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FIELD TRIP A7

The Triassic-Jurassic faunal and floral transition in the Fundy Basin, Nova Scotia

Paul Olsen, Jessica Whiteside, and Tim Fedak

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THE TRIASSIC-JURASSIC FAUNAL AND FLORAL TRANSITION IN THE FUNDY BASIN, NOVA SCOTIA

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ITINERARY

We assemble and depart from the parking lot of Student Union building on the Dalhousie University campus at 7:30 am on Sunday (May 15th), and conclude at approximately 7:30 pm at the same location that day. The drive from Halifax to the first stop is about 2 hours.

SAFETY

For personal and group safety we ask all participants to read and heed the following safety related procedures. We ask for your cooperation and common sense in making this a safe and enjoyable field trip for everyone. Thank you.

1. **ROCK HAMMERS:** Some sites we are visiting (Wasson Bluff, Five Islands) are protected and it is illegal to use rock hammers without a Nova Scotia Heritage Permit. Of course, in general please use caution when hammering: be aware of people around you, use controlled downward blows, and do not hammer indiscriminately.
2. **SUITABLE CLOTHING:** Participants should have sturdy footwear and protection against both wet and cold, including a hat, gloves, and boots. Adequate clothing is important if you are involved in an accident or if you are required to spend an extensive period of time outdoors. Spring weather in Nova Scotia is unpredictable and can change from sunny and warm, to rain, wet snow, and high winds with little notice.
3. **HARD HATS:** Hard hats are recommended anywhere you intend to look at rocks where there are cliff faces or overhangs. We will have a supply of hard hats for use by field trip participants.
4. **CLIFFS AND FALLING ROCKS:** We will be visiting sites that experience tremendously high rates of erosion, which result in the possibility that exposed rock faces will be unstable, therefore posing a major hazard on field trips. Avoid unstable waste rock piles or overhanging cliffs and watch for people below you on slopes.
5. **TIDES:** The Bay of Fundy has some of the highest tides in the world, with a vertical range of 15 meters, which is great for exposing fresh outcrop. However, always note whether the tide is coming in, or going out, and ensure that access routes will not be cut off with an incoming tide. Inter-tidal rock exposures can be very slippery, please be very cautious when walking on wet outcrop or cobbles, and especially on algae covered surfaces.
6. **FIRST AID / MEDICAL CONDITIONS:** Several First Aid kits will be located in the bus/vans and with a leader on site. Participants with valid First Aid certificates are encouraged to identify themselves at the beginning of the field trip. Field trip participants with medical conditions (allergies, diabetes, etc.) may wish to advise the field trip leaders prior to departure
7. **IN THE UNLIKELY EVENT OF AN EMERGENCY:** Call ***911.*** Some areas in Nova Scotia have poor cellular phone coverage, so it may be necessary to use a pay/private phone.

INTRODUCTION

One of the five big mass extinctions of the Phanerozoic, the Triassic-Jurassic event is greater or equal in intensity to that at the more famous K-T boundary (Benton, 1995) (Fig. 1), although dissenters remain (e.g. Hallam, 2002; Tanner et al., 2004). The cause of this mass-extinction remains hotly debated; explanations include sea-level change and anoxia (Hallam, 1990), a methane- and CO_2- generated super-greenhouse triggered by flood basalt eruptions (McElwain et al., 1999; Hesselbo et al., 2002), and bolide impacts (Olsen et al., 1987; Olsen et al., 2002a, b). During the Triassic, all major extant groups of terrestrial vertebrates evolved, including dinosaurs (whose descendants survive as birds) and mammals. The Triassic-Jurassic mass extinction may have cleared ecological space for dinosaurian ascent much as the K-T mass extinction prepared the way for the rise of mammals (Olsen et al., 2003a).

In this guidebook, we will examine outcrops, exposures, cores, and fossils that provide important new clues about the major features of the Triassic-Jurassic boundary and subsequent events in the Fundy basin, one of the richest sources for data on continental ecosystems during this evolutionary transition. We will focus not just on the physical and biological record of the boundary, but on the post-boundary events, especially those recorded above the basin's extrusive interval which may have been characterized by a super-greenhouse environment. We will see spectacular exposures of fossiliferous fluvial, eolian, and lacustrine strata, as well as volcanic structures, including giant flood basalt flows and fossil basalt talus cones. We will see fossiliferous strata that document pre-boundary diversification of the Triassic biota as well as the extraordinarily stressed post-boundary assemblages.

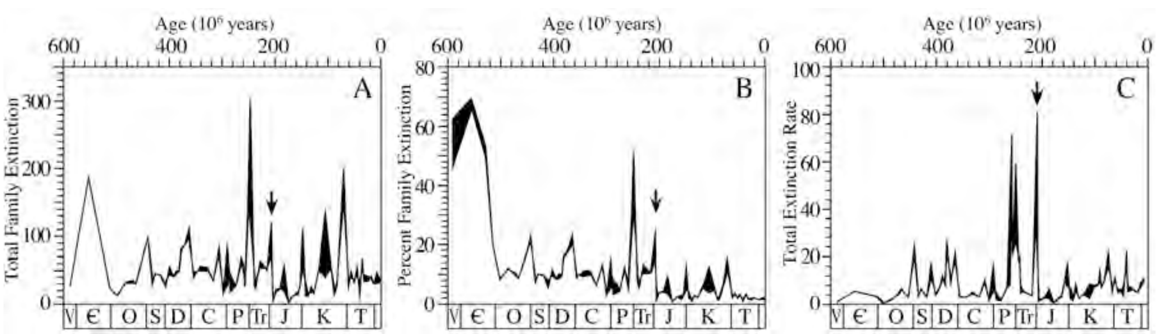


Figure 1. Extinction rate of marine and continental organisms through the last 600 million years (from Benton, 1995) with arrow at Triassic-Jurassic boundary. The upper and lower bounds represent the maximum and minimum curves. A, Extinction rate expressed as the numbers of families that died out in each stratigraphic stage. B, Extinction rate expressed as a percent of families that died out in relation to contemporaneous diversity in each stratigraphic stage. C, Extinction rate expressed as the number of families that died out in relation to the duration of each stratigraphic stage.

Geological and Biological Context

The Triassic and Early Jurassic, with its nearly symmetrical meridional supercontinent Pangaea, represent a period of extreme geography and climate. A "hot house" world, with no evidence of polar ice (Frakes, 1979), it is marked by deposition of coals in polar and equatorial regions and plausibly extremely high pCO_2 (Berner, 1999). Soil carbonates from the Fundy basin and elsewhere suggest CO_2 levels were between 2000 and 3000 ppm (Wang et al., 1998; Ekart et al., 1999; Tanner et al, 2001; Beerling and Berner, 2002). Fossil stomatal indices (McElwain et al., 1999; Royer et al., 2001; Retallack, 2001) offer lower but still extreme concentrations close to 1000 ppm (Beerling and Berner, 2002). Despite vast climate differences from the present, a humid equatorial zone of modern dimensions existed (Kent and Olsen, 2000). Traversing through time the transition zone between this humid region and the arid sub-tropics to the north, the Fundy rift basin developed, recording during its long history, the Triassic-Jurassic boundary and adjacent events (Fig. 2).

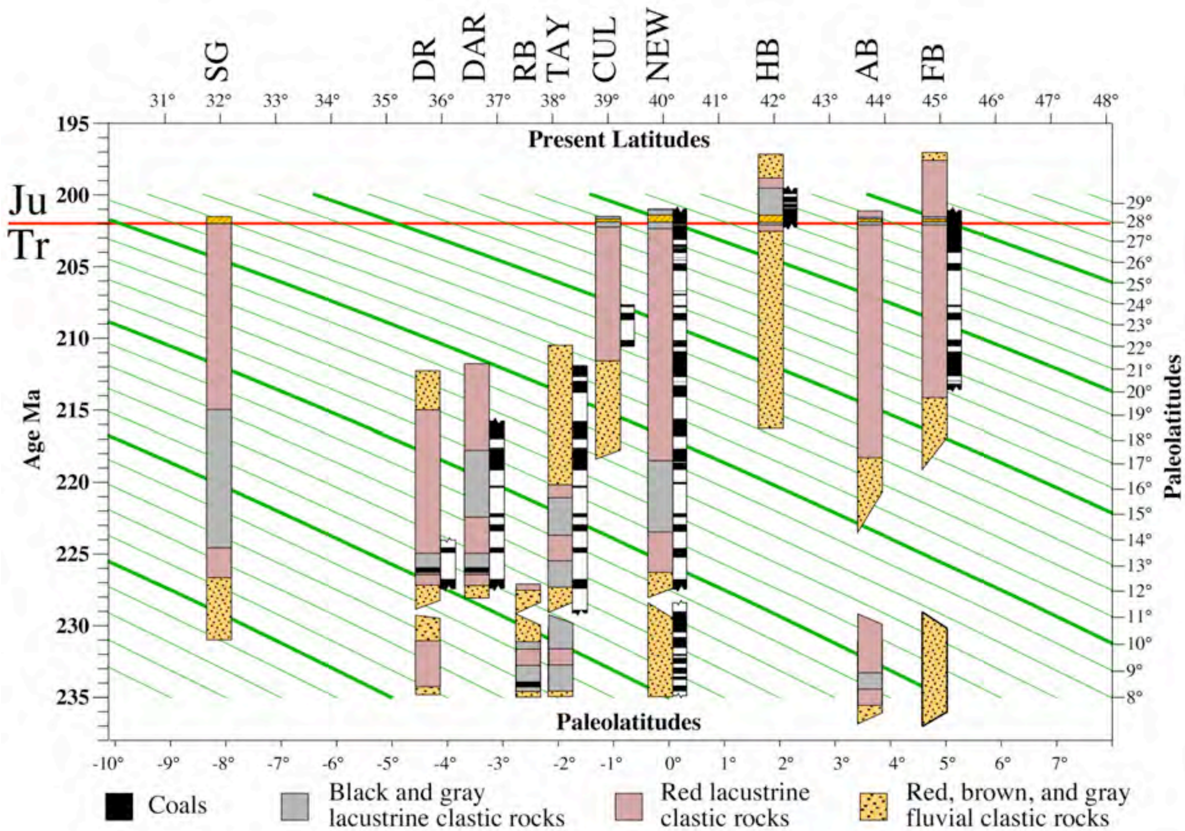


Figure 2. Time-geography nomogram showing the relationship between the main climate sensitive lithologies, age, geography, and latitude. Sections are correlated by magnetostratigraphy as indicated (black, normal; white, reverse). Slightly curved diagonal lines are lines of equal paleolatitude. Modified from Olsen and Kent (2000), Kent and Olsen (2000), and Kent and Tauxe (2005). Basins are: SG, South Georgia Rift; DR, Deep River Basin; DAR, Dan River basin; RB, Richmond basin; TAY, Taylorsville basin; CUL, Culpeper basin; NEW, Newark basin; HB, Hartford basin; AB, Argana basin; FB, Fundy basin.

