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A RECORD OF POST-GLACIAL CLIMATE IN NORTHERN OHIO.*†

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OBJECT AND CHARACTER OF THE INVESTIGATION.

This paper reports the probable course of post-glacial forest succession in northern Ohio, as indicated by a study of fossil pollen deposited in the Bucyrus Bog. The object of the study has been to trace in greater detail than has yet been possible the course of climatic change since the end of the Wisconsin glaciation.

The principle employed is one which has been used in numerous European studies since 1915. It consists of a tabulation of the percentages of pollen grains of each species found in successive levels of bog deposits, and deduction of the prevailing forest composition at each level from this data. From the forest composition conclusions as to climate are drawn.

As in all stratigraphic work, certain assumptions are involved, and numerous sources of error can be pointed out. These matters have been discussed at length and tested by workers cited in a previous paper (1). For the purpose of the present paper it is perhaps sufficient to note the following points: (a) no successful impeachment of the method has appeared, although there have been several attempted (b) pragmatically, the method appears to work, and to give results which agree with those obtained otherwise (c) the method requires a clean and accurate technique, a knowledge of pollen, and an understanding of what constitutes a climatically significant fluctuation in the tabulated results.

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LOCATION AND CHARACTER OF THE BUCYRUS BOG.

This bog of about forty acres I have named from the nearest city. It was evidently overlooked by Dachknowski (2) in his survey of Ohio peat deposits. It lies two miles due east of Bucyrus, Ohio, on the North Robinson Road, fourteen miles south of the 41st parallel, and three miles east of the 83rd meridian. The glacial physiography of this region is mapped and described by Leverett (3), and the natural vegetation by the writer (4).

Located just north of the Ohio-Erie watershed, or crest-line of the state, the Bucyrus Bog is about seventeen miles southwest of the first of the ice-front lakes, now surviving as the New Haven Marsh. It is about twenty miles northwest from a contact of the Wisconsin and Illinoian glaciation, being thus fairly near the last ice edge. While not so old therefore as bogs lying nearer the edge of the ice-sheet, this bog appears to date back nearly to the beginning of post-glacial time, and in any case it gives a record of those subsequent changes which have been most significant in the development of our present floristic complex.

The bog was covered with *Vaccinium* and surrounded by groves of *Quercus* and *Carya* when the country was settled early in the last century. Not more than one-half mile south, on the other side of the watershed, were extensive areas of *Andropogon* prairie, with scattered groves of *Quercus* and *Carya*. Only two miles north, *Fagus, Acer* and other mesophytic hardwoods had established themselves. Nowhere in the immediate vicinity were there any conifers, except such *Larix* as might have been in this or neighboring bogs.

PREVIOUS AND RELATED WORK.

For many years assumptions as to post-glacial climate in the Great Lakes region have been the simplest possible consistent with the known facts of a gradual fluctuating recession of a huge continental ice-mass. On this basis southern species were considered to be advancing, northern retreating, and isolated bog associations have been held to be relicts of a once continuous tundra. In other words, a general moderation of climate has been assumed.

At the same time, observers have known of the existence of western plants, or even associations, far east of their present climatic region. As instances may be cited the occurrence of *Opuntia* on the south shore of Lake Erie, along the Illinois River, and the presence of extensive *Andropogon* prairies, surrounding islands of Oak-Hickory, across much of Ohio.

Had these areas been first investigated by strictly ecological rather than floristic methods it is possible that their significance might have been missed. Gleason (5), 1909, working in Illinois, approached the problem from a floristic standpoint, however. Ascertaining that forest was increasing at the expense of prairie before white settlement, he suggested that there had been a period of widespread continental climate in post-glacial time succeeded by a recent period of increasing humidity. Following the terminology of European workers, he used the word "xerothermic" to suggest that the period of continental climate had been dry and warm.

