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Comment

Comment on "Non-Mineralized Fossil Wood" by George E. Mustoe (Geosciences, 2018)

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1. Introduction

We were pleased to see the summary article in Geosciences on fossil wood by George E. Mustoe [1], which does a very nice job of illuminating general conditions and characteristics of ancient wood preserved in various geological environments, some of which we have worked on. Although the introduction states that the "*paper provides a detailed review of fossil wood occurrences where tissues have not been mineralized*", it is not all-inclusive and falls somewhat short of this claim. It does, however, illustrate both a broad spectrum of circumstances in which this ancient wood is preserved and representative micro-anatomy of the wood. In the interest of accuracy, we respectfully offer a few comments provided below, which are intended to clarify or correct some minor aspects of what has been presented.

2. Discussion

To begin, we want to raise a point about an important term used in this paper versus the standard term used in the body of scientific literature. Specifically, the author [1] chose to define dead wood where "the original organic matter is present in relatively unaltered form" as "mummified". The term "mummified" as a modifier describing preserved wood seems to be preferred by researchers who work with wood in 'deep time' (specimens ranging in age from Pliocene to Oligocene), but the term "subfossil" is used by the much larger group of researchers who work with more recent dead wood (Quaternary). Our disagreement is not with the use of the term "mummified wood" in some contexts, but rather with the breadth of the definition used in the Mustoe (2018) paper [1]. Reasons supporting the use of the term "subfossil" as the modifier of choice in this context include the numbers of scientific journal publications where each term is used, temporal precedence, and denotation.

In considering the numbers of scientific journal publications containing each term, we searched the Web of Science [2] using "subfossil AND wood", with crosschecks to ensure that "subfossil" was modifying "wood". This search yielded over 200 references. A similar search with the same type of crosschecks using "mummified AND wood" or wood-related terms (e.g., conifer, angiosperm, log, forest, etc.) yielded less than 30 references. Many early scientific papers are not indexed by Web of Science, so temporal precedence was assessed using Google Scholar to search scientific journals published prior to 2000 (conference proceedings, government publications and textbooks were excluded). We learned that the term "mummified" when modifying wood or wood-related nouns (e.g., forests, log, oak, pine, etc.) appears less than 10 times in scientific journals prior to 2000, all in the 1990s, while the term "subfossil" as a modifier of wood or wood-related nouns appears several hundred times, including more than 50 instances prior to 1980. Table 1 illustrates selected examples of early references that used "subfossil" in this context.

Table 1. Selected examples from among 50+ pre-1980 references that used "subfossil" in the context of preserved wood. Description includes title and excerpt in which "subfossil" was used in the text, where necessary.

