INTRODUCTION

The Okanagan Highlands: Eocene biota, environments, and geological setting, southern British Columbia, Canada and northeastern Washington, USA[1]

S. Bruce Archibald and David R. Greenwood

Abstract: Climate change is a matter of concern to society, decision makers, and scientists. As part of the debate about the science of climate change, and in particular the extent to which current climate change is due to human activity or part of the natural variability of the global climate system, earth scientists try to understand how climates have changed in the past, and how past warming and cooling episodes affected the landscape and the plants and animals that occupied that landscape. It is also clear from the fossil record that past climate change has played a role in the evolution of animal and plant lineages, as well as plant and animal communities. Preserved in a series of lake deposits across northeastern Washington State, USA., to Smithers in north-central British Columbia, Canada, the Okanagan Highlands fossil deposits preserve a record of a time when the world was much warmer than now because of a naturally enhanced greenhouse effect, and the poles were ice-free and supported great forests. These sites are well known to fossil collectors for their beautifully preserved insects, fish, and plants. The Okanagan Highlands were an upland 50 million years ago, during the Early Eocene, and supported diverse forests swarming with insects and other animals that today are found in both temperate and tropical areas. The trees, shrubs, and herbs of these Eocene forests echo this pattern, including palms and bald cypress, together with spruce and birches. This special issue presents a series of papers that resulted from a symposium held in 2003 on the Okanagan Highlands that details the warm Eocene world of the interior uplands of northeastern Washington and British Columbia. Topics include reconstructing the landscape, biogeography, palaeoclimates, and fossil plants, insects, diatoms, and fish.

Résumé : Les changements climatiques sont une préoccupation pour la société, les décideurs et les scientifiques. Faisant partie du présent débat sur la science des changements climatiques et mesurant l'étendue selon laquelle le présent changement climatique est dû à l'activité humaine ou est une partie de la variabilité naturelle du système climatique global, les géoscientifiques essaient de comprendre comment les climats ont changé dans le passé et comment les épisodes de réchauffement et de refroidissement ont affecté les paysages, les plantes et les animaux qui occupaient ce paysage. Il est aussi clair, à partir des fossiles trouvés, que des changements climatiques antérieurs ont joué un rôle dans l'évolution des lignées d'animaux et de plantes, ainsi que des communautés d'animaux et de plantes. Conservés dans une série de dépôts lacustres à travers le nord-est de l'État de Washington, É.-U., jusqu'à Smithers dans le centre-nord de la C.-B., Canada, les dépôts de fossiles des terres hautes de l'Okanagan enregistrent un temps où le monde était beaucoup plus chaud que présentement, en raison d'un effet de serre naturellement rehaussé et que les pôles étaient libres de glace et supportaient de vastes forêts. Ces sites sont bien connus des collectionneurs de fossiles pour leurs plantes, insectes et poissons magnifiquement préservés. Au cours de l'Éocène précoce, il y a environ 50 Ma, les terres hautes de l'Okanagan constituaient un milieu sec et elles supportaient diverses forêts remplies d'insectes et d'autres animaux qui, de nos jours, se retrouvent dans des régions tempérées et tropicales. Les arbres, les arbustes et

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S.B. Archibald.[2] Harvard University, Department of Organismic and Evolutionary Biology, Museum of Comparative Zoology, 26 Oxford Street Cambridge, MA 02138, USA.
D.R. Greenwood. Environmental Science Program, Brandon University, 270 18th Street, Brandon, MB R7A 6A9, Canada.

[1]This article introduces a selection of papers published in this Special Issue on *The Okanagan Highlands: Eocene biota, environments, and geological setting*.
[2]Corresponding author (e-mail: barchibald@oeb.harvard.edu).

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les herbes de ces forêts éocènes sont l'écho de ce patron; ils comprennent des palmiers et des cyprès chauves ainsi que des épinettes et des bouleaux. Ce volume présente une série d'articles qui sont le fruit d'un colloque tenu en 2003 portant sur les terres hautes de l'Okanagan; les articles traitent en détail du monde chaud, à l'Éocène, et des milieux secs de l'intérieur du nord-est de l'État de Washington et de la Colombie-Britannique. Les sujets traités comprennent la reconstruction du paysage, la biogéographie, les paléoclimats et les plantes, insectes, diatomées et poissons fossiles.

