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Joggins Fossil Institute

ABSTRACTS

1st Joggins Research Symposium

Joggins, Nova Scotia

The first Joggins Research Symposium was held at the Joggins Fossil Centre, Joggins, Nova Scotia, on 22 September, 2018. The Symposium was part of the celebration of the 10th anniversary of the designation of Joggins Fossil Cliffs as a UNESCO World Heritage Site. Its purpose was to highlight recent and current research at the site. The Joggins Fossil Institute staff and Science Advisory Committee facilitated a fruitful meeting, with 12 submitted abstracts and over 25 participants, including academic and government scientists and representatives from the Nova Scotia Museum and the Fundy Geological Museum. Not surprisingly, the conference also included a field trip to the Joggins Fossil Cliffs beach where there was plenty of time for discussion and inspiration.

In the following pages, we are pleased to provide the abstracts of oral presentations from the meeting. As you will see, topics included ichnology, sedimentology, education and outreach, and new vertebrate research.

The Joggins Fossil Institute is grateful for support for this symposium from the Atlantic Geoscience Society.

The Organizers

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Breaking down Late Carboniferous fish coprolites from the Joggins Formation

Nikole Bingham-Koslowski[1], Melissa Grey[2], Peir Pufahl[3], and James M. Ehrman[4]

1. Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada <nikole.bingham-koslowski@canada.ca> ¶
2. Joggins Fossil Institute, Joggins, Nova Scotia B0L 1A0, Canada ¶
3. Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada ¶
4. Digital Microscopy Facility, Mount Allison University, Sackville, New Brunswick E4L 1G7, Canada

The Joggins Fossil Cliffs UNESCO World Heritage Site preserves exemplary Late Carboniferous terrestrial and aquatic environments. The terrestrial environment has been studied in detail; however, little is known about the salinity and trophic structure of the aquatic realm. Late Carboniferous fish coprolites of the Joggins Formation contain undigested material that provide information on the diets of fish and the species interactions that existed within the aquatic ecosystem. Six coprolite morphotypes, representing four trophic levels, can be identified at Joggins. It is here hypothesized that coprolites from different trophic levels will have discrete, identifiable compositional signatures due to dissimilar dietary requirements. This study aims to investigate the elemental and physical composition of each morphotype through scanning electron microscopy-energy dispersive X-ray spectroscopy (SEM-EDS), X-ray diffraction (XRD), and ultrasonic disintegration. Preliminary SEM-EDS analyses indicate variations in elemental composition between cylindrical and equant morphotypes: the equant coprolite morphotype is enriched in barium and the cylindrical morphotype is enriched in zinc. These elemental discrepancies may be due to dissimilarities in diets, supporting the classification of these morphotypes into different trophic levels. Additional analyses will investigate the elemental signatures of all morphotypes to see if SEM-EDS is a viable method for trophic classification of coprolites. XRD analyses of the coprolites will complement SEM-EDS, refining elemental composition. Furthermore, representative coprolites will be physically dismantled via ultrasonic agitation in order to isolate components such as teeth, bones, and scales, with the intention of better defining diet and potentially relating these components to the elemental differences observed in SEM-EDS.

Joggins 30 million years plus 10: thoughts and reflections

John Calder

Nova Scotia Department of Energy and Mines, Halifax, Nova Scotia B3J 3P7, Canada <John.H.Calder@novascotia.ca>

On the 10th anniversary of the inscription of the classic geological section at Joggins on the list of UNESCO World Heritage Sites, the author would like to share some thoughts for the future in the areas of science, engagement, conservation and legislation. Science: (i) taphonomy of tetrapods; (ii) ongoing recording of spatial distribution of lycopsid forests as revealed by erosion; (iii) reassessment of vertebrate and invertebrate traces; (iv) paleoenvironment of beds above Coal 1 of Logan in the Joggins Formation (north of Dennis Point); and (v) careful assessment of the marine vs terrestrial realms. Engagement: 'engagement over science': scientific investigation will proceed, but only the Joggins Fossil Institute and Centre are in a position to advance engagement. Conservation:(i) reclaim the integrity of rocks on the shore, particularly the introduction of exotic rock types brought in to the World Heritage Site as decorative stone or for armour stone; and (ii) pursue funding for construction of a storage facility for curation and study of tetrapod-bearing trees, the single most important aspect of the fossil legacy of Joggins. Legislation: revision of the Special Places Protection Act to empower the staff of the World Heritage Site to engage visitors and school children.

