

Paleozoic Basin Research

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Introduction

The component basin-fill rocks of the Maritimes Basin complex, although predominantly of Carboniferous age, span the mid-Devonian through lower Permian (Calder, 1998). Historically, work has focused on coal resources of Carboniferous age within this succession, but insight into these resources, as well as related hydrocarbons and non-traditional resources, requires research encompassing several disciplines, both related and disparate. Current investigations include Late Carboniferous biostratigraphy, coal geochemistry, paleontology of the Joggins Formation and Devonian-Carboniferous hydrocarbon source rocks. Progress on these topics is reported here.

The exchange of critical ideas with international colleagues that is fundamental to such research was assisted in 1999 by hosting the pre-meeting field trip (Calder *et al.*, 1999) of the XIV International Congress of the Carboniferous and Permian (Calgary), last held in North America in 1979. Such co-operation provides invaluable scientific resources which otherwise would be unavailable or prohibitive in cost.

Biostratigraphy

The accepted geological age assigned to complex lithostratigraphic units comprising the Paleozoic sedimentary basin fill has a profound impact on models of basin evolution and the mineral, energy and paleontological resources in the component basins. In the virtual absence of absolute, radiometric dates, the relative ages provided by biostratigraphy are of key importance. Progress in three key localities of the Maritimes Basin is reported below.

Joggins, Cumberland Basin (NTS 21H/09)

The Joggins section is one of the most important Carboniferous sections in the world and is of strategic importance in interpreting the history of the Maritimes Basin, which in turn links the geological history of northeastern North America and western Europe (Calder, 1998). Long held to be of early Westphalian age (Bell, 1944; Hacquebard and Donaldson, 1964; Dolby, 1991), the age of the coal-bearing Joggins

Formation has recently been investigated and called into doubt (Utting and Giles, 1998), with assertions that the section may be entirely pre-Westphalian. If this conclusion is correct, it will have profound implications on the interpretation of Maritimes Basin history and stratigraphy.

The Namurian-Westphalian boundary is defined in the western European Carboniferous Basin primarily on the basis of the *Gastrioceras subcrenatum* marine band, an open marine goniatite fauna which is not present in the Maritimes Basin. In the terrestrial realm, few plant extinctions or appearances occur across this boundary, which makes its resolution extremely difficult in the absence of the defining marine record. In the Maritimes Basin, this challenge is heightened by the virtual absence of one of the most useful plant groups that make a marked appearance in the Westphalian, this being the densospore-producing group of lycopsids. Their paucity in the Maritimes Basin has been attributed to unfavourable ecological conditions, supported by the interpretation from the rocks of a more seasonally stressed climate in the Maritimes than in Western Europe and the Appalachian and Interior basins of the United States (Calder, 1991, 1998).

Controversy about the age of this classic section has resulted in considerable attention to the floral record by palynologists and macrofloral paleobotanists. It is apparent that the classic coal-bearing section, the Joggins Formation, lies close to the Namurian-Westphalian boundary or transition, with elements of both late Namurian and early Westphalian floras. Current research suggests that it is, at youngest, early Westphalian 'A' (Langsettian) and may in fact span the boundary.

A re-evaluation of key specimens representative of the Cumberland Group (*sensu* Ryan *et al.*, 1991) from the macroflora collections of W. A. Bell at the Geological Survey of Canada was undertaken by R. H. Wagner, Córdoba, Spain, who concluded in his report to the Geological Survey of Canada that the flora are representative of the Westphalian A-B (Wagner, 1999). Joint examination of the section by Dr. Wagner and the author during the pre-meeting field trip of the XIV International Congress of the Carboniferous and Permian in Calgary, however, yielded earlier taxa evocative of the late Namurian, such as *Neuraethopteris larischii* (provisional) which will be studied further.

Systematic identification of macroflora within a stratigraphic context will help to constrain the age of the section as the only major biostratigraphic data set available to complement and test palynological results. Detailed paleo-ecological studies of parts of the section undertaken earlier by the author (Calder *et al.*, 1999, and in preparation) provide important data in this regard. It will be particularly important to constrain the upper age range of the section, represented by strata at Spicer Cove at the far southern limit of the coastal section. Here, a diverse macrofloral assemblage awaits collection and further study.