[Traduit par la Rédaction]

Introduction

The warmest part of the Cenozoic worldwide is recognized from paleontological evidence as the Early Eocene Climatic Optimum (Wing et al. 2003). Early to Middle Eocene climates at all latitudes were predominantly upper microthermal to megathermal and seasonably equable — that is, lacking any significant influence from freezing temperatures (Greenwood and Wing 1995; Wing et al. 2003). Across most of North America, paleontological evidence points to taxonomically diverse forest biotas, with their closest modern analogs found in mesothermal subtropical and megathermal tropical areas (Wolfe 1987; Greenwood and Wing 1995; Wing et al. 2003). Key questions and uncertainties in reconstructing the Early to Middle Eocene world and its climate include the influence of uplands on the climate of North America (Greenwood and Wing 1995; Sewall et al. 2000) and the origins and history of lineages characteristic today of microthermal broad-leaved deciduous and coniferous forests (Wolfe 1987; Manchester 1999).

A richly fossiliferous Early to Middle Eocene series of shale and coal deposits, called the Okanagan Highlands, occur sporadically through about 1000 kilometres of central British Columbia, Canada and northeastern Washington State, USA. The majority of localities occur today at elevations ranging between 500 and 1100 m. Disagreement has occurred over the paleoelevation of these deposits; however, it is clear that this area was an upland in the Eocene, with an elevation similar to or perhaps higher than today (Wolfe et al. 1998) and thus provided a cool upland climate during the Early Eocene Climatic Optimum, in contrast to the warm lowlands of coastal and western interior North America. They represent an ideal system for examining long-standing questions on the origin and evolutionary history of key plant and insect lineages, biogeographical and ecological patterns, and Early to Middle Eocene climates.

The Okanagan Highlands provide a climatic and topographic setting, which, coupled with its rich diversity of fossil biota, allows detailed examination of its mixture of plant and animal lineages, a number of which are today associated with either warm or cool climates. The resultant biotic assemblage differs from those known from Eocene warmer regions of coastal lowlands to the immediate west, or from the continental interior further to the southeast in Wyoming (Wolfe 1987; Wing and DiMichele 1996). The Okanagan Highlands may have served as a centre of origin and diversification for many cool-adapted plant groups that are today dominant in temperate forests (e.g., Wing and DiMichele 1996; Johnson 1996). Many earliest known occurrences at the family and genus level of insects, as well as plants, occur in the Okanagan Highlands (Archibald and Mathewes 2000).

A series of exceptionally fine-grained annual lacustrine varve couplets exposed on the Horsefly River calibrated to many millennia has enabled detailed ecological and taphonomic research (e.g., Wilson 1993). This allows, for example, the birth-year varve of a particular fish to be identified a short stratigraphic distance below that in which it was preserved, or the determination of whether the fish died in the summer or the winter. Wilson's work on these varved Eocene lake sediments and their fossil biota has become a classic study exemplifying taphonomic principles.

The term "Okanagan Highlands" (at times with the American spelling "Okanogan") has been in use at least since the 1920s, applied to the transitional mountain area in southern British Columbia, lying between the Columbia Basin to the south and the Columbia Mountains to the northeast, and into northeastern Washington State (Shedd 1923; Holland 1964). Wehr and Schorn (1992), however, writing from the paleontological perspective of the fossiliferous shales at Republic, Washington, and Princeton, British Columbia, modified this term to mean the Eocene interior uplands region, distinct from other regional Eocene deposits by their particular biotic assemblages, set in a cool upland. The Eocene Okanagan Highlands is now understood to encompass the climatic, biotic, and physiographic region that extended much further northward, to Driftwood Canyon, near the town of Smithers in central British Columbia.

Paleontological and geological studies of these deposits go back about 130 years (e.g., Scudder 1877; Dawson 1890; Berry 1926; Russell 1935; Brown 1935; Arnold 1955). Interest in the Eocene fossils of the region expanded since the mid-20th century, continuing primarily in paleobotany, but also in paleoichthyology, paleoentomology, and in taphonomic and paleoenvironmental studies. Papers in this special issue provide an introduction to this literature.

Contributions to this Special Issue

In light of the growing recognition of the Okanagan Highlands as a study system with potential for addressing questions of broad interest, a special session was organized to bring together workers in various fields of Okanagan Highlands studies at the joint Annual Meeting of the Geological Association of Canada – Mineralogical Association of Canada – Society of Economic Geologists in Vancouver, British Columbia, during May 2003. Presentations at the session covered a wide range of investigation. The majority of the talks focused on paleobotany, as befits the historical predominance of this work in the paleontology of the region. This Special Issue contains nine papers based on talks presented at that meeting, or on related topics.

Archibald (this issue) describes the first North American occurrence of the scorpionfly (Mecoptera) family Dinopanorpidae, with six new species in a new genus found among five Okanagan Highlands localities. This family was previously known only by a single described hindwing and a second briefly reported specimen from the Paleogene of Pacific-coastal Siberia.