Pangaean rift basins developed largely in a continental milieu along a huge rift zone from Greenland through the Gulf of Mexico in the ~40 m.y. preceding the Jurassic opening of the central Atlantic Ocean (Figs. 2, 3). The Fundy basin is the largest of the outcropping and deeply eroded North American rifts. The basin fill, collectively termed the Newark Supergroup (Fig. 2), apparently formed in entirely non-marine settings. Continental rifting initiated in eastern North America sometime within the median Permian (Olsen et al., 2000)

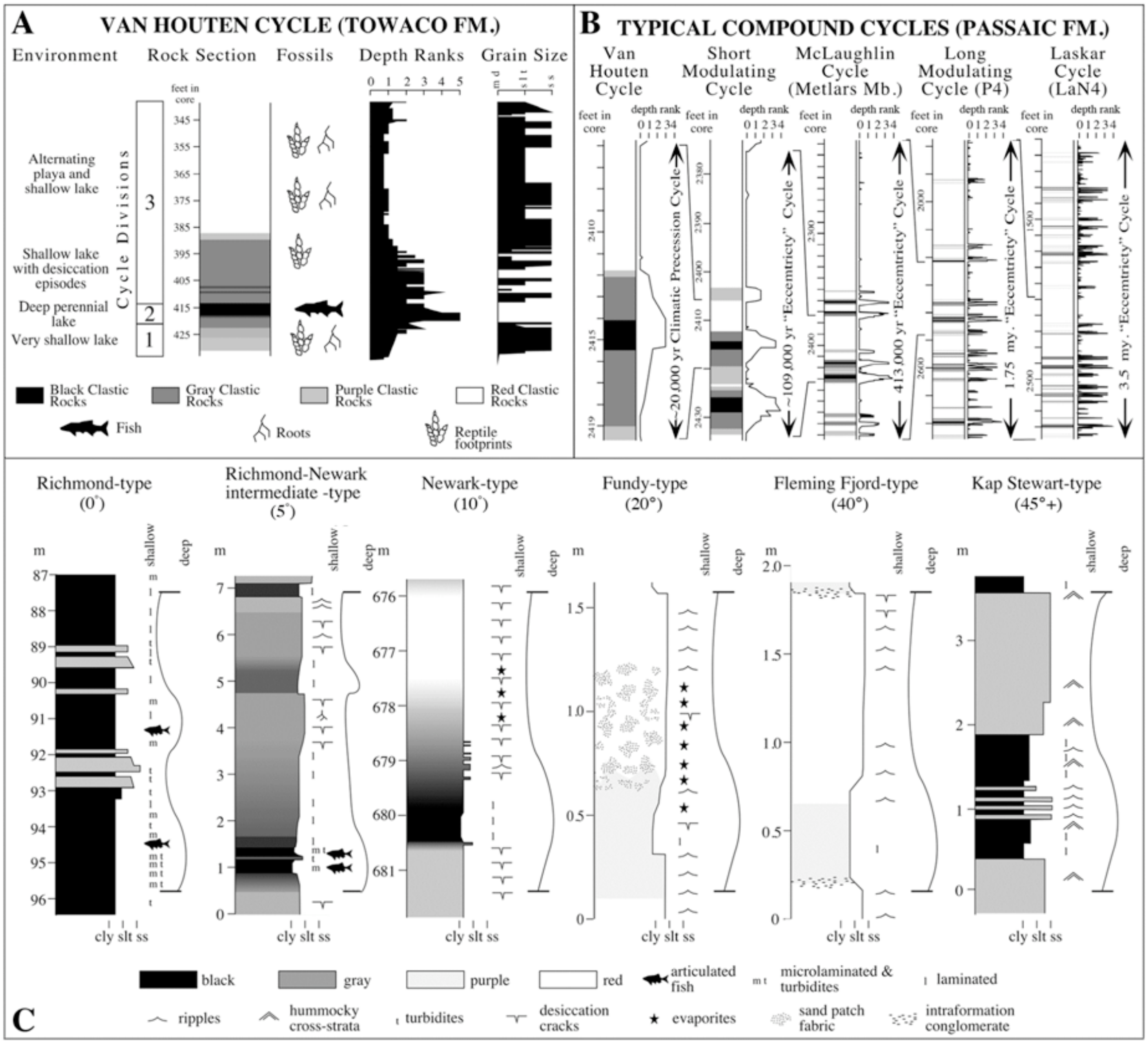


Figure 3. Van Houten cycles and their modulating cycles. A, Example of a Van Houten cycle from the Jurassic Towaco Formation of the Newark basin (depth ranks are a measure of relative water depth); B, Van Houten cycles and the four modulating "eccentricity" cycles (example from the Passaic Formation); C, variation in Van Houten cycles with latitude.

as witnessed by deposits in New Brunswick, and finished in the Early Jurassic, although the exact timing of the termination of rifting is poorly constrained. These rifts also record a major tectonic paroxysm that punctuated the beginning of the Jurassic: the emplacement of basaltic intrusions and extrusions of the Central Atlantic magmatic province (CAMP) (Marzoli, 1999; Olsen, 1999) – Earth's most aerially extensive igneous province.

Our concepts of Late Triassic terrestrial communities are evolving rapidly. Gone are the days of Romer's (1970) three successive faunas of the Triassic. The diversification of the archosaurs is now set back into the early Middle Triassic or even the Early Triassic (Gower and Sennikov 2000), and, by the Late Triassic, the stage was set for the modern fauna.

Dinosaurs and mammals evolved during the Triassic, along with the other major groups of extant terrestrial vertebrates; by the close of the Triassic, there were also a large number of other groups without modern representatives. These extinct groups include the top predators of the Late Triassic, the fully terrestrial rauisuchians and crocodile-like phytosaurs as well as many strange small forms such as the drepanosaurids, prolacertiforms, and the bizarre *Vancleavea* (Hunt et al., 2002). Based on new discoveries of more complete skeletal remains, we now know that most taxa previously identified from fragments as dinosaurs are actually highly derived members of groups restricted to the Triassic. For example, all purported Triassic ornithischian and sauropodomorph dinosaurs from North America are now clearly referable to other archosaurs such as the crocodile-line archosaur *Revueltosaurus* (Parker et al., 2005), allied with the dinosauromorph *Silesaurus* (Dzik, 2003), or indeterminate. Other creatures thought to be Triassic members of later Jurassic and Cretaceous clades are actually chimeras of other mostly non-dinosaurian taxa, or completely unsuspected new herbivorous crurotarsian groups.

These new discoveries have revealed a world populated by rather unfamiliar taxa with communities of different composition, latitudinally distributed. Even though a large archosaur could theoretically walk to any continent in its lifetime, biotic provinciality was a much stronger factor than previously suspected. Although the Nova Scotian and the South Carolinian Late Triassic faunas are only 1000 km apart, what seemed to be tropical tetrapod communities with relatively rare herbivores are actually assemblages with abundant and diverse herbivores belonging to very different groups (e.g., traversodonts vs. procolophonids), but few dinosaurs (Olsen et al., 2001). Hence, the terrestrial Late Triassic was not merely an intermediate between the Early to Middle Triassic and the Jurassic, it was a fully mature world unto itself, unsuspectingly diverse and unique.

In contrast, the Early Jurassic is the dawn of the modern era of terrestrial vertebrate communities exemplified by the assemblages from the Fundy basin (Stops 1, 3, 4). All of the top predatory and herbivorous crurotarsians are gone. The strong biotic provinciality of the Late Triassic has been repla ced by an essentially global distribution of many genera and species. One of the main features of the Jurassic biological record visible in the Fundy basin is the unquestionable ecological dominace of dinosaurs with crocodylomorphs and pterosaurs being the only other remaining archosaurs. Most of the surviving continental tetrapod groups are also familiar and still extant, such as lizards, turtles and lissamphibians; mammals also survived along with the very mammal-like tritheodonts and tritylodonts.

In both the Triassic and Early Jurassic, seed plants such as conifers and cycadophytes were abundant along with various ferns and fern allies, including many extant families. Although there is some evidence that angiosperms (flowering plants) may have evolved by the Late Triassic (Cornet, 1989a,b; Wolfe et al., 1989), they were certainly not abundant. Through the Late Triassic, an extinct conifer group, the Cheirolepidiaceae or cheiroleps became relatively abundant. But not until after the Triassic-Jurassic mass extinction did the cheiroleps, like the dinosaurs, become the most conspicuous element of terrestrial communities. After their ascent however, they remained the most abundant tropical trees for the next 80 million years until the proliferation of the angiosperms.

