Lagerstätten of the Okanagan Highlands (British Columbia and Washington): emergent communities in Early Eocene climates

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Summary

The Early Eocene was a time of globally warm and equable climates (Wing and Greenwood 1993, Zachos et al. 2008, Shellito et al. 2009), and is also noted for the appearance of many modern plant and insect genera, and as the time when terrestrial communities began to take on their modern form. A series of Early Eocene lake lagerstätten collectively called the Okanagan Highlands were deposited in basins from central British Columbia to northern Washington State. These lagerstätten bear a diverse suite of diatoms, plants, insects, and fish (and, rarely, birds), often exquisitely preserved to details of leaf epidermal cell patterns and insect wing membrane hairs and colour patterning.

These factors facilitate ongoing research that examines patterns of diversity, biogeography and lineage evolution in relation to climate, geography and community change using the rich record of plants and insects preserved in key early Okanagan Highlands lagerstätten collected in census-style bulk sampling.

Introduction

The Early Eocene Okanagan Highlands lagerstätten occur across a thousand kilometer transect of southern interior of British Columbia, Canada and northern Washington, USA (Fig. 1). They are well situated to illuminate the origins of modern terrestrial communities, as modern plant and insect families and genera were emergent, in some cases mixed with now (regionally or globally) extinct Paleogene elements, allowing modern taxa with known environmental tolerances and community associations to be evaluated in distinctly non-modern settings. Climates were then globally equable, with the highest temperatures of the Cenozoic, particularly during hyperthermal events associated with atmospheric pCO_2 greatly exceeding modern levels (Zachos et al. 2008). Data from climate proxies such as the size and shape of dicot leaves, the frequency of leaf stomata, the taxonomic composition of micro- and macrofloras, and isotopes, in combination with computer modelling has allowed detailed characterizations of Eocene environments and assessment of potential forcing factors (e.g., Greenwood et al. 2005, Shellito et al. 2009, Smith et al. 2009).

These sites bear rich fossil assemblages that reflect the communities of these lakes and their surrounding forests (Figs. 2 & 3). Preservation is often exquisite, showing fine details of leaves to their epidermal cell patterns and of insects to hairs on the legs of tiny fungus gnats. The regional climate and geochronology is known with increasing precision. The fish and their lacustrine environment have been studied extensively (e.g., Barton and Wilson 2005), and their insects and plants have been examined sporadically for over 100 years, but intensively only recently. Multiple geologic and paleontological indicators suggest that this region was an upland with comparable-to-modern altitude (800-1300m) and a cool climate within this warm Eocene world (e.g., Greenwood et al. 2005; Smith et al. 2009, and references summarized therein). The

exceptional preservation of the fossils is associated with and may be due in part to the post-mortem deposition of a bio-film of diatoms, a pattern also inferred for other Eocene lacustrine shale lagerstätten (Harding and Chant 2000).

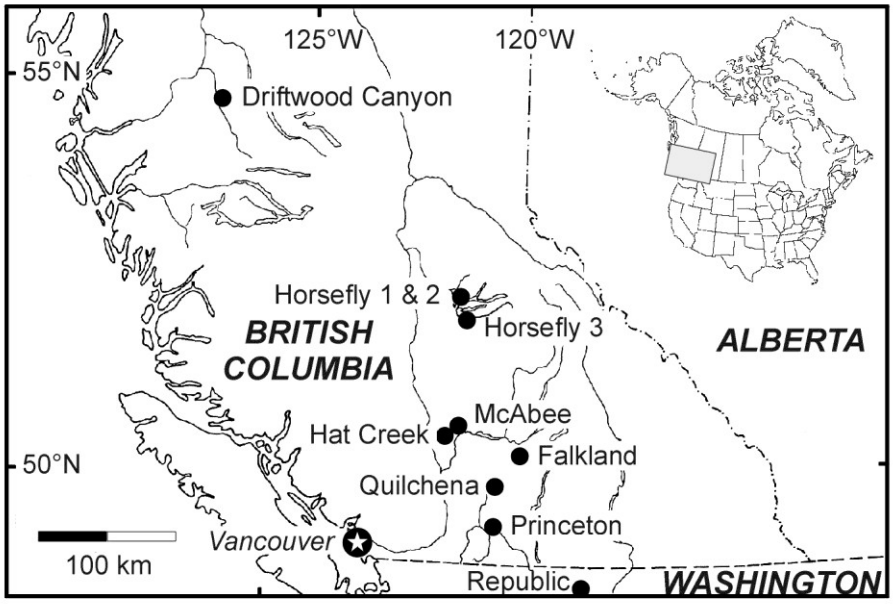

Figure 1: Map showing Okanagan Highlands fossil sites, British Columbia and Washington (Greenwood et al. 2005).