Dachnowksi (6) from a study of the gross characters of peat strata states tentatively that Ohio peats show an irregular series of changes, due to climatic influences. After discussing evidence which deals with fluctuations during the Wisconsin glaciation, he suggests that the last advance of the ice was followed by a prolonged warm and somewhat humid climate. "This appears to have been the period of invasion and wide dispersal of forest trees from the south, and of a more northerly distribution of certain species than is now recorded for them. As to the end of the late glacial time, the climatic characteristics from the last glacial recessions to post glacial and present conditions stand as yet considerably ill defined. The evidences indicate periods during which the climatic zones shifted again somewhat. There appears to have been a return to cooler and drier climatic conditions, followed by a temperate and more humid period than exists at the present time in the same localities. The present period is probably approaching a climate of rising temperatures and (or) decreasing precipitation." He makes clear, however, that the data are insufficient for more definite conclusions, for correlation of the various deposits in this country, or for drawing parallels with other countries.

In 1926 the writer presented a reconstruction of the native vegetation of Ohio (4). On floristic and successional grounds he inferred that western as well as northern species appeared to be receding from the region, and southeastern species advancing into it. In his opinion the retreat of western forms was the more recent, suggesting a period of continental climate in post-glacial time. The survival of bogs and other considerations led him to the conclusion (p. 229) that this arid climate had been cool rather than warm.

Auer (7) in 1927 in classifying the peats of southeastern Canada concluded that certain synchronous layers had been formed under dry conditions and expressed the belief that some correlation with the climatic sequences of Europe was possible.

Lewis and Cocke (8) in 1929 reported a pollen-analysis of the Dismal Swamp peat in Virginia. The analysis is presented and discussed in detail, and while fluctuations and disturbances are recorded, extreme caution is observed in drawing deductions as to climatic significance. The general trend of the record is one of succession from an open sedge-grass marsh to a closed mesophytic forest. At the eight and four foot levels there were disturbances which reduced the percentages of trees. The present mesophytic climax forest begins at the one foot level. It may be pointed out in passing that there is nothing inconsistent here with the assumption of a recent increase in climatic humidity in eastern North America.

Draper (9) working in this laboratory has made preliminary studies of a number of Ohio bogs. Especially noteworthy is her report of a grass-sedge-composite interval at four feet in an otherwise forest profile in the New Haven Bog. This plainly suggests a period of dryness, not far back.

COLLECTION AND SAMPLING OF MATERIAL.

Samples were taken at six inch intervals with a Davis peat sampler. Four columns were taken in different parts of the bog. The samples were wrapped individually in paper and shipped to the laboratory.

The present cover of the bog is a mixture due to secondary succession—largely *Carex*, *Poa*, *Polygonum*, *Populus*, *Salix*. There has been some attempt at drainage, and fires have occurred at several times. In the case of two of the four columns the top layer had been destroyed by fire, but the other two gave an undisturbed sequence. Three of the columns were carried down through the marl to quicksand, a distance of fourteen feet in the case of the longest.

For study, a block was cut from the center of each six-inch piece, the outside being removed to prevent possible contamination. This block was boiled in 10% KOH, centrifuged,