Barton and Wilson (this issue) present a high-resolution environmental study, using fish taphonomy as an indicator of environmental change over a 10 000-year interval represented by a sequence of varved summer and winter couplets at Horsefly. They reconstruct the depositional environment of Eocene Horsefly Lake during much of this interval as deep, quiet, offshore, and hypoxic. They scored fish fossils for articulation as an indicator of water temperature, tetany of oxygenation, and size and species composition of lake depth. They recognize changes in environment through this time, for example, periods of shallower, warmer waters, with better oxygenation are indicated in the 4th and 7th millennia.

Dillhoff et al. (this issue) report the floral diversity of the McAbee locality, finding at least 87 taxa, based on leaf and reproductive remains. These records reveal a hitherto unrecognized richness at the locality, including the earliest well-established occurrence of *Fagus*.

Greenwood et al. (this issue) and Moss et al. (this issue) characterize the climatic and ecological aspects of the Okanagan Highlands, as a whole, and provide an overview of their taxonomic character and age control. The mixture of biota whose nearest living relatives are associated with climates of both temperate and tropical geographic regions is seen in both plants and insects, consistent with Eocene seasonal equability, i.e., winters with few, if any freezing days. The authors of both papers suggest that the Okanagan Highlands forests were the antecedents of the modern eastern North American deciduous forests, but also included taxa that are today known from East Asia (e.g., Manchester 1999; Dillhoff et al. this issue; DeVore et al. this issue), are extinct, or are now restricted to regions of warmer climate in lower latitudes.

Using the microfloral record, Moss et al. (this issue) conclude that plant communities across the Early Eocene Okanagan Highlands were dynamic in response to volcanic and other disturbance and also exhibited significant local and regional floristic variation, reflecting differing edaphic, aspect, and other factors.

DeVore et al. (this issue) discuss the significance of selected Okanagan Highlands plant taxa. The oldest (and sometimes only) fossil record of several genera are found here: *Carpinus* and *Corylus* (Coryloideae), *Neviusia* (Rosaceae), *Trochodendron* (Trochodendraceae), and *Fothergilla* (Hamamelidaceae). They recognize the Okanagan Highlands as a “paleobotanical hot spot” — a region with fossil floras that are key to our understanding of the evolution of modern North American flowering plant diversity and of present Asian – North American disjunct distributions.

Tribe (this issue) reconstructs the Eocene landscape of the central Okanagan Highlands, concluding that it bore many similarities with modern-day southern British Columbia. The lacustrine shale and coal occurrences appear to have been deposited in valleys — some dating to the Cretaceous — that persist to modern times. The drainage pattern of this region was to the northeast, rather than southwest through the Fraser River, as today. The lakes and wetlands in which the shale and coal were deposited were formed by drainage disruption, although the cause of this is not known: possibilities include regional volcanism, uplift, or a number of tectonic causes.

Using major element geochemistry, X-ray diffraction patterns, and relict diatom frustules, Mustoe (this issue) demonstrates that the Eocene beds at Horsefly, McAbee, and Princeton originated as lacustrine diatomite that underwent diagenetic alteration to produce siliceous shale. Mustoe proposes that these beds document wide-spread migration of marine diatoms to freshwater environments by the early Cenozoic. Wolfe and Edlund (this issue) describe a new genus and species of centric diatom from Horsefly that represents one of the oldest freshwater occurrences of diatoms known.

Work by a variety of researchers proceeds both in increasingly higher resolution taxonomic, taphonomic and paleoenvironmental studies, as well as with advances in broad-based studies of biogeographic and regional geologic, climatic and ecological characterizations and comparisons. We expect that ongoing study of the Okanagan Highlands will result in fruitful, and at times unexpected advances in addressing some of the outstanding problems listed here.

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References

Archibald, S.B. 2005. New Dinopanorpidae (Insecta: Mecoptera) from the Eocene Okanagan Highlands (British Columbia, Canada and Washington State, USA.). Canadian Journal of Earth Sciences, **42**: This issue.

Archibald, S.B., and Mathewes, R.W. 2000. Early Eocene insects from Quilchena, British Columbia, and their paleoclimatic implications. Canadian Journal of Zoology, **78**: 1441–1462.

Arnold, C.A. 1955. Tertiary conifers from the Princeton coal field of British Columbia. University of Michigan Museum of Paleontology Contributions, **12**: 245–258.

Barton, D.G., and Wilson, M.V.H. 2005. Taphonomic variations in Eocene fish-bearing varves at Horsefly, British Columbia, reveal 10 000 years of environmental change. Canadian Journal of Earth Sciences, **42**: This issue.

Berry, E.W. 1926. Tertiary floras from British Columbia. Bulletin of the Geological Survey of Canada, **42**: 91–116.

