Petrified Peat from a Paleocene Lignite in North Dakota

Abstract. *The first discovery of a silicified peat in a Paleocene lignite is reported from western North Dakota. The state of preservation of plant structures is comparable to that of Carboniferous coal balls. A sampling of anatomical details is illustrated.*

Permineralized peat of Paleocene age has been discovered in the Sentinel Butte Formation near Medora, Billings County, North Dakota. Detailed plant structures are well preserved, with the state of preservation comparable to that of Carboniferous coal balls (*1*). This deposit is the first reported finding of such material in North America (*2*). Previous knowledge of the Late Cretaceous and Early Tertiary flora of the United States has been derived entirely from studies of compressions, petrified logs, and variously coalified plant remains, which generally do not provide detailed anatomical structures (*3*). A petrified peat deposit reported in Permian strata in Antarctica (*4*) has indicated the potential for a comprehensive understanding of the *Glossopteris* flora of Gondwanaland. The present finding promises to add to our knowledge of the histologic anatomy of the peat-forming swamp flora, the depositional environmentals of the North Dakota lignites, as well as the types of plant remains that comprise the lignite.

The deposit was located in the "petrified forest" area (center of section 11, township 139° N, range 101° W) on a road-cut exposure 16 km east-southeast of Medora. The petrified forest consists primarily of erect petrified conifer stumps of the Taxodiaceae, which are randomly distributed on the same stratigraphic horizon in the lower portion of the Sentinel Butte Formation. Over much of the area studied the stumps are not associated with lignite. The silicified peat was found in a relatively thin (approximately 90 cm) lignite bed exposed at a road cut. The silicified bed, about 15 cm thick and 1 m long (in cross section), occurs near the top of the coal bed. Several petrified stumps are also found associated with this lignite bed. The uppermost parts of the tapering stumps generally penetrate through the coal bed and come in contact directly with the overlying grayish, sandy siltstone.

Macroscopic examination of the upper and lower surfaces of the silicified peat reveals characteristic features similar to those of a modern peat surface, with scattered plant debris in various degrees of decomposition, fragments of wood, twigs, branches, and roots. In cross section, cylinders of xylem (Fig. 1A) of various sizes (from a fraction of a millimeter to several centimeters) constitute an important and most conspicuous portion of the petrified peat. These cylinders are somewhat compressed, the larger with a ratio of approximately 3/1 between the horizontal and vertical axes. The ratio is much smaller for the small xylem cylinders, which are more abundant in the petrified peat.

