The Fossil Forests of the Yellowstone Region

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Remains of ancient trees are preserved in many parts of the world in varied formations — from the rocky bluffs protruding through the ice sheets of Antarctica to the barren lands of Spitsbergen far north of the Arctic circle. Nor are the occurrences restricted to any particular level. Large stumps of extinct types of trees are known in ancient, low-lying Devonian strata. By contrast, in Alaska's Valley of Ten Thousand Smokes, in Oregon's Lava Cast Forest, and in Hawaii's recent lava flows may be found the empty casts of intact wood of trees preserved in the last few centuries, some even within the lifetime of persons now living.

The Petrified Forest National Monument near Holbrook, Arizona, with abundant silicified logs preserved in rock strata of various tints and hues forming a "painted" desert, is certainly the most famous locality. This widespread formation extends far beyond the boundaries of the monument and into several states. Nearly all of the trees here are prostrate, and many give evidence of having been washed around or transported by water. Some seem to have been battered, others charred; still others are near tree-length and intact. The delicate structural features of the wood are seldom well-preserved, and leaf imprints are uncommon.

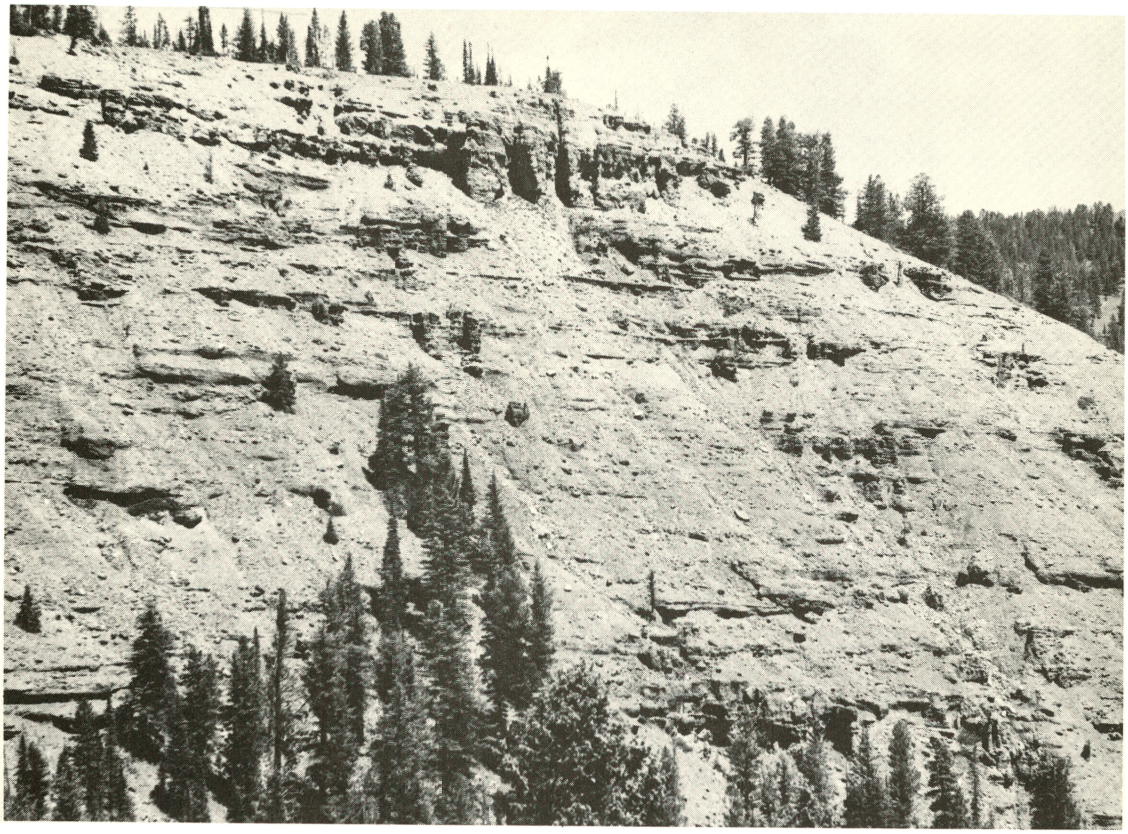
Of all known fossil forests in the world, however, none can equal those in the Gallatin Mountains of northwest Wyoming and southern Montana. Here are found a series of what have been interpreted as more than 40 forests — with stumps standing upright in the position of growth, frequently so well preserved that from a distance the fossil stumps may be difficult to distinguish from those of living trees (FIGURES 1-4). Although the size tends to vary from level to level, stumps range from about an inch to more than 12 feet in diameter and from a few inches to over 20 feet in height.

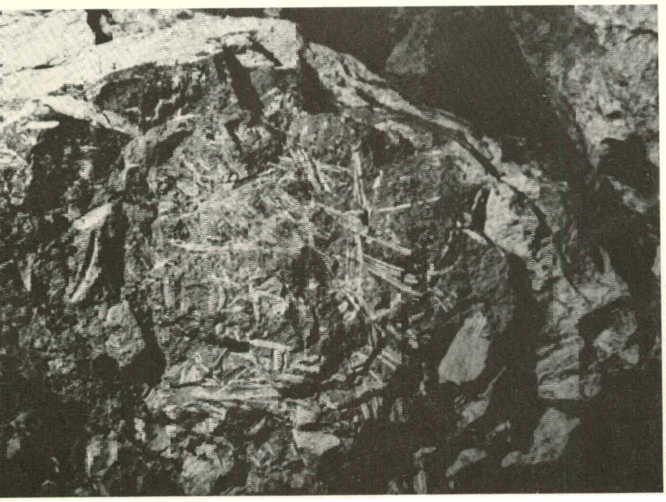
Associated with many of these forests are remains of ancient "soils"[1] with well-preserved leaves, needles, twigs, and occasional cones in the upper portions, and with organic detritus, roots, and rootlets as one proceeds down through the volcanic sediments on which the forests were growing (FIGURES 4-6). The quality of preservation of the wood and leaves is often superb. Well-defined growth-rings and intricate details of cell structure are visible in the wood, and the natural crinkly surface one encounters on dry leaves (with the patterns from the veins and venules) are visible on many of the leaf imprints (FIGURES 7-10, 18).

The fossil remains are not at just one level in the rock strata but at more than 40 successive levels, or zones, spaced through approximately 1,500 feet of volcanic strata (FIGURE 11). The evidence of the mechanism of growth, burial, and preservation (discussed in some detail later in the paper) seems in general to suggest: (*a*) the growth of a forest; (*b*) an episode of volcanism of the "explosive" variety, with resultant distribution of a layer of fragmental volcanic rock; (*c*) redistribution of volcanic materials and volcanic ejecta toward lowlands by wind, volcanic mudflows, and stream action, to cover the ground and surface-litter and to bury the lower portions of the tree trunks; (*d*) death of the trees — with decay of parts exposed above the ground, decay of many of the buried parts of those varieties of trees with wood of insufficient resistance to persist long enough for mineral infiltration, and beginning of petrification in the stump section of resistant types of trees and fallen logs covered by volcanic ejecta; (*e*) growth of another forest on the fragmental volcanic ejecta that destroyed the previous forest; (*f*) renewal of volcanic activity and partial burial of the second forest; (*g*) continuation of successive cycles of growth, burial, and partial preservation through a period of centuries — until many hundreds of feet of volcanic rock and more than 40 levels of forest have been buried. In this way, as a result of the renewed episodes of volcanic activity, a "layer-cake-like" buildup of volcanic deposits is formed, with remnants of forest preserved at many successive levels.

Subsequent to the period of intermittent volcanic activity and buildup of deposits, there is evidence of regional uplift of several thousand feet to form an elevated volcanic plateau. After the uplift, streams and rivers cut valleys in this plateau, dissecting the approximately level strata and leaving the edges of the rock layers exposed along the margins of the newly created valleys. On these exposed edges one can see the successive layers of volcanic ash and breccia (bresh'i-a) deposits, with enclosed zones of logs, leaves, and other plant materials.

FIGURE 1/ Ten-foot *Sequoia* on Ramshorn, at 10,000-feet. One of a series of stumps of approximately equal size on this level. *Opposite.*





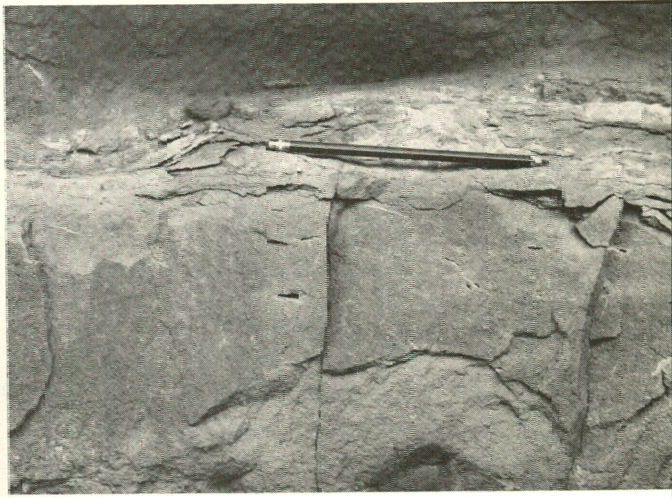
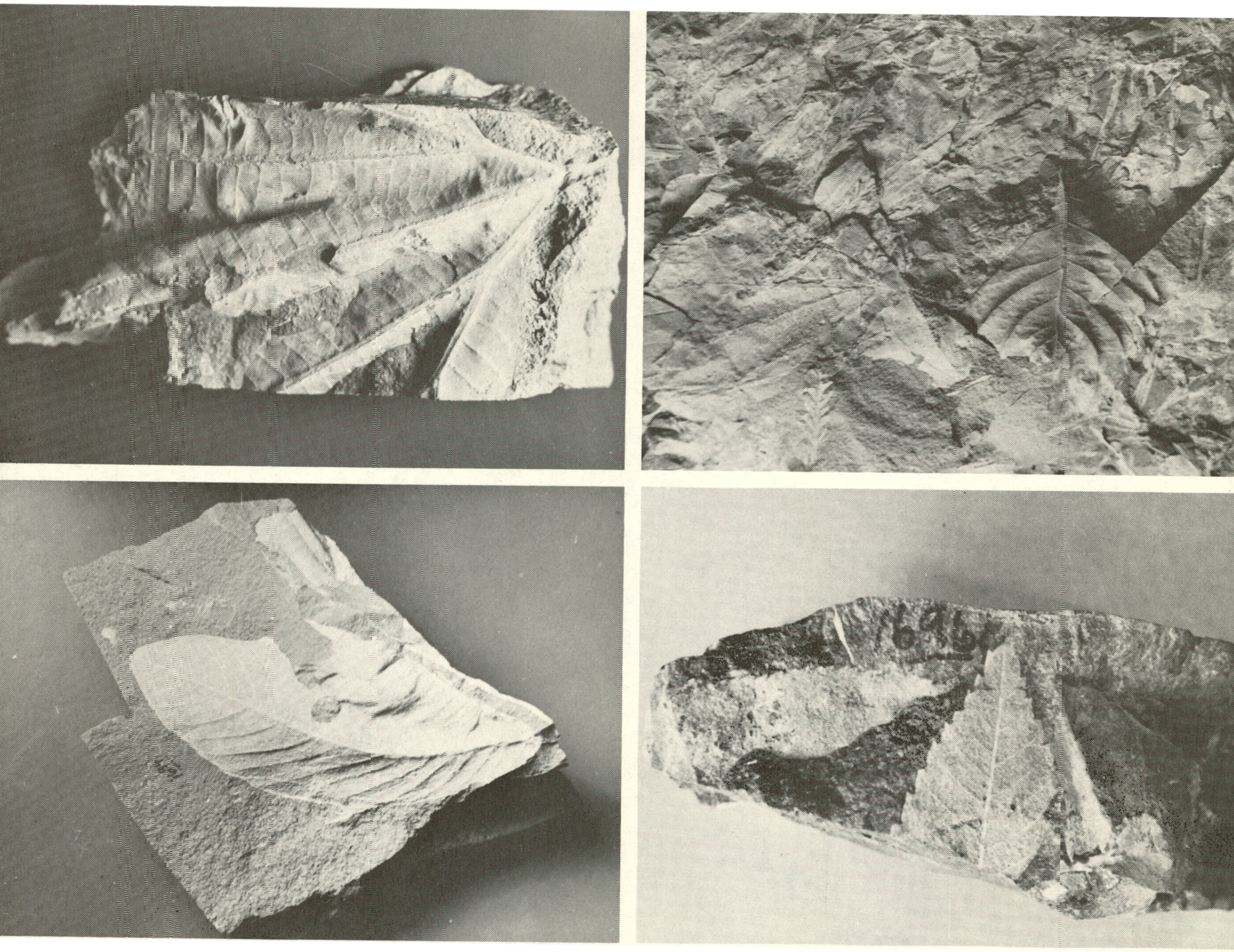


FIGURE 2/ Eastern end of Plot 1-B near Specimen Creek. Observe the approximate level surfaces (bedding planes) that have prevailed as the strata have been deposited. *Opposite, above*. . . . FIGURE 3/ Closer view of Plot 1-B, showing stumps on several levels. *Opposite, below*.

FIGURE 4/ Stumps on level 11 of Plot 1-B, with roots extending into the level just below the organic zone. *Above*. . . FIGURE 5/ Needles on the upper surface of zone, level 11, plot 1-B. *Below, left*. . . . FIGURE 6/ Roots exposed below the organic zone, level 11, Plot 1-B. *Below, right*.



