 mi south of the border of the Wisconsin drift. The altitude and areal position of the peat in relation to abundant remnants of outwash fill in the Ohio River valley and of backwater fill in the tributary invite the explanation that ponding was caused by two episodes of rapid outwash aggradation along the Ohio, both of Wisconsin age. The earlier episode created a pond that filled with sediment and continued as a bog; the later flood of outwash reached a higher altitude, recreated the backwater pond, drowned the bog, and covered it with lacustrine clay. Later dissection led to present conditions. The time interval between the pondings is unknown; Schopf and Cross tentatively referred the peat to the Tazewell-Cary interval. However, the conformability of the peat with the overlying lake clay and its particular boreal ecology (spruce, tamarack, hemlock, pine, and mosses) suggest glacial conditions presaging an advancing ice front rather than warm interstadial conditions.

The sample is from an unknown position in the peat which, however, is only 3.5 ft thick; its date, 23,000 ± 800 yr, is nearly that of the Sidney sample (W-188), and represents a time in which it is probable that glacier ice in eastern Ohio was pouring outwash down the Beaver River into the Ohio River valley. If viewed as an indirect product of the important glacial advance in Ohio, the date is compatible with the Ohio dates cited. Drowning of the bog must then be attributed to increased outwash deposition both at the time of maximum advance (about 18,000 yr ago) and during the subsequent deglaciation when the rate of melting presumably was greater than it was during the glacial advance.

Abri Pataud, France (W-151; W-191). From the important archeological site at Les Eyzies, in the Dordogne region of France, two samples were collected by H. L. Movius (*22*) from the Upper Perigordian IV culture zone. Two independent determinations made on charcoal hearth samples, dated 23,600 ± 800 and 24,000 ± 1000 yr. Although these deposits have not yet been correlated with the nearest glacial drift, that in the French Massif Central, the dates suggest contemporaneity of the Upper Perigordian IV culture with a part of the Wisconsin advance into the United States.

Samples from Iowa

Hancock (W-141). A complete sequence of dates from Iowa affords an interpretation somewhat similar to that made for Ohio. One date, 24,500 ± 800 yr, obtained from wood in a railroad cut near Hancock, is representative of the middle group from Ohio; a series of five dates from two localities, obtained at the Chicago laboratory, represents the young group; two of the dates are from intermediate horizons.

W-141 consisted of wood fragments from the top of a loess sheet 3 to 4 ft thick overlying Loveland loess. Above the sample horizon is a third loess sheet 28 ft thick. According to the collector, R. V. Ruhe (*23*), the third loess contains two gastropod zones, the upper indicative of the Tazewell substage, the lower of the Iowan substage. On the basis of its stratigraphic position, Ruhe (*24*) correlated the sample horizon with the Farmdale loess (*19*) of Illinois; the radiocarbon dates support the correlation.

By the use of radiocarbon dates, the advance of the glacier from which the dated Farmdale loess at Hancock was derived can be correlated with the major advance in Ohio. The logs from Cleveland (W-71, 24,600 ± 800 yr) overlie a similar loess, that is also correlated with the Farmdale loess. However, although the Cleveland area was overriden, the ice of this advance did not reach the Hancock locality. Although a weak incipient soil is developed on the Farmdale loess at Hancock, such a soil does not necessarily imply complete deglaciation. Therefore the section above the Loveland loess can be interpreted as belonging to a

single major fluctuating glacial advance followed by retreat.

Cook Quarry, Story County (C-596, C-653, C-664) and *Lizard Creek, Webster County* (C-912, C-913). Five dates from Iowa reported by Libby (*25, 26*) range from approximately 12,000 to 14,000 yr, placing them in the young group of samples. The occurrences are fully described in a paper by R. V. Ruhe and W. H. Scholtes (*27*). In brief, the Cook Quarry section consists of two tills, the lower one oxidized, separated by a sand-and-gravel layer, also oxidized. C-596 averaged 11,952 ± 500 yr and C-653 averaged 12,200 ± 500 yr. Both samples consisted of wood from the upper till. C-664, a sample taken from the intervening sand-and-gravel layer, was dated at 14,042 ± 1000 yr. The upper till was classified by Ruhe as Cary in age (*28*). Contemporaneous events, correlated by radiocarbon dates from Ohio and Indiana, indicate a somewhat similar glacial fluctuation.

