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TRANSPORTED TREES FROM THE 1982 MOUNT ST. HELENS SEDIMENT FLOWS: THEIR USE AS PALEOCURRENT INDICATORS

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ABSTRACT

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Sediment flows resulting from the 1980 and 1982 eruptions of Mount St. Helens, Washington, transported and oriented numerous stumps and logs. Counts taken soon after the 1982 eruption on unaltered portions of the sediment flow provide meaningful statistics for comparison with fossil wood deposits. Of the transported stump and log population, 4–13% was deposited as upright stumps and 78–94% as horizontal logs with a few diagonal and upside-down stumps. The horizontal logs were oriented parallel to the river channel, showing that trees can be good paleocurrent indicators. Features useful in differentiating transported stumps from in-situ ones are a wide root system (trunk/root ratio <1), short broken trunks, broken large roots, and a low percentage of upright stumps in relation to horizontal logs. The oriented horizontal logs, transported vertical stumps mixed with trees buried in place, and sedimentology of the flows aid in interpreting fossil wood deposits such as the Yellowstone "fossil forests".

INTRODUCTION

In previous investigations, we showed that trees were transported and deposited both as horizontal logs and vertical stumps by sediment flows associated with the 18 May 1980 eruption of Mount St. Helens (Fritz, 1980a; Fritz et al., 1982). This collection of transported logs and stumps was used as a modern equivalent for the depositional environment for Eocene "fossil forests" in Yellowstone Park. However, no quantitative data could be collected during these previous studies due to extensive "anthropoturbation" of the surface of the flows by the U.S. Army Corps of Engineers in their stream stabilization program, Weyerhaeuser Company and others. Thus, even though it could be readily observed that stumps were transported and deposited upright and horizontal logs oriented by the sediment flows, quantitative counts that could be directly compared to the fossil record were unobtainable.

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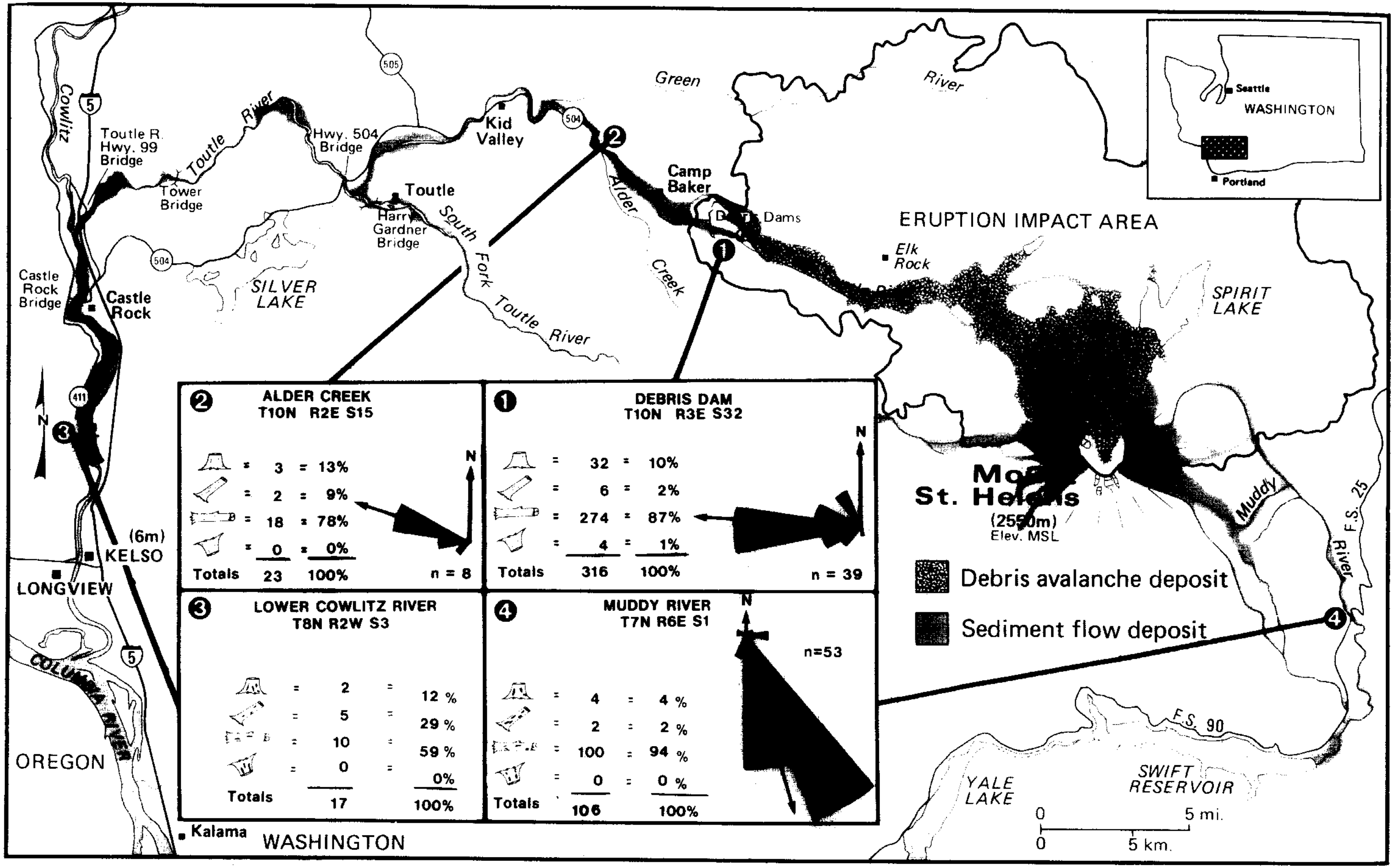

