



The environmental water of the middle Eocene Arctic: Evidence from δD , $\delta^{18}O$ and $\delta^{13}C$ within specific compounds

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ABSTRACT

The extensive vertical exposure (>150 m) of terrestrial sediments on Axel Heiberg Island, which contain thick fossiliferous lignites, presents an exceptional opportunity to follow the establishment and re-establishment of Arctic *Metasequoia* forests during the middle Eocene. We compared δD values in *n*-alkanes of chain length 23, 25, 27 and 29 with $\delta^{18}O$ values in phenylglucosazone (P-G) derived from α -cellulose; we also analyzed %-abundance of ferns, gymnosperms and angiosperms using pollen and spores isolated from each lignite. Our results showed that forest composition was altered upon uplift, as gymnosperms became more abundant within the relatively well-drained upland sediments. This was also reflected in the small (1‰), but significant, increase in the $\delta^{13}C$ value of TOM from lowland to upland environments. However, neither the δD values of *n*-alkanes nor the $\delta^{18}O$ in P-G were statistically different in the upland sediments, as compared to the lowland sediments; from this we inferred that the oxygen isotope signature of environmental water available to the forests for plant growth was relatively uniform throughout the time of the fossil forests. The δD value of environmental water implied by both *n*-alkanes and P-G ranged from −168 to −131‰ and was considerably enriched compared to all environmental water samples available from the modern Arctic region (<−180‰). In addition to indicating a warmer Eocene Arctic, subject to meteoric transport patterns different from today's, these results argue against the presence of an Eocene polar ice cap.

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1. Introduction

Evidence from plant fossils and paleogeographic studies indicates that a lush deciduous conifer forest existed well above the Arctic Circle during the middle Eocene (~45 Ma; Fig. 1; Basinger, 1986; Ricketts and McIntyre, 1986). The Buchanan Lake Formation, which crops out extensively on Axel Heiberg Island, contains more than 30 lignite layers comprised of exceptionally preserved fossil wood, forest litter and amber, many of which are meters in thickness and are horizontally continuous for kilometers (Jahren, 2007). With few exceptions, prior analyses of Axel Heiberg sediments come from the area around the “K–L–M” lignites, a ~5 m thick section within the ~150 m sequence of Buchanan Lake sediments (e.g., Williams et al., 2003). Here we report the results of novel compound-specific analyses across the full sedimentary record of the Arctic middle Eocene, as recovered from Axel Heiberg Island. We present the first detailed and complete stratigraphic section described for the Buchanan Lake Formation and include the first data detailing the isotopic composition of specific compounds with successive establishment of fossil forests

throughout the section. We interpret the results we see in terms of the contrasting ecosystems of meanderplain (lowland) forests, compared with alluvial fan (upland) forests, and the larger hydrological patterns of the Arctic middle Eocene.

2. Field site

The sediment of the Buchanan Lake Formation has been placed within the middle Eocene, based on the recognition of brontothere fossils associated with the upper strata (Eberle and Storer, 1999). Unfortunately, a refined estimate of the time represented by the 150+ m of vertical terrestrial deposits is extremely difficult, because of the large uncertainties associated with terrestrial sedimentation rates. The sequence represents sediment accumulation within a narrow intermontane basin (Fig. 2). The principal controls on sedimentation were differential uplift and elevation of source terrane along tectonic strike leading to aggradation on an alluvial plain (Ricketts, 1991); because the basin is small and tectonically-controlled, very high rates of sedimentation may apply (Blatt et al., 1980). For these reasons, most researchers have concluded that the sediments of the Buchanan Lake Formation represent geologically rapid cycles of forest establishment, coarser sediment deposition, and forest re-establishment. Tarnocai et al. (1991) examined silica content within paleosols near the top of the section, and

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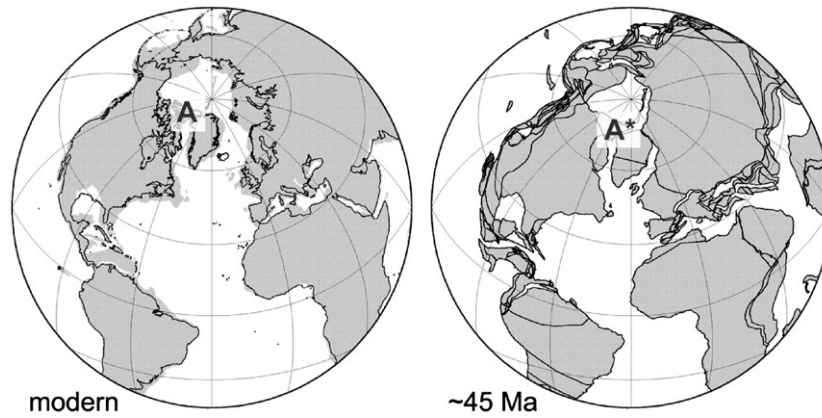