Similar to other lacustrine strata of the Newark Supergroup, many of the sedimentary sequences in the Fundy basin are profoundly cyclical. The fundamental sedimentary cycle seen is named the Van Houten cycle, (Olsen, 1986) (Fig. 3) after its discoverer (Van Houten, 1962, 1964). The Van Houten cycle consists of three lithologically distinct divisions that represent lacustrine transgressive (division 1), high stand (division 2), and regressive followed by lowstand deposits (division 3) attributed to variations in the rate of inflow and evaporation caused by the ~20 ky cycle of climate precession.

Van Houten cycles are modulated in vertical succession by a hierarchy of four orders of cycles (Fig. 3) ascribed to modulation of precession by "eccentricity" cycles, quasi-periodic changes in the shape of the Earth’s orbit from elliptical to nearly circular coupled with the precession in the figure of the orbit itself. These eccentricity cycles average approximately 100 ky, 400 ky (termed the McLaughlin cycle after an astronomer who mapped 400 ky cycles over much of the Newark basin; Olsen and Kent, 1996), and 1.75 and 3.5 m.y. cycles (Olsen, 2001; Olsen and Rainforth, 2003). The 400 ky McLaughlin cycle in the Newark basin serves as a basis for an astronomically-calibrated geomagnetic polarity time scale for the Late Triassic (Olsen and Kent, 1996, 1999) and earliest Jurassic. Employing the 400 ky cycle for time scale calibration for

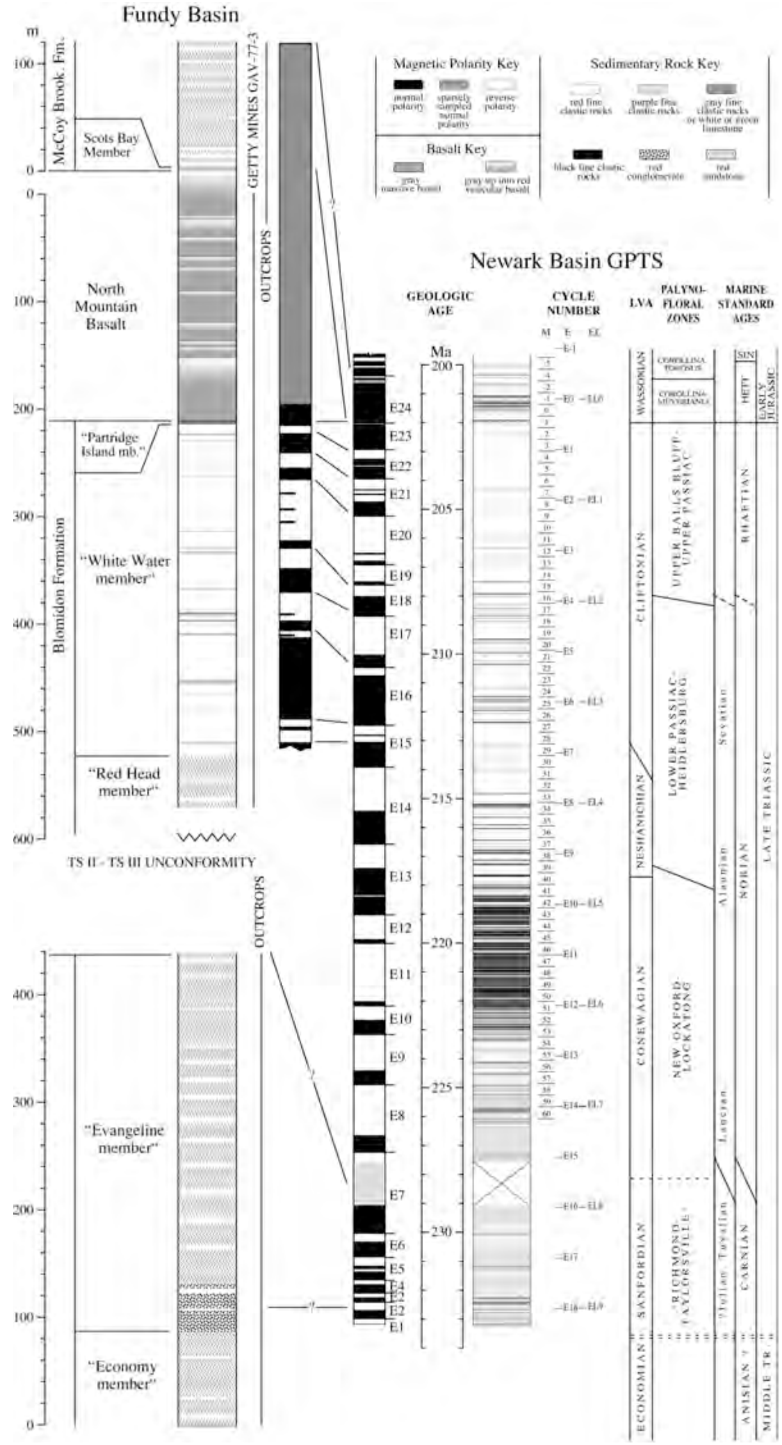


Figure 4.Fundy basin section correlated to the Newark basin astronomically calibrated geomagnetic polarity time scale. Based on Kent and Olsen (2000), Olsen et al. (2003).

an interval hundreds of millions of years ago is justified because this eccentricity cycle is caused by the gravitational interaction of Jupiter and Venus, a cycle which should be stable on the scale of billions of years.

The cyclicity present in the Newark Supergroup changes dramatically with latitude (Fig. 3). Most of the Blomidon and much of the McCoy Brook formations in the Fundy basin show lacustrine cyclicity, although the cyclicity of the Fundy basin is expressed in a much more arid mode, nearly devoid of black shales (Fig. 3). The paleolatitude of the Fundy basin was 25° N by the Triassic-Jurassic boundary, hence the arid facies are fully within expectations of a zonal climate with climate belts of a width comparable to today (e.g., Kent and Tauxe, 2005).

The robust and well-tested Milankovitch cyclostratigraphy and time scale in the Newark basin provides a high-resolution framework for the transition that makes the Newark Supergroup, including the Fundy basin, uniquely suited to document the rates of environmental change through the boundary and the recovery (Kent et al., 1995; Olsen and Kent, 1996; Olsen et al., 1996a, b; Fedosh and Smoot, 1988) (Fig. 4). Recent magnetostratigraphic correlations between Tethyan marine strata and the Newark basin time scale has allowed for the first time a reasonable correlation between the continental and marine sections at a substage level. The magnetostratigraphy of the Blomidon Formation (Kent and Olsen 2000) allows much of the Fundy basin section to be correlated with the marine strata at a similar high level of resolution (Fig. 4).

Tectonostratigraphic Sequences, Stratigraphic Units, and their Biota

Four tectonostratigraphic sequences are present within the central Pangaean rifts, (Olsen, 1997) (Fig. 5) all of which are present in the Fundy Basin. Tectonostratigraphic sequences (TS) are similar in concept to marine sequence stratigraphic units in that they are largely unconformity-bound genetically-related packages, but are controlled largely by tectonic events. Tectonostratigraphic sequence I (TS I) is median to Late Permian in age, and while thus far positively identified only in the Fundy basin and various Moroccan basins, it may exist in the subsurface in other basins. In the Fundy basin, the Honeycomb Point and Lepreau formations belong to TS I. Apart from burrows, root traces and very poor tetrapod footprints, fossils are virtually unknown from TS I. Tectonostratigraphic sequence II (TS II) is of ?Middle (Anisian-Ladinian) Triassic to early Late Triassic (Early to early Late Carnian) age. TS I is present in most Newark Supergroup basins, and is especially well developed in the Fundy basin where it consists of the mostly fluvial Wolfville