Fig. 1. Location map of Mount St. Helens area. The 1982 sediment flows are restricted to the North Fork of the Toutle River and the Cowlitz River. Inset shows orientations of trees transported by 1982 sediment flows (debris dam, Alder Creek, Lower Cowlitz) and 1980 flows (Muddy River). Arrows on the rose diagrams indicate the direction of flow in the stream channel. Base map modified from USFS et al. (1981).

The purpose of this report is to present quantitative counts of oriented trees from subsequent eruptions and to present criteria useful in differentiating transported from in-situ trees.

A series of sediment flows was produced by eruptions of the mountain on 19 March 1982. We were able to obtain counts and orientation data before extensive modification of the surface of the flows by either natural (stream erosion) or human causes. These counts were taken during a visit to the area on 1–5 April 1982, only shortly after the eruption. Later during the summer of 1982, as a result of new road construction on the south and east flanks of Mount St. Helens, we gained access to a previously undisturbed 1980 sediment flow deposit in the Lewis River drainage system. Counts from this Lewis River flow serve as a comparison for data from 1982 flow. We recognize that our quantitative data presented in this paper may seem limited to some. However, due to the previously mentioned problems of disturbance after deposition, these counts are the best obtainable. We recently visited the area during August 1983 to collect additional data and found the surface of both the 1980 and 1982 flows to be too highly modified to trust any quantitative data.

Study areas were in the vicinity of the debris dam constructed across the North Fork of the Toutle River where videotape taken by a local television crew showed deposition of the sediment flow with transported trees, at the junction of Alder Creek and the North Fork of the Toutle River, along the Lower Cowlitz River, and along Muddy River (Fig. 1). These areas were chosen due to the good accessibility and the unaltered condition of the surface of the flow. At the first of the localities the entire populations of transported stumps and logs were counted, whereas at Muddy River, due to an extremely large population, counts were taken along a transect approximately 100 m long and 10 m wide across the surface of the flow.

The significant contributions of this paper over our previous works (Fritz, 1980a; Fritz et al., 1982; Harrison and Fritz, 1982) are the presentation of quantitative data on orientations of trees in a fluvial/sediment flow environment, the presentation in table form of criteria useful in differentiating transported from in-situ stumps, and a discussion of the mechanism responsible for allowing stumps to be transported.

DEPOSITIONAL ENVIRONMENT OF TRANSPORTED TREES

Considerable descriptive material about the 1980 and 1982 eruptions of Mount St. Helens has been previously published. Deposits from the 1980 eruption are best described by Janda et al. (1981), Voight et al. (1981, 1983) and Schuster (1983). The deposits resulting from the 1982 eruption are also described in earlier papers (Harrison and Fritz, 1982; Waitt et al., 1983) and the interested reader is referred to those works for detailed information. For the convenience of those unfamiliar with the Mount. St. Helens depositional systems, we have provided the following brief summary.