Year	Authors	Description
1978	Heine [3]	Höhenstufung von Zentral-Otago (Neuseeland)—Geoökologischer Überblick; "Subfossile Baumreste wurden darin häufig gefunden." [Subfossil tree remains were often found in it.] ('subfossil' used 4 times)
1975	Becker [4]	Dendrochronological observations on the postglacial river aggradation in the southern part of central Europe; "[. . .] Figure 6 [gives] a complication of all published C14-datings made from subfossil wood pieces found in postglacial gravel terraces of Central European rivers."
1971	Alessio et al. [5]	University of Rome Carbon-14 Dates IX; "Wood, subfossil stumps and trunks, found in situ, Mezzano salt valley"
1963	Molloy et al. [6]	New Zealand Journal of Botany; Distribution of subfossil forest remains, eastern South Island, New Zealand.
1957	Poore and McVean [7]	A New Approach to Scottish Mountain Vegetation; "Sub-fossil stems of dwarf juniper are often exposed..."
1957	Sen and Barak [8]	The Chemistry of Ancient Buried Wood; "It has been found that the amount of both cellulose and lignin is more in the inner fresh-looking portion of a subfossil elm wood as compared to the normal sample."
1956	Lombardo [9]	Determinazione di Alcuni Legni Subfossili Rinvenuti in Rovine di Case Romane a Ghirza (Tripolitania); [Determination of Some Subfossil Woods Found in Ruins of Roman Houses in Ghirza]
1948	Watt and Jones [10]	The Ecology of the Cairngorms: Part 1; "In the series of papers by Lewis subfossil pine is stated to occur at various maximum altitudes . . . "
1946	Eshuis [11]	Palynologisch en stratigrafisch onderzoek van de Peelvenen; "The 1st, 2nd and 4th beam in the foreground of the shed in photo 5 has been sawn from a 30 m long subfossil pine."
1935	De Geer [12]	Prehistoric Bulwark in Gotland Biochronologically Dated; "This investigation has shown that subfossil Pinus stocks may be good climatic indicators in teleconnection", "we may by these graphs of subfossil prehistoric tree rings follow their correspondence to Douglass' sequoia record directly by graphic comparison."
1921	Broughton [13]	Notes on the Geology of the Moorlands (South Australia) Brown Coal Deposits; "These subfossil trees occur generally in a horizontal position within the enveloping carbonaceous matrix."
1910	Moss et al. [14]	The Woodlands of England; "In the course of time, as a result probably of decreasing aeration of the soil, the marshy vegetation gains the upper hand: the former woodland becomes submerged and leaves only a sub-fossil tree-layer in the peat of the newly formed moor."
1901	Various [15] [1]	Yew tree distribution; "The evidence was derived from the microscopical examination of subfossil wood . . . "
1889	Nathorst [16]	On the Geological History of the Prehistoric Flora of Sweden; "in West Nyland, in Finland, sub-fossil remains of spruce in a stratum which he estimates to be older than the remains of spruce found in Scandinavia."

[1] No distinct author cited, but the work of Prof. Conwentz (Danzig) is described.

Regarding the denotation of the words "mummified" and "subfossil", the word "subfossil", as an adjective, is used to describe an organism that is "not fully fossilized" or "partly fossilized", meanings that can be applied to any organism after it has died. The word "mummified", a transitive verb, carries with it denotational meanings such as "dried up", "shriveled" and "desiccated", meanings that, if followed, would limit the conditions where the word should be applied to preserved wood.

Usage of "mummified wood" in many papers does fit these definitions, but the breadth of use in the paper about which we are commenting does not. We are not aware of any international commission that precisely defines such terms, but our consensus is that the term "mummified" might more reasonably represent a specific subgroup of subfossil wood that has been preserved in arid, desiccating conditions, in keeping with the accepted dictionary definition. Furthermore, in cases where the mode of preservation is unknown, or where the mode of preservation might include multiple distinctly different processes (e.g., anoxic, waterlogged preservation followed by desiccation), we also favor the more generic, objective 'subfossil' terminology.

The statement "The primary wall, which may be relatively thick, consists mostly of cellulose and hemicellulose, in contrast to the thinner secondary wall that is largely composed of a mixture of cellulose and lignin" contains several inaccuracies. The relative thicknesses noted in the quote are reversed (e.g., "The walls of most mature xylem cells consist of a thin primary wall and a thick secondary wall"; ([17] (p. 62), [18,19]). So, the primary cell wall is actually thinner than the composite secondary cell wall containing S1, S2 and S3 layers, and in fact the bulk of "wood" is dominated by the mass of the secondary cell wall (e.g., [18] (Figure 3–10)). Furthermore, the primary cell wall in woody plants contains roughly equal amounts of cellulose, hemicellulose and pectin (e.g., cell wall Type 1 in [20] (Table 1.1)), whereas the secondary cell wall in xylem (wood) is dominated by cellulose (notably in the S2 layer), but also contains high percentages of hemicellulose [18,19]. In many woody plants, both the primary and secondary cell walls become encrusted with lignin after the cell walls are complete, though the amount of lignification is highly variable "among plant groups and species, cells, and different parts of the same cell" [17]. In addition, the wording "destruction of the wood sugars cellulose and hemicellulose, resulting in relative enrichment of lignin" is not clear. The author might mean "the wood sugars, cellulose and hemicellulose" or "the wood sugar-based cellulose and hemicellulose", but to avoid any confusion, we recommend the wording should simply be "destruction of cellulose and hemicellulose, resulting . . . ".