FIGURES 7-10/ Leafprints, with natural crinkly surface of dry leaves, indicating preservation in dry condition by volcanic ash. *Left to right.*

The transformation of high-level plateaus into mountainous regions by the forces of stream and river erosion is one of the major types of mountain-building represented in many of the mountainous regions of the world. In the Yellowstone region, the Gallatin and Absaroka Mountains, in which the fossil forests are preserved, are built of flat-lying dissected volcanic strata that were once continuous across the valleys before the valleys were cut into the plateau.

As it would require a period of many centuries for accumulation if these deposits represent the remains of a series of consecutive forests, the question is sometimes raised whether the upright stumps are actually in position of growth or have been transported and deposited level upon level in a very short period of time. It is natural that conservative Christians would search for a solution to the seeming discrepancy between the record in the rocks, which is said to point to long time periods, and the scriptural account, which many believe portrays only a few thousand years since the Creation. The question has been brought into sharper focus in the last few years as the number of forest levels recorded has increased from the 12-18 known in the deposits of the northeast sector of Yellowstone Park for nearly a century to 44 or 45 levels as the deposits in the extreme northwest corner of the park have been studied and as the relation of the fossil forests to older and younger strata has been recognized.

Much of the discussion of possible transport models has been oral, and various suggestions have been or are being introduced. The most comprehensive statement of a preliminary model of which we are aware is by Coffin (1968:23-27). Since we have not been able to see how the field evidence can be satisfied by transport models thus far proposed, we do not have any version of such a model to suggest for evaluation or testing.

Perhaps it would be helpful, however, to list some of the features of a minimal model: (*a*) breaking loose from the ground of large numbers of stumps, the tops of which have been broken off (perhaps by high winds); (*b*) transport of some of these stumps, together with floating logs, leaves, etc., to the vicinity of the Absaroka Volcanic Field; (*c*) settling of scattered stumps and other tree remains on a volcanic substrate (the stumps are generally thought to have floated and settled in upright positions because of waterlogged basal ends); (*d*) burial by volcanic rocks from the many active volcanoes in the region (including air-dropped ash and breccia, volcanic mud or debris flows, and volcanic conglomerates or sandstones); (*e*) repetition of many cycles of flotation and burial in relatively rapid succession until thousands of feet of volcanic rocks with levels of stumps and other organic remains have been deposited.

In our exploration of the fossil forests, we have attempted to find a solution to the time problem and at the same time to discover truth. Since the nature and significance of the fossil forest deposits have been the subject of considerable discussion and interest in Adventist circles during the past ten to fifteen years, it seems timely to review several of the lines of evidence bearing on the questions of (*a*) whether a series of forests in position of growth is represented or (*b*) whether the fossil remains have been transported to their sites of deposition in a short time. Studies in progress by a number of investigators on these and other lines of data should provide additional information for understanding the sequence of fossil forest remains.

STUDIES ON THE FOSSIL FORESTS

The petrified forests of Yellowstone National Park were first described and interpreted by Holmes in 1878 as a series of superimposed forests, and it is his cross-sectional diagram of the "fossil forest" that has been reproduced in countless geology textbooks (FIGURE 11). The most comprehensive description and discussion of the fossil forests and associated leaf fossils is the monumental study by Knowlton published as part of Monograph 32 of the United States Geological Survey (1899:651-791). More recently, Dorf, of Princeton, and his students have made a rather thorough restudy of the deposits exposed in the northeast section of Yellowstone, including the stratigraphy, volcanic breccias, and revision of the flora. Thus far, however, only a preliminary report of the revision of the flora and several theses and nontechnical articles on the fossil forests have been published (Brown 1957; Dorf 1960:164). The recent thorough field study on the stratigraphic framework of the Absaroka Volcanic Field by Smedes and Prostka of the U. S. Geological Survey (1972) is an excellent resource on the origin, geological relations, distribution, and stratigraphy of the beds in which the forests are preserved. A number of lesser studies and popular descriptions are listed in the literature cited at the end of this paper (see Weed 1892; Hague 1896; Read 1933; Chapman and Chapman 1935; Andrews 1939; Andrews and Lenz 1946; Sanborn 1951; Beyer 1954; Hall 1961).

Of particular interest to students of science and religion are some of the references to the forests in various apologetic works. Whitcomb and Morris (1961: 418-421) interpret the fossil forests as catastrophically destroyed, uprooted, transported by water to the site of deposition, and there interbedded with volcanic ejecta. It is doubtful, however, that these writers had seen the area in the field or had read the basic studies by Knowlton and others, because several statements made do not agree with facts that have been understood since the time of discovery and early description of the phenomena. For example: "Only occasional trees remain upright;" there are "no limbs or fossil foliage as one would expect if the complete trees had suddenly been inundated."

Cook (1966:273-275), an industrial chemist, suggests a variety of possible solutions, including the idea that the forest levels have resulted from a series of fractures in which the several levels have been slid or thrust one over another. None of the proposals are evaluated on the basis of the field data or the technical literature. No evidence is presented to indicate widespread low-angle faulting between forest levels — which would be conspicuous if faulting had occurred.

Of a very different nature is the much more thorough and carefully worked out proposal introduced by Coffin (1968). In the summer of 1968 he, Donald W. Jones, and two assistants spent six weeks studying the fossil forests of the Speci-

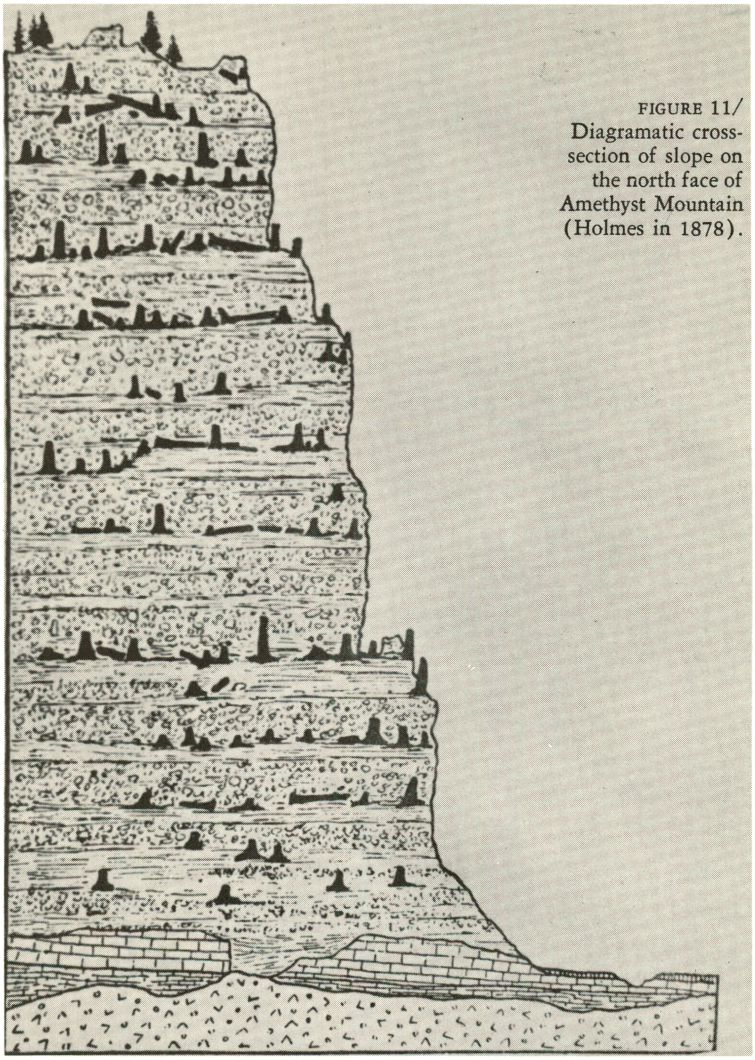
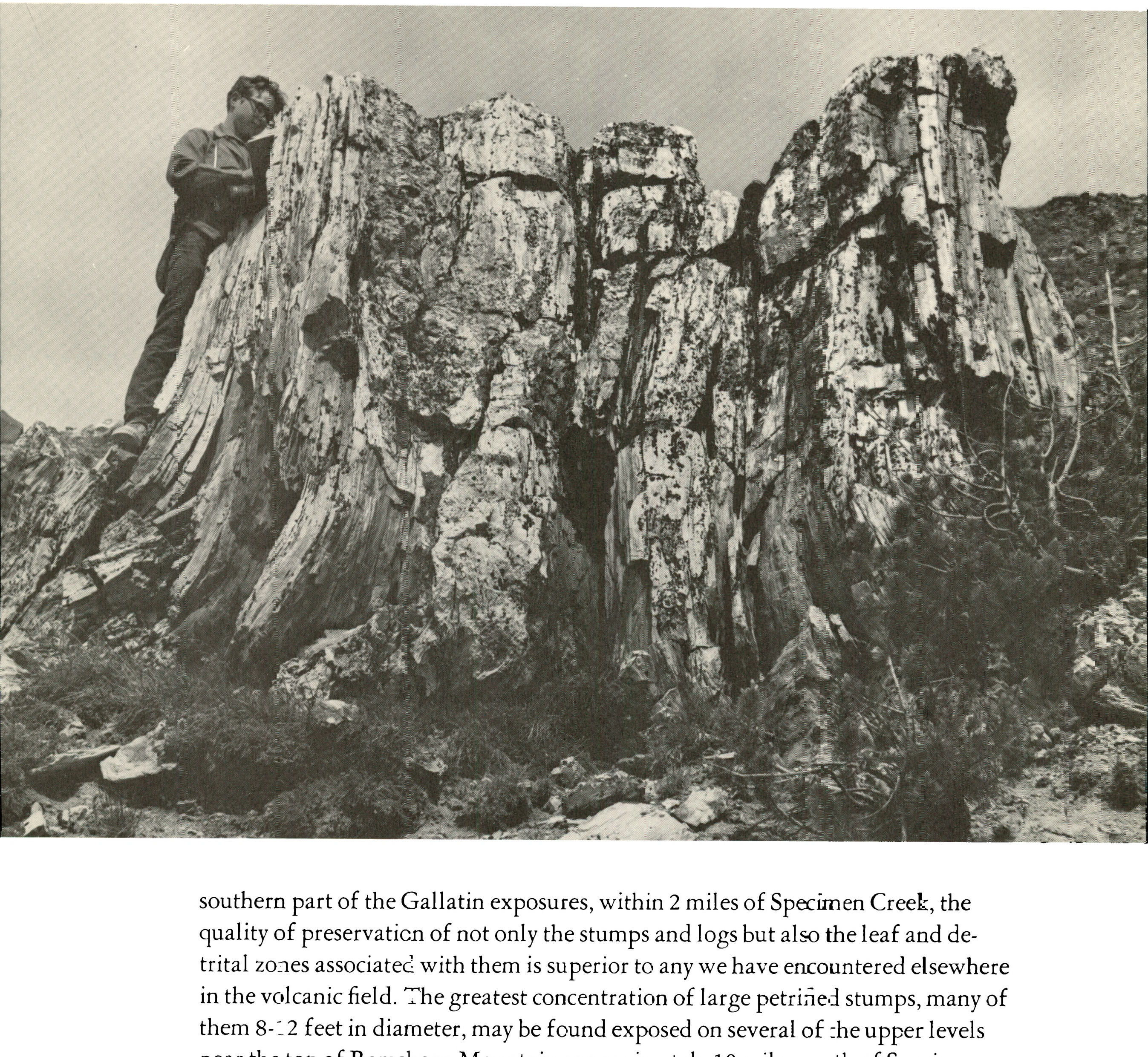


FIGURE 11/ Diagramatic cross-section of slope on the north face of Amethyst Mountain (Holmes in 1878).

men Creek area in the Gallatin Mountains. Using data and plots from our studies in the same area the previous field season, they made additional detailed plots and observations, particularly in the area we had designated Plot 1-B. The results of their observations are summarized in two mimeographed papers (1968) that have been rather widely distributed to science teachers and other associates. Coffin presents an impressive array of points that he deems are not compatible with the interpretation that the fossil forests are in position of growth. He then introduces a tentative transport hypothesis similar in certain respects to the hypothesis he has published as an explanation for the upright stump horizons in the Carboniferous strata exposed in the sea cliffs near Joggins on the Bay of Fundy at Nova Scotia (Coffin 1969). Since 1968, Coffin and several students and associates have spent



southern part of the Gallatin exposures, within 2 miles of Specimen Creek, the quality of preservation of not only the stumps and logs but also the leaf and detrital zones associated with them is superior to any we have encountered elsewhere in the volcanic field. The greatest concentration of large petrified stumps, many of them 8-12 feet in diameter, may be found exposed on several of the upper levels near the top of Ramshorn Mountain approximately 10 miles north of Specimen Creek (FIGURES 1, 12, 13, 38, 39).

In the 1967 field season, three fossil forest exposures north of Specimen Creek, within 3 miles of U. S. Highway 191, were selected for detailed study (FIGURE 14). Plots were constructed on a photographic base map. Petrified stumps, logs, and root and leaf zones were recorded and detailed data of a broad range were gathered for 44 stump horizons, or forest levels (FIGURES 15-23). This number of levels exceeds by 12 the highest number previously reported.[2]

FIGURE 13. Counting rings on a large stump north of Ramshorn.