Microscopic examination of thin sec-

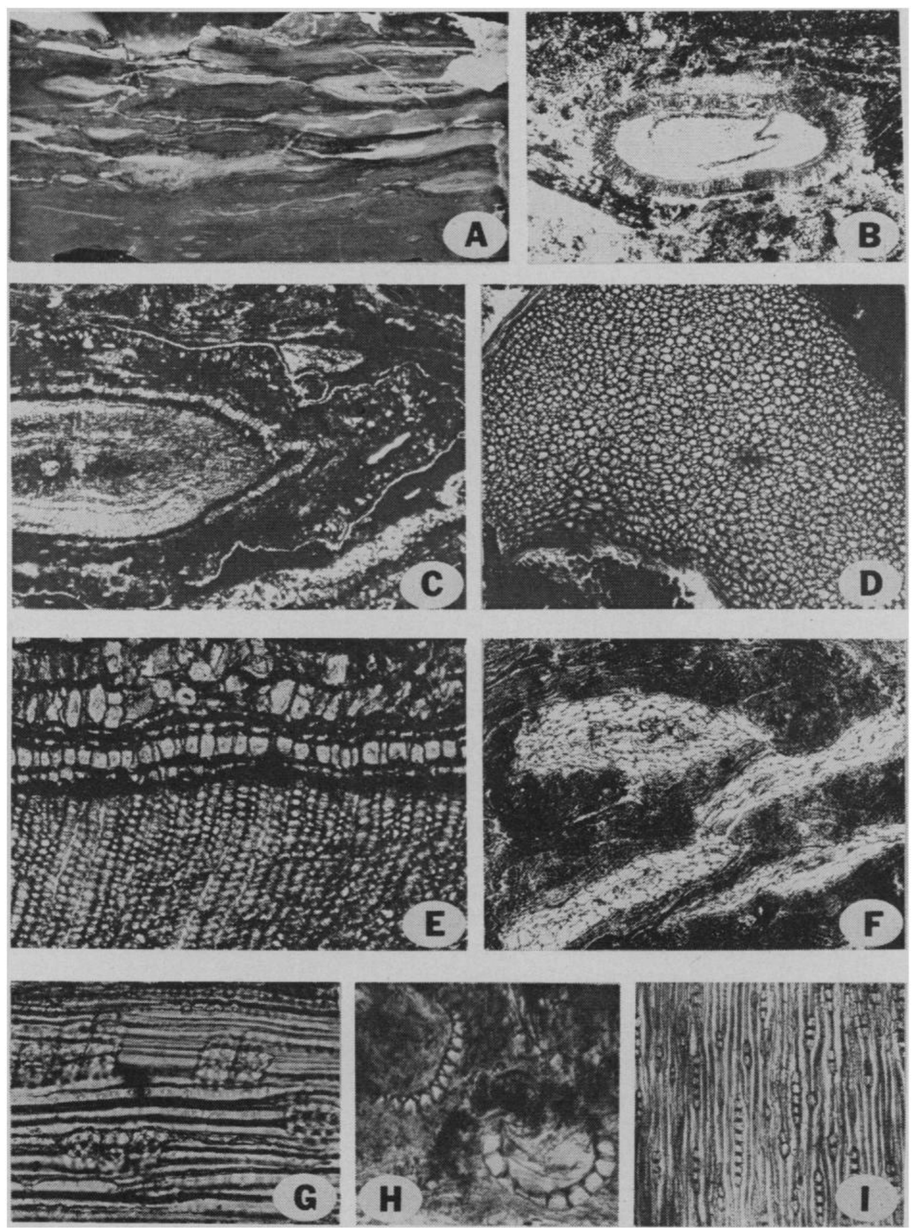

Fig. 1. (A) Cross section of siliceous "coal ball" showing many roots in cross section and oblique section (× 0.37). (B) Section of a possible conifer seed (× 70). (C) Transverse section of a possible young root. The secondary wood and one layer of phloem cells are well preserved. The cambium was not preserved. Epidermal cells are evident (× 70). (D) Unidentified parenchymatous tissue (× 80). (E) Transverse section of a portion of a possible root showing secondary xylem and several layers of well-preserved stone cells (× 100). (F) Rootlets (× 80). (G) Radial section of secondary wood showing tracheids with bordered pits and rays (× 200). (H) Fern annuli (× 200). (I) Tangential section of wood showing uniseriate ray cells and tracheids (× 100).

tions reveals well-preserved plant organs and tissues, with conifer wood possessing distinctive secondary xylem predominating. Young roots with well-developed tracheids and wood rays reveal a tissue surrounding the xylem, which may be phloem with definite alternating rows of thick-walled fibers (Fig. 1E). The cortex is usually not well preserved (Fig. 1C), whereas the epidermis when present is sharply delineated by its rather wavy cuticular layer (Fig. 1C). The tracheids of the primary xylem possess a helical secondary wall; those of the secondary xylem have uniseriate, bordered pits with crassulae on the radial section (Fig. 1G). The rays are uniseriate, ranging from two to eight cells (Fig. 1I).

Other structures observed include a seed of possible conifer origin with a well-preserved embryo and several well-preserved fern annuli.

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References and Notes

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2. Silicified beds of possible lignite origin have been reported in the past, but none possess well-preserved plant structures.
3. R. W. Brown, *U.S. Geol. Surv. Prof. Pap. 375* (1962); E. Dorf, *Carnegie Inst. Wash. Publ. 508* (1942).
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5. I thank V. Facey for critically reviewing the material and offering valuable suggestions. This work was partly supported by a faculty research grant from the University of North Dakota.