The Lizard Creek dates, 12,120 ± 530 yr (C-912) and 13,300 ± 900 yr (C-913), are from samples of hemlock that occur in horizontally bedded silts and sand-and-gravel bodies underlying Mankato till. A late Cary outwash genesis for the sample horizon is logical in view of the agreement between these and previously cited young samples.

Mitchellville, Polk County (W-126) and *Clear Creek, Story County* (W-153). The Iowa series of dates does not show the gap between the middle and young groups that was observed in Ohio; instead the series bridges the gap with samples coming from a generally constant glacial loess accumulation. Samples W-126 and W-153 lie between the middle and young groups of dates in both stratigraphy and radiocarbon age. The Mitchellville sample is from within a 29-ft loess section underlying 5 ft of till; the date obtained at the Washington laboratory was 16,720 ± 600 yr. The overlying till is part of the marginal minor-morainal belt of the Des Moines lobe reclassified by Ruhe in 1952 as of Cary age (*28*). Probably the loess at Mitchellville is correlative with the 28 ft of loess above the Farmdale loess at Hancock, if the faunal descriptions by C. Cameron (discussion of Mitchellville section by Ruhe and Scholtes, *27*, p. 84) are considered. If this correlation is valid, wood giving any date between the 24,500-yr date from Hancock and the young group (12,000 to 14,000 yr) might be obtained from various horizons of this loess.

For example, at the Clear Creek section various layers of silt and loess are sandwiched between two till sheets. The surface till, here 10 ft thick, belongs to the drift reclassified by Ruhe as Cary (*28*). The basal till may be either Iowan or pre-Wisconsin. A sample of hemlock (W-153) obtained from a zone of concentration of wood fragments about midway in the 30 ft of loess and silt in the section gave an age of 14,700 ± 400 yr.

The presence of yew, spruce, and hemlock in the flora of the 58-ft thick loess deposit at Mitchellville (*29*, pp. 169–171) and the presence of hemlock at Clear Creek point to an environment significantly colder and moister than that of present-day Iowa with its prairie grasses and deciduous trees. The burial of wood in accumulating loess is consistent with a glacial rather than an interglacial time of origin, possibly reflecting a fluctuating ice front disturbing the customary equilibrium of loess deposition and vegetal decomposition. The evidence from Iowa is not prejudicial to the interpretation of a single major glaciation made from the Ohio data. The record shows that between 25,000 and 12,000 to 13,000 yr ago, several glacial fluctuations occurred in Iowa. It is not our intention to deny the reality of their existence. We wish to show only that they belong logically within a single major glacial advance and retreat.

Middle Group Samples from Illinois and Indiana

From classic sections of the Wisconsin glacial stage in Illinois come four samples representing the middle group of dates. The large body of information amassed through the years by workers in that state affords a formidable test of the validity of radiocarbon dating.

Farm Creek, Ill. (W-68, W-69). Two samples of wood from the famous exposures along Farm Creek near Peoria described by Leighton (*30*) were previously determined by Libby (C-509 and C-510) to be greater than 19,000 and 20,000 yr old, respectively. The samples were collected by G. D. Smith and C. S. Denny from 0 to 1 ft and 3 to 4 ft below the surface of the Farmdale loess. The stratigraphy of the Farm Creek exposure from surface to base consists of: (i) Shelbyville (Tazewell) till; (ii) Iowan loess; (iii) Farmdale silt and loess of Leighton and Willman (*19*); and (iv) Illinoian till capped by a Sangamon weathering profile including gumbotil. With the improved acetylene method of dating, the top sample gave an age of 22,900 ± 900 yr and the lower sample 25,100 ± 800 yr. These ages are in perfect agreement with the Farmdale sample of Hancock (W-141) and the possible Farmdale of Cleveland (W-71).