Fig. 1. Lambert azimuth map projections showing the location of the fossil forest site at present (A; 79°55'N) and during the time when the trees were alive (A'; ~45 Ma; 78.6 ± 1.6°N). Drawn using www.ods.de/ods.

concluded a soil development time of 10^3 to 10^4 yr, assuming that the silica resulted from a concentration of plant phytolith material. Based on the supposition of 50 paleosols, Ricketts (1991) ventured an estimate of 0.5 million years as the total accumulation rate of the Buchanan Lake

Formation. Given the above, we estimate that the 150+ vertical meters of sediment on Axel Heiberg Island constitute the remains of at least thirty distinct episodes of Arctic forestation that were established and re-established on thousand-to-ten-thousand year cycles.

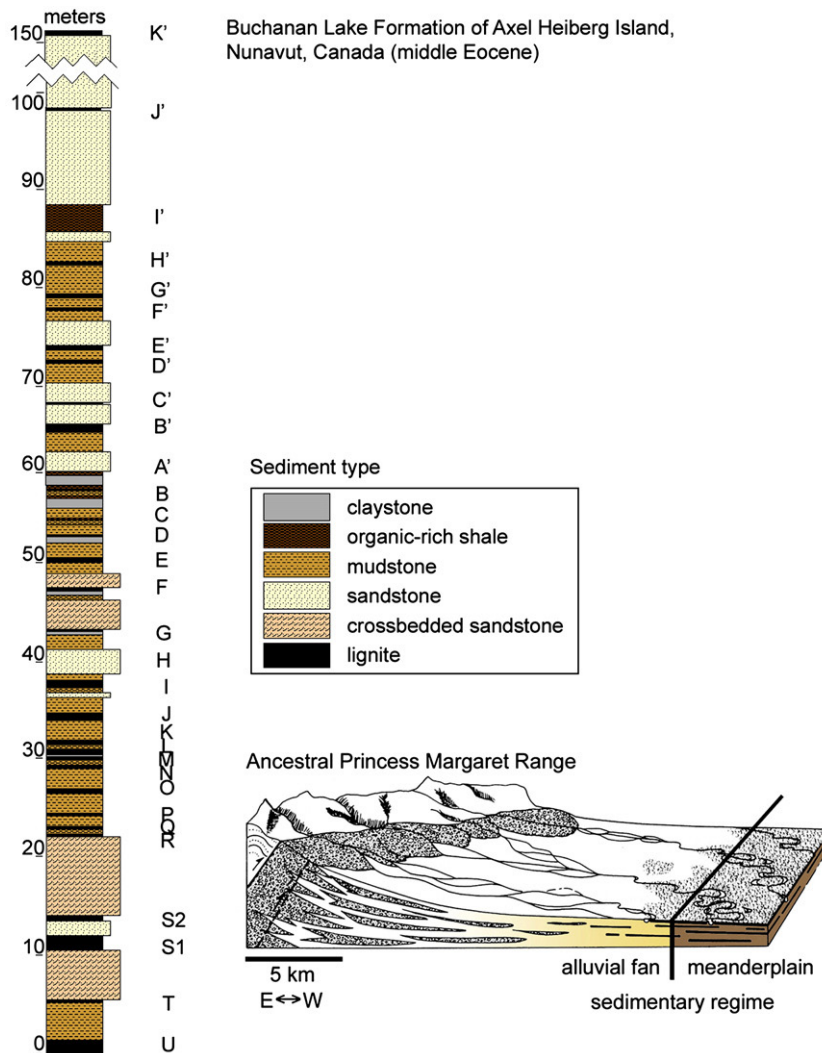


Fig. 2. Stratigraphic column of sedimentary units within the Buchanan Lake Formation of Axel Heiberg Island, Nunavut, Canada. The strata are middle Eocene in age (Eberle and Storer, 1999) and include a rotating sequence of claystones, shales, mudstones, sandstones and lignites, ranging from a few cm to >10 m in thickness. The sequence shows two distinct sedimentary regimes associated with the Ancestral Princess Margaret Range: the lower portion of the column (below A'; <60 m) resulted from terrestrial deposition within a lowland meanderplain, the higher (above layer A'; 60 m and above) portions of the column correspond to relatively upland deposition within an alluvial fan (after Ricketts, 1991).

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