THE GEOLOGIC SETTING

We acknowledge our indebtedness and express our appreciation to Edward N. and Marilyn P. Lugenbeal, Juanita and Stanley Ritland, Brenda Butka, Larry Mitchell, and other students and associates who have worked with us in gathering and interpreting data from these plots and from numerous other fossil forest exposures in the Absaroka Volcanic Field. Field study within the boundaries of Yellowstone National Park was made possible through the interest and cooperation of the National Park Service. Portions of the results of the 1967 field season are included in masters theses submitted to Andrews University by Marilyn Lugenbeal and Juanita Ritland (May 1968).

The fossil forests of the Gallatin Mountains are not a local or isolated series but part of a much wider picture, with other similar spectacular occurrence on the flanks of the Beartooths to the east, at many localities in the Absaroka Range to the south and east, and in Owl Creek Mountains far to the southeast (FIGURE 24, Map 1). These all occur in what seems to have been originally a continuous and considerably more extensive volcanic field, the dissected remnants of which still cover some 9,000 square miles and embrace approximately 7,000 cubic miles of deposits.[3]

The volcanic sequence has been named the Absaroka Volcanic Field because the Absaroka Range represents the heart of the field and its most extensive component. The proper technical designation for the volcanic series, given by Smedes and Prostka (1972), is *Absaroka Volcanic Supergroup.* Most of the exposures are within an area of approximately 70 by 170 miles in a northwest-southeast trending direction from the vicinity of the Stratified Wilderness area north of Dubois, Wyoming, continuing northwest through the eastern and northeastern portions of Yellowstone National Park, and extending well beyond to the mountains just south of Bozeman, Montana. Many of the best-known fossil deposits are in or near the park; hence the fossil remains are often referred to as the fossil forests of Yellowstone.

It is important to recognize that the fossil forests represent only part of a much larger picture. Although it is not possible in a short paper to give an adequate treatment of the geologic setting, a few glimpses may give some idea of the complex and fascinating story. Lying beneath the volcanic strata is a sequence of more than a score of sedimentary rock formations,[4] some with land life (such as mammals, dinosaurs, plants, coal beds, land snails, or freshwater mollusks) and other formations with various forms of sea life (FIGURE 25). Each of these rock formations is a characteristic assemblage that differs from the remains in the beds above and below. Some contain rounded boulders eroded out of fossil-bearing rock and redeposited in a later rock formation. Land and sea deposits may alternate; or several deposits of one may be followed by one or more of the other.

Nor are the fossil forest volcanic strata the final chapters in the story. Above these strata, locally, are other volcanic rocks called welded tuff. After the volcanic activity there has been very extensive stream erosion and glaciation, as is amply demonstrated by the deep valleys, steep mountain faces, glacial lakes, and other features carved into the Absaroka Volcanic Field, originally an area of low relief (FIGURE 26). In some of the newly formed valleys carved into the Absaroka volcanics by erosion are found the stratified remains of ancient Indians, together with typical assemblages of artifacts. Typical sites are found beneath overhanging cliff faces, where natural shelters have been formed by the forces of erosion. One of the better-known sites is Mummy Cave, located on the North Fork of the Shoshone River west of Cody, Wyoming. The fact that the floor of Mummy Cave is only a few feet above the present water level of the river demonstrates that the evidence for ancient Indians at Mummy Cave postdates almost all of the erosion that has occurred in the Absaroka Volcanic Field. Nevertheless, Mummy Cave is said to contain some 38 distinct cultural levels. Radiocarbon dates from 7280 B.C. to A.D. 1580 are reported from 15 of the levels (Wedel et al. 1968:184-186) (FIGURE 27).

It has been possible to present samples of only a few of the salient facts in the general picture. Because of the limitations of space, more is omitted than is in-

FIGURE 14/ Exposures north of Specimen Creek, with 44 levels of petrified stumps plotted (Plots 1-A above in upper left and 1-B below; Plot 2 in lower right).

cluded. Any valid model of the geologic history of the Yellowstone region must include both time and mechanisms for the following phenomena: (*a*) accumulation of more than a score of older sedimentary marine and land strata having an aggregate thickness of thousands of feet, with erosional gaps at certain levels, and with diverse but distinctive fossil assemblages; (*b*) uplift, erosion, and truncation of many strata before the deposition of the Absaroka volcanics; (*c*) deposition of up to 5,000 feet of volcanic deposits during a series of volcanic episodes punctuated by more than 40 intervals, each with sufficient time for the growth of a forest; (*d*) extensive dissection of the volcanic field by stream and glacial erosion, exposing on the canyon walls the forest-bearing strata; (*e*) accumulation of many levels of ancient Indian occupation and artifacts in the posterosion valleys near the present-erosion level.

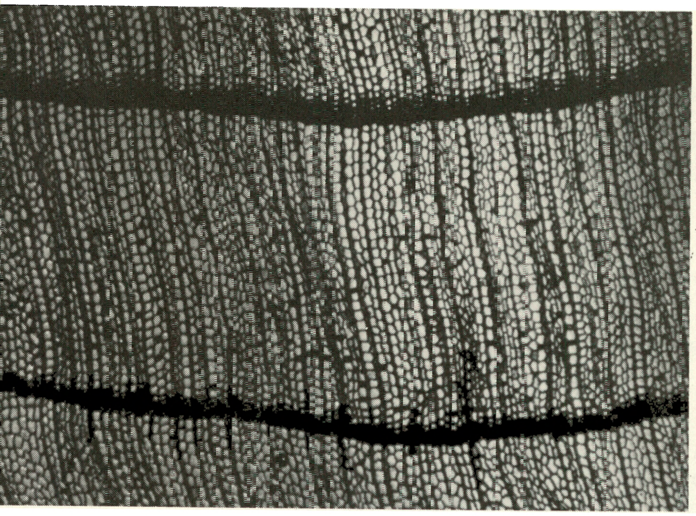
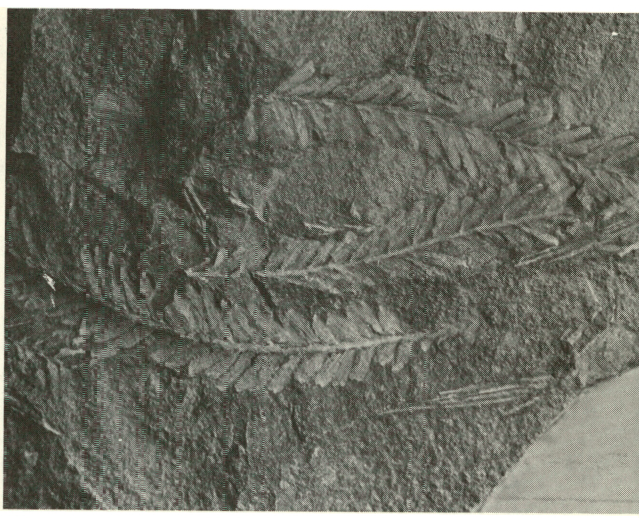
The rocks in which the fossil forests are preserved are derived from material ejected during terrific volcanic explosions. During such explosions, rock fragments ranging from dust-sized particles to boulders many feet in diameter are thrown hundreds to thousands of feet into the air and dropped in chaotic assemblages around the vents from which the rocks have been extruded. The finer the particles, the further they are transported from the vent. The Katmai eruption in

FIGURE 15/ Three-foot conifer (pine type) on level 43 of Plot 1-A.

1912 provides a recent example on a small scale (FIGURES 28-31). A blanket of fine volcanic rock fragments approximately a foot thick was spread over much of the eastern part of Kodiak Island approximately 100 miles from its source-vent in the Katmai area on the mainland. A 55-inch layer of airborne volcanic fragments was deposited at the head of Amalik Bay 15 miles from the volcano. Takli Islands, 21 miles southeast of the volcano, were covered with 3 feet of volcanic detritus (Martin 1913:167-170).

Because of the fragmental and often angular character of the rock, such ejecta are described by the term *pyroclastic* (fire fragments) or *volcaniclastic* (volcanic fragments).[5] These rocks should not be confused with the more familiar type of volcanic eruption where molten rock flows from volcanic vents, or fissures, and cools to form dense crystalline lava rock. *Breccia* is a general term for any rock whose components are angular rather than waterworn or rounded. When the volcanic fragments are mostly fine angular material less than 2-4 millimeters in diameter, they may be referred to as *ash* if loose or *tuff* if cemented to form a solid rock. If coarser angular pieces 2-4 millimeters or more in diameter predominate, the resultant rock is a true *volcanic breccia*. A *volcanic conglomerate* may result when the deposits are reworked by running water and become smoothed

FIGURE 16/ Twelve-foot *Sequoia* on slope south of Plot 1-A (level 29).

and rounded. Deposits that have resulted from rapid mass-flowage of rock debris that originates on the slopes of a volcano are referred to by the Indonesian term *lahar.* Such material is lubricated by water and, depending on the texture, may be referred to as a *debris-flow* or a *mudflow.*

The rocks of the Absaroka Volcanic Field are the result of many episodes of volcanic activity from shield volcanoes scattered throughout 10,000 square miles. As a single period of volcanic activity may result in a range of deposits, the concept of a volcanogenic unit (i.e., those deposits resulting from a single episode of volcanic activity) may be very helpful in the study and description of these deposits (Smedes and Prostka 1972; Parsons 1967).

On the flanks of the volcanoes near the vents and forming the upper portion of the volcanic cone is found a chaotic assemblage of coarse breccias, lava flows, lahars, pumice deposits, and tuffs sloping away from the vent at angles of 30 degrees or more (FIGURE 32). Referred to as the vent facies, these rocks may be interrupted by dikes, plugs, and other extrusive features. The rock fragments in the breccias are relatively angular and are unsorted; they range from less than an inch to several feet in diameter. Progressing away from the volcanoes, the primary slope is reduced to less than 5 degrees. Grading out from the volcanic centers for 10-20 miles, the beds tend to decrease in average size and thickness; the proportion of volcanic conglomerate and sandstone deposits (reworked, more or less rounded, partially sorted, and stratified by stream action) tends to increase. The apron of partially reworked volcanic deposits is referred to as the *alluvial facies.* In this apron there are still many zones of air-dropped volcanic ash and fine breccia (Smedes and Prostka 1972:64; Smedes 1967 personal communication). Tongues of relatively unsorted lahar deposits may include boulders from small size to more than 25 feet in diameter.

FIGURE 17/ Photomicrograph of rings of 12-foot *Sequoia* displaying rows of tracheids in the xylem. *Left.* . . . FIGURE 18/ Fossil *Sequoia* needles. *Right.*

Features of the rock fragments, as well as the beds themselves, are helpful in determining the origin. Dikes and pipes of breccia intruded in and near the volcanic vents indicate that brecciation, or fragmentation, occurred in the volcano; the volume of the deposit suggests whether the extrusion was composed of large volumes of material broken up underground or just material from the walls of the vents and fissures during eruption. Other matrices indicate that some of the flows had magmatic matrix (Parsons 1967). Abundant zones of airfall tuff and fine breccia retain many of the sharp edges on the volcanic glass fragments, whereas those reworked by water show signs of wear on these edges.

After an initial period of volcanic activity, the ejecta often becomes saturated with water from the heavy rains that frequently accompany the activity. Thus saturated, the material may take on the consistency of soft mud or concrete and may flow out for miles into the lowlands, as tongues projecting from the volcanoes. In recent times such lahars have spread out in lowlands, transporting large and small boulders, surrounding trees, and covering large areas of land some miles away from the volcanic vents. They may come to rest as beds with slopes as low as .5 percent (Crandell and Waldron 1956:349-362). Lahars are common features both in the vent and the alluvial facies of the Absaroka Volcanic Field.

FIGURE 19/ Organic zone below 12-foot *Sequoia*. Numerous leaves are preserved on the upper surface. One can be seen to the right of the center. Observe that the tuff is more highly indurated (cemented) in the organic zone.

