FUNDY ISSUES

Fundy's Fascinating Fossils:

The Unique Palaeontology of the Bay of Fundy

"the rocky shores of Fundy bear a rich trove of scientifically important fossils"

The Bay of Fundy has long been known as an exciting and rewarding destination for those interested in fossils, both professionals and amateurs alike. Interest began almost 175 years ago (1836), when medical doctor and amateur geologist Dr. Abraham Gesner wrote about the geology of the region. In 1841, William Logan, founding Director of the Geological Survey of Canada, discovered vertebrate tracks at Horton Bluff, Nova Scotia. International recognition came the following year (1842) when the renowned British geologist Charles Lyell roamed the shores of the upper Bay in search of fossilized plants. A decade later, he returned in the company of Canada's foremost geologist, William Dawson. Together they found *"one of the most famous fossil discoveries in palaeontology"*; namely, the remains of the earliest reptile ever found, *Hylonomus lyelli*. The multi-layered, fossil-bearing cliffs of the upper Bay, now known as Joggins, even warranted a special mention in Charles Darwin's momentous book "The Origin of Species", first published in 1859.

Over the following century and a half, a large number of other scientifically important fossil sites, spanning almost a billion years of geological history, have been found scattered all around the Bay of Fundy. That the rocky shores of Fundy bear a rich trove of scientifically important fossils finally received official recognition worldwide in July 2008, when one of the region's best known locations, the fossil cliffs at Joggins, was designated a "World Heritage Site" by the United Nations Educational, Scientific and Cultural Organization (UNESCO).

It is important to note that both Nova Scotia and New Brunswick have also recognized the scientific value of the provinces' rich fossil deposits by enacting legislation to protect them. In Nova Scotia the *Special Places Protection Act* states that a Heritage Research Permit is required to excavate fossils or disturb any places where they are present. Similarly, in New Brunswick the *Heritage Conservation Act* affirms that fossils are heritage objects that can only be collected by individuals with a provincial permit.

J.A. Percy

Fundy's Fossils are protected by law

BOLUS
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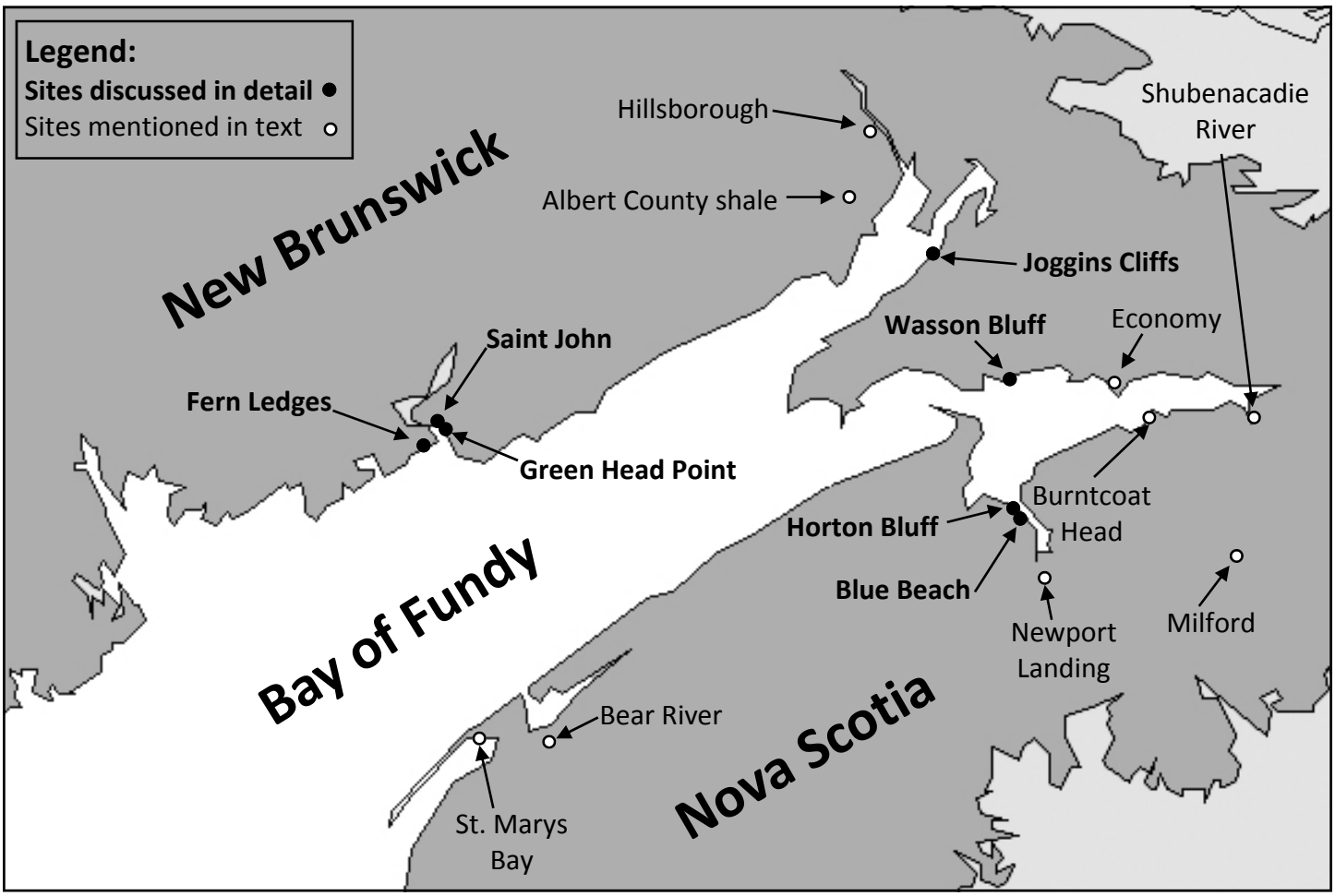
Before we discuss the location and character of the Bay's most prominent fossil sites it may be helpful to consider some of the geological factors that are responsible for this region being such a notable hot-spot in the world of palaeontology (*the science of the study of prehistoric life*).

Fossils Few and Far Between

The formation, preservation and eventual discovery of any fossil are each unimaginably rare and chancy events, which is why the fossil record of evolution still has many perplexing gaps. However, palaeontologists have been able to painstakingly piece together the impressive evidence for the evolutionary story because the geological history of a favoured few places in the world have been especially conducive to the formation, preservation and discovery of fossils at different periods in the history of the earth. These special places provide unique windows into the past, each revealing to us the environment and some of the organisms that existed at a particular time period in the long history of planet Earth. By analyzing the evidence from these different sites it has been possible to put together a coherent story of how living creatures slowly evolved and to ascertain how long ago each of the major evolutionary milestones occurred. The Bay of Fundy is one such scientifically important region, with numerous fossil sites whose rocks bear a record of the life forms and their habitats at the time of some very important evolutionary steps, such as the development of primitive aquatic algae, the movement of vertebrate animals from their watery ancestral home and gradual adaptation to a life on the land, and the very beginnings of the slow evolution of those endlessly fascinating "terrible lizards", the dinosaurs.