Wedron, Ill. (W-79). Another sample from the Farmdale (*19*) is that collected by J H. Bretz from Lake Kickapoo deposits at Wedron. These deposits, originally described by Willman and Payne (*31*, p. 307, sec. 68) as Shelbyville (Tazewell) drift, have since been considered by the Illinois Geological Survey (*32*, p. 38) to represent a Farmdale lake. The radiocarbon age of 24,000 ± 700 yr supports this suggestion. Shelbyville (Tazewell) till overlies the same horizon.

Farmdale Dam, Ill. (W-187). One-eighth of a mile southeast of the point where the Farm Creek samples were taken, a sample was collected by Leland Horberg from an exposure in a railroad cut with an almost identical stratigraphy (*32*, pp. 18–19); Horberg described a weathering profile on the Farmdale here (*33*). The sample (W-187), wood fragments, came from the lowest 1 ft of the Shelbyville till and was dated at 19,200 ± 700 yr. This date agrees with that of sample W-165 from below Tazewell till across the state line in Indiana.

Greencastle, Ind. (W-165). In a section exposed 1 mi southwest of Greencastle, a silt body 14.5 ft thick overlies Illinoian gumbotil and is overlain by 15 ft of till. A sample of wood submitted by C. L. Bieber from 1.5 ft below the top of the silt was dated at

19,500 ± 800 yr. If the boundary between the Tazewell and Illinoian in Illinois is projected eastward to the collecting site, the overlying till becomes a very probable correlative of the Shelbyville (Tazewell) till in Illinois.

These dates from Illinois and Indiana fall into a reasonable relative sequence. The only objection that might be raised is the short span of time allotted for events previously believed to have occupied a much longer interval. Approximately 3500 to 4000 radiocarbon yr are permitted for weathering of the Farmdale loess, deposition of loess of Iowan age, and the advance of Shelbyville ice to the two sample sites (W-165 and W-187). If the measured years are considered to be absolute years, the suggestion made for the samples from other states, that these deposits represent a single major fluctuating advance and retreat, becomes almost necessary. The two dates from Illinois and Indiana are in perfect accord with the dates from the outer limits of the glaciation in Ohio, and the samples mark similar outermost positions of a former ice sheet.

Acceptance of the radiocarbon dates obtained from Illinois samples requires no change in the existing stratigraphic terms, although it might require the addition of a new unit to the base of the Wisconsin sequence as currently understood. A reevaluation of the significance attached to the substages mapped might also be appropriate. Leighton wrote (*32*, p. 9):

> The longest intraglacial interval, according to the record in Illinois, appears to have been that between the deposition of the Farmdale loess and that of the Iowan loess.

As mentioned previously this interval, plus the time required for deposition of loess of Iowan age (and hence for the Iowan glaciation), and plus the time represented by the advance of the Tazewell glacier, can hardly exceed 4000 C^{14} yr.

The brief duration in C^{14} years allotted these events forces a reconsideration of the time relationships among the substages and suggests the possibility that the Tazewell and Iowan are penecontemporaneous substages. Leighton (*32*, p. 8) recognized this possibility and asked,

> Are the Iowan and Tazewell separate substages, or did the Iowan ice, because of shorter distance from its radiation center, reach eastern Iowa before the Tazewell ice reached northeastern Illinois?

Evidence of their near synchronous nature was observed by Ruhe in northwestern Iowa (*28*). He reported no difference in degree of integration of drainage between the Iowan and Tazewell drift surfaces there. The apparent contraction of time proposed here becomes still more plausible if the shortness of the Tazewell-Cary interval in Illinois is considered. Leighton (*32*, p. 9) stated, "The difference in leaching of youngest Tazewell drift and the oldest Cary drift is scarcely significant."

The evidence from Illinois is not adverse to the concept of a major glaciation beginning with deposition of the Farmdale loess at some time prior to 25,000 yr ago, advancing with fluctuations to its outermost Shelbyville (Tazewell) position at 19,000 yr, and retreating with fluctuations (Shelbyville moraine to Marseilles moraine) into the Lake Michigan basin before an oscillating (Cary) advance at 12,000 to 14,000 yr ago. (Minooka, Valparaiso, and Lake Border moraines.)