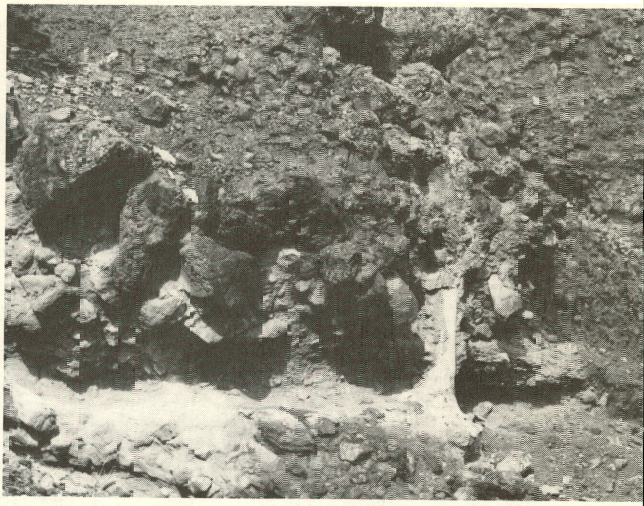
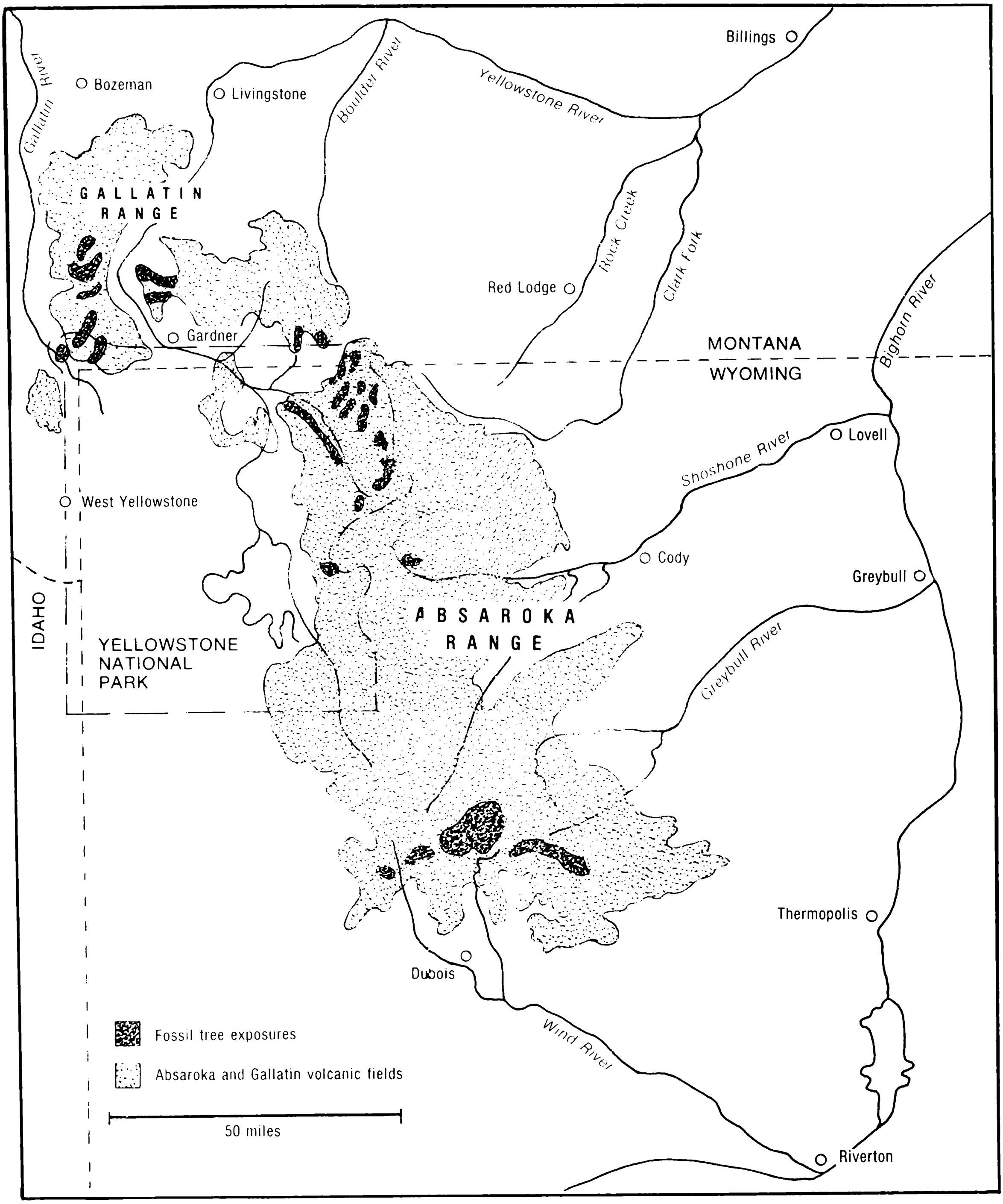


FIGURE 20/ Five-inch conifer of pine type. One of many small trees on level 18 of Plot 1-B. None of the upright stumps on this level exceeded 6 inches in diameter. *Above*. . . . FIGURE 21/ Distant view of the same tree as in FIGURE 20. Note numerous boulders, from a few inches to 3 feet across. Probably a lahar (volcanic mudflow) is represented. *Top, right*. . . FIGURE 22/ Eight-foot *Sequoia* on level 37, Plot 1-A. *Center, right*. . FIGURE 23/ Seven-foot *Sequoia* on level 36, Plot 1-A. *Bottom right*. . . . FIGURE 24/ Map of major fossil forest outcrops in Absaroka Volcanic Field (Map 1). *Opposite*.

It is in the volcanic conglomerates, lahar deposits, breccias, and tuffs of the alluvial facies surrounding the volcanoes that logs and upright stumps are most abundantly preserved (FIGURE 32). Well-preserved fossil leaves may be found in fine-grained zones of air-drop ash in both the vent and the alluvial facies and in fine-grained sediments of the alluvial facies. They are rarely found in coarse alluvial facies deposits from which most of the fine-grained deposits have been reworked basinward (Smedes and Prostka 1972:67).



LINES OF EVIDENCE BEARING ON POSITION OF GROWTH OR TRANSPORT

ORIENTATION

The most striking and compelling feature of the fossil forests is the orientation and spacing of the trees, the vast majority being in either upright or approximately prostrate position, much as in a contemporary forest. Standing erect on the slopes, bleached by the sun or discolored by a growth of lichens, the petrified trees are likely to be mistaken for the stumps of recently living trees. With rare exceptions — such as two trees growing very close together but naturally diverging (see FIGURE 33) — the stumps are perfectly vertical. Sometimes a uniform slight tilt of 4 or 5 degrees, resulting from postdepositional warp of the strata associated with regional uplift or depression, consistently affects the strata and all stumps.

Floating stumps rarely come to rest in a perfectly vertical position, although occasionally the heavier waterlogged basal end of a tree may cause it to float in an approximately upright position because of the movement of water currents and the irregularity of root growth. But it hardly seems likely that thousands of stumps on more than a score of levels over hundreds of square miles will consistently assume and maintain a perfectly vertical position while being drifted by currents and subsequently buried by tens of feet of fine to coarse rock material. The volcanic rocks commonly include pebbles from gravel-size to boulder-size, as much as 2-4 feet in diameter at some levels. To transport such boulders requires swiftly flowing water or suspension in high-density volcanic mud that may move slowly or rapidly. Such forces would be expected to tilt or overturn even short, massive stumps. Slender stumps up to 20 or more feet tall and only a few inches to 2 or 3 feet in diameter could not possibly remain erect before such an onslaught unless they were firmly rooted (FIGURES 35-37; also 20, 21).

Nor is it feasible, for several reasons, to conclude that upright stumps would be transported in lahars (mud- or debris-flows) for significant distances. First, there is no conceivable source for large numbers of stumps on the shield volcanoes from which the lahars arise (FIGURE 32). Second, although occasionally a waterlogged tree may be of approximately the same density as water (so that it can assume an upright position in sluggish waters), lahars have a density approximately twice that of water. This would tend to force even waterlogged stumps toward the surface, where they would fall to a prostrate position on the flow (FIGURES 20, 21, 35). Moreover, in the strata encompassing the stumps (air-drop tuff, lahars, and water-deposited volcanic sediments and conglomerates), individual beds are rarely deep enough to support stumps of even modest height in an upright position.

It is well known that tree-remains transported by rivers or floods are often deposited in a chaotic condition such as one encounters in logjams or tangled masses of driftwood. Such remains have been reported in a number of fossil beds, including in certain lignite or brown-coal deposits that seem to have been formed from log-rafts (Wieland 1935:38, 39, 46; Lyell 1853:267).

An impressive feature of the Yellowstone forests, by contrast, is the apparently natural distribution or spacing of the petrified stumps such as one observes between living trees (FIGURES 38, 39). To compare the tree density in the fossil forests with that of living stands, we calculated the tree density on several levels on which the fossil trees were most common (levels 21 through 24 of a plot above Specimen Creek).[6] In doing so, we assumed that all the trees in a 15-foot-deep section of the slope were exposed. The figures arrived at were:

Level 21	71 trees per acre	Level 23	132 trees per acre
Level 22	133 trees per acre	Level 24	41 trees per acre

These compare favorably with yields of some present-day stands. Examples of trees per acre (Forestry Handbook) for fully stocked stands are:

TREES PER ACRE (by age of stands)

AGE OF STAND	25 YEARS	50 YEARS	100 YEARS	200 YEARS
Eastern Cottonwood (Mississippi Valley)	114	32	—	—
Loblolly Pine	630	325	—	—
Yellow Poplar (medium site)	264	214	—	—
Western Hemlock (medium site)	—	—	212	90

Juanita Ritland (1968:31-33; appendix B, 1-b to 4-b) reports comparable spacing and densities on certain levels in the Specimen Creek and Lamar Valley areas to densities observed in a transect through a living forest. In comparing the densities, one must take into account several factors. It is likely that stands of trees on relatively fresh volcanic deposits would not be as dense as on mature soils. Moreover, not all trees are equally likely to be preserved. Some trees decay before they are preserved, whereas others do not petrify to a state sufficiently harder than the surrounding rock to make them stand out above the loose rock that covers portions of the slope. Hence, more often than not, a significant portion of the trees that would have been growing at the time when the forest was destroyed would be missing.

PREVALENCE OF ONE SIZE CLASS ON EACH LEVEL

An explorer of the fossil forests can hardly fail to be impressed by the changing scenes from level to level. If one starts near the crest of Ramshorn with the magnificent 10-foot *Sequoia* (called King of the Forest) and continues along the side of the mountain on this same level, a whole series of naturally spaced giant sequoias of similar size are encountered, as if one were in an old-growth forest along the California coast (FIGURES 38, 39). By contrast, levels 11 and 12 (on the slope we have designated Plot 1-B north of Specimen Creek) are composed of what woodsmen often refer to as second-growth forests, most of the upright trees ranging from 10 to 18 inches in diameter. On level 18, nearly all of the upright stumps are saplings of no more than 5 inches (FIGURES 20, 21). Other levels average 30, 48, and 72 inches, etc. Although the size may vary from 1 inch to 12 feet or more on the same level, as in most present-day naturally occurring forests, the prevalence of a given size class tends to be the rule.

CHARACTER OF LEAF PRESERVATION

It is often possible to infer much about the events of burial and preservation by the nature of leaf remains. Leaves accumulating under water or in pools and becoming limp are commonly as flattened out as a sheet. Those transported in a mudflow may be rolled or curled. Those entombed by windblown sediments or volcanic ash may retain the natural surface irregularities observed in dry leaves on the floor of a living forest (FIGURES 7-10). Ordinarily a fine matrix is required to preserve leafprints.

Leaves preserved in the volcanic ash beds (tuff) of the fossil forests commonly show the natural surface irregularities. If these leaves had been transported in water for many miles, or even accumulated beneath a body of water, most of them would exhibit the somewhat flattened pattern.

Often the most delicate features in the leaf imprints, including fine veins and margin patterns, are well-preserved in an angular volcanic ash matrix. If extended transport in a mudflow had occurred, such fine features would have been obliterated by the sharp edges of the rock particles.

DIFFERENTIAL DECAY AND PRESERVATION

It is a well-known fact of nature that "dust returns to dust," that even those parts of organisms most resistant to decay ordinarily are decomposed beyond recognition within a few months or years, to be recycled as minerals or nutrients into succeeding generations of life. Some types of wood are reduced to mounds of humus on a moist forest floor in less than a decade. By contrast, stumps of a few types (such as redwood or cedar, with fungicidal properties in the wood)

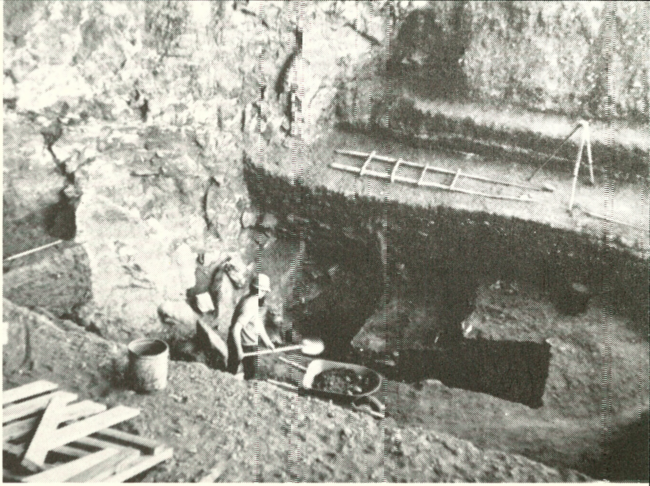
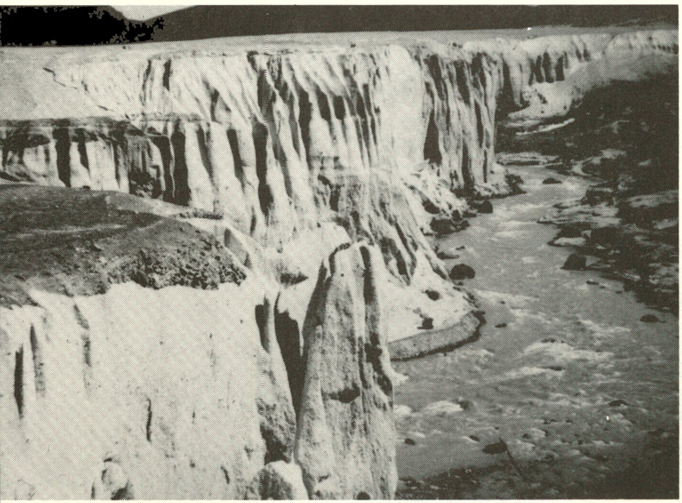
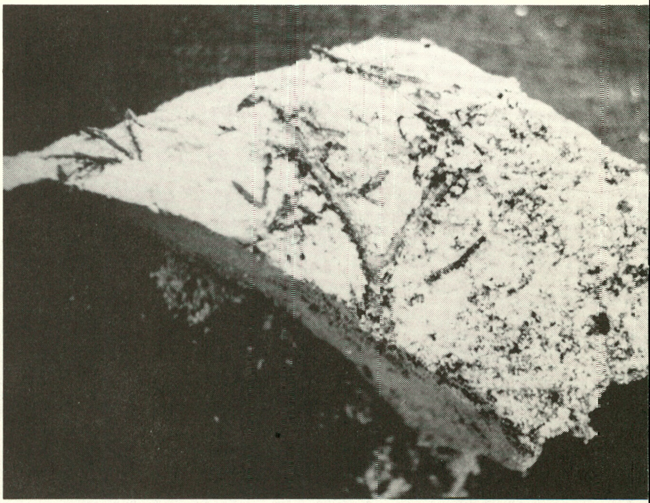
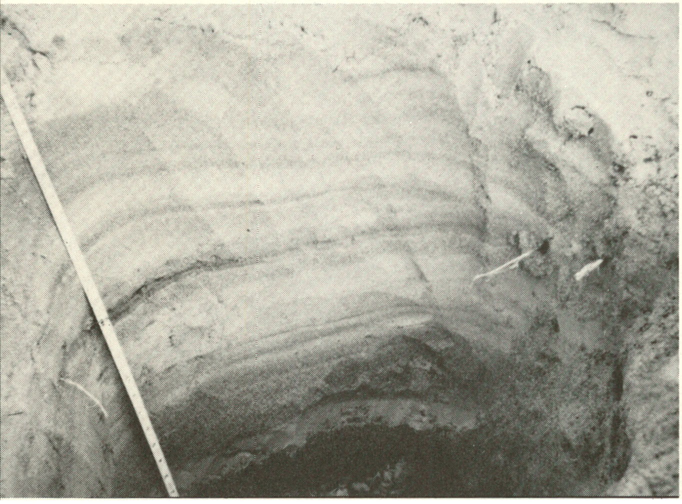
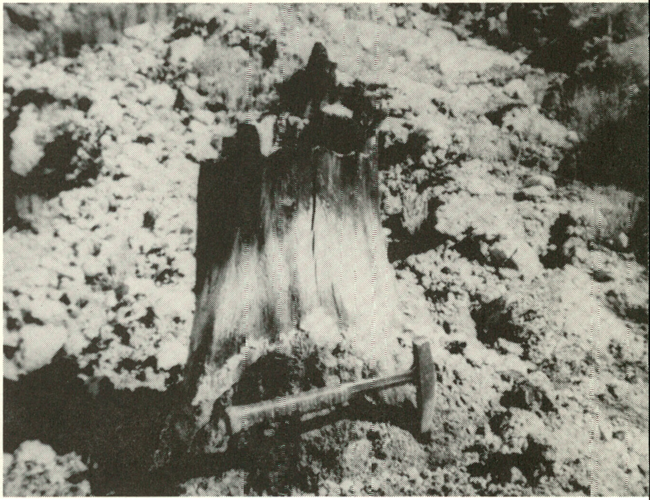