To understand why the rocks around Fundy are yielding such a wealth of diverse fossils in so many different locations, one must know something about how fossils formed

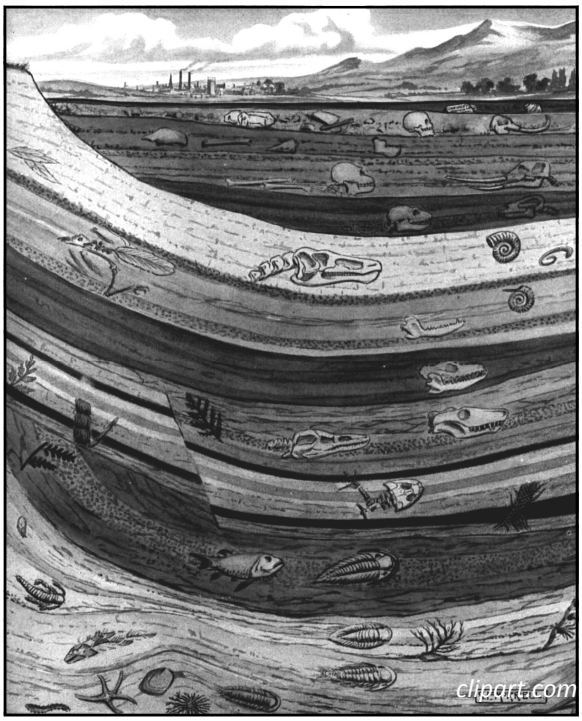


Locations of prominent fossil sites around the Bay of Fundy

The geological time scale showing important highlights in geology and biological evolution, as well as the dating of important Fundy fossil sites. *(Note: the vertical time-line is not to scale)*

EON	ERA	PERIOD	MYA	GEOLOGY	BIOLOGY	FUNDY SITES
PHANEROZOIC	**Cenozoic** *Modern Life*	Quaternary	0 1.8	Periodic glaciations; Continents in present location	Major extinctions of large mammals; humans present 1.8 mya	Mastodons in Maritimes 0.08 mya - Milford NS, Hillsborough NB.
		Tertiary	65	Continents approaching present location; volcanic activity; climate cooling	Hominids appear; mammals and birds diversify and expand	
	Mesozoic *Middle Life*	Cretaceous	145	Continents moving apart; warm climate; elevated sea level	Extinction of dinosaurs 65 mya; flowering plants arise; mammals small, dinosaurs dominant	
		Jurassic	200	Pangaea begins breaking apart; warm climate	First birds appear; large dinosaurs dominant; conifers dominate flora	Basalt flows form North Mountain, Grand Manan etc. 200 mya Wasson Bluff fossils 200 mya
		Triassic	250	Pangaea begins to rift; climate hot and dry	Major extinction; conifers flourish; primitive mammals; reptiles and amphibians dominant	Burntcoat Head dinosaur 230 mya
	Palaeozoic *Ancient Life*	Permian	299	Pangaea present; sea level low; climate variable; widespread deserts, seasonal monsoons	Mass extinction (249 mya); Mammal-like reptiles dominant; diverse tetrapods; conifers	
		Pennsylvanian Carboniferous *Mississippian*	360	Pangaea present; sea level low; mountain building; climate warm at start then cools; Windsor Sea forms; salt and gypsum deposits formed	Coal deposits form; swamps and forests; giant fern, horsetail and club moss relatives dominant; amphibians abundant; lizard-like reptiles, amniote eggs appear	Fern Ledges 313 mya Joggins Cliffs 318 - 300 mya Blue Beach/Horton Bluff 360 - 345 mya
		Devonian	416	Climate warm; contents moving together to form supercontinent Pangaea; Appalachians form; sea level high	Lobe-finned fish move onto land as tetrapods; "Age of Fish"; primitive terrestrial plants spread; arthropods invade land	
		Silurian	444	Continents begin drifting together; climate warming; high sea level;	Bony fish appear; trilobites abundant; first primitive plants move to land	
		Ordovician	488	Continental masses separate entities; volcanic activity; sea level high	Marine invertebrates dominant and diverse	
		Cambrian	542	Supercontinent Pannotia forms and breaks apart; sea level high; extensive coastal seas	Cartilaginous fish appear; complex hard bodied invertebrates abundant (readily fossilize); land barren except for microbial mats	
PRECAMBRIAN	**Proterozoic**		2500	Supercontinent Rhodinia forms and breaks apart; mountain building; oxygen increasing in atmosphere	Single celled and multicelled organisms abundant; algal mats form stromatolites.	Green Head/Saint John 900 mya Oldest rocks in Maritimes form 1200 mya (Cape Breton)
	Achean		3800	Earth hot; volcanic and tectonic activity; no free oxygen; Canadian shield forms; oldest know rocks form 3800 mya.	Cyanobacteria abundant; single celled organism without nuclei; primitive algae form stromatolites.	
	Pre-geological		12000	Planet Earth condenses and cools; crust forms 4600 mya; "Big bang" produces universe	Primitive life forms develop	

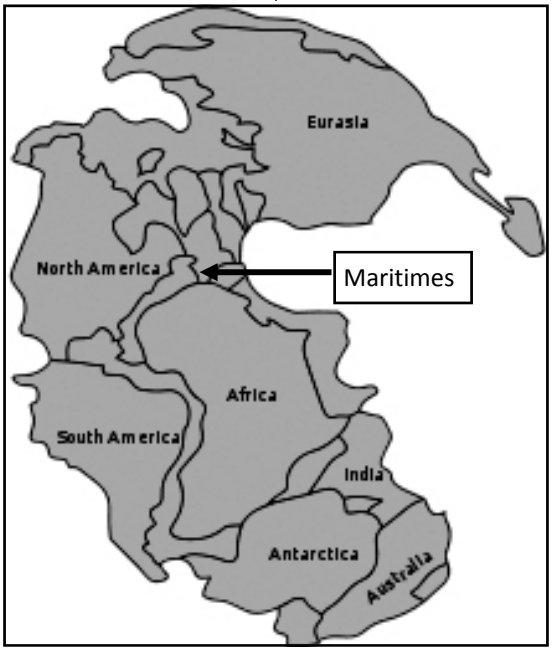
long ago, what subsequently happened to the fossil bearing rocks and why they are now reappearing in such great numbers? Fossils are typically embedded in sedimentary rocks, which can form on land or in water by the steady deposition of air or water-borne particles such as silt or sand to form layers or strata. Dead animals or plants buried by the accumulating sediments may leave impressions of their bodies as the particles fuse together to form rock by the growing weight of sediment accumulating above. Some fossils are not formed from the actual remains of organisms, but nevertheless, provide clear circumstantial evidence that a particular type of animal was there. Such "trace" fossils include footprints or other tracks left in soft mud, the remnants of burrows or tubes once occupied by animals, and the petrified remains of animal droppings (*coprolites)*. The Fundy region has yielded examples of all the different types of fossils in great abundance.