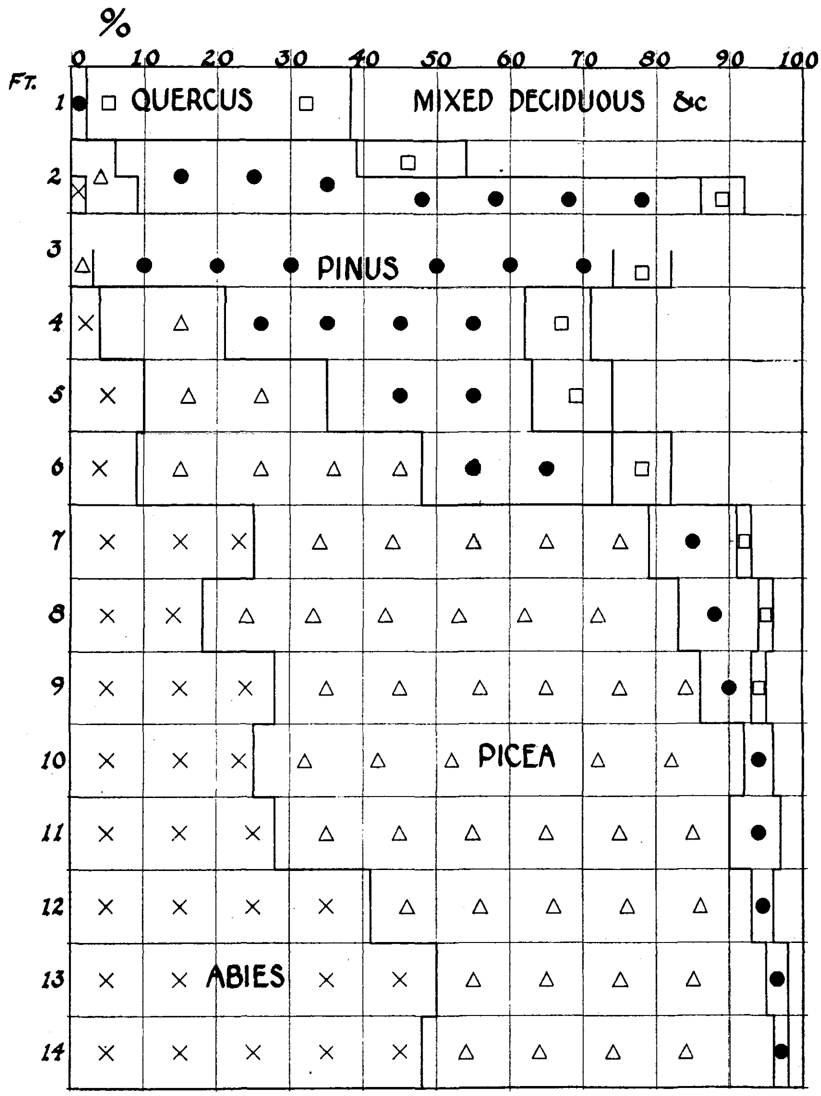

FIG. 1. POLLEN DIAGRAM OF THE BUCYRUS BOG.

At left is shown depth in feet, and across top is a percentage scale. Proportions of the four genera, *Abies*, *Picea*, *Pinus* and *Quercus* are shown for each level as they occur. Any remainder is designated as "Mixed Deciduous, etc." This includes some conifers, i. e., a little *Larix* and occasional *Tsuga*, a few herbs, e. g., *Typha*, *Graminales*, *Cyperaceæ*, but is mostly *Carya*, *Betulaceæ* and other deciduous forms. The break at 2′ 6″ represents a water pocket in the peat. In the 2′ level *Pinus strobus* replaces *P. banksiana* (and *resinosa*?). Distinct climatic equivalents are as follows: 12–14 feet—northern Labrador (cold, wet); 4–6 feet—southern Manitoba (cool, dry); 2 feet—northern Michigan (cool, moist); 1 foot—northern Ohio (increasing warmth and moisture). Generic symbols are the standard ones used by Erdtman who employs, however, graphs.

decanted, rinsed with filtered distilled water, centrifuged again and decanted. The material was then drawn up in a clean pipette, spread on a slide, dried and mounted in glycerine jelly. In strata like the lower marl and the weathered 3-foot layer where the pollen frequency was very low, the use of a centrifuge was indispensible in securing enough grains to count. At least two slides were prepared from each sample.

A key has been prepared (1) which includes most of the pollen found in this material. Wherever possible, at least 100 grains were counted from each slide. Only actual pollen was considered in figuring percentages, although spores of Sphagnum, & c. were tallied so that results could be computed if desired, as number per 100 pollen grains. It is believed that this is a more accurate procedure in dealing with cryptogamic spores than to add them in to the total. Pollen frequency (grains per sq. cm. of slide) was determined, and the presence of humified material roots and fungi noted. Valuable suggestions on method and some useful figures of American pollen will be found in the paper by Lewis and Cocke (8) as well as in the European papers cited in (1).

RESULTS.

In the accompanying tables I–IV are given the percentages of pollen at each six inch level. It will be noted that because of burning at the surface, columns 1 and 2 do not give as recent a record as columns 3 and 4 which extend to very recent times. Table VI is a condensed summary of all borings, by feet. This was obtained by connecting what, in my judgment, were corresponding levels of the four borings and grouping the results accordingly (see Table V).

The purpose of presenting the borings separately is to emphasize that pollen analysis is a clue to trends and in no sense an absolute statistical index. If the figures in each boring for *Quercus* are plotted all curves will have the same trend, but there will be no identity. Fluctuations of an order of 5-10% are to be expected. I have suggested *Quercus* because any errors in discriminating conifer pollens would not affect it. The same fact is clear, however, in comparing the conifers in those levels which were critically rechecked, and which are marked with an asterisk in the tables. But it should also be noted that while considerable fluctuation does occur at corresponding levels in different sections of the bog, *the principal* *trends are equally clear in each section.* The critical points which will be shown in the consolidated graph of table V are all unmistakeable in the individual graphs of each column, if one cares to make them, as I have done in my own analysis of the data.