Old Group of Samples

A group of 15 samples from 13 localities in eastern North America is distinct from the middle group previously described in that they belong in a separate category consisting of much older materials. Each of the dates for samples in this old group is a *minimum date only*; it is not known in the case of any sample how much older the sample is than the minimum date quoted. In this respect this group of samples is in the same state of uncertainty as were most of the pre-Two Creeks samples in 1950, the time when the C^{14} date of the horizon at Two Creeks was established by Libby (see, for example, Flint and Deevey, *1*).

Most of the samples within the old group were presumed to be a part of the Wisconsin stage, but in no case could the sample be conclusively shown to be Wisconsin in age. Accordingly, in each instance the possibility that the sample is pre-Wisconsin must be admitted.

We begin the descriptive comments with the samples from Ohio, for the substantial time interval between the middle group and the old group is most clearly evident in the samples from that state.

Germantown, Ohio (W-96). A portion of a log collected between 1870 and 1890 from the section at Twin Creek near Germantown by either G. F. Wright or Edward Orton was submitted by R. P. Goldthwait and was dated as older than 34,000 yr. The complete section as described by Leverett (*34*) is no longer exposed, but Goldthwait described the section on the basis of borings from wells drilled more recently on farms nearby (*16*). The well logs indicate 60 to 90 ft of till underlain in turn by organic matter (the sample horizon) and by a thick valley fill of gravel. Goldthwait believes the till overlying the sample horizon is the till sheet from which sample W-37 (Table 1) was collected.

North Hampton, Ohio (W-152). This sample, a piece of a log from a stream-bank exposure 2.5 mi west of North Hampton, was dated as older than 39,000 yr. According to R. P. Goldthwait, who submitted the sample, the position of the forest bed, from which it was taken in the Ohio stratigraphic section is not certain. However, the section was believed originally to represent deposits of Wisconsin age.

Otto, N. Y. (W-87). At Otto, near Cattaraugus, in western New York, a layer of peat overlies leached Illinoian(?) till and is overlain by gravel interpreted as outwash of MacClintock and Apfel's Olean drift of early Wisconsin(?) age. Pollen analysis of the peat indicated dominant fir, spruce, and pine, implying a cooler climate than that now existing at the locality. MacClintock and Apfel (*35*, p. 1152) tentatively assigned the peat to a late part of the Sangamon interglacial stage. A sample of the peat, collected by C. S. Denny, was dated as older than 35,000 yr.

Lake Bloomington Spillway, Ill. (W-67; W-186). Two samples of wood fragments were run from a section exposed along the spillway of Lake Bloomington, McLean County, the second because of the apparently anomalous date obtained from the first run. The samples were collected by J H. Bretz and L. Horberg from just above (W-67) and just below (W-186) a boulder pavement in gray till. Because of field relationships the exposure is considered to represent only Tazewell till. The samples come from a low position in a stratigraphic section containing tills of Shelbyville, LeRoy, Bloomington, and Normal age. The first sample (W-67) was determined to be older than 34,000 yr and the second (W-186) 31,000 yr or older.

Independence, Iowa (W-139). From a section originally classified as Wisconsin(?), W. H. Scholtes and R. V. Ruhe submitted a sample of wood that gave an age of greater than 38,000 yr. The wood came from a layer of peat and silt underlying a sequence of deposits, from surface downward to sample horizon, as follows: 3 ft of Iowan loess; 6-in. pebble band; 7.5 ft of Iowan till; and 2 ft of silty clay. The sample horizon was designated by the collectors "pre-Iowan Wisconsin(?)" [*sic*], younger than Illinoian and older than Iowan.

Brookings, S. D. (W-115). In 1953 a piece of wood from a well-drilling operation in sec. 26, T110N, R48W, Brookings County, was submitted for dating by G. A. Avery. The surface drift sheet at this locality is Iowan in age (*36*). The wood came from a depth of 140 ft, but from the information available it was not possible to form an opinion about the stratigraphic position of the wood, beyond the statement that it is either Iowan or pre-Iowan. Its C^{14} age is greater than 30,000 yr.