The statement "Three months of continuous darkness during Arctic Circle winters favored conifers rather than angiosperms" needs some elaboration, as it is unclear on what this statement is based. For example, the Eocene polar biome of Arctic Canada may have macrofossils that, although dominated by conifers, also include several other species (e.g., [21–23]). The author himself even mentions this later in Section 3.3 of the paper. Harrington et al. [23], based on a palynological study, concluded that the biome of the Eocene Arctic forests at Stenkul and Strathcona Fiord was broadly similar to the broadleaved forests of the southeastern United States. Poole [24] presented several examples of angiosperm wood from fossil forest deposits in Antarctica and argued that the fact that the bias towards coniferous wood found in polar Paleogene deposits may have more to do with preservation bias than true site diversity. In modern circumstances, as far as we know, it is the particular characteristics of conifers such as tree shape (conical to shed snow), leaf shape (needles to shed snow), leaf protective surfaces waxes (retaining moisture), and capacity to limit freezing damage in cells [25] that are more likely to favor them at high latitudes. Some angiosperm genera such as *Betula* (birch) and *Populus* (poplar) also grow at high latitudes and are both present in Pliocene-aged Arctic forest deposits (e.g., [26,27]).

Although the section discussing the Pliocene-aged Arctic forests is small, there are a few minor inaccuracies in the descriptions of the Pliocene deposits on Ellesmere Island. For one, the only citation for the Beaver Pond fossil wood is incorrect. The paper cites Davies et al. [28] which in fact describes wood from Meighen Island, not Ellesmere Island. There has been a considerable amount of work done on the Pliocene forests, including the wood, from Ellesmere Island [29–32]. The author also could have cited Rybczynski [33] when mentioning the evidence for beaver activity. It would have been good of the author to describe these logs, in some cases as large as 80 cm in diameter, in the same detail as the other sites. It should be noted that the provenance of the single Cornwallis Island sample is disputed, and as there is only a single reference to a single sample collected from the side of a road; we would hesitate to call it a site. The Prince Patrick Island localities, which include the type locality for the Pliocene Beaufort Formation wherein most of the fossil wood deposits of this age occur is not mentioned [34–36]. Finally, the citation listed for the Meighen Island locality is incorrect and cites Jahren [37], which is a paper discussing the Eocene forest of Axel Heiberg Island.

In the section on the Miocene Ballast Brook formation it should be noted that although Len Hills was the first to describe the stratigraphy of the site in modern times, Ballast Brook has been known as a locality of Tertiary plant material since 1868 [38].

It is unusual that Section 3.6, which describes wood recovered from kimberlite pipes in the Northwest Territories, is the only section that makes mention of stable isotope values obtained from cellulose from the mummified deposits in the Arctic. There has been a wealth of material published on stable isotopes, and even compound specific isotopes from cellulose of fossil wood from several of the Arctic sites mentioned in this paper, including several studies from the Axel Heiberg fossil forest that are cited elsewhere in the paper [37,39,40].