Fossilized bones embedded in sedimentary layers

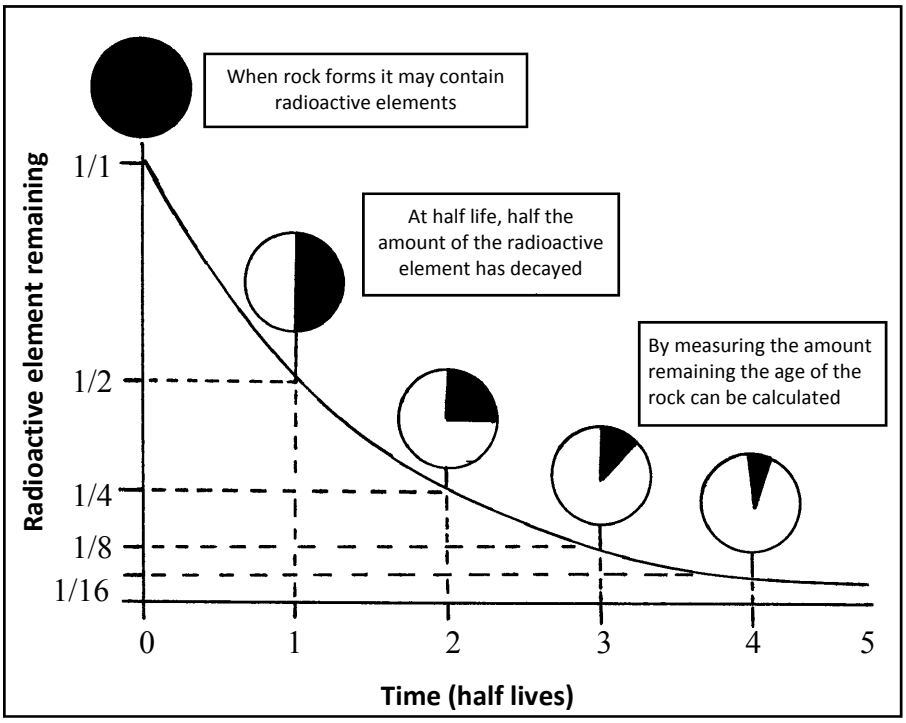
Meandering Maritimes

The Maritimes and the Bay of Fundy have not always been located midway between the Equator and the North Pole, neither have its different parts always been together. Beginning over 400 mya (million years ago), several large continental land masses began drifting together on their way to forming a supercontinent called Pangaea. The land area that would eventually become the Maritimes would come to lie near the middle of Pangaea, virtually on the equator, and was formed by the fusing together of bits of three of these different continental masses. It was at that time attached to what is now Morocco in North Africa. All this movement of the land masses caused some parts of the earth's crust to rise and others to become depressed. These depressed areas are called "basins" and were ideal environments for the accumulation of sediments washed in from nearby highlands. The earliest sediments occurring in the Maritimes Basin after the Acadian mountain building event are those of the Late Devonian-Early Carboniferous Horton Group, deposited in large estuaries and bays between 365 and 345 mya. The tropical forests and swamps of this period were home to the first known terrestrial arthropods (invertebrates) and tetrapods (vertebrates). The final stage of Pangaea's formation, sometime around 340 mya saw several episodes of further subsidence, lowering the basins and allowing seawater to flood in to form the so-called "Windsor Sea". Over a 15 million year period the level of this sea rose and fell numerous times. Salts in this sea became highly concentrated by evaporation in the hot climate and settled to the sea floor as "evaporites". These now comprise the thick subterranean beds of gypsum and salt found around much of the inner Bay of Fundy. By about 325 mya, the Windsor Sea had retreated and much of the Maritimes was swampy lowland surrounded by the highlands of the growing Appalachian Mountain range. The region still lay near the equator and the climate was tropical and humid during this "coal age" or Late Carboniferous Period. Some 295 mya the Maritimes was still nestled within Pangaea near the equator, but the climate had changed so that periods of very hot arid conditions were interspersed with monsoon-like intervals of torrential downpours. Gradually the climate became drier and by 250-245 mya the landscape of the region was a parched desert-like region covered



Approximate location of the Maritimes near the centre of Pangaea about 340 mya

by extensive sand dunes created by tropical winds. About 250 mya Pangaea began to slowly break apart and the new continents began their drift to their present locations. As the continents drew apart (at a speed that has been likened to the growth of a fingernail), the seafloor between them thinned and great cracks or "rifts" formed along lines of weakness in the crust. The Bay of Fundy was formed by one such rift. However, this initial splitting ceased when another great fissure opened up further offshore and became the final demarcation line between the separating continents. The Bay of Fundy is thus known geologically as a "failed rift". It is interesting to speculate that if this initial rifting had not failed, much of Nova Scotia would now be in North Africa, separated from New Brunswick by the Atlantic Ocean instead of the Bay of Fundy!

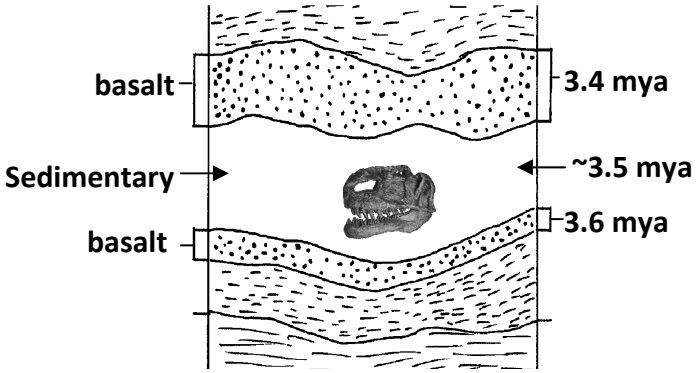


Dating rocks by radioactive decay

Clearly, hundreds of millions of years ago environmental conditions in what is now the Fundy region were very different from today. For long periods, conditions were ideal for the formation of sedimentary rocks and the preservation of fossils. Eventually, the fossil bearing sedimentary rocks became buried deep underground as the geologic processes of crustal sinking, erosion of highlands and volcanic activity built up deep layers on top of them. Immense geologic forces, associated with the moving continents, were also at work over the aeons, twisting, tilting, warping and fracturing these layers of sedimentary rocks. Today, they no longer resemble the orderly flat layers that once formed on a lakebed, riverbed and seafloor or in a swamp. Over time, continuing buckling, weathering and erosion of the land has brought some of these layers back to the surface. The cliffs now exposed along the shores of much of Fundy are made up of layers of rock formed at particularly critical times in the evolution of life on earth. Similar layers were also formed at many other places around the world, but many of these are now largely inaccessible to scientists…. either still buried far underground or long ago eroded away to dust. In contrast, in the Fundy sites, scientifically important fossil bearing layers are right there on the faces of the cliffs, awaiting the observant researcher. Furthermore, Fundy has yet another feature that attracts professional and amateur fossil enthusiasts in droves. In many parts of the world, fossil deposits, although present near the surface, have to be actively and meticulously excavated to reveal their treasures. Layer by layer, inch by inch, the overlying rock has to be painstakingly chipped, drilled and brushed away. Not so in Fundy - the fossil layers in the seashore cliffs are constantly being savaged and scoured by relentless currents and smashing waves powered by the highest tides in the world. The soft sedimentary rocks erode rapidly, continually revealing new surfaces, with the exposed material eventually falling to the beach below. In the Bay of Fundy palaeontologists can patiently work according to the tides and currents and allow nature to excavate the fossils.

Dating Deposits

Some of the fossil-bearing rock formations of Fundy are particularly important scientifically for an even more fundamental reason. Normally, it is not possible to accurately date sedimentary rocks. The relative ages of their layers are typically determined by the types of fossils they contain. For example, a layer with only primitive fish remains would normally be deemed much, much older than one bearing dinosaur footprints. But exactly how many hundreds of million years separate the two different rocky layers is usually difficult to ascertain. It is fortunate that in the Fundy region some of the important sedimentary, fossil-bearing layers were covered by flows of volcanic lava at various times in the far distant



Dating fossil bones in sedimentary rock sandwiched between layers of volcanic basalt

past. Such lava comprises, for example, the basalt layers of the North Mountain range on the Nova Scotia side of the Bay and Grand Manan Island in New Brunswick. While the basalt itself contains no fossils, the time of its hardening can be dated very accurately. The flowing lava contains a radioactive isotope of potassium that very slowly (half life of about 1.25 billion years) decays to form the gas argon. As long as the rock is hot and molten, the argon produced escapes to the atmosphere. However, when the lava cools and solidifies, the argon no longer escapes and it gradually accumulates in the rock. By measuring the ratio of the amount of potassium remaining to the amount of argon present, it is possible to accurately calculate the date when the lava solidified. This makes it relatively easy to infer the time of formation of adjacent layers of sedimentary rock that may bear important fossils. Few other places in the world allow such accurate dating of fossils and thus the confirmation of the age and length of major geologic time periods.

As a result of the geological processes and sequences described above, the different fossil sites around Fundy provide a unique window into the world as it existed at particular times in the past. Indeed, as we shall see, the rocks from different Fundy sites offer informative glimpses into the Earth's distant past at intervals over a period of almost a billion years.