Fish coprolites and new insights into the brackish Carboniferous ecosystem of the Joggins Formation

Max Chipman[1], Melissa Grey[2], and Peir Pufahl[1]

1. Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6, Canada <max.chipman@gmail.com> ¶
2. Joggins Fossil Institute, Joggins, Nova Scotia B0L 1A0, Canada

The Joggins Fossil Cliffs UNESCO World Heritage Site (Nova Scotia) holds a wealth of fossils, terrestrial and aquatic, from the Late Carboniferous Period. Fossils from the aquatic realm have historically been understudied and the ecosystem they represent is poorly understood. Our research aims to broaden our understanding of the aquatic ecosystem, specifically the food web, by examining fish coprolites, which are abundant in the limestones of the Joggins Formation. Coprolites preserve undigested material that gives us a window into the diets of fish and the interactions between species. The coprolites have been studied in thin section and hand sample, as well as cathodoluminescence and computed tomography to determine their contents. We found that specimens could be divided into six categories based on size and shape: cigar/cylindrical; conical; small/equant; spiral; irregular; and massive (samples greater than 5 cm in length). The small coprolites are the most abundant

and the massive coprolites are the rarest. They range in size from <1 cm to >10 cm and are 2–3 centimetres on average. The composition of the coprolites is high calcium phosphate, similar to that of bone. This observation suggests that the fish producing the coprolites were carnivorous and that herbivores were lacking. Bone fragments have been found in almost all samples, however species identification has not been possible thus far. This research provides both a foundation for further studies on coprolites and a deeper understanding of aquatic ecosystems as fish diversified further into fresh water during the Paleozoic.

Terrestrial to marine transitions recorded in invertebrate trace fossils of the Joggins Formation

Lynn Dafoe[1], Matt Stimson[2], and Martin Gibling[3]

1. Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada <lynn.dafoe@canada.ca> ¶
2. Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada ¶
3. Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada

The Joggins Fossil Cliffs, a renowned Carboniferous UNESCO World Heritage Site, is found along the shores of Chignecto Bay, Nova Scotia. This spectacular outcrop has a well-established stratigraphy, with 14 cycles comprising alternations between open-water, poorly drained floodplain and well-drained floodplain facies assemblages. The ichnology of the formation has been previously studied; however, the trace fossils identified primarily include surface trails and vertebrate trackways, resulting in a limited record of infaunal activity. Analyses of primarily invertebrate trace fossils from both the Joggins Fossil Cliffs and approximately 700 m of Joggins Formation onshore core (REI B2-1) provide further documentation of the trace fossil record for these Carboniferous rocks. The diverse suite of traces includes: *Acanthichnus*, *Arenicolites*, *Beaconites*, *Chondrites*, *Cochlichnus*, *Diplichnites*, *Diplocraterion*, *Diplopodichnus*, fugichnia, *Gordia*, *Haplotichnus*, *Kouphichnium*, *Limulichubichnus*, *Lingulichnus*, *Palaeophycus*, *Phycosiphon*, *Planolites*, *Protichnites*, *Rhizocorallium*, *Skolithos*, *Stiaria*, *Teichichnus*, *Thalassinoides*, *Treptichnus*, *Undichnia*, tunnel and chamber structures, plausible wood borings, and rhizoliths. A number of these traces fossils have not been previously recognized from the formation and reflect the work of annelids, arthropods, fish and mollusks. Combining the trace fossil record with the sedimentological framework provides a robust approach in interpreting depositional settings. Within alluvial plain to fluvial channel margin settings, the trace fossil suites include both the *Skolithos* and *Scoyenia* ichnofacies. In marine-influenced strata, including bayhead-delta and brackish-bay settings, trace-fossil suites reflect proximal to archetypal *Cruziana* Ichnofacies and include some strictly marine trace fossils such as *Chondrites* and *Phycosiphon*.