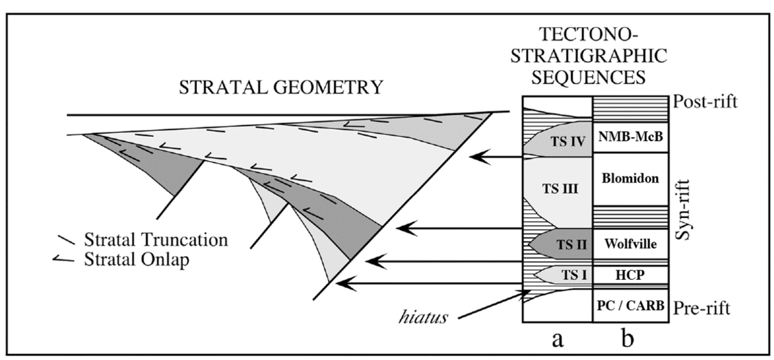
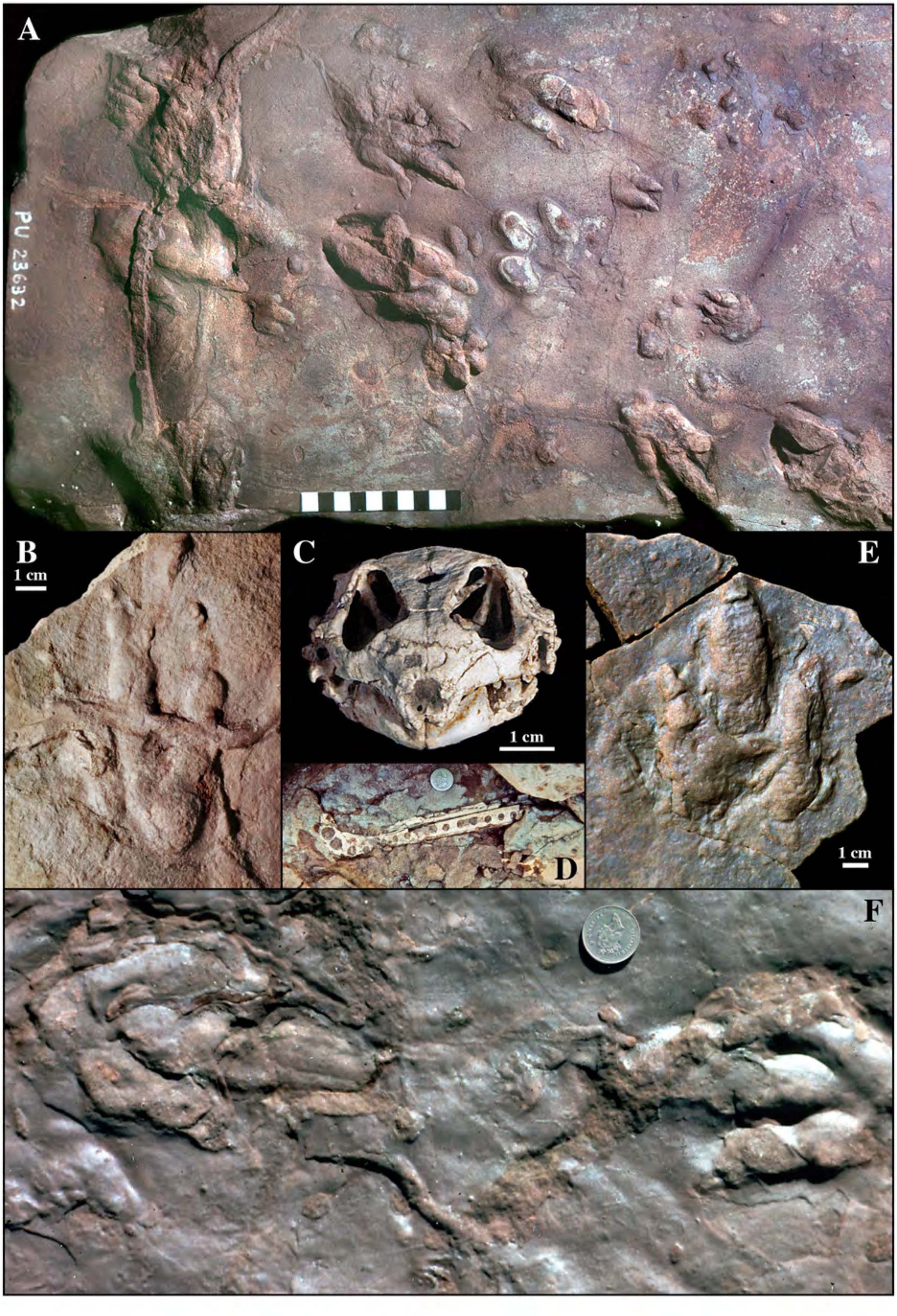


Figure 5. Tectonostratigraphic divisions of the Fundy basin. Adapted from Olsen (1997).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Formation and its equivalents (e.g., Quaco and Echo Cove formations). TS II is very fossiliferous, producing Carnian age microfloras and scrappy macrofloras from New Brunswick and diverse skeletal remains from Nova Scotia. We will not visit units of TS I and TS II on this field trip, rather we will concentrate on TS III and TS IV because these are most relevant to the Triassic-Jurassic transition.

Tectonostratigraphic sequence III (TS III), of early Late Triassic age (Late Carnian through early Late Rhaetian), is the most widespread of the sequences and dominates nearly all Newark Supergroup basins. TS III is also widespread in the Fundy basin, where it consists exclusively of the Blomidon Formation. In dramatic contrast to TS II of the Wolfville Formation, TS III of the Blomidon Formation consists mostly of cyclical, evaporite-bearing lacustrine strata.

The basal portion of the Blomidon Formation, referred to as the “Red Head member”, named for Red Head (Stop 1), often has beds of eolian sandstones that are occasionally spectacularly developed (Hubert and Mertz, 1980; 1984).These eolian sandstones were originally grouped within the Wolfville Formation as they are sandstone-dominated sequences, however, they are interbedded not only with fluvial sandstones, but also with well-developed evaporite-bearing cyclical sequences identical to the overlying Blomidon Formation. Critically, the Blomidon Formation is separated from the underlying Wolfville Formation *sensu stricto* by a locally profound unconformity along the north shore of the Minas basin. The Whitewater member overlies the Red Head member, and consists of meter-scale sedimentary cycles, mostly comprised of “sand patch fabric”, within sand-patch cycles (Smoot and Olsen, 1988; Smoot, 1991), and sand-patch cycles are the arid expression of Van Houten cycles (Fig. 3). This part of the Blomidon Formation is named for outcrops at Whitewater, near Blomidon.

Fossils are locally abundant within the TS III portion of the Blomidon Formation. Two sites yielded nearly all of the remains: “Paddy Island” in the Red Head member, and Rossway in the Whitewater member (Fig. 6). Magneto- and cyclostratigraphy constrain the Paddy Island assemblage to late-middle Norian in age (late Alunian to early Sevatian). Without magnetostratigraphic data, the Rossway assemblage is poorly dated, except that it is significantly younger than that from Paddy Island, and therefore is late Norian or Rhaetian in age (Fig. 4)

Tectonostratigraphic sequence IV (TS IV) is of latest Triassic (Late Rhaetian) to Early Jurassic (Hettangian and Sinemurian) age. It contains the Triassic-Jurassic boundary, extrusive tholeiitic basalts of the CAMP, and occasionally extensive post-CAMP sedimentary strata. TS IV is very well represented in the Fundy basin where it consists of the distinctive uppermost Blomidon Formation, the overlying North Mountain Basalt and succeeding McCoy Brook Formation. The latter is the youngest unit in the Fundy rift basin section.

The uppermost Blomidon Formation comprises the “Partridge Island member” named for outcrops at Partridge Island (Stop 4) (Fig. 5). It consists of a distinctive sequence of

Figure 6. Representative tetrapod fossils of the Red Head (A-C, from the “Paddy Island” locality) and Whitewater (D-F, from the Rossway locality) members of the Blomidon Formation (TS III): A, Slab with several trackways of *Atreipus acadianus* and one of *Brachychirotherium* cf. *parvum* (*bp*, pes; *bm*, manus) (photo courtesy of Donald Baird); B, new dinosaur-like ichnogenus; C, skull of *Hypsognathus* cf. *fenneri*; D, *in situ* rostrum of phytosaur; E, cf. *Atreipus milfordensis*; F, *Eubrontes* (*Anchisauripus*) cf. *tuberosus* and Rhynchosauroides sp. (*r*).

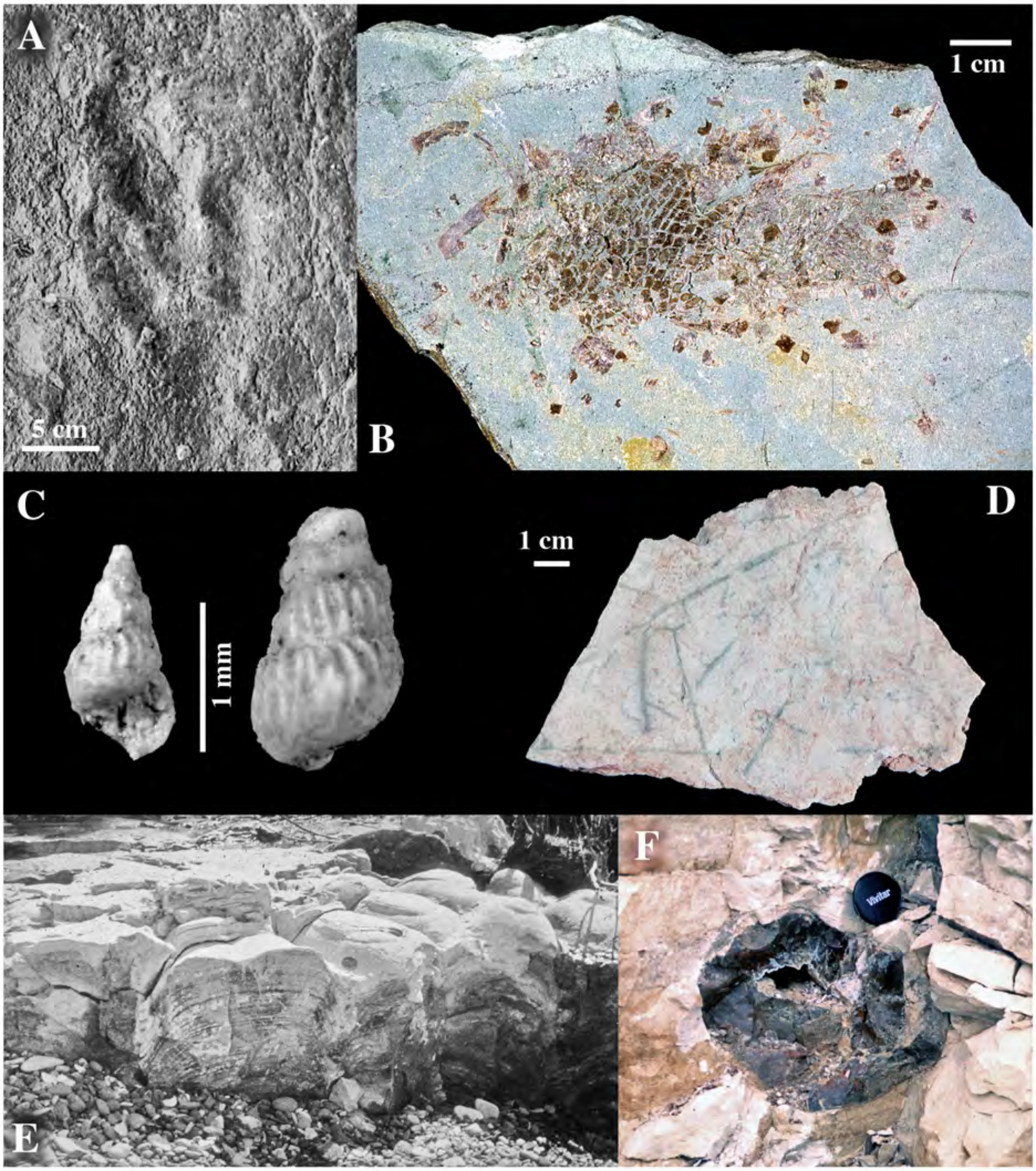


Figure 7. Representative fossils from the Scots Bay Member of the McCoy Brook Formation at its type area: **A**, *Eubrontes* (*Anchisauripus*) *tuberosus*; **B**, *Semionotus* sp.; **C**, hydrobiid gastropods (courtesy Steve Good); **D**, plant fragments; **E**, domal stromatolites; **F**, silicified stromatolites surrounding a branch or truck.