FIGURE 26/ Glacially grooved boulder above the Lamar Valley fossil forests. *Top, left.* . . . FIGURE 27/ Excavation of Mummy Cave west of Cody, Wyoming. Prostrate fossil logs are preserved in the ceiling of the cave, and uprights are found not far distant. The floor of the cave is close to the level of the present erosion, or water level, of the Shoshone River nearby. *Top, right.* . . . FIGURE 28/ Volcanic ash deposit from Katmai eruption of 1912. Near lower end of the Valley of Ten Thousand Smokes. *Center, left.* . . . FIGURE 29/ Ash from the level immediately above the humus, with spruce needles and twigs preserved. *Center, right.* . . . FIGURE 30/ Hot-ash flow in the Valley of Ten Thousand Smokes. *Bottom, left* . . . FIGURE 31/ Small stump preserved by hot-ash flow. Note charred upper end. *Bottom, right.*

Prevalence of Conifer Wood

In the known fossil-plant deposits of the world, such as the vast coal deposits of the Cretaceous and Tertiary strata, wood of conifers is nearly always much better represented than wood of broadleafed trees; and leaves, pollen, and spores are still better preserved. Among the conifers, the wood of types that are slow to decay (such as *Sequoia*) are most likely to be petrified by infiltration with minerals from ground water. This is also true in the Yellowstone fossil forests.

To get the most complete picture of any fossil flora, it is necessary to study all types of fossils, including pollen, spores, leaves, and wood. Some species may be preserved in several ways, others in only one. Many other plants leave no identifiable trace of any kind.

The leafprints of nearly a hundred kinds of trees, shrubs, and ferns[8] are preserved in the sterile volcanic ash zones in Yellowstone. These include a variety of warm-temperate to subtropical broadleafed and coniferous species. On the basis of relative abundance of fossil leaves in the northeastern part of the park, Dorf (1960:257) concludes that sycamores, walnuts, magnolias, chestnuts, oaks, redwoods, maples, and dogwoods are the dominant species, with significant numbers of figs, laurels, bays, pines, and other types. The better indurated tuff (ash) zones yield a similarly varied assemblage of fossil pollen and spores (Fisk and DeBord 1974:442). This is similar to the composition of numerous other Eocene fossil floras in western North America.

As one might expect, however, petrified stumps and logs of conifers are more common than broadleafed tree stumps — undoubtedly reflecting the bias introduced by differential decay and preservation. Sycamore, the commonest leaf-fossil in Dorf's collections, is only occasionally encountered in wood samples. Lugenbeal (1968 appendix A) and Ritland (1968:35-36 appendix A) found conifer stumps nearly six times as abundant in the Specimen Creek area as broadleafed

FIGURE 32/ Hypothetical cross-section of vent and alluvial deposits from two volcanoes in the Absaroka Volcanic Field (after Smedes and Prostka).

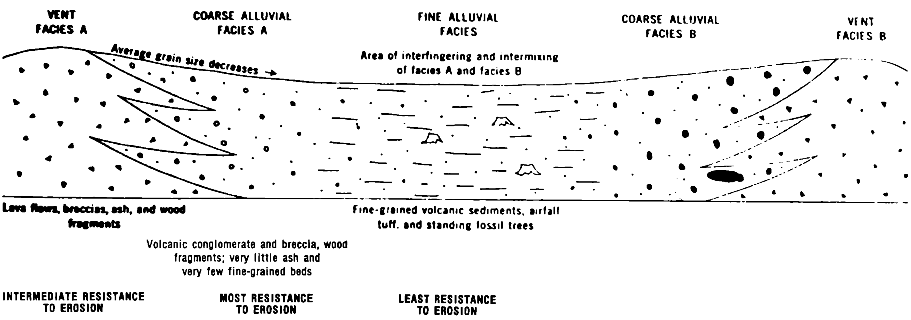


FIGURE 33/ Diverging petrified *Sequoia* stumps on Ramshorn not far from the tree shown in FIGURE 1. Trees that root close together diverge to separate their branches. A natural divergence seems to fit better with growth-in-position than with transport hypothesis. *Left*. . . . FIGURE 34/ Exactly the same phenomenon (as in FIGURE 33) exhibited by cedar stumps from a logged-over area in northwestern Washington. *Right.*

tree stumps. Of approximately 400 identified, 17 percent were broadleafed types. Among those of small diameter, however, the ratio increased to 36 percent. More than three-fourths over 30 inches in diameter were *Sequoia* or similar to *Sequoia.*

Many broadleafed tree species with nonresistant wood might be expected to decay before the volcanic ejecta would be sufficiently consolidated to form a cast and before mineral infiltration of the wood could take place. In such instances no remains of a stump could be detected. Sometimes there was sufficient consolidation of the strata so that a cast was preserved. Such casts may be filled with opal, amethyst, or pure white quartz, without a trace of wood fiber remaining.

Preservation of Pollen

It has been suggested in recent discussions that the occurrence of leaves and pollen of a variety of plants not known to be represented among the petrified stumps and logs is evidence that an unnatural assemblage is represented in the Yellowstone fossil flora and that the stumps must not be in position of growth. A brief statement on the interpretation of fossil pollen floras is essential, therefore. For a more comprehensive discussion, the reader should consult papers by Davis (1963, 1969, and others), whose recent contributions have placed the analysis of fossil pollen floras on a level of objectivity heretofore not attained by most European and American workers.

The study of fossil pollen and spores should contribute to our understanding of the Yellowstone flora in at least two ways: (*a*) numerous pollen species should be preserved which are not preserved as macrofossils; (*b*) plants from beyond the immediate region of the fossil forests should be represented.

The first point hardly needs documentation, since it is the common experience of workers on contemporary lake, bog, river, and other sediments to encounter pollen and spores of scores of species from which no leaves or wood are found. Considering the many varieties of plants (including trees, grasses, ferns, etc.) in which pollen or spores are adapted for wind transport, the second point is self-evident. For example, in sediments of present-day tundra ("grassy" plains without trees) 80-90 percent of the total preserved pollen may be from nontundra plants — usually from forest trees growing in the general area, but some from trees such as oak, which are not found within several hundred miles of the tundra (Davis 1969:322). In fact, in contemporary sediments it is often impossible to distinguish between surface sediments in pure tundra, mixed forest and tundra transition, and northern forest by the proportional species representation of pollen alone (Davis 1969:323)

FIGURE 35/ Three-inch upright tree in a volcanic mudflow. Note abundant unsorted large volcanic boulders which have not damaged the tree or caused it to bend from the upright orientation. *Left.* . . .
FIGURE 36/ Twenty-one-foot upright near the base of Plot 2 north of Specimen Creek. *Right.*

There are numerous habitats in which more accurate inferences are possible, but not necessarily by simple intuitive deduction based on proportional representation of fossil pollen. The pollen of pine trees may be two hundred times as common as the proportional basal area pine trees occupy (Davis 1963:903). On the other hand, conifers such as larch may be so underrepresented that they are completely missed in even relatively large samples. Only one larch pollen grain was encountered in 6,925 tree- and shrub-pollen grains from six surface samples in lake sediments where larch was present in the vicinity (Davis 1963:906-907). Factors of production, dispersal, decay, etc., must be evaluated quantitatively; and contemporary controls are highly desirable, if not absolutely essential, for significant inferences. Polunin (1960:181) makes the following observation:

> In connection with the wide acceptance of sub-fossil pollen grains as evidence of former climates, the author cannot forget that through much of the summer of 1950 he found the most plentiful pollen in the air near the ground in West Spitsbergen to be that of *Pinus sylvestris,* the nearest trees of which were growing on the Scandinavian mainland several hundreds of miles away to the south. This indicates the need for caution in interpretation — including the desirability of statistical comparisons and, above all, avoidance of any tacit assumption that a small deposit or reasonable amount of an airborne pollen was necessarily produced locally.

The simple fact that some types are represented as pollen or leaves but are not represented by wood in the fossil forests must be expected, therefore, under any model of deposition.

In any paleofloral analysis it is also necessary to consider the possibility that species similar to living types may have changed in ecological tolerances at times. As is exhibited in nature today, phenotypically similar species often possess differing ecological requirements. One should expect to encounter ancient pollen assemblages for which there are no precise living counterparts. It is well known that such is the rule in many Mesozoic and all known Paleozoic pollen floras.

Stumps, Not Trees

Upright stumps on what appear to be growth levels are the commonest petrified remains. On some levels, prostrate logs are also common. This is exactly what one might reasonably expect if the basal ends of the trees and prostrate logs, such as are encountered below most forests, were covered by volcanic ejecta. Although the exposed and near-surface parts rot away, the covered basal stump portions of types more resistant to decay may be preserved, eventually becoming infiltrated by dissolved minerals from the mineral-rich ash and breccia. It is difficult to envision a transport mechanism which would break off the trees, sort out and dispose of the limby upper portions, break loose the stumps from the ground, transport them for many miles in an upright position, and bury them in volcanic deposits.

The condition of the top end of the stump, where not eroded or broken down by the forces that have removed the overlying strata, may be useful in inferring the history of the tree. In a transport hypothesis — recall — a force such as a high wind would need to break off vast numbers of trees and carry away many of the tops, so that mostly stumps remain. As far as we have been able to determine from limited observations on trees destroyed by major winds, such as the destructive 1962 storm in the Pacific Northwest, most trees tend to uproot rather than to break off under such forces. Trees that break display oftentimes a broad splintered zone, sometimes with the stump split to the base. Trees weakened by decay may exhibit more of a clean break. The tops of most of the fossil stumps that are still intact seem to have cleaner breaks. In the fossil forests it is not common to find prostrate trees with roots still attached. Data on living and fossil stumps is being gathered for further analysis.

Differential Decay in Stumps and Surface Preservation

The bark of fossil stumps and trees is rarely preserved, because of the impervious nature of bark tissue, which tends to inhibit mineralization. It is also quite possible that the less resistant sapwood may be lost at times. In petrified stumps of large dimension, the heartwood, or center, often is not preserved, leaving only a rim or a ring of petrified wood 6-16 inches thick around the tree, as though it had been hollow. The relative frequency of large petrified stumps without centers seems to be significantly higher than the frequency of hollow trees in living forests. This suggests that often the central deficiency may be a result of slow or incomplete mineral infiltration during the petrification process.

Though commonly the contact of the preserved fossil wood with the tuff or breccia is fairly sharp, in a few instances we have observed evidence of poor preservation, or decay, at the upper end or sides of fossil stumps. In such cases the rings at the exposed-end surface appear crushed, spread out, or otherwise distorted. Very rarely the upper surface wood may have the appearance of chipboard, which suggests that partial decay may have occurred before the terminus was covered and distorted by a load of rock detritus. In recently dead trees, decay patterns also vary considerably, in some cases fungal activity being superficial and in other cases permeating throughout the wood.