The age of rocks below the Joggins Formation are being revised currently by palynologists J. Utting and G. Dolby and their results are being prepared for publication by the Geological Survey of Canada. In general, their current research suggests that the ages represented in descending order by the Boss Point, Claremont and Shepody formations are older than previously recognized. A possible hiatus between the Boss Point Formation and underlying Claremont Formation would lend support to exclusion of the Claremont from the Cumberland Group as presently defined (Ryan *et al.*, 1991). The implied disconformity corresponds to the mid-Carboniferous Break, which has been described as the most profound event recorded in the geological evolution of Carboniferous fill in the Maritimes Basin (Calder, 1998).

Resolution of the age of the lower Carboniferous Shepody Formation has major implications for global magnetostratigraphy, as the redbeds of this unit have been used to define a global magnetic polarity reversal (DiVenere and Opdyke, 1991, and others) that is widely used to constrain the lower Carboniferous time scale (M. Menning, personal and written communication, 1999) and paleocontinental reconstruction (Scotese and McKerrow, 1990, and others).

Brule, Cumberland Basin (NTS 11E/14)

The Brule walchian forest and tetrapod trackway site provides a data set that helps to constrain the age of the problematic redbeds, specifically the Cape John Formation of the Pictou Group, that constitute the uppermost fill of the Cumberland Basin in northern Nova Scotia. Compression fossils of the walchian conifers, evocative of the *Auracaria* such as Norfolk Island pine, are typical of lower Permian redbed localities in paleotropical North America and Europe, but their occurrence has been reported from older strata. The conundrum of diachronous appearances of the

walchian conifers in response to different timing of the onset of increasing aridity in the late Carboniferous and early Permian remains a concern in their biostratigraphic utility. The temnospondyl-cotylosaur-pelycosaur ichnotaxa represented at Brule is consistent with the Lower Rotliegend of Europe and lower Wolfcampian of southwestern USA, although similar concerns of earlier, ecologically controlled appearances in the Maritimes Basin apply to the vertebrate record as well. Ecological influences notwithstanding, the weight of paleontological evidence at Brule is consistent with a post-Stephanian age, within the lower or more probably middle Autunian (R. H. Wagner, written communication, 1999).

Spring Valley 1 Well, Prince Edward Island

The macrofloral record of the 1706 m succession cored in the Spring Valley 1 well was assessed at the request of industry in order to help constrain stratigraphic interpretation in the subsurface of this portion of the Maritimes Basin, for which little biostratigraphic data exist. Interpretation of the basin fill on Prince Edward Island provides an important constraint to geological interpretations of the geology of northern Nova Scotia. The age of the cored sequence, which was sampled with the assistance of Lyndon Jensen under contract to the P. E. I Gas Co. Ltd., can be constrained provisionally from near total depth of the well to within 800 m of surface, above which the redbeds are barren of macroflora.

Strata near the base of the well at 1646.59 m yielded an uncommon flora provisionally identified as *Palmopteris furcata*. This taxon has been reported from the Westphalian B (Duckmantian) of Britain (Cleal and Thomas, 1994) but its range is not well constrained (R. H. Wagner, personal communication, 1999). It is possible that strata at the base of the Spring Valley well may be considerably older than Westphalian B, given the simple, primitive structure of this enigmatic fern-like foliage. A rich assemblage in a dark grey interval from 1079-1080 m, dominated by *Neuropteris* sp. with *Cyperites* sp., less common *Lobatopteris*, and rare ? *Mariopteris* and ? *Eusphenopteris* spp., is no younger than Stephanian nor older than Westphalian D. This assemblage in particular, and macroflora generally from 893 to 1216 m depth, are evocative of the Sydney Mines Formation of the Sydney Basin, which ranges in age from Westphalian C to Cantabrian. Lobate pectopterids found at 893 m make their first appearance at the Westphalian D and persist through the Stephanian, indicating that the barren redbed sequence above, nearly

900 m in thickness, is no older than Westphalian D. The presence or absence of Permian age strata within this interval, however, remains unknown.

Correlation of the subsurface record across Prince Edward Island holds regional significance for Permo-Carboniferous stratigraphy in the Gulf of St. Lawrence and has been undertaken by P. S. Giles of the Geological Survey of Canada Atlantic (Giles and Utting, 1999).