Saint John Stromatolites

The geology around Saint John, New Brunswick is particularly complex, consisting of exposures of rock formations from many geologic eras. Over the past century and a half some of North America's most eminent geologists and palaeontologists have studied these rocks and have succeeded in piecing together a fascinating story about the area's geologic history. The oldest fossils in the Maritimes are found here, embedded in the grey marble of the Green Head rock group. This geological formation, named after Green Head Point where its presence was first scientifically described, is located at the mouth of the St. John River on the tip of the peninsula on which the main part of the city lies. The same formation is also exposed at other locations around the region.

These grey marble rocks date from the Precambrian era. This was the very long period of the Earth's history extending from about 4.5 billion years ago, when the Earth first solidified, to about 540 mya, when the primitive hard-bodied animals that fossilised easily first appeared. During this long period, four-fifths of the age of the earth, small, very primitive soft-bodied animals and plants were evolving slowly, but leaving scant trace of their existence. Imagine the excitement amongst palaeontologists when, in 1870, strange concentric structures, that seemed to be of biological origin, were found in the grey marble of Green Head Point. However, further analysis led to the initial conclusion that these were "concentric nodular masses ……apparently destitute of organic structure and probably concretionary", in other words not formed by living organisms. However, in 1890, George Matthews in an article in the Bulletin of the Natural History Society of New Brunswick ascertained that they were indeed "stromatolites", the remains of a primitive life form that existed through much of the later Precambrian Period. He named the New Brunswick organisms *Archaeozoon acadiense,* making it one of the first definitive Precambrian fossils to be reported and the first to be given a double-barrelled scientific name according to the genus and species naming convention es-

New Brunswick Museum

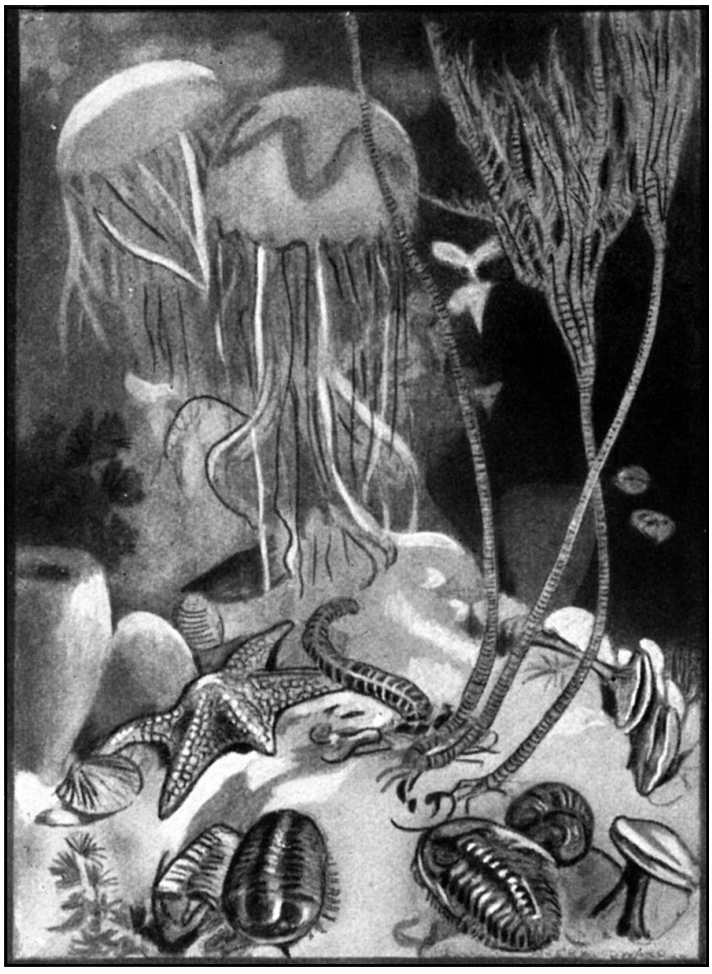
***Archaeozoon acadiense* , a Precambrian stromatolite in Green Head Marble**

tablished by the great European taxonomist Linnaeus. The organisms were large mat-like colonies of blue-green algae, primitive single-celled plants without a discrete nucleus but able to photosynthesize. These algal mats, probably growing in shallow warm water at low latitudes, trapped settling sediments within their structure and these eventually fossilized into the distinctive concentric shapes of the stromatolites. They were initially formed in sedimentary rock known as limestone (formed by the deposition of calcium carbonate), but early in the Cambrian Period heat and pressure caused the deeply buried limestone to metamorphose into the marble that comprises the Green Head rock formation. However, traces of the stromatolites still remained visible in these altered rocks. Although similar structures have been found in rocks as old as 3.5 billion years, those found in the Saint John area are from 900 million to one billion years old, and thus from the Proterozoic Era. They are the only evidence to date of Precambrian life found in the Appalachian area of eastern Canada.

Near the end of the Precambrian, many new types of living organisms appeared, ushering in the Cambrian Period (542-488 mya). Notably, many of these newly evolving animals had hard skeletons or shells that fossilized more readily. Rocks from the Cambrian (as well as the subsequent Ordovician Period - 488-443 mya) lie beneath much of the central area of Saint John. Canada's leading 19th century expert on the Cambrian Period, George Matthew (father of palaeontologist William Matthew), described the geology and fossils of the area in a number of publications. The fossil finds include early sponges (Protospongia), brachiopods (a large group of two-shelled animals called lamp shells, most of which are now extinct), primitive stalked echinoderms called crinoids (distantly related to sea urchins and starfish), snails, bivalve molluscs, worm-like creatures with shells, as well a variety of fossil track ways and burrows. The well-known trilobites also appeared during the Cambrian Period. Interestingly, George Matthew's son William found in the Saint John area a fossil of one of the world's largest trilobites, now on display in the New Brunswick Museum.

Fossil Fern Ledges

In the early 1860s, Charles F. Hartt and members of the Steinhammer Club (a Saint John amateur geology group) began exploring an outcropping at Duck Cove on the shore of the Bay of Fundy, about 3.5 km southwest of the city centre. Here, in the intertidal zone, was exposed a 90 m long series of ledges consisting of a 45 metre thick bed of sedimentary rocks with alternating layers of grey to greenish sandstone and grey to black shale. Hartt named the area Fern Ledges because of the abundance of ancient fern fossils in the rocks and he and the group collected over 8,000 fossil samples from the area. Although mostly plants, including ferns, seed ferns, sphenopsids (ancestors of our horsetails) and bryophytes (ancestors of our mosses), animal remains were also found. These included a wide variety of early insects, centipedes and millipedes, sea scorpions, spiders, land snails, phoronids (commonly known as horseshoe worms), and horseshoe crabs, as well as early fish and the tracks of primitive amphibians. These fossils attracted the attention of William Dawson, professor of Geology at McGill University, who worked with the group over the next few years and published some of their findings.



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Trilobites and other marine invertebrates of the Cambrian Period

Dawson concluded that the Fern Ledges fossils were from either the Silurian (443-416 mya) or the Devonian (416-360 mya) periods. This pronouncement launched a lengthy controversy about the actual age of the deposits. Many palaeontologists were sceptical of Dawson's claim, because similar insect and amphibian fossils had not been found before in rocks older than the Carboniferous Period (360 - 300 mya). The controversy continued unabated until 1910 when the Director of the Geological Survey of Canada, exasperated by the lack of agreement amongst his staff, brought in an independent expert, Marie Stopes, a palaeobotanist from Great Britan, to finally settle the matter. In a masterful classic study of the plant material that appeared as a monograph in 1914, she unequivocally showed that the rocks, and thus the associated insects, fish and amphibian fossils, were indeed much younger than previously thought and dated from the late Carboniferous Period (Pennsylvanian subdivision) about 313 mya. In fact, the rocks are similar in age to those of the 'Coal Age' Joggins area in Cumberland Basin (described below) at the head of the Bay of Fundy. Ongoing studies of the geology, animals and plants of Fern Ledges indicate that three distinct coastal habitats were once present in the area. Inland was an upland dry community with forests of giant trees ancestral to our conifers and cycads, as well as large extinct seed ferns; then came a lowland, marshy community with shrubbier vegetation and finally a shallow brackish coastal embayment. River channels cutting across the coastal plain drained into the sea. The rich trove of fossils was probably formed by a sudden subsidence and subsequent burial of a stretch of this coastline. Fern Ledges is truly a remarkable site, scientifically renowned for the diversity of its "world famous fossil biota" including some of the world's oldest insect and land snail fossils. The fossil of the early moss, *Thallites lichenoides*, is one of only a few found anywhere in North America.