In both the 1980 and 1982 eruptions of Mount St. Helens, the production of pyroclastic material combined with snowmelt and surface water to cause extensive destructive sediment flows in the surrounding drainages (Fig. 1). Deposits within 22 km of the peak are variously termed "rockslide-avalanche", "debris flow" or "debris avalanche" and are more poorly sorted and thicker (average depth of 45 m) than more distal flows deposited more than 22 km (just upstream from the debris dam on Fig. 1) from the peak (Janda et al., 1981; USFS et al., 1981; Voight et al., 1981, 1983; Schuster, 1983). The distal flows, which we studied and which were the transporting medium for the trees, produced a characteristic three-unit sequence

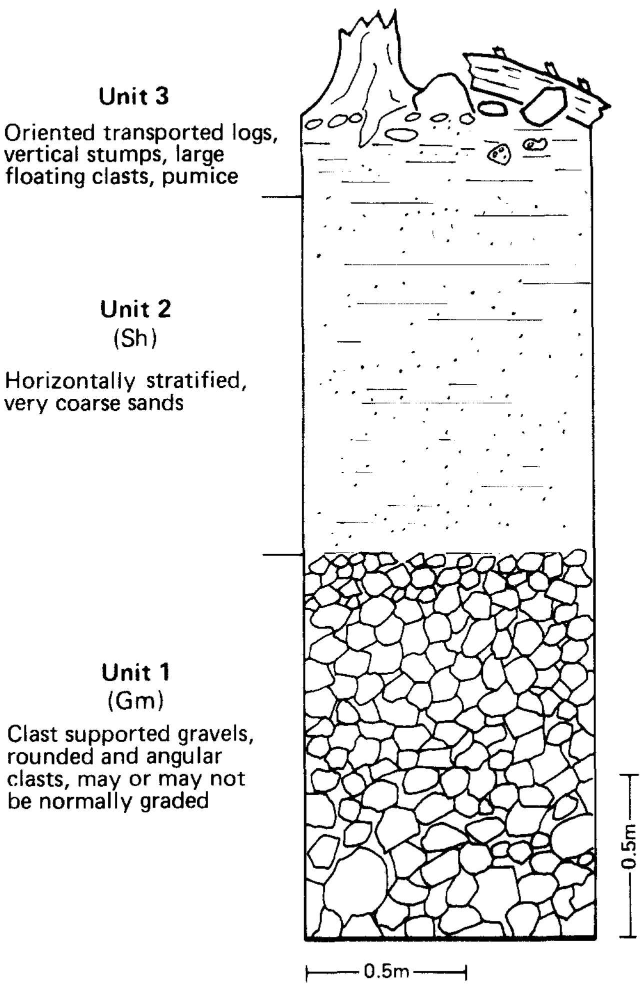

Fig. 2. Three-unit sequence produced by the 1982 sediment flows near the debris dam shown in Fig. 1. Stumps and logs discussed in this article were carried in Unit 3. Modified from Harrison and Fritz (1982).

(Harrison and Fritz, 1982; and Fig. 2) consisting of a basal coarse-grained clast-supported layer, a middle finer-grained horizontally stratified layer and an upper matrix-supported layer containing very large floating clasts and transported debris. The thickness of the three-unit sequence decreases distally from over 3.5 m 24 km from the peak to approximately 0.5 m thick 70 km farther downstream. Most of the transported logs, stumps and plant debris occur on the surface of the flows in the matrix-supported upper unit. Even though streams had dissected channels into the flows, very little, if any, reworking of this material in Unit 3 by later stream flow was apparent at the time and place of this study.

The deposits probably formed in a grey area between highly fluidized "mud" or debris flow and extremely rapid fluvial deposition. Although some have argued that these deposits fall within the spectrum of those produced by normal fluvial processes (Smith, 1983), we continue to employ the descriptive term "sediment flow", which we believe avoids premature connotation of processes but conveys the dense nature of the depositional material (Fritz and Harrison, 1983).