Bronson, Minn. (W-102). A sample of peat from a boring at Bronson, Kittson County, collected and studied by C. O. Rosendahl (*37*), was dated by the solid-carbon method (sample C-496) as older than 19,000 yr; its stratigraphic significance was discussed by Flint and Deevey (*1*, p. 289). Representing a spruce-tamarack forest overwhelmed *in situ* and overlain successively by stratified sediments, till, and silt deposits of glacial Lake Agassiz, the peat, dated by the acetylene method, gave a date of greater than 36,000 yr. The climate implied by the peat is much like that in the same district today. The assembled evidence clearly records a glacial advance over the locality.

Redwood Falls, Minn. (W-99). A piece of spruce wood found at a depth of 9 ft in till exposed in a stream bank 3.5 mi east of Redwood Falls was collected by R. Schneider and submitted by H. E. Wright, Jr. The till was presumed to be Mankato in age, and the wood, though probably transported and conceivably derived from an older till, was expected to give a Mankato or Two Creeks date. The actual date, older than 31,000 yr, suggests the presence of a much older till in the general region.

Ironton, Minn. (W-101). A third Minnesota sample comes from sand and silt beneath several tills in the Manuel strip mine, Cuyuna iron range, central Minnesota. H. E. Wright, Jr., the collector, described two Mankato drifts and one or two Cary drifts in the immediate area (*38*). The sample, spruce wood, was taken from a depth of 180 ft, 12 ft above bedrock, and was determined to be older than 32,000 yr.

The rather young limits placed on these last two samples and on sample W-115 do not necessarily mean that they are younger than the other samples in the old group. They were run during a time of unusually high atmospheric radioactive contamination, and conservative limits were therefore set. Conceivably the three samples from Minnesota may have come from a single stratigraphic horizon.

Port Talbot, Ontario (W-100). Near Port Talbot, and about 1 mi northeast of the Plum Point exposure previously described (W-177) in this article, the Lake Erie cliff exposes gyttja beneath the base of the lower of the two till sheets present at Plum Point (*39*). Pollen examination of the gyttja yielded evidence that forests near the locality consisted mainly of jack pine and spruce (*40*). A sample of the gyttja yielded a C^{14} date of greater than 33,000 yr. Therefore the nonglacial time recorded by the gyttja antedates by at least 5500 C^{14} yr the nonglacial time represented by the wood from Plum Point (W-177). The actual interval between the two times is unknown and may be very much greater.

Toronto Subway; Ontario (W-121). Excavations for the recently completed rapid transit subway beneath Toronto exposed two tills. These are separated from a third underlying till by peat and other sediments correlated by Watt (*41*) with the well-known Toronto formation of Coleman (*42*) and considered by Watt to be Sangamon in age. The peat, collected by Watt and examined for pollen by N. W. Radforth (*43*) proved to be rich in pine and birch with substantial quantities of spruce and fir in addition. The pollen study suggested a climate not unlike the present climate of Toronto, and slightly cooler than that implied by the flora of the Toronto interglacial beds. A C^{14} date on the peat, greater than 30,000 yr, is consistent with Watt's correlation, although it does not exclude a Wisconsin correlation of the peat exposed in the subway.

Amber, Ontario (W-194). A peat ball, taken by A. Dreimanis from the Markham gravel pit, 1.5 mi north of Amber gave a C^{14} date of greater than 34,000 yr. On the west side of the pit 10 ft of late Wisconsin till overlies 100 ft of stratified gravel containing clay balls and a few balls of peat or muck. This in turn overlies till considered by the collector to be of Wisconsin age. The measured peat ball came from a depth of 65 ft below the top of the gravel, which is believed by Dreimanis to have been deposited by meltwater from a late Wisconsin ice tongue in the Lake Ontario basin. According to J. Terasmae, who made a pollen analysis showing a tree-pollen assemblage of spruce 70 percent, pine 27 percent, with non-tree pollen 20 to 30 percent (based on total tree pollen 100 percent), the peat accumulated during a climate cooler than the existing climate of the district and records an interstadial or the end or beginning of an interglacial age.