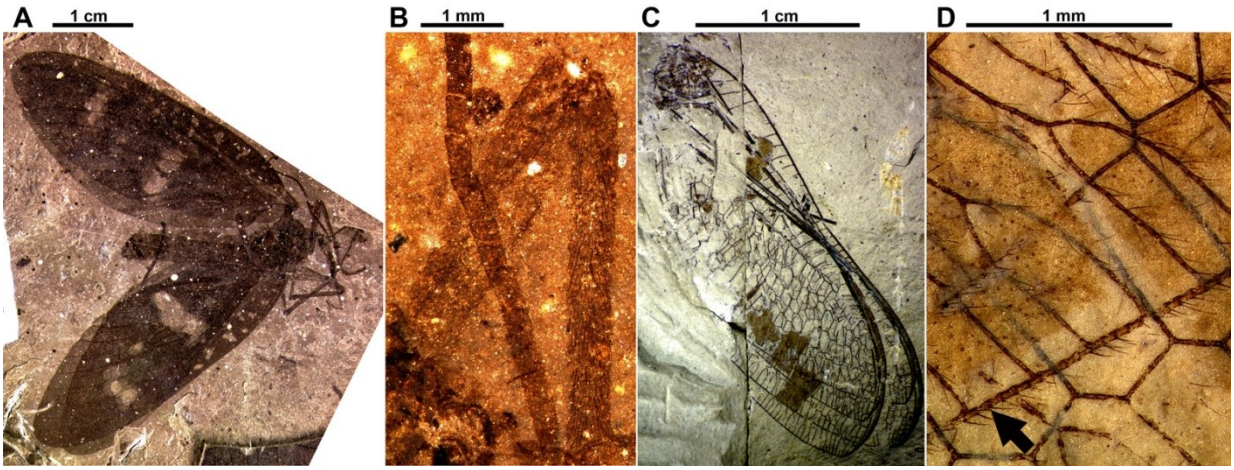

Figure 2: Fine-level insect preservation: A), the scorpionfly (Mecoptera: Dinopanorpidae) *Dinokanaga hillsi* (named for L.V. Hills) from McAbee; B), close-up of (A), showing leg and antenna details; C), unnamed green lacewing (Neuroptera: Chrysopidae) from Republic; D), close-up of (C) (rotated), showing trichosors (possibly sensory organs) on wing margin (arrow). To scales as indicated, (B) and (C) wetted with ethanol.