TREE ORIENTATIONS

Counts of transported logs and stumps in the vicinity of the debris dam show that 10% of the transported wood was deposited as upright stumps (Fig. 1). These totals

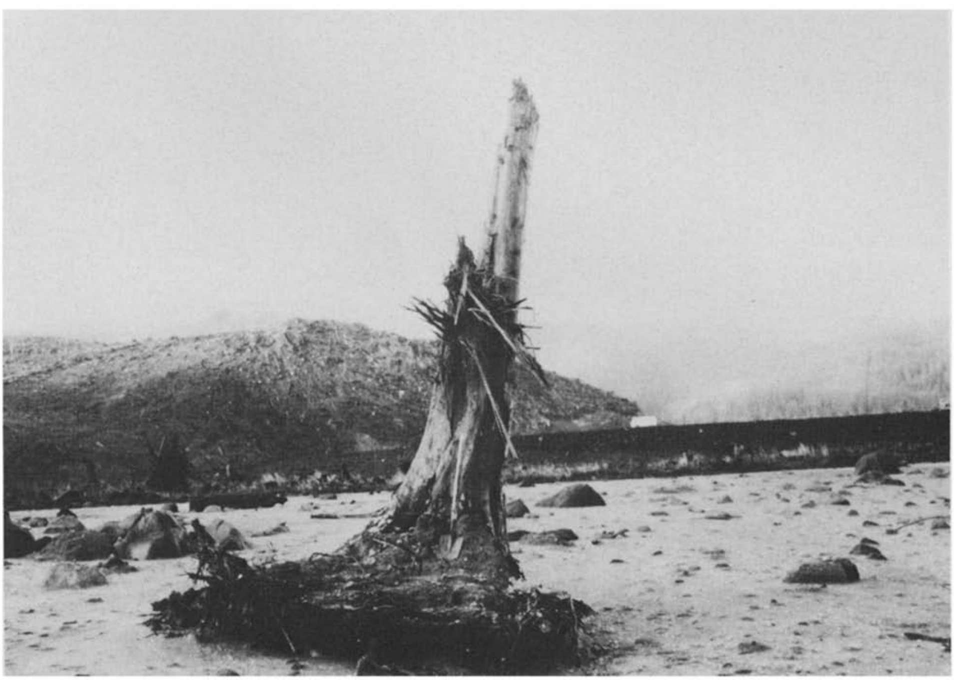

Fig. 3. Upright tree transported by the 1982 sediment flows. Note that even though this stump appears to have a long slender trunk, the trunk/root ratio is approximately one.

compare well with 13% vertical stumps at Alder Creek, 12% on the Lower Cowlitz and 4% from the 1980 sediment flow on Muddy River (Fig. 1). As predicted earlier (Fritz, 1980a), short stumps with wide root systems, broken by the original volcanic blast, by sediment and debris flows, or by logging, were transported and deposited upright (Figs. 3–5), whereas logs with long trunks remained horizontal. These horizontal logs were strongly oriented by the flow and by subsequent fluvial processes with roots or butt ends pointing upstream (Figs. 6 and 7; see rose diagram inset of Fig. 1). Orientations shown in the rose diagrams are not given for all horizontal logs counted; we could see and count many logs that were inaccessible due to the treacherous unstable behaviour of Unit 3. Horizontal logs comprise the largest component of transported wood, ranging from 59% on the lower Cowlitz River to 94% from the 1980 flows on Muddy River. The debris dam and Alder Creek had 87 and 78% transported logs, respectively. A small percentage of the logs were deposited in a diagonal position, and at the debris dam, a very small number were upside-down.

These counts show facies changes away from the vent area over the distance that the wood was transported (Fig. 8). The debris dam and Muddy River are the closest areas studied to the mountain; they also have a higher percentage of horizontal logs (Fig. 7) and fewer vertical stumps. Conversely, areas farther downstream at Alder

Fig. 4. Upright transported stump on the surface of the 1982 sediment flow at the debris dam in Fig. 1. Shovel to right of stump is 80 cm long.

Fig. 5. Upright transported stumps on Unit 3 of the 1982 sediment flow of the North Fork of the Toutle River 2.5 km downstream from Kid Valley. Note oriented horizontal logs and large clasts on the surface of the flow in the background.