In early October 2010, the Global Geoparks Network, an organization assisted by UNESCO, recognized the international scientific importance of all these geological formations, not only in Saint John and Fern Ledges, but across a wide swath of southern New Brunswick bordering on the Bay of Fundy. It designated the new Stonehammer Geopark encompassing 2,500 square kilometres between Lepreau and St. Martins and extending inland as far as Grand Bay-Westfield and Norton. One of 77 such geoparks worldwide, it is the first North American member of the Global Geoparks Network. UNESCO describes a geopark as "*A territory encompassing one or more sites of scientific importance, not only for geological reasons but also by virtue of its archaeological, ecological or cultural value."* The geopark program seeks to conserve and enhance our geological heritage, foster educational and research opportunities in geology and palaeontology, and foster socio-economic development associated with sustainable geotourism or agritourism. The rich and complex fossil history of south western New Brunswick is well interpreted in the collections and displays of the New Brunswick Museum in Saint John.

"The rich and complex fossil history of south western New Brunswick is well interpreted in the collections and displays of the New Brunswick Museum"

Jungles of Joggins

Without question, one of the best known jewels in the rich Fundy palaeontological treasure trove is the site at Joggins, Nova Scotia. On the north-western shore of the Chignecto Peninsula that juts into the upper Bay of Fundy, the fifteen kilometre stretch of crumbling, fossil-rich, sea cliffs have been aptly termed a "Coal Age Galapagos" by palaeontologists because of the abundance and diversity of plant and animal remains dating from the late Carboniferous Period (a geologic subdivision known as the Pennsylvanian, 320-299 mya). The battering tides of Fundy and the probing frosts of winter are steadily eroding away these 30 metre high cliffs, continuously exposing fresh rocks and new fossils. Walking

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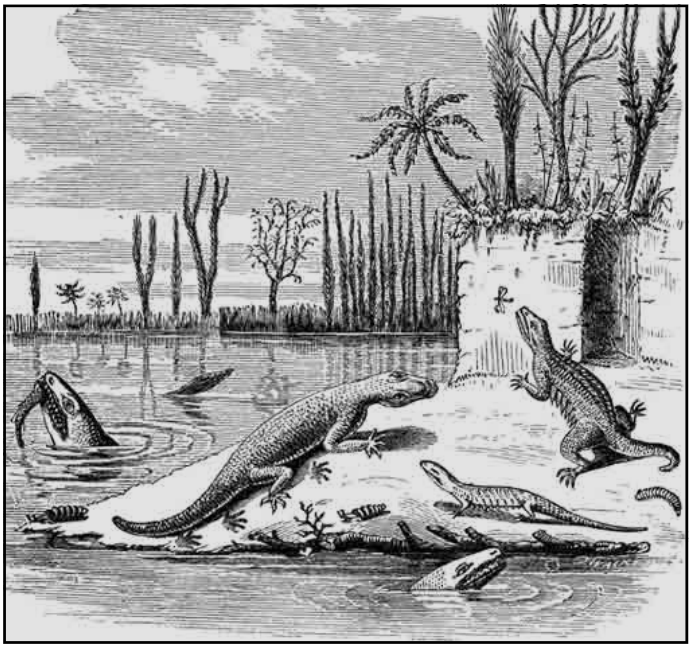
A "Coal Age" forest

A section of the fossil cliffs at Joggins

along the narrow beach, one cannot help but be impressed by the many different hued striations showing on the cliff face, comprising sandstone, siltstone, and shale layers as well as the characteristic ebony seams of coal that once supported a burgeoning mining industry in the region. Originally laid down horizontally, the rocky layers have over time been depressed by the great weight of accumulating sediments to form a bowl - shaped structure, so that the cliff layers near Joggins now tilt upwards towards the north at an angle of about 20 degrees. This means that as you walk northeast along the beach, deeper and deeper sedimentary layers are being revealed on the face of the cliff – you are literally walking backwards in time through a lengthy geological epoch. The deposit of reddish material at the top of the cliff is a six or seven metre deep mix of clay and boulders left behind by kilometres-thick glaciers that finally receded from the area only late in the Quaternary Period, a mere 13,000 or so years ago.

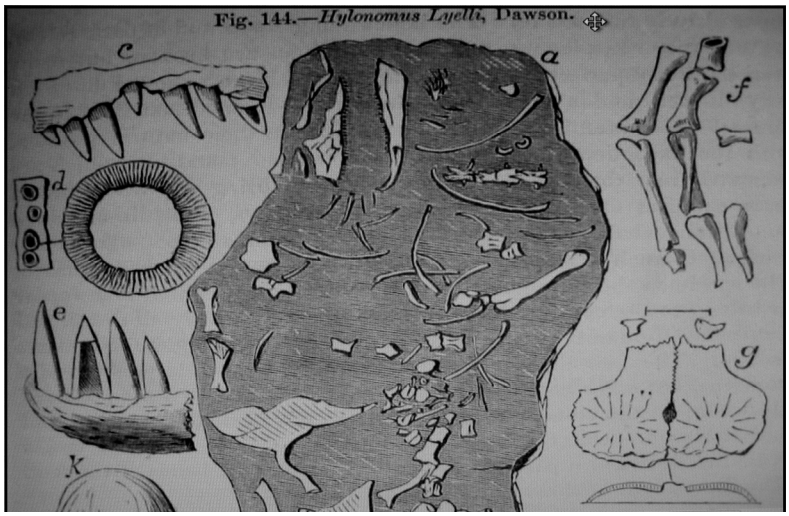
Scientists from around the world have been excited by these cliffs ever since the mid 19th century, when two renowned British and Canadian geologists visited the area and uncovered the oldest fossil of a reptile ever found. This notable find even influenced the evolutionary thinking of Charles Darwin, who noted in his earth-shaking book, On The Origin of Species, *"thus Sir C. Lyell and Dr. Dawson found carboniferous beds 1400 feet thick in Nova Scotia, with ancient root-bearing strata, one above the other at no less than sixty-eight different levels."* Since then, steady streams of prominent geologists, palaeontologists and amateur fossil enthusiasts have scoured the cliffs and beaches and amassed, catalogued and analyzed the many different types of fossils that have come to light. During more than a century and a half, over 200 different plant and animal species have been found, allowing palaeontologists to piece together the intriguing story about how this remarkable geological formation developed and what it tells about life in the area over 300 million years ago.

The story begins about 310 mya, towards the end of the Carboniferous Period or 'Coal Age', when the world's vast coal deposits were forming in lush tropical swamps. The Cumberland Basin area around Joggins was then located in tropical latitudes near the centre of the newly formed Pangaea. The Earth's crust in this area was being deformed by immense geologic forces and the surface



J.W. Dawson. Air breathers of the Coal Period

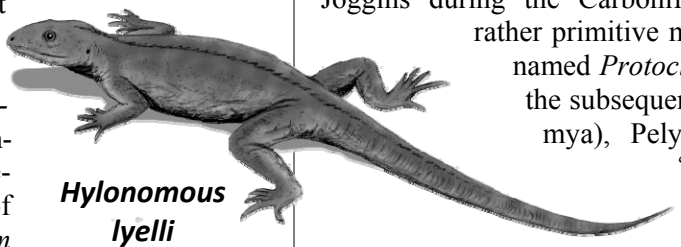
Carboniferous amphibians and reptiles



Dawson's sketch of the fossilized bones of *Hylonomous lyelli*

was slowly subsiding. Across this flat sinking plain many rivers meandered, carrying heavy loads of sediments eroded from nearby mountainous regions that are now the Caledonia Highlands to the north and the Cobequid Mountains to the south. Some of the mud, settling along the shores of these slow, winding streams, built up the banks into levees, which raised the rivers above the adjacent landscape. Occasionally, very heavy rains would cause the rivers to rise and break through the levees, flooding the surrounding lands and leaving behind a thick blanket of sediment. Over a period of about 10 million years, the accumulating sediments more or less kept pace with the sinking crust, allowing the build up of kilometre thick deposits. Entombed within these sedimentary layers were representative samples of the plants, animals and landforms that existed at various times over the 10 million year period.