Several inaccuracies are presented in relation to the wood found in the Two Creeks Buried Forest, which is found across an area of at least 5000 km^2. The location of the deposit was inaccurately identified in Figure 7, where it is placed in Iowa, when it should have been in northeastern Wisconsin, about 300 km to the northeast [41]. We offer two comments on the mode of preservation: First, the reason for the unusually pristine preservation is the presence of late Pleistocene lacustrine sediments and glacial tills that overlie the buried forest and contain abundant low permeability silt and clay as thick as 5 m or more. Second, the author describes shrinkage cracks as the typical appearance of the exterior of the wood. While this might be frequently true, this is probably an artifact of modern exposure. Fresh exposures of spruce (*Picea*) logs, including some that are more than 3 m long and up to 30 cm in diameter, are not desiccated upon initial exhumation (Figure 1). In contrast, Two Creeks wood is often water-saturated and in organic-rich horizons when discovered in excavations. Prevention of desiccation cracks can be accomplished by wrapping the logs in plastic food wrap to allow for slow dehydration. For these reasons, we do not feel that preservation mode for Two Creeks Buried Forest wood is appropriately described as "mummified wood".

(**a**) (**b**)

Figure 1. Subfossil spruce wood (*Picea*) from the Two Creeks Buried Forest in northeastern Wisconsin, USA showing no significant desiccation cracking, despite storage in the laboratory for over two years in plastic wrap. Locality is the Ebben Quarry near Green Bay, Wisconsin (44.440279° N, 88.173981° W) and is a confirmed Two Creeks site by Hooyer and Mickelson [41]. (**a**) View of outside of log. Scaly portion at top left is a remnant of the original bark. (**b**) View of transverse section showing lack of desiccation cracking. Log diameter is 26 cm.

Mummification requires desiccation, whereas preservation of non-mineralized wood only requires absence of microbial and chemical degradation. Despite the fact that many famous fossil wood localities appear not to have involved the desiccation process to a significant degree, they are still described by the author as "mummified wood". Perhaps a fourth category of organic preservation in acidic and anoxic sediments might be justified here (e.g., subfossil wood, waterlogged wood, wet-preserved wood), similar to how clothing, wood artifacts, and human tissues are remarkably preserved in wet boglands of Europe and Florida (e.g., [42]). In our experience many aspects of the Two Creeks Buried Forest appear consistent with a water-saturated, organic-rich system encased with clay-rich sediments, including the fact that trees in growth position are sometimes preserved in proglacial lacustrine sediments. Perhaps others, such as the author's description of the Ipolytarnóc Fossil Forest in Hungary (Section 3.12), along with some of the Arctic sites, might also benefit from a similar classification because its preservation mode involved "deep burial in water-saturated sediment."

Finally, we would like to report an error in the handling of radiometric ages indicated for the Two Creeks Buried Forest. The author appears to have switched the radiocarbon ages and calendar ages from how they originally appeared in the literature, yielding a calendar age that is far too young for the corresponding radiocarbon age. The correct ages, as noted in Mickelson et al. [43] should be an average radiometric age of 11,850 ^{14}C yr BP and a calendar age of 13,500 cal yr BP. Many of the Two Creeks-age sites are mapped and described in [44], as are numerous other subfossil wood sites in the Great Lakes region, and in fact, tree-ring chronologies have been developed from them [45].

Several additional references to localities, ages, and other items appear not to have been dealt with carefully, making parts of the paper confusing to the reader. For example, Figure 2's caption indicates Meighen Island as Miocene (incorrect), but later the correct age of Pliocene is given in the text and in Figure 3's caption. Section 3.11 indicates Siberia as a European locality, and the numbered references (74–79) appear to be all shifted by one number.

The citation given for the 6:1 ratio compression of wood on Axel Heiberg appears to be incorrect. The given citation is Fyles et al. [46], which is a paper focused on the Miocene Ballast Brook and Pliocene Beaufort Formations on Banks Island and not on the Eocene forest of Axel Heiberg. The only reference we can think of for this compression ratio would correctly be to Basinger et al. [21].

3. Conclusions

As the use of tree rings continues to expand to address important scientific questions, undoubtedly more research will enlist the ancient wood deposits such as those described by Mustoe [1]. In addition to new examination and analysis of samples already collected in past decades, new deposits are likely to be discovered and our understanding of tree growth, physiology, and anatomy will be applied to them to extract valuable environmental information.

Conflicts of Interest: The authors declare no conflict of interest.

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