Fig. 6. Horizontal log oriented and transported by the 1982 sediment flows. Downstream is to the left. Note (*A*) broken large roots, (*B*) unbroken resilient small rootlets and (*C*) a boulder transported in the entwined roots.

Fig. 7. Oriented horizontal logs and an upright transported stump on the surface (Unit 3) of the 1980 sediment flow at the Muddy River locality shown in Fig. 1. Flow was from left to right.

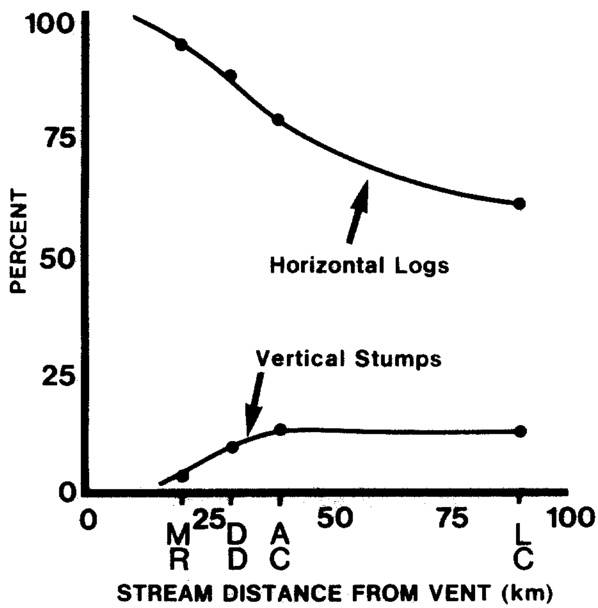

Fig. 8. Graph of the percentage of vertical transported stumps and horizontal logs showing facies changes away from the vent peak. *MR* = Muddy River, *DD* = debris dam, *AC* = Alder Creek, *LC* = Lower Cowlitz.

Creek and the lower Cowlitz show a slightly higher percentage of vertical stumps. In all areas, horizontal logs were oriented parallel to the stream channel and not necessarily radially away from the vent peak as in the blast zone.

This orientation with the stream channel shows that trees are reliable paleocurrent indicators for direction of stream flow. Previous authors have also assumed that streams orient transported trees. Roadifer (1966, pp. 44–46) used the long axis orientation of petrified horizontal logs to argue for stream deposition and paleocurrents in the Triassic Chinle Formation at Petrified Forest National Park, Arizona. However, little or no quantitative data from modern streams exists to corroborate these conclusions (see Pettijohn, 1975, pp. 71, 512; Potter and Pettijohn, 1977, pp. 46–47, for a partial discussion of this lack of data), and no one has spoken of the unique role of volcaniclastic sediment flows in orientating trees.

In addition to determining stream paleocurrents, oriented trees have been used to determine paleocurrents in lahar flows (Coffin, 1976), vent position (Froggatt et al. 1981), paleosouth (Smirnoff and Connelly, 1980) and wind direction (Wnuk and Pfefferkorn, 1983). Yet no attempt has been made to differentiate between these different means of orienting trees or to see if the orientation patterns vary. We believe that our observations provide needed, albeit tentative, data on sediment flow/fluvial orientations of trees.

Care should be taken in determining vent position from oriented trees as was attempted by Froggatt et al. (1981) because the trees may also be oriented by fluvial processes in the direction of local channels and not radially away from the vent. Our study also shows that because some stumps can be deposited upright, care should be taken when attempting to use vertical ones as indicators of paleosouth (Smirnoff and Connelly, 1980). In this case the likelihood of in-situ stumps must first be determined. This is especially important because stumps transported by the sediment flows are often deposited among standing trees buried in place (Fritz, 1980a), making it easy to confuse the two types. In commenting on using trees to indicate paleosouth (or north) neither Schroder and Sewell (1981) or Schwarzbach (1981) or Connelly and Smirnoff (1981) in their reply, considered that some of these trees might have been transported or at least turned and oriented by the volcaniclastic sediment flows.