When did plants influence river landscapes much as they do today? Evidence from Early Pennsylvanian strata of the Joggins Fossil Cliffs

Martin R. Gibling

Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada <mgibling@dal.ca>

Vegetation profoundly influences modern river systems, but direct evidence for these dynamic relationships is usually difficult to find in ancient deposits. The Joggins cliffs (~310 million years old) display interactions between a range of river systems and upright and transported vegetation in wetland and dryland settings. Observations in the Joggins Formation show that upright vegetation with deep roots stabilized rivers banks and bars. Groves of lycopsids and calamitaleans colonized the channels during periods of reduced flow and trapped sediment after the flow resumed, forming river bars. Upright trees along the banks of meandering channels are locally tilted towards the channel, implying that they stabilized the banks. Narrow, fixed channels of anastomosing rivers are prominent in the Joggins Formation but rare in older strata. In braided-river deposits of the Boss Point Formation, cordaitalean logs are present in nearly 20% of channel deposits, lining channel bases, filling deep channels, and serving as nuclei for shallow sandbars. Within some channels, thick log accumulations are interpreted as log jams that caused blockage and the formation of new channels. Rooted sandstones with upright trees are interpreted as vegetated islands in the braided rivers – the oldest yet described. Better than anywhere else on Earth, the Joggins cliffs show that fluvial landscapes crossed a threshold into a fully ecological mode in the Early Pennsylvanian, with feedback loops between vegetation and fluvial processes. Thereafter, patterns of interaction between rivers and vegetation broadly resembled those of today, with profound consequences for aquatic, soil and other terrestrial ecosystems.

Kouphichnium aspodon, a new occurrence of invertebrate traces from the Joggins Fossil Cliffs UNESCO World Heritage Site, Nova Scotia, Canada

Olivia A. King[1] and Matt Stimson[1,2]

1. Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada <Olivia.King@smu.ca> ¶
2. New Brunswick Museum Paleontology Section, Natural Sciences Division, Saint John, New Brunswick E2K 1E5, Canada

The vertebrate ichnofossil record at Joggins is a template for Paleozoic vertebrate ichnotaxonomy that dates back to the early 1900s. However, despite some of the earliest descriptions of invertebrate ichnofossils (*Diplichnites*) being noted by Dawson at Joggins in the 1800s, invertebrate

ichnofossils from there have yet to be systematically studied. Although the ichnogenus *Kouphichnium* is known from the Joggins Fossil Cliffs, the ichnospecies *Kouphichnium aspodon* has only been recorded previous to this study from the Mississippian-aged Mauch Chunk Formation (Pennsylvania), and from the Pottsville Formation at the type locality of the ichnospecies in Alabama. A third occurrence of this species has now been discovered at the Joggins Fossil Cliffs from the Springhill Mines Formation at Denis Point. This specimen was discovered by the late citizen scientist Donald Reid. The invertebrate trackway is associated with other invertebrate ichnofossils including different ichnospecies of *Kouphichnium*. *Kouphichnium* has been ascribed to xiphosuran locomotion. A single specimen of *Kouphichnium aspodon* is here interpreted to be produced by either a eurypterid or synxiposurian from the lower most Springhill Mines Formation. Like limulids, eurypterids are known to travel inland from the oceans to quiescent brackish conditions to moult and mate. Although body fossils of eurypterids are rare at Joggins, they have been described from cuticle fragments that were found inside lycopsid trees by Dawson in the nineteenth century, associated with tetrapod bones, millipedes and land snails. This discovery suggests that the strata exposed at Dennis Point may have been at least distally connected to marine waters.

Leveraging Nova Scotia's Carboniferous to communicate earth science concepts: following Ireland's lead

Jason Loxton

Geology, School of Science & Technology, Cape Breton University, Sydney, Nova Scotia B1P 6L2, Canada <Jason_Loxton@cbu.ca>

Ireland and Nova Scotia share similar Paleozoic geological histories, with Carboniferous bedrock exposures especially widespread. Carboniferous sites in both regions share UNESCO status (the Burren and Joggins Fossil Cliffs), and Carboniferous strata are intimately connected with each region's industrial and cultural histories (related to coal, kiln lime, building materials, gypsum desalination). In Ireland, however, educational, conservation, and tourism infrastructure is more fully developed than in Nova Scotia, including two Geoparks and county-level geoheritage surveys. In addition, materials describing and celebrating Irish geology and its connection to human history are readily available in print and online, including overviews aimed specifically at teachers and tourists (e.g., *Understanding Earth Processes, Rocks and the Geological History of Ireland*—also known as "the School's Book"). These materials describe the specifics of Carboniferous geology and paleontology, but perhaps more importantly leverage the period to communicate more general earth science concepts, e.g., the relationship between climate change and sea level, ground water pollution in karstic environments, the carbon cycle, and the geography of deltaic and carbonate platform environments. As a geological and cultural "sister", Ireland provides an example of how Nova Scotia can develop its geotourism and earth science communication potential, especially the potential of its Carboniferous geology.