TABLE I.

POLLEN PERCENTAGES OF FIRST BORING.

Depth in inches‡	Abies	Picea	Pinus	Quercus	Other Genera	Pollen Grains	Pollen Frequency†
6*	05	14	49	05	27	257	60
12	01	17	43	07	32	136	167
18	00	27	47	07	19	120	81
24*	10	28	41	07	14	364	16
30*	04	33	38	08	17	342	27
36	0	22	30	10	38	92	24
42	01	32	29	05	33	110	17
48*	18	51	22	02	07	206	19
54*	23	59	13	01	04	222	33
60	05	75	09	03	08	112	37
66	10	75	07	02	06	100	37
72*	23	51	11	02	13	347	21
78*	26	71	02	00	01	360	126
84	13	84	02	0	01	123	82
90	17	76	04	0	03	118	132
96	25	70	01	0	04	106	160
102	32	61	02	0	05	122	70
108	47	49	02	0	02	129	143
114	45	53	02	0	0	131	157
120	47	51	02	0	0	118	175
126	48	47	02	0	03	121	120
132	50	41	05	01	03	109	21
						3,845	

‡Surface had been burned at this place.

*These depths were rechecked, as the numbers counted indicate. Some errors in determining coniferous pollen doubtless occurred in the original count, but the order of magnitude was small and the general trend not affected thereby.

†Grains per sq. cm. of slide. This has no standard significance, merely indicating order of relative abundance in the present study.

The results summarized in table V are diagrammed in figure 1. The most striking feature of this diagram, Fig. 1 is the successive appearance and waning of *Abies*, *Picea*, and *Pinus*, all finally supplanted in the youngest layers of *Quercus* and other deciduous trees. On its face is indicated a rise in temperature from the time the bog began to the present, with a rather recent period of maximum dryness expressed in the dominance of pine at the 4-foot level, and increasing moisture since. That much may safely be inferred from a knowledge of the ranges and ecological characters of the various genera which are most conspicuous.

In terms of present-day climates, I consider the 12-14 foot, 4-6 foot, and 2 foot levels of critical importance. In the lowest

TABLE II.

POLLEN PERCENTAGES OF SECOND BORING.

Depth in inches‡	Abies	Picea	Pinus	Quercus	Other Genera	Pollen Grains	Pollen Frequency†
6	01	11	53	08	27	165	453
12	01	24	50	05	21	111	273
18	03	08	50	10	30	358	39
24	08	16	14	23	39	139	12
30	12	50	25	04	10	52	11
36	20	55	08	06	12	51	1
42	28	62	06	03	03	404	36
48	29	66	03	01	02	341	119
54	30	52	05	05	09	60	122
60	40	52	01	01	06	109	100
66	28	60	08	02	05	414	160
72	43	51	02	01	04	481	210
78	44	53	0	0	03	116	100
84	36	56	03	0	05	129	97
90	42	56	0	0	02	120	180
96	46	51	0	0	03	114	53
102	48	50	02	0	0	128	20
108	53	47	0	0	0	73	15
114	....	....	....	....	....	0	....
120	57	43	0	0	0	7	2
126	63	37	0	0	0	8	2
						3,380	

‡Surface had been burned at this place.

*These depths were rechecked, as the numbers counted indicate. Some errors in determining coniferous pollen doubtless occurred in the original count, but the order of magnitude was small and the general trend not affected thereby.

†Grains per sq. cm. of slide. This has no standard significance, merely indicating order of relative abundance in the present study.

levels, first mentioned, *Abies* and *Picea* both appear with a minimum of *Pinus*. This condition is found today (10) in the cold, oceanic, humid climate of northern Labrador, where *Pinus* appears not to withstand conditions as well as the other two genera. At the intermediate levels, notably the 7 foot level *Picea* and *Pinus* are most abundant, with much less *Abies* and some deciduous genera. This condition appears today in southern Manitoba, a cool, dry continental climate, where

Abies ranges west chiefly in the immediate vicinity of the larger lakes.