Occasionally *Sequoia* stumps extend or reach nearly to the root zone of the next level of stumps. This may indicate that the overlying surface, in turn, was covered by volcanic ejecta before a prolonged lapse of time, certainly during the first generation of tree growth. At several levels, partially buried trees remained, protruding through the breccia cover until the next young forest developed and was in turn also buried by volcanic cover. In such cases, the level of the younger tree

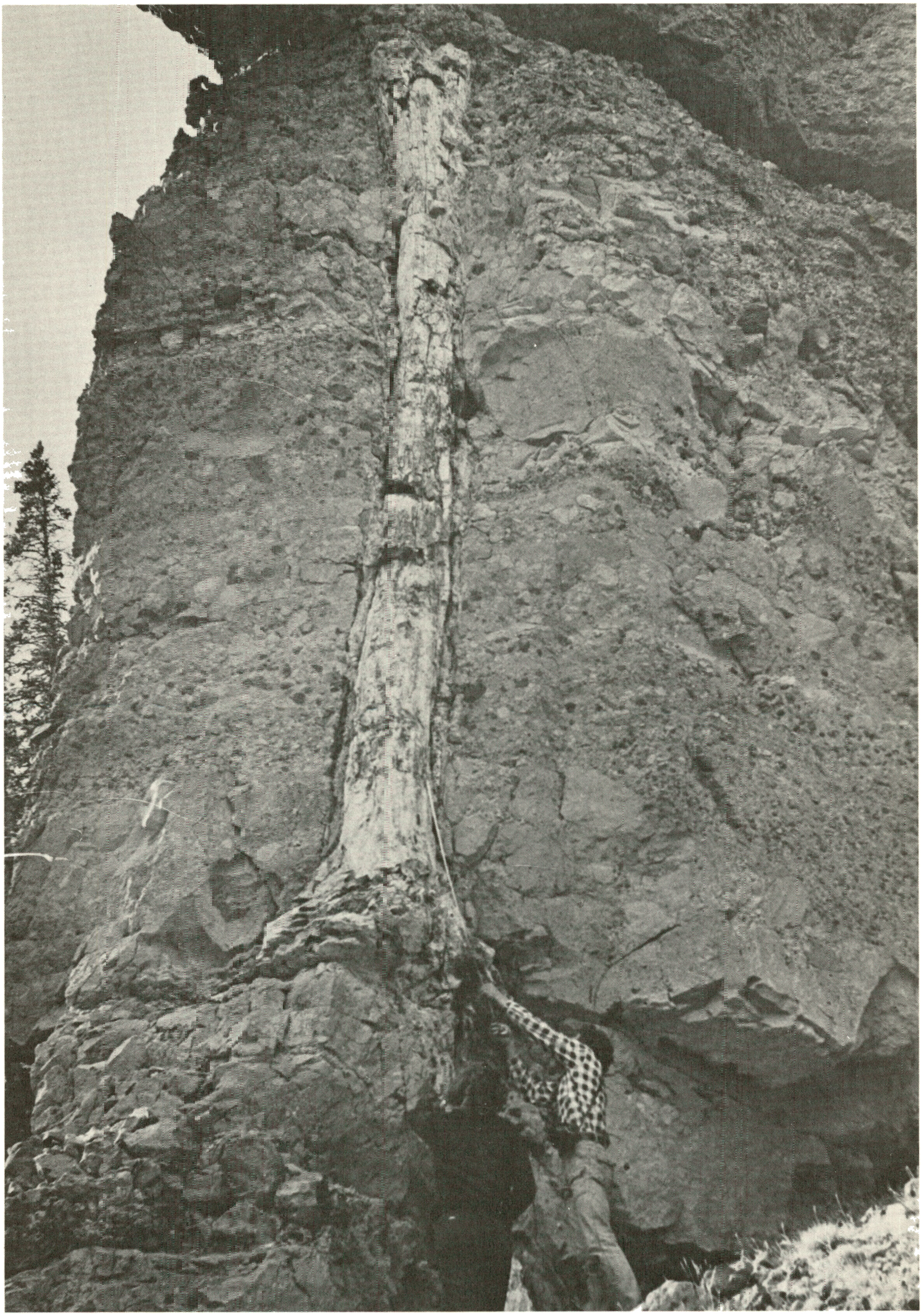


FIGURE 37/ Twenty-two-foot upright petrified tree exposed on a vertical cliff of breccia northeast of Daly Creek. Note that the trunk has begun to divide where it terminates not far below the next breccia level.

FIGURE 38/ Two of the series of large *Sequoia* on one of the levels of large stumps near the top of Ramshorn. *Above*. . . . FIGURE 39/ Twelve-foot *Sequoia* not far from those in FIGURE 38. *Below*.

roots overlaps the trunks of the trees or snags from the lower growth-level several feet above their bases. This phenomenon of small trees overlapping a level of older *Sequoia* stumps can be seen at the lowest two levels in the classic fossil forest locality of the Lamar River Valley, at a low level on Plot 2, and on levels 21 and 22 of the Specimen Creek slope designated Plot 1-B (FIGURES 43, 44).

In the latter location, numerous stumps on the upper overlapping level (22) have approximately 50 rings — which suggests that the large *Sequoia* persisted half a century or more protruding above the breccia as a dead snag while the new forest grew on top of the covering layer of breccia and ash. Additional evidence of the duration of a period of decades between the destruction of these forest levels is a peripheral ring or zone of decay of the snag at the level that intersects the second overlapping soil level. Here the trunk would have been exposed to the forces of wetting and drying that naturally promote decay. In FIGURES 43 and 44 it can be seen that the root level of the small stump continues across the large tree exactly where the zone of decay occurs. In the field it is far more distinct, since plant detrital material and abundant leaves mark the root zone of overlapping small stumps. We see no way that this phenomenon could occur without a period of years between the destruction of successive *in situ* forests.

ORGANIC ZONES

The presence of a soil zone with leaves, ground litter, roots, and rootlets corresponding perfectly with the root levels of the stumps, together with the erect condition and natural spacing of the stumps, seems to provide the most compelling evidence that the stumps are in position of growth. Since it is necessary, in developing a transport hypothesis, to suggest that these zones together with the stumps are brought in from a distant source, the nature of the organic zone needs to be considered in some detail.

At least two types of organic zones may be distinguished in the fossil forests. The first type is commonly associated with the root zones of trees and is composed of fossil leaves, detrital material, and roots and may be termed "soil."[9] The second, though sometimes referred to as a soil, is composed of fossil leaves but has none of the characteristics of a growing surface. In some areas and at certain levels, organic zones are not well preserved, but in the exposures north of Specimen Creek the preservation is superior.

Soil Zones

Most of the soil zones are characterized by the same basic features. The prominent portion of the soil zone usually ranges from 1 to 3 inches in thickness (FIGURES 4-10). Beginning at the top of the zone, one often finds well-preserved

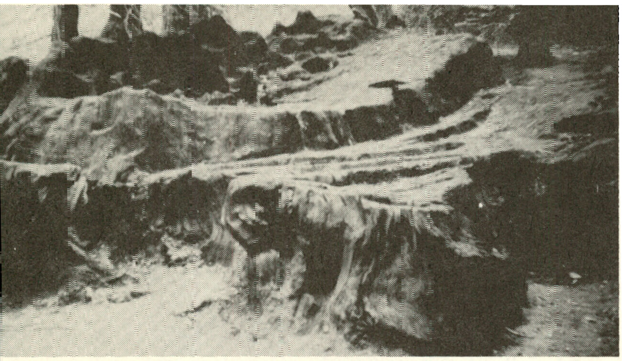
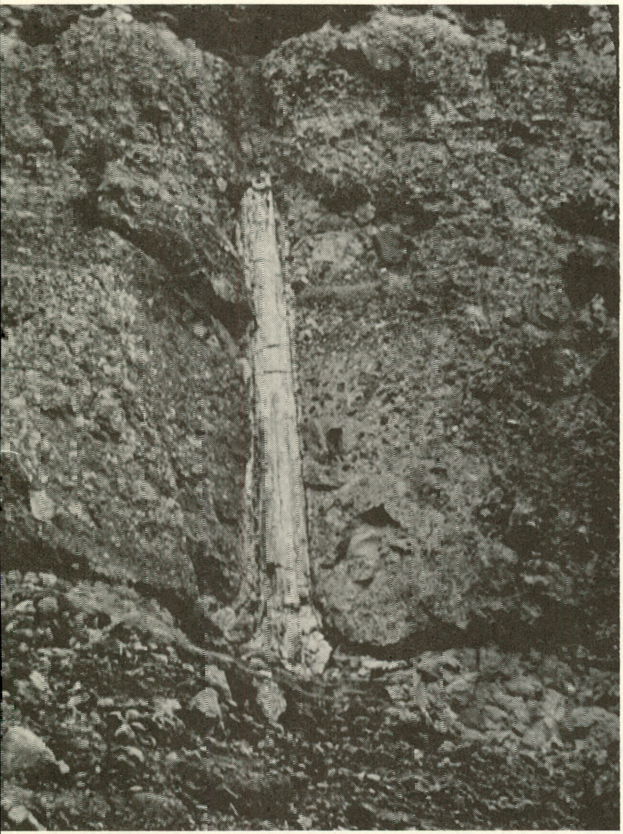
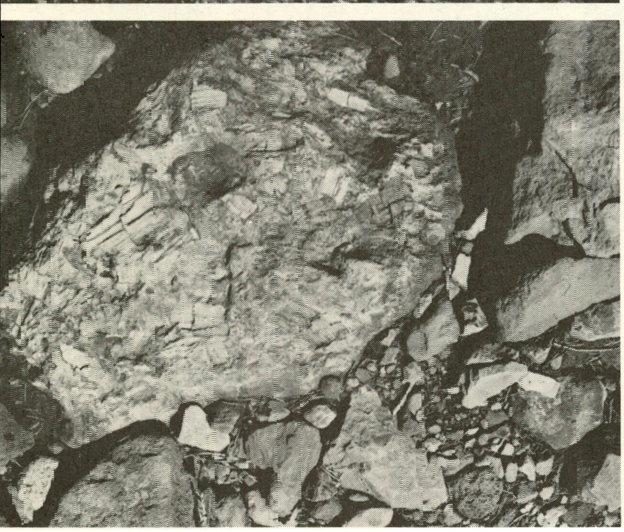


FIGURE 40/ Centennial stump in Kings Canyon National Park. Cut in 1875 for Philadelphia World's Fair. Note excellent preservation. (Photograph courtesy of Marilyn Lugenbeal; in 1967.) *Left, top*. . . . FIGURE 41/ Twenty-foot-tall tree in perpendicular cliff face. The top appears to have broken out from the overlying ground level about 3 feet above the upper end. Upper portion (1-2 feet) appears to have suffered some decay. *Left, center*. . . . FIGURE 42/ Petrified wood fragments such as are sometimes found at the upper end of the stump, where partial decay has taken place. *Left, bottom*. . . . FIGURE 43/ Overlap zone. Note decay in the large tree at the ground level on which the small overlapping level of trees was growing. *Right, top*. . . . FIGURE 44/ Close view of the same (FIGURE 43). *Right, bottom*.







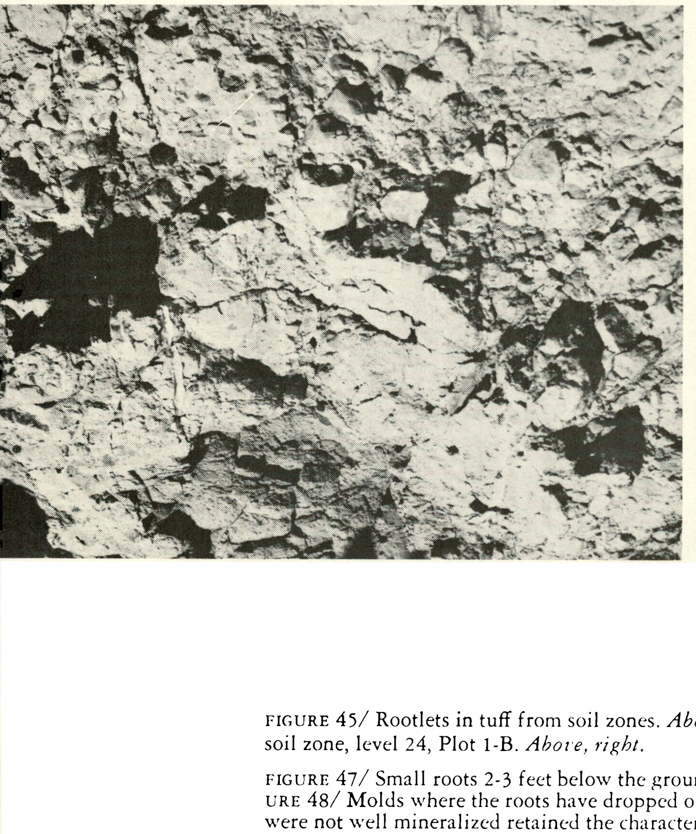
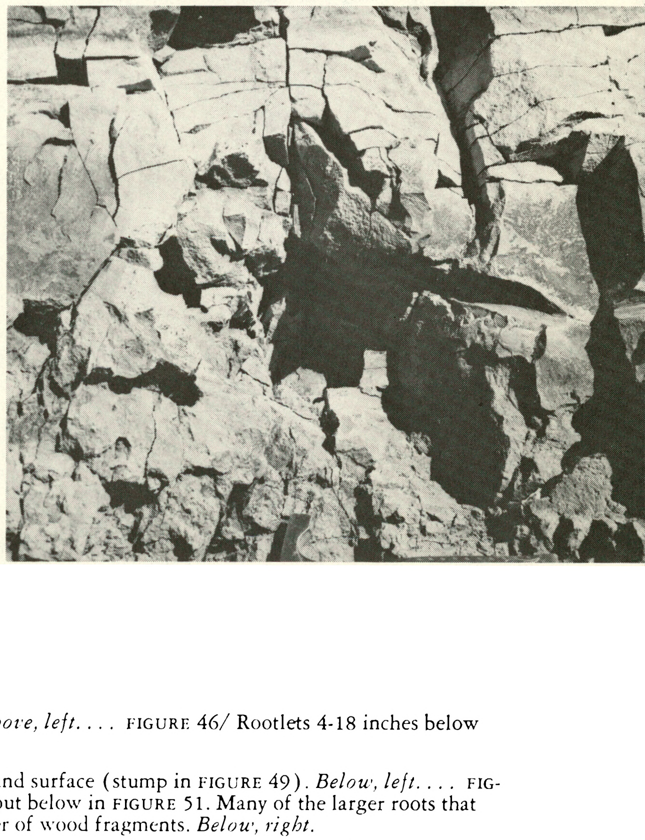