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Around-the-World Atomic Clocks: Predicted Relativistic Time Gains

Abstract. *During October 1971, four cesium beam atomic clocks were flown on regularly scheduled commercial jet flights around the world twice, once eastward and once westward, to test Einstein's theory of relativity with macroscopic clocks. From the actual flight paths of each trip, the theory predicts that the flying clocks, compared with reference clocks at the U.S. Naval Observatory, should have lost 40 ± 23 nanoseconds during the eastward trip, and should have gained 275 ± 21 nanoseconds during the westward trip. The observed time differences are presented in the report that follows this one.*

One of the most enduring scientific debates of this century is the relativistic clock "paradox" (*1*) or problem (*2*), which stemmed originally from an alleged logical inconsistency in predicted time differences between traveling and reference clocks after a round trip. This seemingly endless theoretical debate, which has flared up recently with renewed vigor (*2, 3*), begs for a convincing empirical resolution with macroscopic clocks. A simple and direct experimental test of the clock problem with portable atomic clocks is now possible because of the unprecedented stability achieved with these clocks (*4*).

In this first of two reports, we present relativistic time differences calculated from flight data for our recent around-the-world flying clock experiments. The theory predicts a detectable effect with cesium beam clocks if they are flown around the world at typical jet aircraft speeds (*4*). Moreover, it predicts an interesting asymmetry in the time difference between the flying clocks and a ground reference clock, depending on the direction of the circumnavigation (*4*). Predicted time differences are compared with our observed time differences in the following report.

A brief elementary review of the theory seems appropriate, particularly because of some confusion about the capacity of such experiments to produce meaningful results (*5*). Special relativity predicts that a moving standard clock will record less time compared with (real or hypothetical) coordinate clocks distributed at rest in an inertial reference space. For low coordinate speeds ($u^2 \ll c^2$), the ratio of times recorded by the moving and reference coordinate clocks reduces to $(1 - u^2/2c^2)$, where c is the speed of light. Because the earth rotates, standard clocks distributed at rest on the surface are not suitable in this case as candidates for coordinate clocks of an inertial space. Nevertheless, the relative timekeeping behavior of terrestrial clocks can be evaluated by reference to hypothetical coordinate clocks of an underlying nonrotating (inertial) space (*6*).

Table 1. Predicted relativistic time differences (nsec).

Effect	Direction	
	East	West
Gravitational	144 ± 14	179 ± 18
Kinematic	—184 ± 18	96 ± 10
Net	−40 ± 23	275 ± 21

For this purpose, consider a view of the (rotating) earth as it would be perceived by an inertial observer looking down on the North Pole from a great distance. A clock that is stationary on the surface at the equator has a speed $R\Omega$ relative to nonrotating space, and hence runs slow relative to hypothetical coordinate clocks of this space in the ratio $1 - R^2\Omega^2/2c^2$, where R is the earth's radius and Ω its angular speed. On the other hand, a flying clock circumnavigating the earth near the surface in the equatorial plane with a ground speed v has a coordinate speed $R\Omega + v$, and hence runs slow with a corresponding time ratio $1 - (R\Omega + v)^2/2c^2$. Therefore, if τ and τ_0 are the respective times recorded by the flying and ground reference clocks during a complete circumnavigation, their time difference, to a first approximation, is given by

$$\tau - \tau_0 = -(2R\Omega v + v^2)\tau_0/2c^2 \qquad (1)$$

Consequently, a circumnavigation in the direction of the earth's rotation (eastward, $v > 0$) should produce a time loss, while one against the earth's rotation (westward, $v < 0$) should produce a time gain for the flying clock if $|v| \sim R\Omega$.

General relativity predicts another effect that (for weak gravitational fields) is proportional to the difference in the gravitational potential for the flying and ground reference clocks. If the surface value of the acceleration of gravity is g and the altitude for the circumnavigation is $h \ll R$, the potential difference is gh, and Eq. 1 then reads

$$\tau - \tau_0 = [gh/c^2 - (2R\Omega v + v^2)/2c^2]\tau_0 \qquad (2)$$

The gh/c^2 term, which is related to the gravitational "red shift," predicts a time gain for the flying clock irrespective of the direction of the circumnavigation. For typical aircraft speeds and altitudes, both the gravitational and kinematic terms in Eq. 2 are comparable in absolute magnitude, and $v^2/2c^2$ is small compared with $R\Omega v/c^2$. For a westward circumnavigation ($v < 0$) both terms are positive and they add to give a large net time gain, but for an eastward circumnavigation ($v > 0$) they tend to cancel and produce a net time differ-