St. Pierre-les-Becquets, Quebec (W-189). A composite section on the south shore of the St. Lawrence River in the vicinty of St. Pierre-les-Becquets, Nicolet County shows two distinctly different till sheets separated by stratified sediments including peat and pieces of wood. No weathering zones are reported from the section. Collected by Nelson R. Gadd, a sample of the wood (Y-242) was sent to the Yale laboratory, but proved to be older than the reach of the method in use at the time of measurement. Accordingly it was forwarded to Washington for measurement, where its age was determined to be greater than 35,000 yr. One glacial advance postdating the peat can be inferred.

Hillsborough, Nova Scotia (W-157). A section broadly similar to the preceding one is exposed near Hillsborough Church, near Mabou, Cape Breton Island. Measured in 1952 by L. R. Wilson, the section consists, in brief, of two till sheets separated by marine clay and other stratified material including a layer of peat with imbedded spruce logs. The section as recorded includes no evidence of weathering intervals. Preliminary pollen-and-spore sampling of the basal part of the peat layer by Wilson revealed spruce and fir with subordinate ferns, fungi, and mosses. A piece of one of the spruce logs (Y-232) submitted to the Yale laboratory proved to be older than 21,000 yr and was transmitted to Washington where it was measured with a resulting date of older than 38,000 yr. The youngest drift sheet in Nova Scotia has been considered to be not younger than Cary in age; data upon which a more definite correlation might be based are lacking.

Whether the samples constituting the old group represent an interstadial zone within the Wisconsin stage, dating back to a time outside the present range of C^{14} measurement, cannot be said with certainty at present. Together with the evidence from Sidney, Ohio (W-188), the ages of the samples in the old group appear to indicate an early Wisconsin glaciation, older than any recognized in Illinois so far, and separated from the later glaciation by an indefinite period of time.

Godarville, Belgium (W-173). Just as the European sample from Poggenwisch (W-93) fits into the young group described in this article, so another European sample, W-173, belongs with the older group of American samples. In response to a request for samples having known stratigraphic relationships to the Fourth Glacial loess sequence in Belgium, Jean de Heinzelin assembled a group, one of which, collected by De Heinzelin and Roger Vanhoorne in 1953, is from a lens of peat 6 ft below the base of Younger Loess II (Loess récent II) in a canal excavation at Godarville, between Mons and Namur. Zones of frost-disturbed sediment intervene between peat and overlying loess, and also between the peat and an underlying occupation site with Mousterian culture, mammoth, and rhinoceros. The C^{14} date of the peat, which antedates Younger Loess II, is older than 36,000 yr. Unfortunately the relationship of the peat to Younger Loess I is unknown because that loess is not present in the Godarville section.

Summary of Inferences

1) A group of samples from horizons previously correlated with the upper part of the Cary substage confirms the correlation as reasonable and is consistently related in time to the dates of the peat layer at Two Creeks and subsequent Mankato events.

2) A major glaciation affected the Great Lakes region beginning 25,000 or more yr ago and reaching its maximum extent about 18,000 yr ago. It is represented by drift correlated in Ohio with the Cary substage and, at least in part, with the Tazewell substage; in Illinois and adjacent states it is correlated with most of the Tazewell substage and with the Farmdale loess.

3) The ecology and other associations implied by the dated samples are more consistent with glacial than with nonglacial conditions.

4) The lower till at Sidney, Ohio (W-188), on which is developed a soil considered a correlative of the Fox series soil on gravels and also buried by till of the major glaciation of 25,000 to 18,000 yr ago, indicates an earlier glaciation extensively exposed in Ohio and believed to be an early Wisconsin event.

Table 2. List of samples and dates arranged by age groups.