Recent tetrapod discoveries and the changing view of the Carboniferous

Hillary C. Maddin[1], Arjan Mann[1], Jade Atkins[1], Ryan Paterson[1], Brad Mcfeeters[1], Brian Hebert[2], Gabrielle Adams[1], and Michael Thompson[1]

1. Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6, Canada <HillaryMaddin@cunet.carleton.ca> ¶
2. Fundy Treasures, Joggins, Nova Scotia B0L 1A0, Canada

Over five years ago, a long-term field program focused on the fossil tetrapods of the Carboniferous of Nova Scotia was launched. It is widely known that Nova Scotia's fossil tetrapods are of global significance due to the earliest records of several key taxa represented by *Hylonomus*, *Archaeothyris* and *Paleothyris*. Our efforts have contributed new aspects of significance to Nova Scotia's Carboniferous tetrapods, including possible new growth series and CT data for *Dendrysekos* (=*Dendrerpeton*) with taxonomic re-evaluation, new embolomere diversity data for Point Edward, and new earliest occurrence data for several taxa otherwise known only from the Permian. The recent discovery of a fossiliferous stump from the Sydney Mines Formation, Cape Breton Island, remarkably, contains the remains of at least six taxa. Most notable among these is a virtually complete skull of a large pantylid recumbirostran. CT scanning reveals a highly specialized dental apparatus composed of opposing dental fields on the palate and coronoids, well advanced to that of any known tetrapod of equivalent age. As well, three partial, articulated skeletons of a varanopid synapsid, including an associated very small fourth, alludes to the possibility of a social aggregation — a behavior otherwise unknown from this clade until the Late Permian. A fragment of a large proximal femur is also attributable to a varanopid, and approaches the size and morphology of later occurring varanodontines, such as the Permian *Varanops*. Together these new data revise much of our current understanding of the composition and evolution of some of the earliest terrestrial tetrapod communities and their constituents.

Fossil Finder: a case study of the use and development of machine learning models to identify fossils in situ

Nathan Rowbottom

Halton District School Board, Burlington, Ontario L7P 5A8, Canada <rowbottomn@hdsb.ca>

Machine learning has developed rapidly over the last few

years, both in complexity, versatility and ease of use. A myriad of different cloud platforms and application programming interfaces exist in the common marketplace that could be of use to both professional and citizen scientists alike. However, the machine learning development has been so rapid, that it is somewhat intimidating for anyone that is not a data scientist, or at least an experienced programmer. I am conducting an initial inquiry for the development of machine learning models for scientists in the context of making a smart-device app to identify fossils that can be found in situ at the Joggins Fossil Cliffs, a noteworthy representation of Pennsylvanian Carboniferous flora and fauna. The purpose of the app will be for citizen scientists to use the app to identify fossils and, over the long term, develop a heat map for locating various types of fossils. Various trade-offs between several machine learning platforms are compared and contrasted in the context of the app. A specific platform was chosen for a proof of concept prototype of using machine learning for fossil identification and its effectiveness was analyzed over several iterations.

An Upper Mississippian rhizodontid (Sarcopterygii, Tetrapodomorpha) from the Bluefield Formation of West Virginia, USA

Michael J. Ryan

Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6, Canada <MichaelPJRyan@gmail.com>

Sarcopterygian rhizodontids are poorly understood due to the incomplete nature of most available specimens. Although postcranial remains are known from *Strepsodus*, *Gooloogongia*, and *Sauripteris*, many specimens consist only of incomplete mandibles, making taxonomic assignment difficult. A rhizodontid left dentary (CMNH 10940) from the Upper Mississippian Bluefield Formation of West Virginia preserves a single symphyseal tusk, 12 marginal teeth, and a row of dentary teeth in pairs with each marginal tooth. There is no evidence of marginal teeth anterior to the tusk and the ventral margin has been broken away. The dentary appears to lack evidence of a lateral or vertical pit line on the labial surface. A restricted rhizodontid phylogenetic analyses was conducted using either *Glyptolepis* or *Kenichthys* as the outgroup on a dataset empathizing mandibular characters. Each analysis resulted in two best trees, the strict consensus of which both recovered the rhizodontid taxa as a polytomous monophyletic clade with the same ingroup topology. Although the placement of CMNH 10940 could not be resolved, the clade of UK rhizodontids [(*Strepsodus* + (*Rhizodus*+*Screbinodus*)], was resolved and is congruent with previous analyses. Both analyses supported the validity of the CMNH 10940 as representing a distinct taxon based on one unambiguous character, the presence of long, smoothly curving longitudinal striations on the marginal teeth that are separated by broad bands of enamel, and teeth that are polished labially.