Table I summarizes features useful in differentiating between transported vertical stumps and those preserved in place. Two features appear particularly useful. As Yuretich (1981) argued, stumps with long trunks over twice as long as the width of the root system are rarely, if ever, transported and deposited upright. Such a stump in the fossil record most likely remains where it grew. On the other hand, short stumps with a root system as wide or wider than the height of the stump are generally deposited upright if transported. We have attempted to quantify this concept in the form of a ratio of trunk height to root width, here called the trunk/root ratio. Thus, stumps with a trunk/root ratio of one or less are candidates for transportation while a ratio significantly greater than one precludes transporta-

TABLE I

Criteria that should be considered when attempting to differentiate transported upright stumps from those preserved in place. Critical features are designated with an asterisk. Note that items 4 and 5 do not differentiate between the two types, but are included here because they superficially appear to be useful criteria

Transported stumps	In situ stumps
*1. Large diameter roots broken	1. Large roots intact
*2. Short broken trunk with a wide root system. Trunk/root ratio of 1 or less.	2. Often have long trunks with a high trunk/root ratio significantly greater than 1
3. May include a mixture of ecological taxa not able to co-exist in a single paleoenvironment	3. All fossil trees should be compatible with the same paleoenvironment
4. Small rootlets may be present	4. Small rootlets may be present
5. Roots can surround large clasts	5. Roots can surround large clasts
6. Associated plant litter, but no true paleosols	6. Some true paleosols should exist
7. High energy depositional environment competent to transport tree-size clasts	7. High or low energy environment
8. May comprise up to 10–15% of the total amount of wood	8. If over 10–15% of the total amount of wood are upright stumps, some are preserved in place

tion by the mechanisms described here. The short stumps are only candidates for transportation and are not unequivocally transported because both short and tall stumps were also buried in place along the edges of the stream channels.

The mechanism responsible for deposition of upright stumps with ratios of one or less is a low center of mass in combination with a wide base (root system). Thus, either the stumps cannot be pushed over due to the wide roots or, if they are pushed over, gravity pulls them upright due to the low center of mass. In this manner they behave like a child's "push toy" that pops back up when knocked down. We thought at first that the vertical stump shown in Fig. 3 was an exception to this rule because it appears to have a long slender trunk. However, this appearance is only an optical illusion and the trunk/root ratio is approximately one. In addition, the narrow splintered top in combination with rocks and mud bound in the roots produces a very low center of mass.

A second feature useful in differentiating in situ from transported stumps is the presence of large broken roots. In all cases that we observed, transported stumps showed the largest roots to be broken when the stumps were uprooted (Figs. 4–9). In-situ stumps should show intact large roots. The presence of very small rootlets is not an important criterion in distinguishing transported from in-situ stumps because they are resilient and do not break off during transportation (Figs. 3–7 and 9). Also roots entwining cobble and boulder size clasts are not an important consideration because many of the transported stumps also transported the clasts entwined by the roots (Figs. 6 and 9). Dunbar and Rodgers (1957, p. 175) also depict an uprooted transported tree with a large boulder trapped in the roots. These boulders contribute to the low center of mass and the mechanism for depositing trunks upright.

Fig. 9. Detail of roots on a transported log exhibiting: (*A*) broken large roots, (*B*) unbroken resilient small rootlets, and (*C*) a boulder transported in the entwined roots of the stump.

However, roots wrapping around boulders as large as the stumps would seem to preclude transportation.

Our counts from Mount St. Helens indicate that a maximum of 10–15% of transported trees are deposited in an upright position. Higher percentages of upright trees were commonly encountered along the edges of the stream channels where transported stumps were preserved alongside trees buried in place. We argue therefore that a significantly higher proportion of preserved upright trees requires the presence of in-situ trunks. If anything, this percentage may be too high in the Mount St. Helens areas because at least some of the transported upright stumps were artificially produced by logging activity prior to the eruption. We see this 10–15% as a maximum percentage. This criterion should be used with some caution, however, because such factors as the dominant root system morphology and the nature of the depositional event could conceivably affect the ratio of vertically to horizontally transported trees. Additional populations must be examined to establish the variability of this ratio. Especially needed are studies in a volcaniclastic environment where there has been no logging activity prior to the eruption. Recent eruptions of the El Chichon volcano in southern Mexico may provide such an opportunity.