cyclical red, gray, and black clastic rocks, unique within the Fundy section, that contain the palynological Triassic-Jurassic boundary (Fowell and Traverse, 1995), apparently globally correlative isotopic anomalies (to be discussed on site), and a modest Ir anomaly (Tanner and Kyte, 2004).

The thoeliitic North Mountain Basalt (Stops 1, 2, 4) consists of a series of high-Titanium quartz-normitive basalt flows that lack significant sedimentary interbeds. It is the source of both U-Pb and $^{40}Ar/^{39}Ar$ ages that provide the most direct and precise dates available for the initial flood basalts of the CAMP, as well as a date for the palynological Triassic-Jurassic boundary.

Much of the McCoy Brook Formation consists of red beds resembling the Whitewater member of the Blomidon Formation. Both units have abundant sand patch cycles, and were long confused with each other (e.g. Powers, 1916), but other facies are present as well. The basal beds of the formation consist of a distinctive and apparently basin-wide suite of carbonate-rich lacustrine units that are generally in direct contact with the underlying North Mountain Basalt (Stop 4). These beds are termed the Scots Bay Member for the outcrops along the south shore of Scots Bay (Tanner, 1996). Overlying strata have abundant sand-rich fluvial and deltaic intervals as well as gypsiferous sand patch cycles (Stop 1).

Fossils are abundant in the Scots Bay Member and in much of the overlying red strata (Fig. 7). Typical Newarkian Jurassic palynomorphs and sparse macrofossil plant remains occur in the Scots Bay Member (Cameron 1986; Bujak, quoted in Olsen et al., 1987), along with varied stromatolites, some silicified around tree branches and trunks (de Wet et al., 2002; Whiteside, 2004; Whiteside et al., 2003, Whiteside and Olsen, 2005) and the green "algae" *Chara* (de Wet and Hubert, 1989). An unusual dwarf assemblage of mollusks is present along with ostracodes (Good et al., 1994; Hassan, 1999; Hassan and Cameron, 1998). Vertebrates include articulated and disarticulated remains of the holostean *Semionotus*, occasional tetrapod remains (c.f., *Clevosaurus*; Cameron, 1986), and dinosaur footprints.

Locally along the Minas fault zone, strata of TS IV were profoundly affected by syndepositional faulting. A series of micro-basins tens to hundreds of meters long filled with unusual and richly fossiliferous syn-tectonic strata that produce among the oldest if not *the* oldest Jurassic dinosaurs in the world. This is best seen at the Wasson Bluff special area (Stops 3 and 4). Based on cyclostratigraphy, the Wasson Bluff assemblage is within 100 ky of the Triassic-Jurassic boundary, and nearly all the major facies, from eolian to lacustrine (Stop 4), yield vertebrate remains.

In summary, the strata of the Fundy basin record in great detail the earliest Jurassic faunas. They provide evidence that by the first 100 ky of the earliest Jurassic, all typical Triassic taxa were replaced by a terrestrial regime that would last 137 million years and with modification, extend to the present.

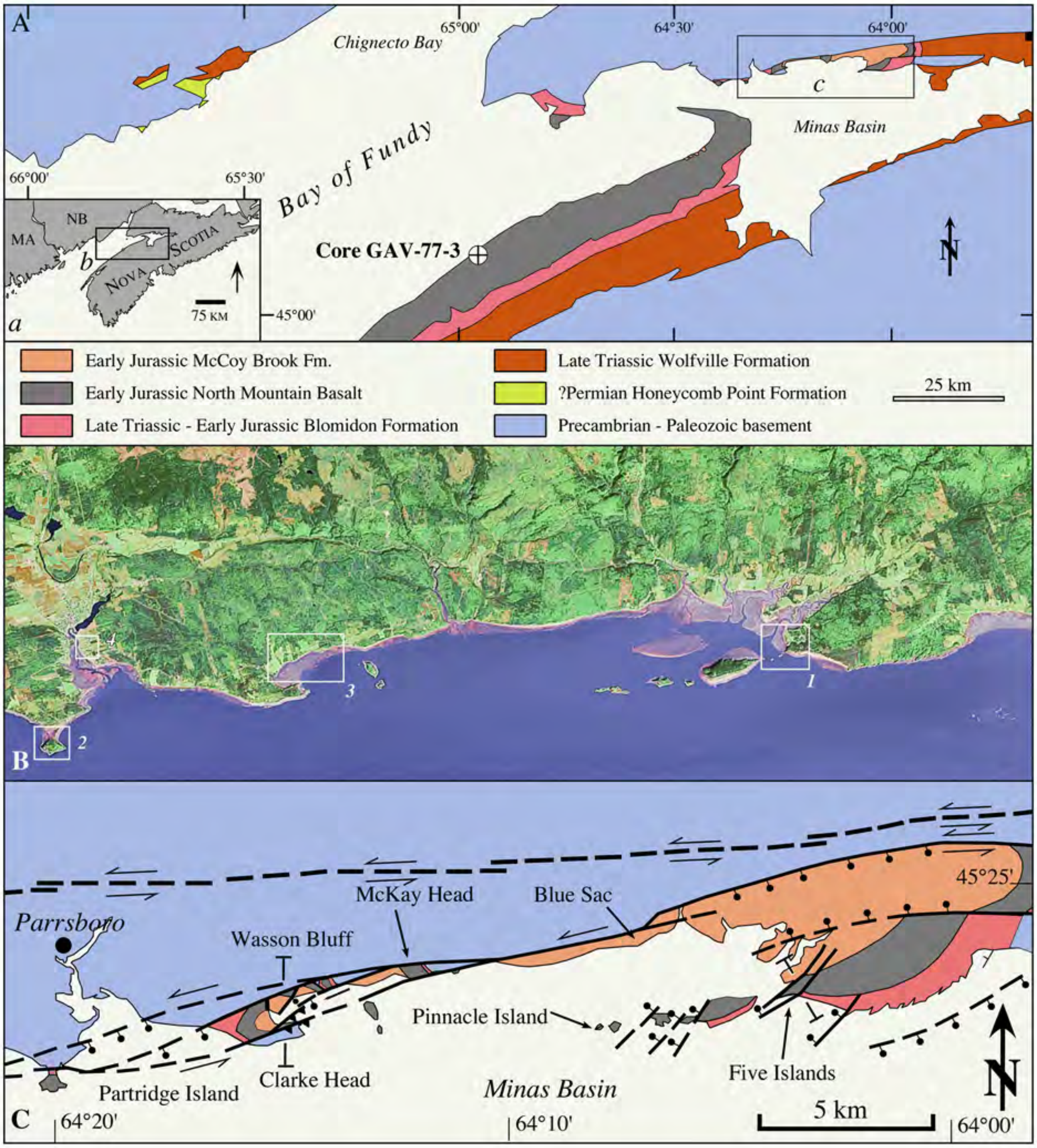


Figure 8. Map of Field trip area. A, Location map showing basic geology of the Fundy basin in the region of the field stops: a, parts of the Maritimes, Canada, and Maine, USA; b, location of geological map; c, inset showing location of areal photograph (B) and detailed geological map of the field trip area (C) (adapted from Kent and Olsen, 2000). B, Satellite photograph of field area with field stops shown as white boxes 1 – 4 (2005 GlobeXplorer). C, Detailed geological map of field area showing areas discussed in text and positions of cross sections shown in Figure 9 (Five Islands) and Figure 21 (Wasson Bluff to Clarke Head) (adapted from Withjack et al., 1995). Key to rock units in (A).

FIELD TRIP STOPS

This field trip will concentrate on outcrops on the north shore of the Minas physiographic basin (Fig. 8), in sections producing the most diverse data.We will begin our field trip in Halifax, traveling northeast across the Meguma terrane into the Carboniferous and then enter the Triassic-Jurassic Fundy basin at Truro. We then turn east towards Parrsboro.

Our stops are organized to take advantage of the tides. Stop 1 (Five Islands) and Stop 3 (Wasson Bluff) are tide dependent. Stop 2 and Stop 3 involve hour-long walks. Fieldtrip participants should have foot-gear that can get wet and should be prepared for chilly weather in the event of cloudy, rainy, or windy conditions. Hard hats are required for Stop 3.