Until the two foot level, the species of pine appears to be *Banksiana*, with a characteristic small pollen, although *resinosa*

TABLE III.

Pollen Percentages of Third Boring.

Depth in inches	Abies	Picea	Pinus	Quercus	Other Genera	Pollen Grains	Pollen Frequency
6*	0	0	01	34	65	350	1,860
12*	0	01	02	46	52	444	640
18	0	07	19	15	60	137	252
24	....	....	....	....	....	0	....
30	....	....	....	....	....	?	....
36*	01	01	64	08	27	291	3
42	0	06	44	18	32	115	7
48	07	13	16	11	53	45	....
54*	08	29	16	09	37	107	6
60*	19	40	16	09	15	158	7
66	0	52	21	10	16	42	9
72	0	42	42	0	15	69	11
78*	23	49	15	04	09	304	....
84*	25	55	12	02	07	362	26
90	01	79	17	01	02	111	33
96	01	78	17	01	02	86	9
102	29	61	07	01	02	121	43
108	19	68	11	01	01	155	21
114	16	68	14	0	02	107	14
120	18	63	10	0	08	94	11
126	20	64	16	0	0	125	30
132	21	59	20	0	0	80	9
138	24	55	07	0	14	42	5
144	42	54	02	0	02	48	4
150	49	49	0	0	03	101	....
156	61	28	11	0	0	18	20
162	34	66	0	0	0	3	0.3
						3,515	

*These depths were rechecked, as the numbers counted indicate. Some errors in determining coniferous pollen doubtless occurred in the original count, but the order of magnitude was small and the general trend not affected thereby.

†Grains per sq. cm. of slide. This has no standard significance, merely indicating order of relative abundance in the present study.

?Through error this level was not counted.

may also be present. In any case a continuance of cool xerophytic conditions seems clear. In the two foot level, along with an abrupt increase in deciduous genera, the species of pine changes to *P. strobus*, with a larger pollen. Although this pine is rated by Hutchinson (11) as fairly low in moisture requirements, it is commonly regarded as the most mesophytic of the northern pines, and its appearance probably indicates an increase in humidity. Today *P. strobus*, with deciduous species, is found in the fairly cool, semi-humid region of the northern Great Lakes.

In the one-foot level *Quercus*, with *Carya* and other deciduous trees represents substantially the present vegetation. A trace of pine pollen appears, but no native pine is known nearer than

TABLE IV.

POLLEN PERCENTAGES OF FOURTH BORING.

Depth in inches	Abies	Picea	Pinus	Quercus	Other Genera	Pollen Grains	Pollen Frequency†
6*	0	0	02	26	73	421	?
12	0	01	02	46	50	129	530
18	0	05	46	16	33	125	625
24*	02	07	77	06	08	355	410
30	....	....	....	....	....	0	?
36	0	0	74	10	17	111	190
42	0	07	77	06	11	124	140
48*	15	34	28	09	08	225	53
54	21	33	13	15	19	107	122
60	39	36	0	18	08	28	12
66	25	53	12	02	08	64	5
72	38	51	09	01	01	405	?
						2,094	

*These depths were rechecked, as the numbers counted indicate. Some errors in determining coniferous pollen doubtless occurred in the original count, but the order of magnitude was small and the general trend not affected thereby.

†Grains per sq. cm. of slide. This has no standard significance, merely indicating order of relative abundance in the present study.

about 35-40 miles within historical times. As compared with the preceding level the one-foot stratum indicates warming and probably further increase in humidity.

In other words the diagram indicates the following climatic sequence:

14–12 feet. Cold, wet climate of northern Labrador.
11– 7 feet. Gradual shift from oceanic to continental climate.
6– 4 feet. Cool, dry climate of southern Manitoba.
3–2.5 feet. Period of maximum dessication.
2 feet. Abrupt increase in humidity. Cool, moist climate of Northern Great Lakes.
1 foot. Moderation of temperature and continued increase in humidity, present climate of north-central Ohio.

TABLE V.

EQUIVALENCE OF BORINGS.