Sample No.	Locality	C^{14} age (yr)
	Young group samples	
C -596	Cook Quarry, Story Co., Iowa	11,952 ± 500
C -912	Lizard Creek, Webster Co., Iowa	12,120 ± 530
C -653	Cook Quarry, Story Co., Iowa	12,200 ± 500
W-161	Dyer, Ind.	12,200 ± 350
W- 58	Avilla, Noble Co., Ind.	12,380 ± 360
W-140	Dyer Spit, Ind.	12,650 ± 350
W- 46	Durham Meadows, Conn.	12,700 ± 280
W- 65	Fremont, Steuben Co., Ind.	13,020 ± 400
W- 64	Laketon, Wabash Co., Ind.	13,140 ± 400
C -913	Lizard Creek, Webster Co., Iowa	13,300 ± 900
W- 33	Lake Arkona, Cleveland, Ohio	13,600 ± 500
C -664	Cook Quarry, Story Co., Iowa	14,042 ± 1000
W-198	Edon, Ohio	14,300 ± 450
W-153	Clear Creek, Story Co., Iowa	14,700 ± 400
W- 93	Poggenwisch, Holstein, Germany	15,150 ± 350
W-126	Mitchellville, Polk Co., Iowa	16,720 ± 600
	Middle group samples	
W- 91	Chillicothe, Ohio	18,050 ± 400
W-187	Farmdale Dam, Ill.	19,200 ± 700
W-165	Greencastle, Ind.	19,500 ± 800
W- 92	Oxford, Ohio	19,980 ± 500
W- 37	Dayton, Ohio	20,700 ± 600
W- 88	Newark, Ohio	21,400 ± 600
W-127	Harrisburg, Ohio	21,600 ± 1000
W- 68	Farm Creek, Ill.	22,900 ± 900
W-188	Sidney, Ohio	23,000 ± 800
W- 66	Bridgeville, Pa.	23,000 ± 800
W-151	Abri Pataud, Les Eyzies, France	23,600 ± 800
W-191	Abri Pataud, Les Eyzies, France	24,000 ± 1000
W- 79	Wedron, Ill.	24,000 ± 700
W-141	Hancock, Iowa	24,500 ± 800
W- 71	Cleveland, Ohio	24,600 ± 800
W- 69	Farm Creek, Ill.	25,100 ± 800
W-177	Plum Point, Ontario	27,500 ± 1200

Sample No.	Locality	C^{14} age (yr)
	Old group samples	
W- 67	Lake Bloomington Spillway, Ill.	> 34,000
W- 87	Otto, Pa.	> 35,000
W- 96	Germantown, Ohio	> 34,000
W- 99	Redwood Falls, Minn.	> 31,000
W-100	Port Talbot, Ontario	> 32,000
W-101	Ironton, Minn.	> 32,000
W-102	Bronson, Minn.	> 36,000
W-115	Brookings, S.D.	> 30,000
W-121	Toronto, Ontario	> 30,000
W-139	Independence, Iowa	> 38,000
W-152	North Hampton, Ohio	> 39,000
W-157	Hillsborough, Nova Scotia	> 40,000
W-173	Godarville, Belgium	> 36,000
W-186	Lake Bloomington Spillway, Ill.	31,000 or older
W-189	St. Pierre-les-Becquets, Quebec	> 40,000
W-194	Amber, Ontario	> 34,000

5) An earlier glaciation, or glaciations, is implied at several localities by peat, gyttja, or wood more than 30,000 yr old, overlain by till.

6) The time interval between the middle group and the old group of samples, which has been determined within conservative radiocarbon limits to be greater than 3000 yr, is possibly of the order of 16,000 yr, as suggested by the depth of leaching at Sidney, Ohio. (The ages of all the samples discussed are listed in Table 2.)

7) An attempt should now be made to fix more closely the dates of the old samples and to reexamine in the field the stratigraphic sequence in the light of the radiocarbon dates discussed.

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Calvin Perry Stone, Investigator and Teacher

BORN in 1892 in Portland, Indiana, Calvin Perry Stone was educated at Valpariso University, Indiana University, and the University of Minnesota. He began his career as a high school principal and superintendent. After receiving his master's degree in 1916, he became director of research of the psychology laboratory of the Indiana Reformatory. During World War I he served in the U.S. Army as a Medical Corps lieutenant, then as a captain, and was assigned for a period as a psychological examiner. After the war he was appointed instructor of psychology and histology at the University of Minnesota. In 1922 he became assistant professor of psychology at Stanford University. Promoted to associate professor in 1925 and professor in 1929, Dr. Stone served Stanford University almost continuously for 32 years.

Characteristically, Dr. Stone continued to study