Paleontology of the Joggins Section

New insight into the paleontology of the Joggins Formation was advanced by the continuing field work and discoveries of Brian Hebert, student at Saint Mary's University, and through the collaboration of Andrew Milner, vertebrate palaeontologist at Birkbeck College, University of London, with whom collaboration was made possible by the author's receipt of a Palaeontology Research Grant from the Nova Scotia Museum.

The rare find by Brian Hebert of an intact lycopsid stump cast containing tetrapod bone material presented the opportunity to assess for the first time in a century the taphonomy of the Joggins tree stump fauna. The occurrence of this fauna is central to the community's application to the United Nations Educational, Cultural and Scientific Organization (UNESCO) for recognition of the Joggins section as a World Heritage Site (see next paper, this volume). A multidisciplinary research group, whose activities were jointly funded by DNR, the Fundy Geological Museum, and the Palaeontology Research Grant of the Nova Scotia Museum, included the author, Hebert, preparator Tim Fedak (Fundy Geological Museum), vertebrate paleontologist Milner (Birkbeck College, University of London) and paleobotanist Andrew Scott (Royal Holloway, University of London). Work on the specimen will continue at Fundy Geological Museum in 2000. It is hoped that this work will provide insight into the mechanism by which the Joggins tetrapods became entombed in the once hollow trees.

Important faunal discoveries from the lower Joggins Formation were found and prepared by B. Hebert at the Fundy Geological Museum. They include the now largest collection in the world of an enigmatic, rare, large unionoid bivalve, *Archanodon (Asthenodonta) westoni*. The discovery of a pelvic girdle, which may have affinities with the stem tetrapod group, the Baphetidae ('Loxommatidae'), represents the largest tetrapod yet discovered from the Joggins section. These discoveries, which will be described more fully

elsewhere, provide important new insight into the paleoecology and sedimentary environment of the lower Joggins Formation redbeds.

Minerotrophic Coals of the Joggins Formation

The petrography, geochemistry and palynology of several coal beds from the Joggins Formation were investigated by Dr. J. C. Hower, Centre for Applied Energy Research, University of Kentucky, in collaboration with the author. The Joggins coals have been shown to be pervasively enriched in chalcophile elements, particularly zinc, arsenic and lead (Hower *et al.*, 2000). Zinc, in concentrations ranging up to 1.52 % (ash basis), commonly occurs as sphalerite infilling cell lumens in fusinite (charcoal). Arsenic and lead each may exceed 0.6 % (ash basis) in these high-pyrite coals, which are exceptional values for Euramerican coals.

Hydrocarbon Source Rocks

A project continuing since 1998 in collaboration with Dr. Prasanta (Muki) Mukhopadhyay, Global Geoenergy Research Ltd., entails sampling of possible hydrocarbon source rocks with specific attention to 'unconventional' sources in the coal measures of the Cumberland Group. The reader is referred to preliminary results in the field guide of the annual meeting of The Society for Organic Petrology (Calder *et al.*, 1998), which was co-hosted in Nova Scotia during 1998.

In 1998 and 1999, the mid-Devonian McAdam Lake Formation on Cape Breton Island was sampled as part of a broad sampling of the Maritimes Basin fill sequence. The occurrence of newly exposed organic-rich beds was brought to the attention of the author by Dr. Chris White (DNR), who recently co-described their geological setting (White and Barr, 1998). A 40 cm thick organic-rich bed approaching a coaly shale was sampled and submitted for organic petrography, vitrinite reflectance, palynology, Rock Eval pyrolysis and gas chromatography-mass spectroscopy. The extent and hydrocarbon potential of these rarely exposed sub-Horton rocks, which constitute the initial organic deposits of the Maritimes Basin, are as yet poorly understood. The McAdam Lake occurrence is of particular interest for hydrocarbon exploration because the organic-rich rocks record a surprisingly low maturation history ($R_o \sim 1.0$), given their age and stratigraphic position at the base of the Maritimes Basin succession.