Brown, R.W. 1935. Miocene leaves, fruits, and seeds from Idaho, Oregon, and Washington. Journal of Paleontology, **9**: 572–587.

Dawson, W.J. 1890. On fossil plants from the Similkameen Valley and other places in the southern interior of British Columbia. Transactions of the Royal Society of Canada, **VIII**: 75–90.

DeVore, M.L., Pigg, K.B., Wehr, W.C. 2005. Systematics and phytogeography of selected Eocene Okanagan Highlands plants. Canadian Journal of Earth Sciences, **42**: This issue.

Dillhoff, R.M., Leopold, E.B., and Manchester, S.R. 2005. The McAbee flora of British Columbia and its relation to the

Early–Middle Eocene Okanagan Highlands flora of the Pacific Northwest. Canadian Journal of Earth Sciences, **42**: This issue.

Greenwood, D.R., and Wing, S.L. 1995. Eocene continental climates and latitudinal temperature gradients. Geology, **23**: 1044–1048.

Greenwood, D.R., Archibald, S.B., Mathewes, R.W., and Moss, P.T. 2005. Fossil biotas from the Okanagan Highlands, southern British Columbia and northeastern Washington State: climates and ecosystems across an Eocene landscape. Canadian Journal of Earth Sciences, **42**: This issue.

Holland, S.S. 1976. Landforms of British Columbia: a physiographic outline. 2nd ed. British Columbia Department of Mines and Petroleum Resources, Bulletin 48, Victoria, B.C.

Johnson, K.R. 1996. The role of the Republic flora in documenting the floristic evolution of the Northern Hemisphere. Washington Geology, **24**(2): 41–42.

Manchester, S.R. 1999. Biogeographical relationships of North American Tertiary floras. Annals of the Missouri Botanical Gardens, **86**: 472–522.

Moss, P.T., Greenwood, D.R., and Archibald, S.B. 2005. Regional and local vegetation community dynamics of the Eocene Okanagan Highlands (British Columbia – Washington State) from palynology. Canadian Journal of Earth Science, **42**: This issue.

Mustoe, G.E. 2005. Diatomous origin of siliceous shale in Eocene lake beds. Canadian Journal of Earth Science, **42**: This issue.

Russell, L.S. 1935. A Middle Eocene mammal from British Columbia. American Journal of Science, **29**: 54–55.

Scudder, S.H. 1877. The insects of the Tertiary beds at Quesnel (British Columbia). Geological Survey of Canada, Report of progress 1875–1876, pp. 266–280.

Sewall, J.O., Sloan, L. Cirbus, Huber, M., and Wing, S. 2000. Climate sensitivity to changes in land surface characteristics. Global and Planetary Change, **26**: 445–465.

Shedd, S. 1923. Topography and geology of the Okanogan Highlands and Columbia Plateau of Washington. Geological Society of America Bulletin, **34**: 1–75.

Tribe, S. 2005. Eocene paleo-physiography and drainage directions, southern Interior Plateau, British Columbia. Canadian Journal of Earth Sciences, **42**: This issue.

Wehr, W.C., and Schorn, H.E. 1992. Current research on Eocene conifers at Republic, Washington. Washington Geology, **20**(2): 20–23.

Wilson, M.V.H. 1993. Calibration of Eocene varves at Horsefly, British Columbia, Canada, and temporal distribution of specimens of the Eocene fish *Amyzon aggregatum* Wilson. Kaupia. Darmstädter Beiträge zur Naturgeschichte, **2**: 27–38.

Wing, S.L., and DiMichele, W.A. 1996. The Republic Highlands. Washington Geology, **24**: 40.

Wing, S.L., Gingerich, P.D., Schmitz, B., and Thomas, E. (*Editors*). 2003. Causes and consequences of globally warm climates in the early Paleogene. Geological Society of America, Special Paper 369, pp. 1–614.

Wolfe, J.A. 1987. An overview of the origins of the modern vegetation and flora of the northern Rocky Mountains. Annals of the Missouri Botanical Gardens, **74**: 785–803.

Wolfe, A.P., and Edlund, M.P. 2005. Taxonomy, phylogeny, and paleoecology of ***Eoseira wilsonii*** gen. et sp. nov., a Middle Eocene diatom (Bacillariophyceae: Aulacoseriraceae) from lake sediments at Horsefly, Britsh Columbia, Canada. Canadian Journal of Earth Sciences, **42**: This issue.

Wolfe, J.A., Forest, C.E., and Molnar, P. 1998. Paleobotanical evidence of Eocene and Oligocene paleoaltitudes in midlatitude western North America. Geological Society of America Bulletin, **110**: 664–678.