At that time, the Joggins area was a lush, tropical, swampy jungle dominated by towering Lycopods or scale trees, ancient relatives of present day club mosses that were up to a metre across at the base and reaching 30 metres high. The two most abundant types found at Joggins are *Lepidodendron* and *Sigillaria*. Also common was the 30-metre tall tree-like *Calamites*, a close relative of modern day horsetails (*Equisetum* sp.) as well as species of *Cordaites*, primitive conifer-like trees, growing 5 – 10 metres high. Ferns and fern-like plants festooned the damp forest floor. However, there were no flowering plants of any sort, because their evolution lay another 150 million years into the future.



Hylonomous lyelli

Scurrying amongst this lush vegetation were many unusual types of animals, perhaps the most impressive being a giant 'bug' called *Arthropleura*. Up to two metres in length and a third of a metre wide, this millipede-like animal is one of the largest land living arthropods (animals with exoskeletons and jointed limbs) known. Its broad sinuous trackways are abundantly engraved in the Joggins rocks. The forest was also home to many other types of crawling and flying insects and other invertebrates. Three hundred million years ago, the most advanced vertebrate animals that had evolved were fish, amphibians and primitive reptiles, all of which were represented in the rivers, lakes and forests of Joggins. This is one reason why the Joggins fossils are so scientifically important – they provide a detailed snapshot of the time not long after amphibians had emerged from the water and were in the early stages of becoming reptiles, the first true land dwelling vertebrates that lived independently of the water and didn't have to return to it to breed. Some of these early reptiles would, within a period of another 100 million years, evolve into the great array of massive, fearsome dinosaurs that would come to dominate the Earth. Joggins thus provides a rare early peek at the "dawn of the age of dinosaurs".

Another group of reptiles found in tropical swamplands of Joggins during the Carboniferous Period were small, rather primitive members of the Pelycosaura named *Protoclepsydrops haplous*. During the subsequent Permian Period (299-251 mya), Pelycosaurs evolved as large "sail-reptiles", named for a large fan-like appendage on its back. It is thought that this sail helped the 3-4 m long animal regulate its body temperature by acting as a radiator to absorb or dissipate heat. This, and other characteristics, such as tooth and skull structure and architecture of the limbs, leads palaeontologists to characterize them as 'mammal-like' reptiles (Synapsida) to distinguish them from the typical 'lizard-like' reptiles (Anapsida). Through the Permian Period such mammal-like reptiles evolved into many different forms and dominated the landscape. Much later, during the Jurassic Period (200-145 mya), when the larger dinosaurs began to rule the

United Nations Educational, Scientific and Cultural Organization

The Joggins Fossil Cliffs inscribed on the World Heritage List in 2008

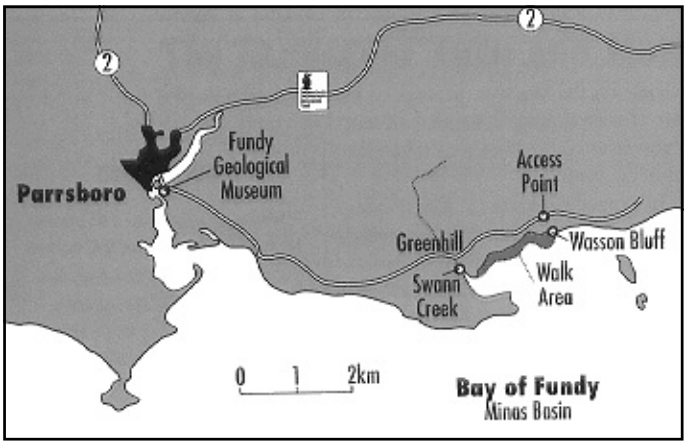
land, there was a sharp reduction in the number and variety of these mammal-like reptiles. However, some of them continued evolving into small, secretive warm-blooded mammals that would eventually explode into world-wide dominance immediately after the catastrophic extinction of dinosaurs at the end of the Cretaceous Period (65 mya).

But all this lay far in the future. Only relatively small early amphibians and a few primitive reptiles were roaming the Joggins forests in the late Carboniferous. The top predator seems to have been a large tetrapod (primitive four-limbed early land vertebrate) of the genus *Baphetes*, nicknamed 'Rex' by the staff. at the Fossil Cliffs Centre. Another sluggish metre long primitive amphibian inhabiting the swamps was named *Dendrerpeton*. However, one of the earliest, and probably still the most famous, fossil animal found at Joggins is the small (20 cm long) insect eating reptile *Hylonomus lyelli.* Its remains were found by Dawson and Lyell in 1852 encased in a fossilized tree stump. They theorized that occasionally a large jungle tree would fall, leaving just a stump protruding from the ground. The softer heartwood decayed more rapidly than the harder, resistant bark, which remained as a hollow cylinder. As sediments accumulated around the stump, such tubes became deadly pitfall traps for unwary animals scurrying across the forest floor. Subsequent flash flooding may then have overtopped the rim of the stump filling it with sediments that hardened to rock around the remains of the trapped animals. *Hylonomous* is scientifically important because it is the earliest reptile ever found - the first known vertebrate truly adapted for living on land. Its limbs were much sturdier than those of the water-dependent amphibians and much better designed for walking efficiently on land. Also, its dry skin didn't need to be kept constantly moist like that of an amphibian. Perhaps most importantly, its eggs, protected as they were by a thick membrane, didn't have to develop and hatch in water. This remarkable little reptile is providing crucial insights into that point in the Earth's history when the ancestors of all reptiles, and ultimately birds and mammals, were coming to terms with a very different life on land. It was officially designated the Provincial Fossil of Nova Scotia in 2002.

Entrance to Joggins Fossil Cliffs Centre

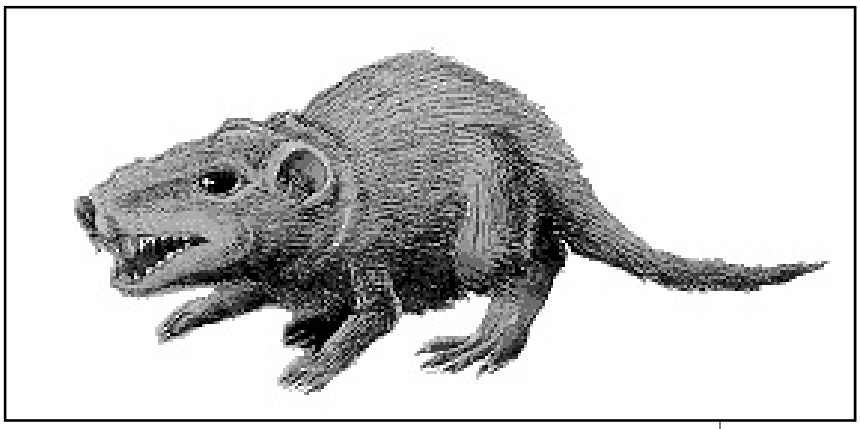
— J.A. Percy

The Joggins site received official international recognition on July 7th, 2008, when UNESCO recognized its outstanding universal value by designating it a World Natural Heritage Site. The organization affirmed that this section of Fundy coastline *"represents the finest example in the world of the terrestrial tropical environment and ecosystems of the Pennsylvanian 'Coal Age' of the Earth's history.*" A few months earlier, on Earth day (April 22nd, 2008) the Joggins Fossil Cliffs Centre officially opened its doors to visitors. This 13,000 square foot building incorporates in its design the latest in green technology, such as a wind turbine, solar water heating and water conservation features. The Centre's innovative dis-



Nova Scotia Museum

Wasson Bluff



A trithelodont - a mammal-like reptile
— Nova Scotia Museum

plays interpret the many unique features of the site for growing numbers of visitors from around the world. It also provides ample space for educational programs and continuing research on the fossils. Guides also lead informative tours along the nearby fossil-rich cliff face.