References

- Bell, W. A. 1944: Carboniferous rocks and fossil floras of Nova Scotia; Geological Survey of Canada, Memoir 238, 277 p.
- Calder, J. H. 1991: Controls on Westphalian peat accumulation: the Springhill Coalfield, Nova Scotia; Ph. D. thesis, Dalhousie University, 310 p.
- Calder, J. H. 1998: The Carboniferous evolution of Nova Scotia; in Lyell: the Past is the Key to the Present, eds. D. J. Blundell and A. C. Scott; Geological Society (London), Special Publication 143, p. 261-302.
- Calder, J. H., Boehner, R. C., Brown, D. E., Gibling, M. R., Mukhopadhyay, P. K., Ryan, R. J. and Skilliter, D. M. 1998: Classic Carboniferous sections of the Minas and Cumberland basins in Nova Scotia, with special reference to organic deposits; The Society for Organic Petrology, Annual Meeting Field Trip, 29-30 July, 1998; Nova Scotia Department of Natural Resources, Open File Report ME 1998-5, 86 p.
- Calder, J. H., Davies, S. J. and Gibling, M. R. 1999: Classic Upper Carboniferous sections of the Maritimes Basin in Nova Scotia; field trip of the XIV International Congress of the Carboniferous and Permian, Calgary, 95 p.
- Calder, J. H., Gibling, M. R., Scott, A. C., Davies, S. J. and Hebert, B. 1999: Palaeoecology and sedimentology of fossil lycopsid forest successions in the classic Upper Carboniferous section at Joggins, Nova Scotia; XIV International Congress on the Carboniferous and Permian, Calgary, Programme with Abstracts, p. 19.
- Cleal, C. and Thomas, B. 1994: Plant fossils of the British Coal Measures; Palaeontological Association, Field Guides to Fossils, No. 6; The Palaeontological Association, London, 222 p.
- DiVenere, V. J. and Opdyke, N. D. 1991: Magnetic polarity, stratigraphy and Carboniferous paleopole positions from the Joggins Section, Cumberland Structural Basin, Nova Scotia; Journal of Geophysical Research, v. 96, p. 4051-4064.
- Dolby, G. 1991: The palynology of the western Cumberland Basin, Nova Scotia; Nova Scotia Department of Mines and Energy, Open File Report 91-006, 39 p.
- Giles, P. S. and Utting, J. 1999: Maritimes Basin stratigraphy: Prince Edward Island and adjacent Gulf of St. Lawrence; Geological Survey of Canada, Open File 3732.
- Hacquebard, P. A. and Donaldson, J. R. 1964: Stratigraphy and palynology of the Upper Carboniferous coal measures in the Cumberland Basin of Nova Scotia, Canada; Comptes Rendus, V Congrès International de Stratigraphie et de Géologie du Carbonifère, Paris, v. 3, p. 1157-1169.
- Hower, J. C., Calder, J. H., Eble, C. F., Scott, A. C., Richardson, J. D. and Blanchard, L. J. 2000: Metalliferous coals of the Westphalian A Joggins Formation, Nova Scotia, Canada: petrology, geochemistry and palynology; International Journal of Coal Geology, v. 42, p. 185-206.
- Menning, M., Weyer, D., Drozdowski, G., Wendt, I. and Drozdowski, G. 1999: Carboniferous time scales: the range of possible interpretations; GeoForschungs Zentrum, Potsdam, Open File Illustration.
- Ryan, R. J., Boehner, R. C. and Calder, J. H. 1991: Lithostratigraphic revision of the Upper Carboniferous to Lower Permian strata in the Cumberland Basin, Nova Scotia, and the regional implications for the Maritimes Basin in Atlantic Canada; Canadian Society of Petroleum Geologists Bulletin, v. 39, p. 289-314.
- Scotese, C. R. and McKerrow, W. S. 1990: Revised world maps and introduction; in Paleozoic Palaeogeography and Biogeography, eds. W. S. McKerrow and C. R. Scotese; Geological Society of London, Memoir 12, p. 1-21.
- Wagner, R. H. 1999: The composition and age of the Cumberland flora, Nova Scotia; unpublished report to the Geological Society of Canada, 36 p.
- White, C. E. and Barr, S. M. 1998: Stratigraphy and tectonic significance of the Lower to Middle Devonian McAdams Lake Formation, Cape Breton Island, Nova Scotia; Atlantic Geology, v. 34, p. 133-145.