ANALOGIES WITH THE EOCENE FOSSIL FORESTS OF YELLOWSTONE NATIONAL PARK

We believe that features observed in transported trees around Mount St. Helens are directly comparable to petrified trees preserved in volcaniclastic/sedimentary deposits such as Eocene "fossil forests" in the Lamar River Formation of Yellowstone National Park. Previous workers (Holmes, 1879, and Dorf, 1964, 1980, among others) interpreted most of the wood to have been preserved in place. Later analysis of the sedimentary facies (Fritz, 1980b, c, 1982) indicated that an undetermined number of the stumps and logs may have been transported, causing an admixture of plant taxa representing several ecological niches. We have previously argued that the modern depositional facies around Mount St. Helens are comparable in every major respect to the Lamar River Formation (Fritz, 1982; Harrison and Fritz, 1982) and now conclude that the orientations of the trees is also analogous. This conclusion leads to interpreting less of the trees as transported than in the original paper by Fritz (1980b) but still demands some transported stumps.

Petrified trees in the fossil forests exhibit the range of features previously mentioned and given in Table I to differentiate transported logs and stumps from those preserved in place. We therefore argue that many in-situ trees may exist in the "fossil forests". We continue to agree with earlier conclusions presented by Fritz (1980c, p. 15, 1981, 1982) and Retallack (1981) that the three classic trees on Specimen Ridge recently studied by Yuretich (1984) are in place with preserved paleosols. These stumps (Retallack, 1981, fig. 2; Fritz, 1982, fig. 1; Yuretich, 1984, fig. 2) meet all of the criteria listed in Table I for trees preserved in place. Our work suggests that many more in-situ trees may exist in Yellowstone than indicated earlier (Fritz, 1980b).

We continue to argue however, that transported upright stumps exist in the Lamar River Formation and play an important role in producing the admixture of taxa from different ecological habitats. As an example, the stump shown in Fig. 10 from the Mount Hornaday section of Fritz (1982) exhibits the characteristics listed in Table I as representative of transported upright stumps. If workers like Yuretich (1984) really want to test for the presence of transported upright stumps in the Lamar River Formation, they should investigate stumps previously said to be transported (Fritz, 1982, fig. 21; and Fig. 10) and not ones that all have agreed are in place. We would like to stress at this point that our model of some transported stumps and logs along with many preserved in place differs significantly from a model proposed by Coffin (1979a, b, 1983a, b, p. 15) in which all or most trees are transported in a large body of water by a major flood.

Figure 11 shows orientation data for several representative intervals in the Lamar River Formation comparable to the Mount St. Helens area shown in Fig. 1. Because roots were not exposed on all of the petrified logs, mirror images are given in the rose diagrams indicating that true paleocurrents might have been in either of two