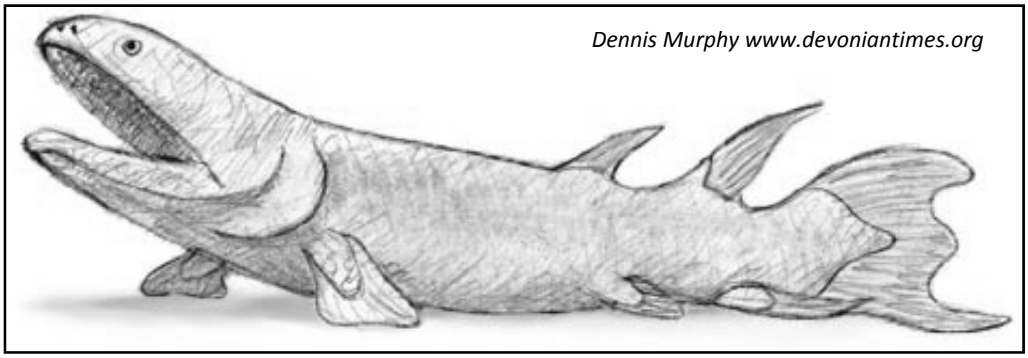
The Joggins Fossil Institute, a registered charitable organization, focuses on promoting, developing and protecting the cliffs as well as raising general awareness of the Carboniferous Period. It manages the World Heritage Site and runs the Centre, while also conducting and fostering further research, recognizing that the site still has much to teach us about the past. The UNESCO designation and the work of the Fossil Cliffs Centre will ensure that the Joggins site will long continue revealing its intriguing palaeontological secrets.

Wasson's Wonders

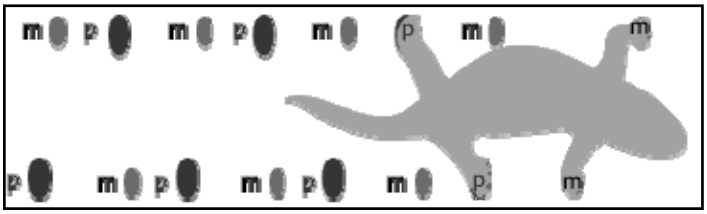
Forty Km due south of Joggins, on the Minas Basin side of the Chignecto Peninsula, can be found yet another of Fundy's world-famous palaeontological sites. The eroding coastal cliffs of Wasson Bluff are located some 6 Km east of Parrsboro. Although geographically almost next door to Joggins, these cliffs reveal the world as it existed about 100 million years after the great coal age swamps of Joggins were formed. It is renowned for what it tells us about life in the early Jurassic Period (200 mya). A number of different ancient environments are represented in different areas of the extensive cliff face at Wasson Bluff. Tremendous fracturing, shifting and twisting of the rock layers over time created an enormously complex geological jigsaw puzzle that scientists have painstakingly reconstructed during recent decades.

Interest in the area was first stimulated in 1984, when amateur fossil hunter Eldon George found tracks of one of the earliest dinosaurs ever found in Canada. In 1984 and 1985, a team of American palaeontologists, led by Paul Olsen of Columbia and Neil Shubin of Harvard, visited the area and with permission collected over 3 tons of rocks containing fossilized bone. Over the next couple of years they teased over 100,000 fossil fragments from the stoney matrix, making it one of the largest finds of fossils from the early Jurassic Period ever discovered. These bones appear to have accumulated in an ancient valley, where they may have been washed in from surrounding higher ground by repeated massive flooding. The sandstone matrix also has basalt rocks and boulders embedded in it, which were probably also carried in by the floods.

The Wasson collection is particularly important because slightly earlier, at the end of the Triassic Period (199 mya), there was a massive extinction of life on earth when almost half of all species of animals died out. The fossils found at Wasson Bluff provide strong supporting evidence for this extinction event and allow it to be dated with greater accuracy. This great die-off ended the dominance of the mammal-like reptiles. With little competition remaining, the dinosaur-like reptiles were able to diversify, multiply and eventually rule the Earth during much of the Jurassic and Cretaceous "Age of Dinosaurs" (200 – 65 mya). It is thought



A lobe-finned fish of the type that evolved into land-living tetrapods



A lumbering tetrapod making tracks
(manus = forefoot, pes = hindfoot)
— Dennis C. Murphy, "www.devoniantimes.org"

that the creatures present in the rocks of Wasson Bluff represent those that survived this mass extinction; they are mostly small to moderate in size (less than 25 kg) and include early crocodiles, lizards, freshwater sharks and small dinosaurs. The latter are important because they are early forms living at the "dawning of the age of dinosaurs" and may shed more light on the early evolution of the great dinosaurs. In recent years the remains of six sauropod dinosaur skeletons, including 3 adults almost 5.5 m long, have been teased from the eroding rocks of the cliff face. These lizard-hipped herbivorous dinosaurs were the early forerunners of the renowned gigantic species that evolved during the Jurassic Period. Other scientifically important fossil finds include trithelodonts or mammal-like reptiles such as *Pachygenelus sp.* In fact, the Wasson Bluff site comprises the world's largest deposit of trithelodont fossils. Such mammal-like reptiles had dominated the landscape for well over a million years but were largely wiped out in the great extinction at the end of the Triassic Period (199 mya). The rare survivors amongst the trithelodonts gradually evolved into true mammals (albeit initially tiny, unobtrusive shrew-like creatures) that would only blossom forth into the great array of mammals we see today, after the dinosaurs died out at the end of the Cretaceous Period (65 mya).

" [The Wasson Bluff site represents]... one of the largest finds of fossils from the early Jurassic Period (200 mya) ever discovered ".

The early Jurassic fossils found at Wasson Bluff are embedded in the latest (youngest) sedimentary rocks found in the Fundy basin area. At the time they were being deposited, the continents were drifting apart and the major coastal rifting had ceased. The land surface was no longer sinking steadily and the rapid build up of sediments had virtually ceased. The geological and fossil history of Wasson Bluff and adjacent areas of the coast are on display at the Fundy Geological Museum, which opened in late 1993, located in the coastal town of Parrsboro, NS. The museum comprises not only a large exhibition gallery, whose displays were completely revamped in 2010, but also a laboratory, a multipurpose room and a gift shop. Staff members conduct public field trips to Wasson Bluff and several other geologically important sites in the region.

Avon's Amazing Tetrapods

Directly south of Wasson Bluff, on the opposite shore of the Minas Basin, lies Horton Bluff/Blue Beach, another crumbling stretch of rocky cliffs along the western flank of the mouth of the Avon River near Avonport. Geographically the distance between Wasson and Horton Bluff/Blue Beach is a mere 30 km, but geologically they are separated by almost 150 million years. The cliffs at Horton Bluff/Blue Beach, which are steadily eroding and releasing their palaeontological treasures, comprise over 30 distinct sedimentary layers, or strata, stretching along about four kilometres of shoreline. The very much older Horton Group strata found here were laid down around 350 mya, near the beginning of the Carboniferous Period, about 40 million years before the Joggins Cliffs site. What makes the fossil found here especially exciting and scientifically important is that they are from an age that corresponds to the time when vertebrates were emerging from the water and finding ways of adapting to a much different life on land.