FIGURE 45/ Rootlets in tuff from soil zones. *Above, left.* . . . FIGURE 46/ Rootlets 4-18 inches below soil zone, level 24, Plot 1-B. *Above, right.*

FIGURE 47/ Small roots 2-3 feet below the ground surface (stump in FIGURE 49). *Below, left.* . . . FIGURE 48/ Molds where the roots have dropped out below in FIGURE 51. Many of the larger roots that were not well mineralized retained the character of wood fragments. *Below, right.*

FIGURE 49/ Examining tuff below 7½-foot *Sequoia* for small roots (west end of Specimen Ridge, Lamar Valley). *Opposite.*

leaves and needles. As one proceeds down through the zone, there may be a higher concentration of less well-preserved organic remains, frequently a mass of needles, poorly preserved leaves, and other organic detritus a half-inch or more in thickness. Near the base of the zone, and below, occur what appear to be scattered roots and rootlets. If well displayed, these roots or rootlets may be distinguished from stems or above-ground parts by the irregularity of branching and shapes; this irregularity contrasts sharply with the regular patterns characteristic of the above-ground parts in flowering plants. Roots found range in size from about 1 millimeter up to large roots coming directly off the stumps (FIGURE 45).

Since in discussions it has been stated that small roots and rootlets are not preserved (or are present only in insignificant numbers in the organic zones) and that this is primary evidence of shearing off during transport, we thought that careful observations should be made on this feature. Undoubtedly only a fraction of the small roots are ever preserved; and roots, in contrast with leaves, do not conform to a bedding plane. Consequently, roots are less likely to be exposed or detected on fractured surfaces of the tuff and more likely to be overlooked than are leaves — which commonly conform to bedding planes and are frequently beautifully exposed. Careful examination reveals that some small roots are almost always present in the several inches beneath the organic detrital zone. Beneath some large stumps they may be found 2 feet and more below the original ground level. On level 24 in our Specimen Creek study Plot 1-B, there is a beautiful exposure of

FIGURE 50/ Lava Cast Forest near Bend, Oregon. Note large pine growing on essentially barren rock surface. *Left*. . . . FIGURE 51/ Same as FIGURE 50. *Right*.

fine roots on the side of a boulder from 4 to 18 inches below the soil zone. (FIGURE 46). At a number of locations where the organic zones were well preserved, we were able to observe roots and rootlets at and near the bases of stumps and at other locations along the organic zone.

In a sample of 25 levels in the Specimen Creek study plot, we made a careful check of every level with a well-preserved soil zone. Roots and rootlets, in each case, were found below the soil zones, as would be expected. Small roots and rootlets were also encountered (FIGURES 47-49) in comparative, but more limited, checks of the fossil forest exposures 40 miles to the east in the Lamar Valley and more than 100 miles to the southeast in the Stratified Primitive Area.

It has been suggested (Coffin 1968:6-7) that the absence of a thick layer of humic material (composed of dense mats of fine roots such as one may find under a temperate or boreal forest) is evidence that the organic zones associated with fossil forest root levels are the result of transport. Three significant factors should be considered.

First, because of the high degree and rate of biological decay under most forests in warm, humid climates, very little organic remains persist.[10]

Second, accumulations beneath a first-generation forest on volcanic ejecta cannot be thought comparable to the remains beneath many generations of forest growth. If one observes the sparse remains beneath first-generation trees on volcanic deposits in the vicinity of Sunset Crater (near Flagstaff, Arizona), Lava Cast Forest (near Bend, Oregon), or the volcanic beds north of Lake Kivu (in

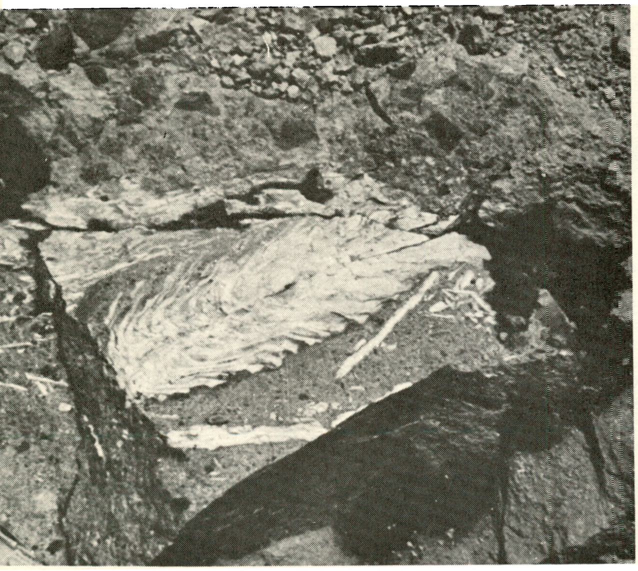
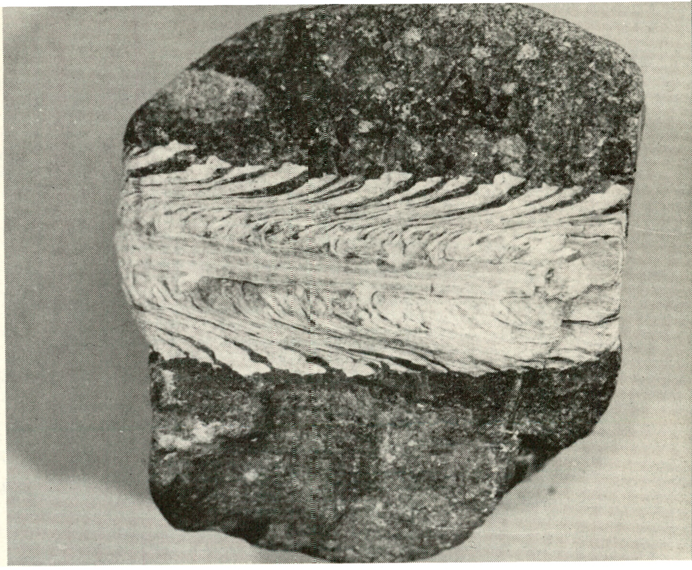
 

FIGURE 52/ Petrified pine cone from organic zone in Plot 1-B. *Left*. . . . FIGURE 53/ Petrified pine cone from loose rock in Specimen Creek area. *Right*.

East Africa), one cannot help being impressed by the areas of bare cinder or rock exposed (FIGURES 50, 51). The organic litter beneath a stand of Douglas fir 2-4 feet in diameter growing on the nearly bare surface of a lava flow in an area of high rainfall near Santiam Pass in the high Cascades of Oregon is so sparse and incomplete that the lava flow looks surprisingly fresh. Moreover, unless the rock matrix or cover that buries the soil level is fine material, even the sparse remains would not likely be preserved.

Third, this view fails to recognize the unequal likelihood of preservation of various plant parts. Fine roots include little of the resistant types of tissues most readily and regularly preserved. They are surrounded by bark, parenchyma, and phloem, with only a tiny strand of xylem. Bark is seldom preserved, because of the high proportion of phellem (or cork) tissue, cortex parenchyma, and phloem (tissues). Cork is impervious — therefore not subject to mineral infiltration as wood is. Phloem and parenchyma are delicate living tissues that are unlikely to persist until mineral deposits have been laid down in the cells by groundwater. By contrast, the xylem of wood (which tends to be resistant to decay) is a series of tubes readily permeated by mineral-rich groundwater and petrified by the deposition of mineral in the cell cavities. Roots several inches in diameter sometimes decay after the encompassing sediments have hardened, leaving only an empty mold (FIGURE 48).

It is undoubtedly for a similar reason that petrified pine and *Sequoia* cones are less common than petrified wood (FIGURES 52, 53). The tissues of the cone axis and scales (not as readily infiltrated by mineral as wood is) are likely to decompose before petrification can occur.

Leaf-Drop Zones

The second type of organic zone seems to represent a leaf-drop zone above the root level, not a soil zone, and consequently exhibits characteristics quite different from the soil zones. Such zones ordinarily occur in air-dropped ash from a few inches to several feet above the surface of the soil zone. They may be composed entirely of scattered, well-preserved leaves and needles, without the detrital material found in the soil zones. The leaves, as in the surface level of the soil zone, retain their natural texture and shape instead of the flattened condition characteristic of leaves that accumulate beneath water. These zones also lack the roots and rootlets found associated with the soil zone.

In present-day volcanic activity, similar circumstances may be observed. In the region of Mount Katmai, which ejected from five cubic miles of pyroclastic depos-

FIGURE 54/ Fossil forest breccias exposed in the valley of Frontier Creek in Stratified Primitive Area 140 miles southeast of the Gallatin Forest exposures.

its in June 1912, a snowlike layer of volcanic ash a foot thick covered the ground nearly 100 miles from the volcano. Much ash clung to the leaves and branches of standing trees, which tended to clog stomata and kill the leaves. In the weeks following, leaves and ash from the forests filtered to the ground. Wind removed ash from high areas and filled in the valleys. Two months after the eruption, Martin (1913:167-170) observed freshly fallen willow and alder leaves on the ash surface. Juanita Ritland (1968:27-29) cites many such examples (see also Dorf 1951:317). Some species may retain their leaves longer than others, giving rise to leaf zones with leaves of various species deposited in a nonrandom order above detrital material. Such post-eruption leaf-drop combined with wind and water reworking of the volcanic ash can also result in complex patterns in which organic zones appear to divide or split.

A failure to distinguish between postdepositional leaf-drop zones and organic zones associated with growth horizons may lead to mistaken observations on supposed soil zones.

FIGURE 55/ Fossil stumps were recorded at 15 levels on this slope, from about 9,000 to 10,500 feet. Wood is found up to at least 11,500 feet (in Stratified Primitive Area).

ABSENCE OF ANIMAL AND CERTAIN TYPES OF PLANT FOSSILS

Although fossil stumps, logs, roots, twigs, and leaves of trees and shrubs are common fossils at many levels, there are numerous types of organisms that are conspicuous by their absence. No land animals such as mammals, birds, insects, or spiders have been reported. Nor have any traces of fish, amphibians, aquatic insects, or marine or freshwater invertebrates been encountered. Among plants, the countless varieties of herbs such as lilies, orchids, buttercups, sunflowers, grasses, and a host of other common types have not been reported.

The suggestion that the absence of many types may have resulted from selective transport by water rather than from differential preservation hardly fits the data. If the fossils preserved and recovered represent a relatively unbiased sample of most of the life present in the area when the volcanic deposits were laid down, then selective transport must have operated at a high level. Among the woody plants one must have a source for are: (*a*) stumps with abundant roots, yet from which the trunks and branched crowns have been removed; (*b*) logs, twigs, a few limbs; (*c*) leaves and needles, plant detritus of about a hundred species of mostly trees and shrubs, together with a few ferns, but no leaves of the vast majority of herbaceous types.

The waters that transported the plant remains would have to leave behind the dead or living mammals, birds, insects, crustaceans, fish, or amphibians that may have been killed or displaced by whatever force broke off and uprooted the trees. The waters would also need to leave behind the stumps and logs of numerous species of trees represented by leaves only. The waters would need to leave behind all suspended particles of clay, mud, and silt, and all nonvolcanic sediments so characteristically transported by moderately active waters, particularly waters not enclosed within a streambed from which fine sediments have already been removed.

Such selective transport is extremely improbable on each of these counts, especially transport of organic remains without at least clay- and silt-sized sediments. Suspended sedimentary materials would be deposited as widespread thin clays or silts — which would be represented in the fossil forests, if present, by shales or siltstones. The total lack of such sediments easily distinguished from reworked volcanic sediments is one of the most serious objections to any transport hypothesis that would bring in organic remains from a distant source — the only possible source other than the shield volcanoes, which would hardly be an adequate source for 30 or 40 levels of forest remains.