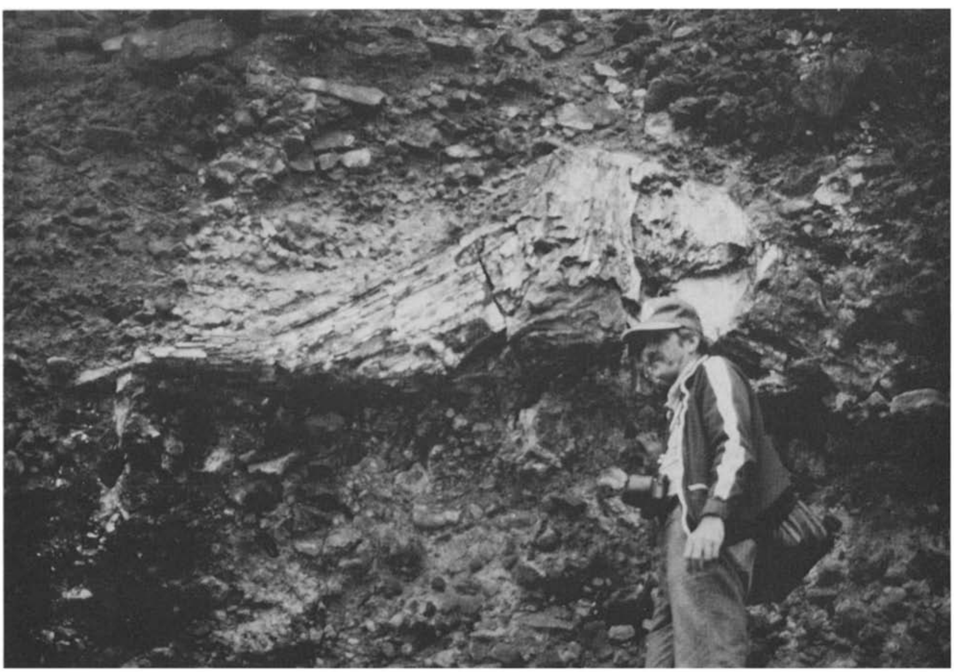

Fig. 10. An upright stump buried in sediment flow conglomerate near the base of the conglomerate unit of 355–380 m in the Mount Hornaday measured section (Fritz, 1982) in the Eocene Lamar River Formation. Based on criteria given in Table I, this stump is probably transported.

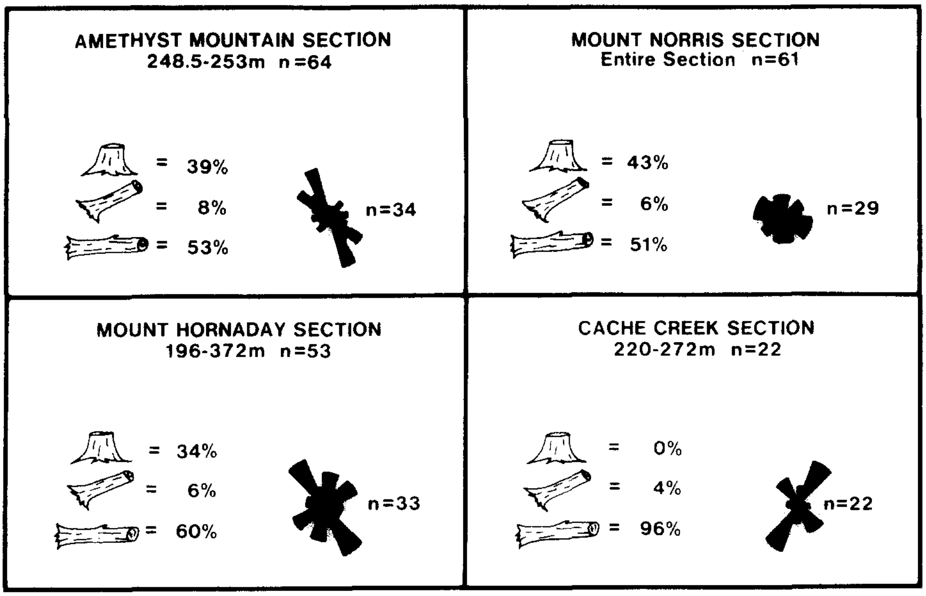

Fig. 11. Orientations of petrified trees from the Yellowstone "fossil forests" (Eocene Lamar River Formation). Compare with inset on Fig. 1. Exact locations are given in Fritz (1982).

opposite directions. Arguing from the Mount St. Helens data, because intervals on Amethyst Mountain, Mount Norris, and Mount Hornaday contain more than 10–15% vertical stumps, they contain many trees preserved where they grew in addition to transported ones described earlier (Fritz, 1980b, 1982). Additional studies of petrified trees in other volcaniclastic deposits such as the Sepulcher, Clarno, Challis, and Eagle Creek Formations are needed to test the reliability of using Mount St. Helens as a modern counterpart for the fossil record.

CONCLUSIONS

The strong orientation of horizontal logs suggests that logs preserved in sediment flow or fluvial deposits are reliable paleocurrent indicators for local river channels but do not necessarily point radially to the vent. Thus, care should be taken when attempting to determine the vent position to be sure that only trees in a blast zone are used. In a depositional environment such as Mount St. Helens, up to 10–15% of the total wood transported can be deposited as upright stumps. When studying fossil wood deposits, reliable indicators (such as those given in Table I) should be used to determine if there is a transported component to the trees. Finally, Mount St. Helens serves as a modern counterpart for fossil wood deposits such as the Yellowstone "fossil forests".

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