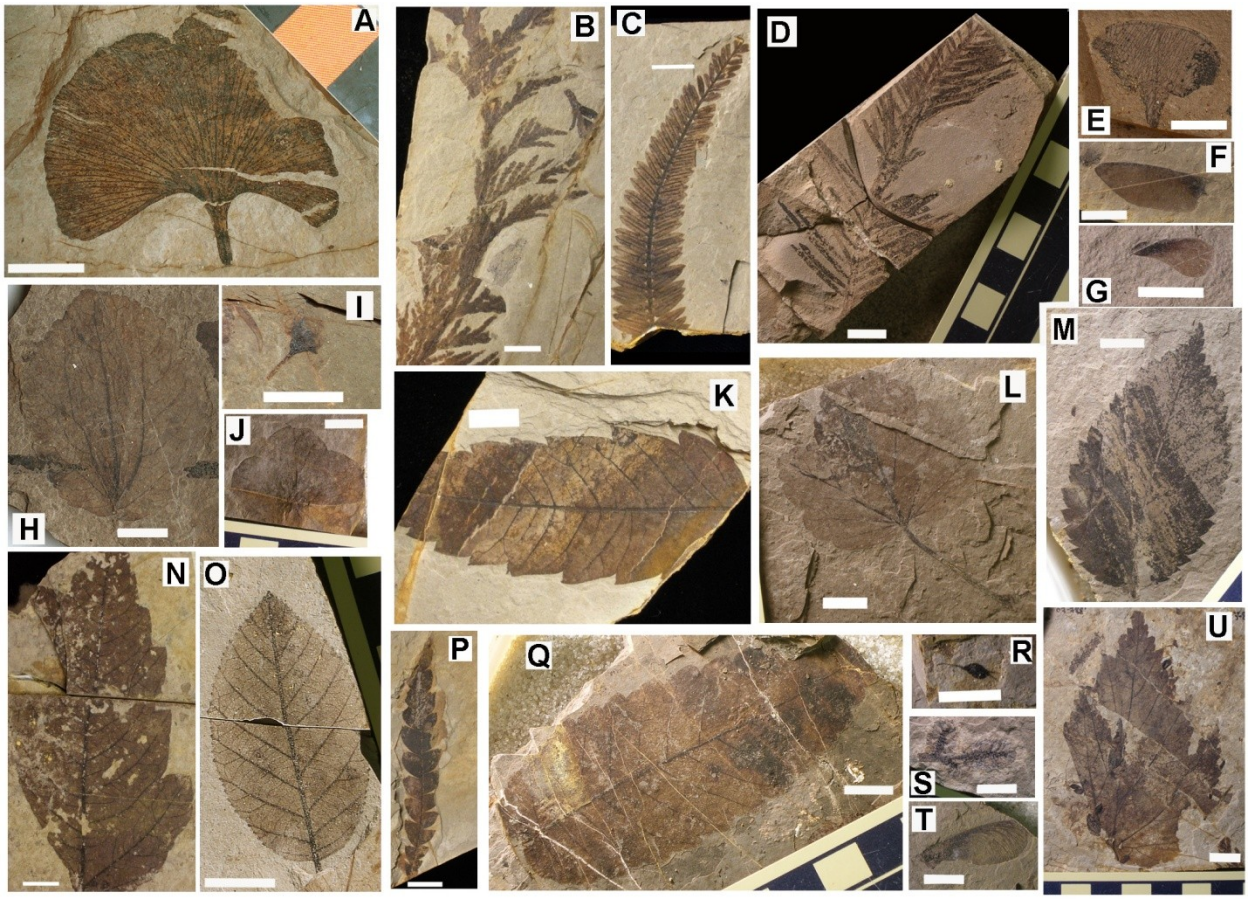

Figure 3: Typical taxa from the Falkland flora. Based on Smith et al. (2009). Scale bars = 1 cm. (A) *Ginkgo*; (B) Cupressaceae foliage; (C) *Metasequoia*; (D & E) *Abies*; (F) *Pinus*; (G) *Picea*; (H) *Cercidiphyllum*; (I) *Trochodendron*; (J) *Florissantia*; (K) *Rhus* ? (Anacardiaceae); (L) cf. *Ribes*; (M) Ulmaceae; (N) *Bohlenia*; (O) *Alnus*; (P) *Comptonia*; (Q & R) *Ulmus*; (S) *Alnus*; (T & U) *Acer*.

Materials and Methods

Climate is characterized by leaf physiognomy and nearest-living-relative analyses, and plant and insect communities by bulk-sampled unbiased collections (e.g., Wilf et al. 2005) and identified to orthotaxa or parataxa (Archibald and Mathewes 2000, Greenwood et al. 2005, Moss et al. 2005, Archibald 2007, Smith et al. 2009). New radiometric dates are being estimated by Ar^{40}-Ar^{39} and U-Pb methods as applicable (Mortensen and Archibald, current research).

Examples

Recent compilations characterizing broad-scale and regional Okanagan Highlands climates and communities include those by Greenwood et al. (2005), Moss et al. (2005), Archibald (2007), and Smith et al. (2009). Recent and current research includes investigations of lake environments and depositional settings (e.g., Wilson and Barton 2005); diversity relative to climate within and across Okanagan Highlands communities (Archibald and Mathewes 2000, Smith et al. 2009, Archibald et al. in press, and current research); Okanagan Highlands biota large-scale biogeography (intra- and intercontinental dispersals) (DeVore et al. 2005, Archibald and Makarkin 2006, Archibald 2009); and range extensions of tropical-associated (today) biota into cool higher latitudes creating community compositions not found today (current research as above, Wing and Greenwood 1993, Greenwood and Wing, 1995, Archibald and Mathewes 2000, Archibald and Farrell 2003, Greenwood et al. 2005).

Conclusions

The Okanagan Highlands lagerstätten are uniquely suited to elucidate the origins of modern terrestrial communities and the climates and geographic settings in which they formed, as they contain specimen- and taxon-rich fossil communities with fine level preservation, allowing detailed characterization of climates and communities and greater understanding of their relationships.

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