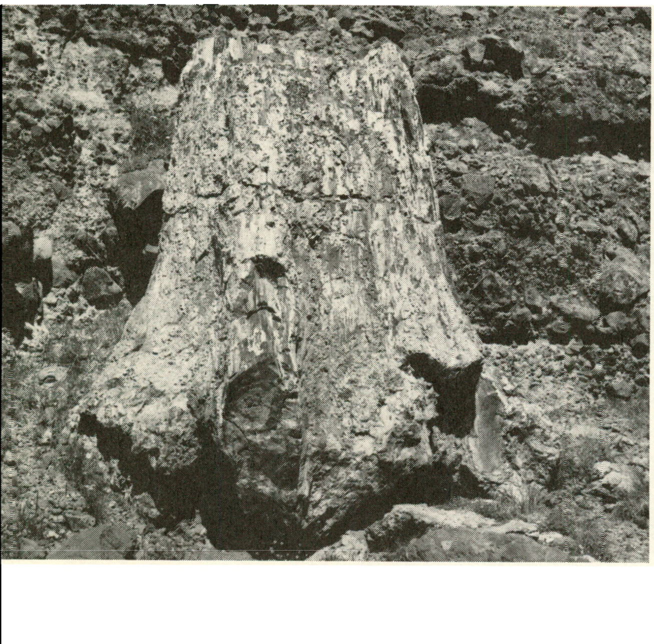
To those who are familiar with the nature of fossilization and fossil-bearing formations throughout the world, the absence of animals and many types of plants is not as strange as it might at first appear to be. The chances for various types of organisms to be preserved as fossils even under the most favorable circumstances are enormously unequal. Volcanic ash and breccia, like sandstone, have a high degree of porosity. Oxygen-rich waters filtering through volcanic deposits would tend to promote decomposition and solution of all except the more resistant remains. The less resistant woods, soft herbaceous plants, and animal materials would tend to disintegrate and be lost.

After early eruptions at Paracutin Volcano in Mexico, scientists observed that most birds and mammals, with the exception of field mice, migrated from the area. Deer and rabbits left first, followed by coyotes and other animals as their food supply was exhausted. Insects remained numerous. (Dorf 1951:317; Segerstrom 1956:23; Foshag and Gonzales 1956:129.) Williams (1962:21), the geologist, points out that animals killed by stream pollution, or suffocation, or after volcanic activity usually are devoured by scavengers or decay before being buried adequately for preservation.

It may be suggested that burrowing animals such as moles and gophers would not migrate. But two points should be recognized. First, burrowing forms would not be expected to thrive in substrates on which the fossil forests grew — volcanic tuff rich in fine volcanic glass fragments (Vaughan 1972:255-256). Second, the likelihood of small scattered bones being preserved or recovered in a porous substrate is minimal on both counts.

Selectivity, as usually seen in preservation, and the *exodus* of many forms seem to give the most reasonable explanation for the pattern of remains preserved in the fossil forest deposits.

FIGURE 56/ Forty-inch stump exposed on slope in FIGURE 55. *Left.* . . . FIGURE 57/ Distant view of stump and glacier-fed stream in Stratified Primitive Area. *Right.*



REGIONAL GEOLOGY AND TRANSPORT

One of the most significant factors related to possible stump transport concerns the geological processes prevailing in the region at the time of forest burial and preservation. Because of the general and technical information required to evaluate this factor, only the major features essential to the point are stated here. Those who wish to may validate the facts by investigating the regional geology and stratigraphy of the central and northern Rocky Mountain region.

The sequence of events in the region is inferred from the thousands of feet of sedimentary and volcanic strata. In general terms, portions of the sequence relevant to the fossil forests are as follows: (*a*) widespread deposition of flat-lying sediments with marine fossils; (*b*) extensive beds with dinosaurs and other land types of animals and plants, including a few strange mammals; (*c*) more marine strata with fossils; (*d*) more land strata with fossils; (*e*) major uplift in Rocky Mountain ranges, creating basins and ranges (more than four miles of relative uplift; Upper Cretaceous to Lower Eocene); no marine sediments or fossils anywhere in the Absaroka Volcanic Field or the Rocky Mountain region subsequent to this time; (*f*) extensive erosion of mountains and filling of the basins; various fossil mammals and plants, including coal seams preserved in the basin fills; lake deposits in basins locally, especially in the Green River basin far to the south; (*g*) widespread intermittent volcanism, especially of the explosive variety, which gives rise to volcanic ash and tuff and burial of the fossil forests; no evidence of lake sediments or deposits anywhere in the Absaroka Volcanic Field.

The last evidence of marine deposits in the Rocky Mountain region is well below, clearly antedating the volcanic field and fossil forests (Robinson 1972:233). Incursions of fresh or marine waters, bringing in stumps, logs, and plant remains from beyond the boundaries of the volcanic field would bring in, at the least, thin but widespread layers of nonvolcanic sediments and leave characteristic sedimentary features. But, as has been stated, such layers are not found. The deposits radiate out from volcanic vent areas and exhibit marked local facies changes.

GROWTH FEATURES

It may come as somewhat of a surprise that trees in natural stands of timber often exhibit more growth on one side than another. When the thickness of the tree-rings is measured in radii at various directions from the center of the tree, one side will generally be thicker (thus, a long axis in the cross-section resulting). There may be good reasons for this phenomenon. On the side of a tree exposed to prevailing winds, the branches are often less developed, because of increased evaporation from exposed leaf surfaces. This may be reflected in the development of wood on the same side, with resultant asymmetry in the cross-section of the tree

FIGURE 58/ Wood from the stump in FIGURE 59 exhibits the thinnest rings we have encountered (up to 40 or 50 rings per inch near the outer margin, with one interval of a half-inch with 48 rings).

trunk. Quite possibly other factors, such as intensity of radiation, may also have an effect. The distorted trees near timberline or on seacoasts, so frequently portrayed by artists or photographers, are an extreme example of the distortion resulting from prevailing strong winds. To a much less but still recognizable degree, this trunk asymmetry is exhibited in many forests.

From measurements made in a wide range of forest habitats in stands of lodgepole pine, ponderosa pine, Douglas fir, Sitka spruce, western hemlock, cedar, and redwood (whether in protected valleys or exposed slopes), our data indicate that the long axes tend to be somewhat parallel. Exceptions are to be expected in any stand — such as the adjacent surfaces of trees close together, streamside trees, and so forth — but the direction and trend are usually unmistakable. Although it is often difficult to make accurate measurements on petrified stumps, this same phenomenon in ring development seems to be exhibited on a number of limited samples measured. Again, a natural growth seems to be indicated. One might conjecture that such a directional orientation could be related to a corresponding asymmetry in the tree roots and a transport orientation. But when one observes the irregularity of the roots which have accommodated in growth to irregularities in the subsurface (boulders, water, etc.) rather than to atmospheric conditions, such an explanation seems highly improbable.

ORIENTATION OF PROSTRATE LOGS

Prostrate logs tend to show various degrees of directional orientation both in present-day forests and in the fossil forests. This is what would be expected — considering the influence of storms, prevailing winds, slope, and other environmental factors on the direction of tree-fall, as well as the effects from the deposition of volcanic sediments in the fossil forests. Any sample of exposed prostrate logs is biased because of the relationship between the orientation of the long axis of the log and the probability of exposure on a sloping outcrop. Hence, careful study of the factors governing exposure is required for a valid analysis of their orientation.

In twelve plots in a variety of exposed and protected situations, measurements of the direction of prostrate trees beneath living forests exhibited patterns similar to those recorded for prostrate logs in the petrified forests. Two exceptional localities with the greatest number of parallel trees among living or fossil trees were encountered beneath living forests on the slopes of Mount Lassen (in California) and under stands of lodgepole pine north of West Yellowstone. Both of these areas had been subjected to unusual windstorms in recent years.

CONCLUSIONS

The picture which emerges is that the significant lines of evidence find their most natural interpretation according to the generally held model of trees in position of growth. Although a few features (such as orientation of prostrate logs or prevalence of conifers) could easily accord with any model, a number of findings seem to have no other feasible explanation than that the remains are *in situ* (in position of growth): the perfectly erect orientation of even, tall, slender tree stumps; the natural spacing; the character of leaf preservation; the "soil" zones; the existence of stumps without the tops of the trees; the differential decay on stumps; and still other factors. Moreover, the distribution of stumps in relation to volcanic centers or vents and the absence of any marine sediments or freshwater sediments (such as shale or siltstone that would inevitably be brought in if transport from a distant source had occurred) seem to rule out transport except from the shield volcanoes. In no way could such volcanoes be an adequate source for the stumps, logs, and other organic remains.

There is no question that the time problem to which the fossil forests contribute has an important bearing on fundamental theological issues. We are entirely sympathetic with any thorough and careful effort to solve the problem by endeavoring to encompass earth history in a short period. Nevertheless, as we have carefully studied the fossil forest outcrops throughout the volcanic field and evaluated the converging lines of data bearing on their deposition, together with the broader geological picture in which they fit, the weight of evidence has led us to conclude that successive forests are represented.

This is not to imply that the Inspired Record is wrong. But it is to suggest that our understanding of its essential message may not always be perfect or complete. It is to suggest that we Adventists, as conservative Christians, might well make a renewed search of both science and revelation to discover those subtle relationships and insights that may help to demonstrate the consistency and harmony that exist between truth from the two sources. We are confident that the ultimate resolution will require neither distortion of facts nor grossly unnatural interpretations in either science or revelation.

WHAT WE DO NOT KNOW

We close with a passage by Richard Foster Flint (1941), emeritus professor of geology at Yale University, from an introductory book on geology. This selection, entitled "What We Do Not Know" (a subtitle we have borrowed), can appropriately be applied to this article — and indeed to most other articles in both science and theology!

Much of the information contained in this book is within the well-lighted zone of proved fact. But no one ought to embark upon a study of even the elements of geology without realizing that we quickly pass from fact into a twilight zone of inference in which we can say, not "This is true," but only "Probably this is true," and that thence we pass into a region of darkness lit here and there by a guess, by speculation. Speculation is a legitimate and desirable thought process just as long as the thinker fully realizes that he is only speculating. But when he speculates, and at the same time persuades himself (and also, alas, his listeners) that he is drawing sound inferences, then knowledge does not progress. The reader of this book should remember at every page that fact, inference, and speculation are three wholly different things, that "We do not know" must be said or implied at nearly every turn, and finally that *what we do not know at present* would fill an indefinite number of volumes, many of which, we hope, will in the course of time be written.

Only — let every man take heed, lest he comfort himself with the dangerous assumption that the factual and the firm elements of science are mere speculation, and thereby seek to escape the intellectual responsibility of facing the issues and the hard decisions that the times demand of conservative Christians.

NOTES

1/ The term *soil* is here used in a nontechnical sense, as discussed later in the paper.

2/ Brown (1957) reports 32 levels, and Dorf recognizes 27 levels in the Lamar Valley exposures about 50 miles east of the Specimen Creek locality.

3/ It is quite possible that these volcanics may be genetically related to the vast Columbia River Plateau field that blankets 200,000 square miles in Oregon, Washington, Idaho, and northernmost California, generally younger but where its roots are exposed (Clarno Series) nearly equivalent to the volcanics of northwest Wyoming (cf. Van Houten 1969:1506-1508).

4/ Along the margins and deeply eroded areas within the volcanic field, volcanic rock may be seen lying directly on top of older strata ranging from Precambrian to Paleocene and Lower Eocene levels. The reason for the various levels immediately below is that major mountain uplift and erosion throughout the Rocky Mountain region (Laramidian orogeny) left exposed Precambrian rocks in the mountain "cores" and successively younger strata as one proceeds toward their flanks. And it was on this deformed heterogeneous surface that the extensive volcanic ejecta which entombed the fossil forests were deposited.

5/ For precise definitions of the various classes of volcaniclastic sediments and rock types, see Fisher (1960, 1961) and Parsons (1969).

6/ Concerning levels in which fewer stumps are preserved, see the discussion in the paragraph following the data on the age of stands referred to.

7/ Three perceptive analyses of this phenomenon, each from a somewhat different perspective, are recommended: (Lyell 1851; Newell 1959; Simpson 1960).

8/ Knowlton (1899:651-791, 773) reports about 150 species. More recent studies generally tend to reduce the numbers reported by earlier workers on fossil floras by recognizing greater variability in species.

9/ The term *soil* is used in this article in a nontechnical sense. One would not expect below these trees, most of which must represent, as we shall see, the first generation of arborescent growth on volcanic ash or breccia, a fully mature soil with well-developed A, B, and C horizons. Such horizons are the products of rock weathering, together with plant decomposition products of not one, or a few, but sometimes scores of generations of trees and other plants. Moreover, since soil in any stage of development is characterized by high rates of biological activity that may tend to continue for a time after burial, it is particularly vulnerable to the destructive forces of diagenetic change (decomposition of A zone particularly). Caution in the use of the term *soil* in reference to fossil deposits, which is always indicated, is particularly necessary here. The terms *organic detrital zone* or *organic zone* may be helpful to avoid mistaken connotation.

10/ Dorf (1960), judging by the flora, concluded that the climate probably varied from warm temperate in the rolling uplands to subtropical in the lowland, with rainfall being 50-60 inches per year. That the breadfruit, figs, laurels, and bays found in the forests are all more at home today in subtropical and tropical than in temperate forests suggests very moderate conditions. There were also many warm temperate types. The climate may have been similar to that found in southeastern United States and parts of Central America today, a climate that favors prolific growth. However, such a climate also provides good conditions for rapid decay, so that very little humic material is accumulated, even after many generations of forest growth. In tropical rain forests today, conditions are such that very little humic material is allowed to collect. After a rain forest is slashed and prepared for agriculture, the area is productive only one to three years. In many areas the soil is red, indicating a high degree of oxidation (see Richards 1963:63-65). Plant geographer Polunin (1960:437) states: "The forest floor normally is covered by a thin litter of leaves, and commonly shows through in frequent bald patches, or these last may support cryptogams."

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FIGURE 59/ Eleven-foot *Sequoia* near the ridge crest above Daly Creek in the Gallatin Mountains.

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