STOP 1: Five Islands Provincial Park: Norian to Hettangian

Units: Blomidon Formation, North Mountain Basalt, McCoy Brook Formation

Main Points: Spectacular overview of Triassic-Jurassic transition; Structurally condensed section; CAMP basalts; Jurassic McCoy Brook faunal elements

Enter Five Islands Provincial Park from the main entrance and proceed to the beach parking area. Walk down to the beach and continue southeast along the cliffs to the basalt peninsula of Old Wife Point. Climb up onto the peninsula itself; facing the cliffs from the Old Wife, we have a great view of one of the most spectacular outcrops of Triassic-Jurassic strata in eastern North America (Fig. 9). The section is unique in having a structurally shortened transect across the Triassic-Jurassic transition with thick sections of the Triassic-Jurassic Blomidon Formation and Jurassic North Mountain Basalt and McCoy Brook Formation beautifully displayed. Because of time constraints, our visit to this locality will concentrate on the North Mountain Basalt and the McCoy Brook Formation. Our dialogue will begin at Old Wife point and we will discuss our observations at a series of stations from southeast to northwest as we walk back towards the parking area.

<u>Station 1, Old Wife Point looking east:</u> To the distant east you can see a point of brown rock jutting out to the south. This is an outcrop of the Red Head member of the lower Blomidon Formation. The strata consist of about 33 m of eolian dune sands (Fig. 10) and several meters of interbedded fluvial sandstone and pebbly sandstone and conglomerate, as described by Hubert and Mertz (1980, 1984). Although these strata were originally thought to be part of the Wolfville Formation, mostly because they were coarse grained (Klein, 1962), they are interbedded with facies typical of the lacustrine portions of the Blomidon Formation, relationships that can best be seen further to the east at Lower Economy (Fig. 10). At the latter locality, the Red Head beds overly the Wolfville Formation with a profound angular unconformity, a relationship we will discuss at Station 4.5. According to Hubert and Mertz (1984), the eolian strata were deposited as barchan-type dunes by winds bowing to the southwest (254º) winds. The direction of these winds is consistent with the Northeast Trade Winds and a location near the Tropic of Cancer in Triassic time (Fig. 2).

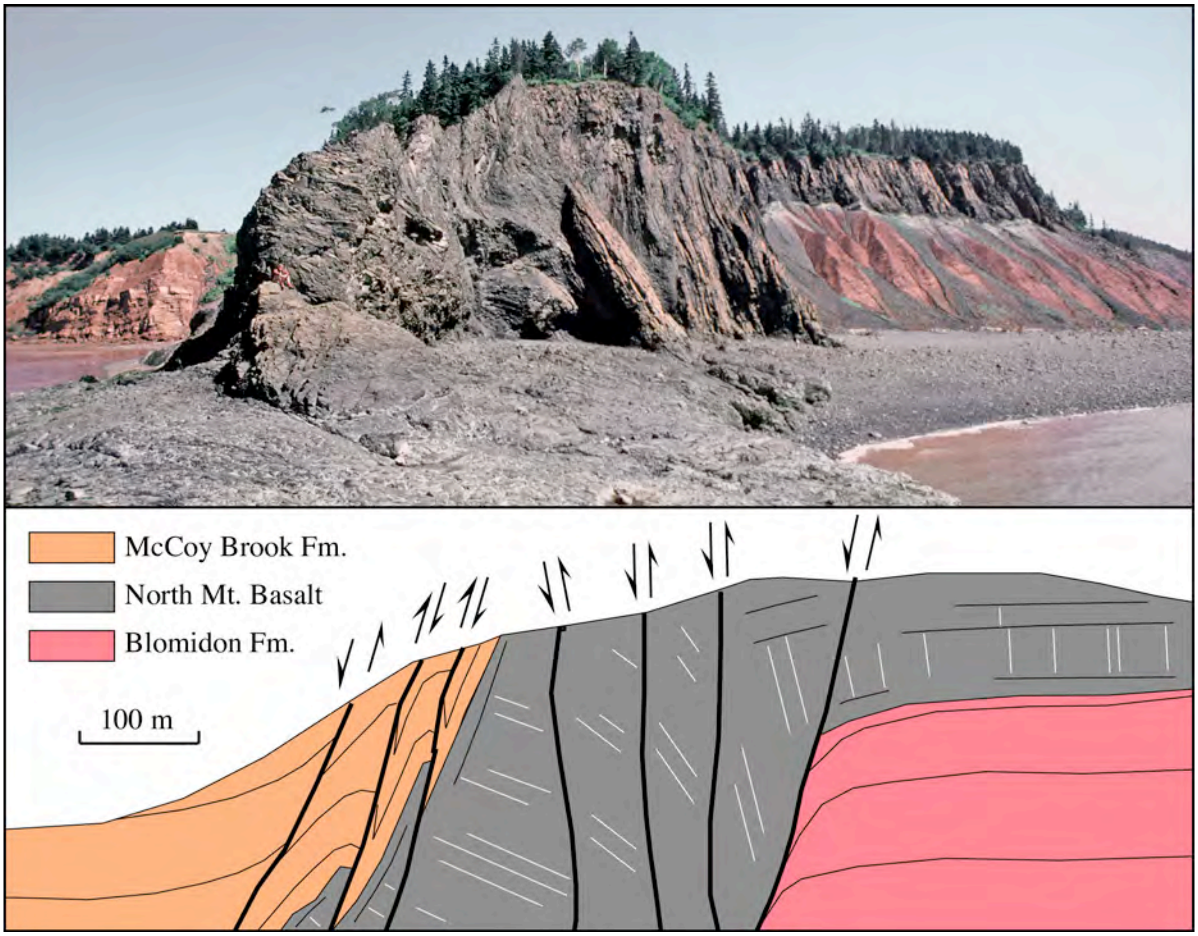


Figure 9. View from Station 1, Stop 1: above, wide-angle view to the NE from just NE of the Old Wife showing Blomidon Formation conformably overlain by North Mountain Basalt on the right, down faulted North Mountain Basalt straight ahead; and down faulted and reverse faulted McCoy Brook Formation on left. Below, interpretative cross-section (from Withjack et al., 1995).

A southwest striking, northwest dipping fault separates the Red Head member from the middle Whitewater member of the Blomidon Formation (Fig. 8). Strata immediately to the west of the fault are comprised of a distinctive suite of deformed, mostly lacustrine beds that correlate to the middle of the Blomidon Formation to the southwest at Cape Blomidon and the GAV-77-3 core (Fig. 4). There are two fish-, conchostracan-, and ostracode-bearing Van Houten cycles present, the upper cycle has a "division two"(highstand) that is distinctly laminated with purple, yellow, and green bands. This upper laminite is brecciated downward to contorted sands and siltstones, and overlain by a granule-bearing conformable sandstone bed. Strata below the lower fossiliferous laminite are deformed by numerous bed-specific normal faults of various sizes. This deformation is not local, as it is seen in the same stratigraphic interval at several locations across the Minas basin at Cape Blomidon (Olsen et al., 1989; Ackermann et al., 1995). The deformation of this interval was interpreted by Olsen et al. (1989) and Ackermann et al. (1995) as a result of salt (halite) dissolution, but by Tanner (2003) as due to a strong synsedimentary seismic event, namely the impact of the bolide that produced the Manicouagan structure. We believe that a seismic event was not responsible because the structures and the internal stratigraphy require multiple dissolution and deposition events and a downward, not upward motion of material. In addition, based on magnetic polarity stratigraphy of the GAV-77-3 core, these strata lie within the E17r reverse polarity magnetic chron of the Newark basin time scale (Kent and Olsen, 2000) while Manicouagan is of normal polarity (Fig. 11). Furthermore, the age of the strata is 210 Ma, significantly younger than the newer 214±1 Ma date for the impact structure (Hodych and Dunning, 1992).

Figure 10. Red Head member of the Blomidon Formation: left, eolian strata just east of fault separating the Whitewater member from the Red Head member, at Red Head; right, lacustrine strata typical of Whitewater member interbedded with eolian and fluvial strata of Red Head Member at Lower Economy.

The polarity stratigraphy of the Blomidon Formation (Fig. 4) (Olsen and Kent, 2000) shows that by this time (latest Norian, late Sevetian) the typical Germanic, Knollenmergel type *Plateosaurus* type faunal assemblages were dominant in the high northern latitudes as seen in Greenland (Kent and Clemennson, 1996; Jenkins et al., 1994). (Fig. 11) In contrast, no prosauropods are known from the Triassic anywhere in North America; the previously reported remains consist of non-diagnostic or misidentified material. Several other groups prevalent in this Germanic-type faunal assemblage are also unknown from age equivalent strata in North America, notably the plagiosaurid amphibians that are common in the high latitudes up to the Triassic-Jurassic boundary. This high resolution stratigraphy suggests these faunal provinces are real and not an artifact of miscorrelation.

The rest of the Whitewater member at these outcrops is comprised of vertically varying Van Houten cycles of the sand patch variety. Some of the cycles are especially well developed. The majority of the section is of Rhaetian age. Hundreds of mostly small-displacement normal faults subtly cut the section, and at least one large northwest dipping fault cuts out enough section to prevent us from measuring a complete section from the basalt through the salt dissolution structures.