The *Diplichnites aenigma* enigma: ichnotaxonomic implications of a restudy of Dawson's type locality at Coal Mine Point, Joggins, Nova Scotia

Matt Stimson[1,2], Andrew Macrae[1], John Calder[3], Brian Hebert[4], and Len Reid[5]

1. Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada <mstimson29@gmail.com> ¶
2. New Brunswick Museum Paleontology Section, Natural Sciences Division, Saint John, New Brunswick E2K 1E5, Canada ¶
3. Nova Scotia Department of Energy and Mines, Halifax Nova Scotia B3J 3P7, Canada ¶
4. Joggins, Nova Scotia B0L 1A0, Canada ¶
5. Maccan, Nova Scotia B0L 1B0, Canada

In 1862, William Dawson, while exploring the Coal Mine Point strata at Joggins, discovered the site's first example of arthropod footprints that would later be attributed to the largest terrestrial invertebrate in the fossil record, *Arthropleura*. Dawson later named the trace fossil *Diplichnites aenigma*, the first species of the new and now widely-used genus *Diplichnites*. Unfortunately, no type specimen was selected, presumably due the huge size of the sandstone blocks that erode from Coal Mine Point. The lack of a collected type specimen for Dawson's trackway, the simplicity of its published woodcut illustration, and a limited description has caused confusion for ichnotaxonomists over the past 150 years. For example, a new ichnospecies (*Diplichnites cuithensis*) from Arran, Scotland was erected in 1979, avoiding Dawson's species because of the uncertainties. More recent explorations by multiple researchers have added new specimens of *Diplichnites aenigma* for study. Key specimens recovered by the late Laing Ferguson, the late Don Reid, Bob Grantham, and the authors have allowed for an ichnotaxonomic re-evaluation of the ichnogenus and its type species from the type locality. New observations shed light on the morphological variability of *Diplichnites* and has refined the type concept, accounting for underprint fallout, gait variability, substrate variability and microbial mat sediment stabilization. This work lays the foundation for a long-overdue re-evaluation of the genus concept and all species of *Diplichnites*.

Marine Influence and other controls on organic matter preservation in Langsettian, Carboniferous lacustrine source rocks of the Joggins Formation, Nova Scotia, Canada

Todd G. Ventura[1], Andrew R. Macrae[1], Yaisa Owino[1], and Matt Stimson[1,2]

1. Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada <todd.ventura@smu.ca> ¶
2. Steinhammer Paleontology Laboratories, New Brunswick Museum, Saint John, New Brunswick E2K 1E5, Canada

The Joggins Fossil Cliffs UNESCO World Heritage Site

represents one of the most continuous exposures of a Carboniferous coal-basin succession in the world. Much of this section is composed of the Joggins Formation, which extends for 2.8 km along the coastal section of the Cumberland Subbasin. Subsidence from salt-withdrawal deeper in the basin's subsurface resulted in rapid accommodation to produce 14 distinct parasequences. Many of these parasequences reflect repeating transgression events, composed of fluvial/deltaic mudrocks overlain by bioturbated paleosols and bituminous coal measures. Parasequences begin with the deposition of carbonaceous-rich, freshwater limestone units marking the maximum flooding surface of the shallowing upward interval. Although the Joggins Formation was deposited ~2500 km inland from the Tethys paleo-shoreline, the basal section contains evidence of marine incursions. In this study we investigate whether geochemical data can (1) help resolve the temporal extent of these events and (2) determine what effects marine conditions had on the type and preservation of the organic matter in these prospective source rocks. Specific emphasis is focused on resolving whether sulfurization of organic matter was involved in kerogen formation. Forty samples spanning seven distinct parasequences extending from the base to the top of the formation are analyzed for transition metal and elemental sulphur concentrations using portable X-Ray Fluorescence. These data are compared with bulk pyrolysis measurements to evaluate factors controlling the richness, quality, and maturity of the host rock's organic matter. Additional geochemical constrains are provided via biomarker-based paleoecological reconstruction using comprehensive two-dimensional gas chromatography.