The earliest four-legged animal (tetrapod) fossils found previously in other parts of the world were clearly fish-like in nature and not much evolved beyond lobe-finned fishes similar to that famous "living fossil", the coelacanth. These aquatic tetrapods of the late Devonian Period (365 million years ago and known as "the age of fishes") were unable to bring their primitive limbs completely underneath their body and thus could not have walked effectively on land and were largely water dwellers. They have been characterized as essentially "fish with legs". Then there is a rather perplexing 30 million year gap in the fossil record, with few traces of tetrapod fossils found anywhere. By the time tetrapod fossils appear again during the latter part of the early Carboniferous Period (about 335 mya) they had evolved into the primitive ancestors of all subsequent land-dwelling vertebrates. This fossil hiatus has

Fossilized footprint, an "ichnite"

long been known in palaeontological circles as" Romer's Gap", after eminent palaeontologist Dr. Alfred Romer, who first noticed the apparent blank space in the fossil record. The question of how life on land started is considered to be one of evolution's greatest mysteries. The fossils from Horton Bluff/Blue Beach, dating from about 350 million years ago, are scientifically important because they are some of the few fossils to date that have been found from Romer's intriguing gap. As some of the oldest land vertebrates ever found, they may help us gain a better understanding of the types of animals that were the successful intermediates in the pivotal move from water onto land.

The first indication that Horton Bluff/Blue Beach yielded interesting fossils came in 1841 when Canadian geologist Sir William Logan came across a slab of stone that had fossil footprints of an unidentified tetrapod larger than a crocodile. At the time these were considered the oldest fossil footprints ever found. Such fossilized footprints, which are not the actual remains of an animal but simply traces of its passing, are called "trace fossils" or "ichnites" by palaeontologists. More than a century later, in 1964, two students (one of them was Dr. David Mossman, now a professor of Geoscience at Mount Allison University in Sackville NB) carrying out a hydrological survey in the region found a series of 27 fossil tracks extending for over 20 metres. The tracks were spaced about 30 cm apart and each was about 30 cm in length. Located intertidally, about 50 metres offshore, this track way had been exposed by an exceptionally low tide and an earlier storm that had flushed away the overlying layer of mud. The prints, in rocks dating from the early Carboniferous Period, are thought to be the oldest tracks of vertebrates ever found anywhere and are still the oldest found in Canada. Although it was not possible to identify the animal, it may have been an early amphibian that was probably about 2 metres long and lived in shallow coastal waters. More recently, it has also been suggested that it could be a trail left by a lobe finned rhizodont fish (see below) stranded in shallow water that left the trackway as it struggled to get back to deeper water. A fibreglass cast of this trackway made by the Nova Scotia Museum in 1979 provides a permanent reproduction of a natural feature that has long since been eroded away by Fundy's relentless tides. The Nova Scotia Museum of Natural History in Halifax has this cast in its collections as well as other fossil material collected from Horton Bluff/Blue Beach and many other areas around the province.

During the early Carboniferous Period (350 mya) the area that is now Horton Bluff/Blue Beach was situated along the margin of a very large tropical estuary or bay. These shallow waters were not fresh, nor fully marine, but were probably brackish. These waters were populated by a variety of different archaic fishes, whose fossilized bony remains are far more common than the tiny populations of tetrapods. Among these were giant lobe-finned fishes called "rhizodonts" that could reach lengths of five metres. Over 2000 fossil bones of a species of large rhizodont (in 2005 it was named *Letognathus* or "jaws of death, annihilation or ruin") have been found at Blue Beach. These voracious predators probably dominated the deeper areas, leaving only the surrounding shallows as safe places for smaller fishes and tetrapods. Furthermore, many additional species of fish and invertebrates have also been found at the site, providing useful insight into the ecology of the food chain in the early Carboniferous. Tree-bark fossils and other plant remains give us a sense of the nature of the early Carboniferous forests that mantled the shorelines and provided habitat for these very early tetrapods. At least five kinds of tetrapod footprints have already been named from the current fossil collection, but the many unnamed species represented by bones suggest that between 7 and 10 species of tetrapods have now been discovered here.

"the Fundy region will long continue to be an important and exciting arena for palaeontological research, discovery and education".

A recent resurgence in the recognition of the rich fossil

Chris Mansky *(3rd from right)* **guides fossil enthusiasts on Blue Beach**
— J.A. Percy

wealth present at Blue Beach is largely attributable to the dedicated collecting efforts over many years by amateur fossil enthusiast Chris Mansky and his partner Sonja Wood. In 2002, they established a small but comprehensive museum and research centre at the Blue Beach site to display their remarkable and rapidly expanding fossil collection and make it more accessible to the scientific community and the general public. Chris also leads guided tours along the fossil cliffs backing Blue Beach. The collection of fossils that they have amassed over the past decade and a half has in recent years attracted increasing attention from the scientific community. Researchers from Dalhousie and McGill Universities, the Nova Scotia Department of Natural Resources and from as far away as the New Mexico Museum of Natural History, Sweden and Australia, to name a few, have been avidly studying Chris's collection and publishing scientific papers on their interpretations. They have concluded that these are some of the oldest tetrapod tracks ever found. They clearly show that there were four-legged, five-toed vertebrates fully capable of walking on land early in the Mississippian sub period (360-345 mya). While much remains unclear about the creatures and habitat of the ancient Blue Beach site and more study is obviously required, gradually an interesting and scientifically important story is emerging.

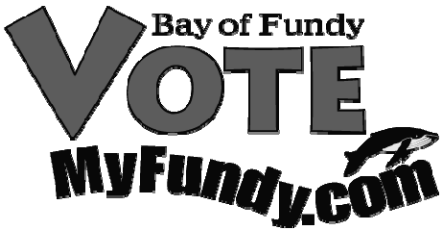
J.A. Percy

Display of tetrapod trackways At Blue Beach Museum

Future Fossil Fame?

This overview has only touched on some of the more prominent coastal fossil sites in the Fundy region. Much of the shoreline of the Minas Basin has rich fossil deposits, including the remains of Canada's oldest mammal-like reptile (*Arctotraversodon*) found at Burntcoat Head, NS, fossil-bearing limestone deposits at Newport Landing and along the Shubenacadie River, and Devonian plant fossils found near Economy, to name but a few. Further afield, phytosaur (early crocodile-like reptiles) remains have been found along the shores of St. Marys Bay, NS, Ordovician/ Devonian marine invertebrate fossils are present at nearby Bear River, and remains of early bony fish are abundant in the oil shales of Albert County, NB.

Without question, the eroding sedimentary cliffs rimming much of Fundy contain a unique, truly remarkable and scientifically valuable record of great geological changes and biological evolution from a number of particularly important periods in the history of the Earth's development. This is one of the reasons (along with its stunning beauty, bountiful marine resources, diverse coastal habitats and abundant wildlife populations, and not forgetting the highest tides in the world) that the Bay of Fundy is now one of 28 finalists, and the sole Canadian entry, in an international competition. The Bay of Fundy Tourism Partnership is spearheading the campaign to have the Bay of Fundy declared one of the "New7Wonders of Nature". The winners will be announced in November 2011. Whatever the outcome of this competition, the Fundy region will continue to be an important and exciting arena for palaeontological research, discovery and education.



Canada's only finalist for the "New7Wonders of Nature"

The growing number of research facilities in the Maritimes devoted to palaeontology, as well as the expanding cadre of researchers staffing or carrying out studies at these facilities, bodes well for the ongoing efforts to unravel the many fascinating chapters in the story of the Earth's distant past that are slowly being revealed in the crumbling cliffs around Fundy.

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