At the top of the Blomidon Formation the sand patch cycles become indistinct and increasingly mud-rich followed by a transition upward to white weathering mudstones within a few meters of the North Mountain Basalt. The upper beds of this interval have produced blackened grains of *Corollina* pollen, and elsewhere the uppermost Blomidon typically has grey and black palynomorph-bearing mudstones that often weather white. This is the Partridge Island member (Stop 3). However, at this locality the thickness of the

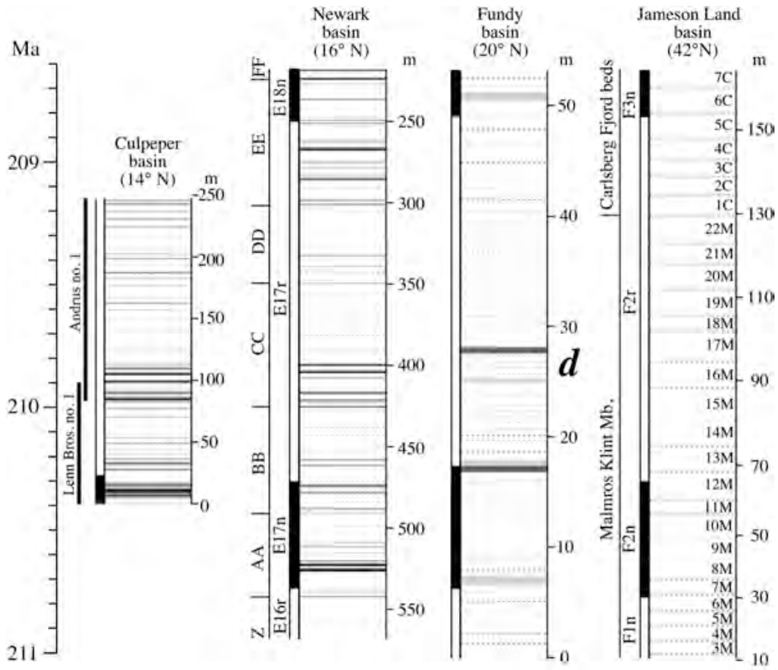


Figure 11. Correlation of sections of the Culpeper, Newark, Fundy, and Jamesonland (Greenland) basins (modified from Kent and Olsen (2000). E16r-E18n are magnetic polarity zones from the Newark basin GPTS (Fig. 4). See Figure 4 for rock color. ***d***, shows position large scale dissolution features in outcrop described by Ackermann et al. (1995).

Partridge Island member is clearly enhanced by metamorphism from the overlying North Mountain Basalt, a pattern seen in several other areas including Grand Manan Island (P.E.O., pers. obs.). Based on the occurrence of the palynological transition at Partridge Island and the lateral continuity of the member, the Triassic-Jurassic boundary almost certainly lies within the upper meter of the white layer.

Neither the stratigraphy of the Partridge Island member nor the visible manifestation of the metamorphism measurably change laterally here. The apparent lateral changes in thickness of the white layer and its occasional apparent disappearance are actually the result of the numerous small faults, some of which strike parallel to the face of the cliff. A less metamorphosed section of the Partridge Island member can be seen nearby on Pinnacle Island to the southwest, where typical black and gray mudstones are interbedded with red mudstones and gray sandstone within a meter of the North Mountain Basalt contact.

Along the top of the cliff is the lower part of the massive lower flow of the North Mountain Basalt. The entablature of the flow has a thickly splintery fracture, not a hexagonal columnar jointing. This style of jointing persists along the entire length of outcrop of this flow.

<u>Station 2, Old Wife Point looking north and south:</u> The complex structure of this section of outcrops is described and interpreted in detail by Withjack et al. (1995). Looking to the northeast, the lower flow of the North Mountain Basalt is truncated by a series of high-angle faults that drop the section down to the west. With each more western fault, the splintery basalt columns are rotated progressively counter clockwise (Fig. 9). Further to the northwest and along strike of the low-tide peninsula that supports the sea stack known as the Old Wife, a succession of high angle faults and basalt rubble zones are present between the faults and rubble zones are bands of horizontal hexagonal columns. Like all the surfaces of the individual clasts in the basalt rubble zones, which are monomict, all surfaces of the columns are slikensided. This zone of horizontal columns was originally interpreted as a dike that fed the North Mountain Basalt (Powers, 1916; Stevens, 1987). Olsen et al. (1989) and Withjack

et al. (1995), however, argue that this zone is simply a rotated zone of the middle part of the North Mountain Basalt, the thinner flows of which commonly have columnar jointing. The rotation follows the pattern seen in the less deformed, lower flow of the North Mountain Basalt to the east. There is no evidence of metamorphism in the surrounding basalt, and there is a complete lack of intrusive apophyses into the surrounding basalt or sediment, as seen in undoubted dikes intruding or feeding basalt flows (e.g., Philpotts and Martello, 1986; Olsen et al, 2003). All the contacts are instead brittle faults with slikensides.

Further to the west are fault slices of vesicular to massive and columnar basalt that appear to be parts of the upper flows of the basalt. Bedding generally is steep to the northwest, but shallows progressively in more westerly fault slices.

Looking to the southwest we see the Old Wife sea stack of tectonically brecciated North Mountain Basalt. Note the presence of numerous small fault planes and slickensides on all clasts.

Station 3, Contact with the McCoy Brook Formation: Proceed northwest onto the beach and walk along the beach contact with the North Mountain Basalt. All along this contact, depending on the tide and sand movements, we will be able to see steeply dipping and sheared red beds of the McCoy Brook Formation in contact with mostly polymict breccia of the North Mountain Basalt, often with red matrix. Outcrops on the tidal flat have rapidly shallowing dips away from the basalt.

The contact between the McCoy Brook Formation and North Mountain Basalt on the shoreline is partly sheared (Fig. 9). At the contact he McCoy Brook Formation contains polymict cobbles and pebbles of North Mountain Basalt. The northwest steeply dipping red bed section is sheared and the sense of motion is down to the northwest. The McCoy Brook Formation is in fault contact with North Mountain Basalt again on the west. Because the fault is vertical or dipping to the northwest there is older (North Mountain Basalt) over younger (McCoy Brook Formation) and the fault thus has apparent reverse throw. Careful examination of the steep western slope of the North Mountain Basalt reveals several other similar faults and contacts with apparent reverse motion. The most westerly block of basalt is overlain by steeply dipping McCoy Brook Formation red beds, which are again sheared. But they are intact enough to reveal that the contact with the North Mountain Basalt is gradational passing from vesicular basalt upward into a polymict basalt breccia, a polymict cobble conglomerate and finally a red siltstone with basalt clasts. The contact therefore seems a normal sedimentary one, albeit somewhat sheared.

Examination of the fault surfaces reveals at least two sets of slikenlines. One set is oriented essentially parallel to dip, another is clearly strike slip, in some cases nearly horizontal. In some cases the strike slip slikenlines seem superimposed on the dip-slip slikenlines but this relationship is far from unambiguous.

The northwestern block of basalt has some very interesting internal contacts. There are at least two internal flow contacts with chilled margins that have nearly horizontal dips. The upper one has lovely pipe vesicles stained with malachite. However, these flows pass seamlessly both laterally and vertically into breccia and the bedding attitude of the flows seems irreconcilable with the contact with the McCoy Brook Formation.