Equivalent Depth in Feet	Borings in Inches from Present Surface				Peat Character	Forest Dominants	Climate
	I	II	III	IV			
1..........	Destruction by fire and perhaps surface erosion		6 12	6 12	Brown Black	Oak, Hickory	Warmer, Humid
1–6..........			18	18	Coarse brown	Oak, Pine	Cool, moist
2–0..........			......	24	"	Pine	
2–6..........			24	30	Water pocket		
3..........			*(30) 36	36 42	Clayey "	Pine	Cool, dry
4..........	6 12	6 12	42 48	48	" "	Pine, Spruce " "	Cool, dry
5..........	18 24	18 24	54 60	54	" "	" " " "	
6..........	30 36	30 36	66 72	60	" "	Spruce, Pine	
7..........	42 48	42 48	78 84	66 72	Marly "	Spruce	
8..........	54 60	54 60	90 96	....	" "	Spruce	Increasing dryness
9..........	66 72	66 72	102 108	....	Marl....... "	Spruce	
10..........	78 84	78 84	114 120	....	" "	Spruce	
11..........	90 96	90 96	126 132	....	" "	Spruce	
12..........	102 108	102 108	138 144	....	" "	Spruce, Fir " "	Cold, humid " "
13..........	114 120	114 120	150 156	....	" "	" " " "	" " " "
14..........	126 132	126	162	....	" "	" " " "	" " " "

*Not included in count.

As confirmatory evidence of the dry conditions of the 4-2 foot level may be cited the low pollen frequency and the presence of numerous roots and much highly humified material. These plainly suggest a low water table and poor conditions for peat formation or pollen preservation.

The presence of clay in the peat deposited at the 6–3 ft. levels can, apart from the evidence of the pollen statistics, be construed with reasonable assurance as an evidence of increased dessication.

TABLE VI.

CONSOLIDATED SUMMARY BY FEET.

Feet	Abies	Picea	Pinus	Quercus	Other Genera	Total Pollen Grains Counted
1–0	0	0	02	36	62	1,344
1–6	0	6	33	15	46	262
2–0	02	07	77	06	08	355
2–6	....	....	....	....	....	0(water)
3	00	03	71	08	18	526
4	04	17	41	09	29	1,054
5	10	25	28	11	26	1,353
6	09	39	26	08	18	676
7	25	54	12	02	07	2,196
8	18	65	11	02	04	700
9	28	58	07	02	05	1,618
10	25	67	04	0	04	929
11	28	62	07	0	03	663
12	41	52	03	0	04	542
13	50	45	03	0	02	375
14	48	48	2	0	02	241
						12,834

It should also be noted that the unpublished work of Mr. George H. Lane on Iowa peats, carried out in this laboratory, confirms the above sequence in a striking way. In Iowa the period of gradual dessication caused a replacement of coniferous forest by prairie via deciduous forest. This prairie has been dominant since. But at the four foot level, corresponding to the *Pinus* period in Ohio, there is a strong increase in *Chenopodiaceæ* and *Amaranthaceæ* at the expense of grass. This suggests a xerophytic climax marked by strong evaporation and possibly alkaline or saline conditions in Iowa during the period of maxiumum dessication in Ohio. Above this level the grasses have again become dominant, additional confirmation of a recent increase in humidity.

In conclusion it appears that the climate of Ohio today is warmer than it has ever been since the Wisconsin glaciation. Since the continental maximum appears to have been cool, it seems inadvisable to use the term "xerothermic" to describe it, at least for the present.

SUMMARY.

1. Four cores were obtained in different parts of an old bog two miles east of Bucyrus, Ohio. Each one showed the same general trend of post glacial vegetation by means of the percentages of stratified pollen, counted at six inch intervals.

2. There was sufficient individual difference between cores to demonstrate that small fluctuations must not be regarded too seriously.

3. Corresponding levels in the four cores were readily located and the results grouped.

4. The sequence of vegetation appears to have been Abies-Picea, Picea-Pinus, (Pinus maximum), Pinus-Quercus, Quercus-Mixed Deciduous.

5. In terms of present local vegetation this sequence would be Northern Labrador, Southern Manitoba, Northern Michigan, Northern Ohio.

6. The sequence of climate to be inferred appears to be cold-wet Oceanic, cool-dry Continental, (Continental maximum) cool-moist Sub-continental, warmer-moister Sub-oceanic.

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