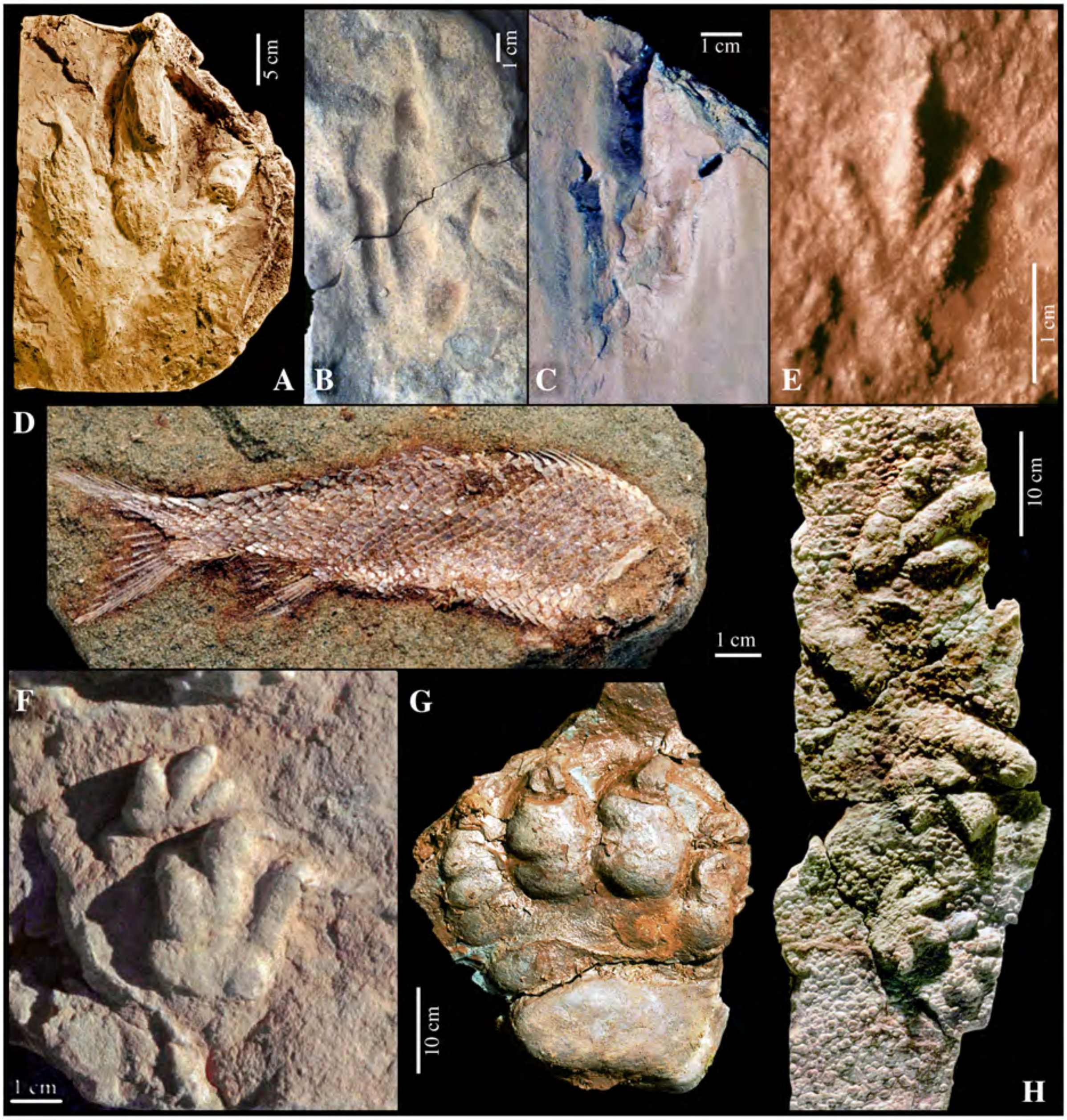


Figure 12. Representative vertebrate fossils from the McCoy Brook Formation of Five Islands (A-D), and Blue Sac and McKay Head (E-G): **A**, *Eubrontes* cf. *giganteus*, plaster cast of original, not collected; **B**, *Eubrontes* (*Anchisauripus*) cf. *hitchcocki* (FMG specimen); **C**, *Eubrontes* (*Grallator*) cf. *cursorius*; **D**, *Semionotus* sp. (photo by Heinz Wiele); **E**, cf. *Eubrontes* (*Grallator)* sp., (Princeton, YPM collection); **F**, *Batrachopus deweyii*, Eldon George collection; **G**, *Otozoum* cf. *moodii* (FMG 998 GF53); **H**, *Anomoepus scambus* (FMG-994-GF).

As we look further to the northwest along the cliff face, the bedding attitudes of the McCoy Brook Formation shallow dramatically and the shearing disappears. A steep cliff face of relatively undisturbed McCoy Brook Formation then continues to the northwest.

There are no indications of the Scots Bay Member at the contact here, however, nearby, P.E.O. has observed typical purple limestones and green sandstones in contact with the upper surface of the North Mountain Basalt on Long Island to the southwest.

In summary of tectonic inferences from Stations 1-3, the large-scale sense of motion from looking east to west from Station 1 is clearly down to the northwest consistent with the sense of rotation of bedding and fractures, as well NW-SE early Mesozoic extension. However, at the smaller scale there are reverse faults that indicate later shortening along the same fault zones. This is some of the primary evidence for post earliest Jurassic tectonic inversion in the Fundy basin (e.g., Withjack et al., 1995; Schlische et al., 2003). In addition, there is evidence of some syn-basalt tectonism, which consists of the discrepant bedding attitudes of the basalt flows seen at this station (3). One way to account for these bedding attitudes is that the flows were rotated prior to the deposition of the overlying McCoy Brook Formation, impling syn-extrusive faulting. As there is very strong evidence for syndepositional faulting effecting McCoy Brook sedimentation at Wasson Bluff (Stop 3), syn-basalt faulting at this location would not be surprising. This is also consistent with the apparent lack of the Scots Bay Member here and its widespread presence elsewhere including on the adjacent islands. It may not have been locally deposited because this portion of the North Mountain Basalt may have remained above the level of the lakes that deposited the Scots Bay Member.

<u>Station 4, Cliffs and beach outcrops of the McCoy Brook Formation:</u> Proceed northwest, along the long cliff outcrops of the shallow-dipping McCoy Brook Formation. We will stop at 5 spots along the outcrop, derived from Olsen et al. (1989).

Station 4.1: Large-scale channel and delta sequence. This section has thin-bedded mudstones and sandstones succeeded upward by a large sandstone complex part of which has downward tapering tilted surfaces compatible with small delta forests. Centimetre- to decimetre-scale beds high in the sequence have dinosaur footprints, and were the source of the very first found by P.E.O. in fallen blocks in the 1970's.

Station 4.2: Location of common rock falls from fish-bearing thin-bedded sandstone and mudstone in cliff. Fish-bearing unit consists of a climbing-ripple cross-laminated or convolute-bedded sandstone overlying a laminated, purple-red claystone. Complete *Semionotus* sp. (Fig. 12) occur densely packed at the top of the clay and in the base of the sandstone. The underlying claystone also has some partial to complete fish and coprolites. The fish-bearing sandstone represents a single sedimentation event that entombed the dead fish after a mass kill. All of the fish have the same type of dorsal ridge scales, the same type of granular ornamentation around the nape region, and the same proportions. Several distinct size classes of fish are present, however, and these probably represent different year-classes. This assemblage shows the kind of individual variation we can expect in a single species of *Semionotus* and it stands in dramatic distinction to the huge amount of apparently intra-specific variation seen in the species flocks of semionotids in the Towaco Formation of the Newark basin (e.g., McCune, 1996). This example shows that these fish had about the same amount of variation within a population of one species that one might expect from a modern lacustrine teleost population.

Station 4.3: Thin- to thick-bedded, climbing-ripple cross-laminated sandstone alternating with red fine mudstone and claystone with widely-spaced desiccation cracks and reptile footprints. The structural analysis of Liew (1976) and these footprints provided some of the first evidence of the Jurassic age of these strata (Olsen and Schlishe, 1990). Ichnotaxa identified, using the nomenclature of Rainforth (2005) so far include the brontozoids (grallatorids of older literature=theropod dinosaur tracks) *Eubrontes* cf. *E. giganteus*, *Eubrontes* (*Anchisauripus*) *E. parallelus*, *Eubrontes* (*Anchisauripus*) *E. sillimani*, *Eubrontes* (*Anchisauripus*) *E. hitchcocki*, *Eubrontes* (*Grallator*) sp., and the probable protosuchid crocodylomorph track *Batrachopus* sp. (Fig. 12). One of the most interesting aspects of this assemblage is the presence of *Eubrontes* cf. *giganteus*. While *Eubrontes giganteus* is one of the most common dinosaurian ichnites in the Jurassic of eastern North America, it is so far rare in the Fundy basin. It is found only at this site and at the top of the Scots Bay Member at Central Broad Cove near Ross Creek, Kings County. It is so far absent from the well-preserved and prolific track assemblages from McKay Head and Blue Sac, Cumberland County, which are geographically close. The latter have abundant small brontozoids, and more importantly abundant *Anomoepus* (ornithischians) and *Otozoum* (prosauropods) (Fig. 12). *Otozoum*, surprisingly abundant at Blue Sac and McKay Head, has never been found within the same strata as *Eubrontes giganteus*, suggesting some habitat separation.

Station 4.4: Channel-fill and lacustrine sandstones with fish bone- and coprolite-bearing intraformational conglomerate at base. The intraformational conglomerate is apparently the lateral equivalent of or derived from the fish-bearing, thin-bedded sandstone exposed in the cliff face to the east. The only identifiable remains consist of scales and a ceratohyal of a large *Semionotus* sp.

Station 4.5: Poorly-exposed lacustrine strata of McCoy Brook Formation, with sand-patch cycles and gypsum nodules. Units resemble the Blomidon Formation, which they were previously confused with (e.g., Powers, 1916; Klein, 1962).

Turning around and looking southwest towards the islands it is clear that at this stratigraphic level we are quite high in the McCoy Brook Formation. The fault block we are standing on is in structural and stratigraphic continuity with the dip slope of the islands, particularly Moose Island, rather than the basalt ridge and Old Wife Point to the southeast. Assuming a rough estimate of 10° average dip gives us a stratigraphic distance of about 120 m from Station 4.5 to the top of the North Mountain Basalt, which may be stratigraphically higher than any of the other outcrops in the basin.

Figure 13. View at low tide on the south side of Pinnacle Island looking north. In the foreground are east-dipping sandstones and conglomerates of the Wolfville Formation. In the background are north-dipping Red Head member sandstones of the Blomidon Formation, Between and to the right are the basal-most Red Head beds resting with a profound angular unconformity upon the Wolfville Formation.

The next to the last island to the west is Pinnacle Island. On the south side of the island is a truncated and coarse-grained Blomidon Formation with the aforementioned red, gray, and black Partridge Island member. The Whitewater Member seems unusually coarse and thin here, although part of this thinning may be apparent because several faults are present. The Red Head member is also thin and seems to lack obvious eolian strata. However, the base of the member, and base of the Blomidon Formation, is well exposed in the tidal flat and accessible at low tide and rests with a profound unconformity upon Wolfville Formation sandstones and gravels. The basal Blomidon strikes about 270° to 300° and dips about 35°to 40° N, while the Wolfville Formation strikes about 340° to 360° and dips about 20°E (Fig. 13). This is probably the best area to see the TS II – TS III unconformity in the Fundy basin. The high degree of discordance implies a long hiatus in this area, which is in agreement with the 14 m.y. gap inferred from the combined bio- and magnetostratigraphic correlation of the Fundy section to the Newark basin time scale (Fig. 4). Return to vehicles.

STOP 2: Partridge Island: Rhaetian to Hettangian

Units: Upper Blomidon Formation, North Mountain Basalt

Main Points: Excellent and accessible outcrop of the Triassic-Jurassic boundary; pollen and spore extinction level; carbon isotopic and iridium anomalies

Park along the gravel spit connecting Partridge Island with the mainland and proceed to the west face of the "island". On the west side of the island is an excellent outcrop of the uppermost Blomidon Formation and lower half of the North Mountain Basalt (Fig. 14). It is a relatively easy climb up to the contact, which is highly recommended.

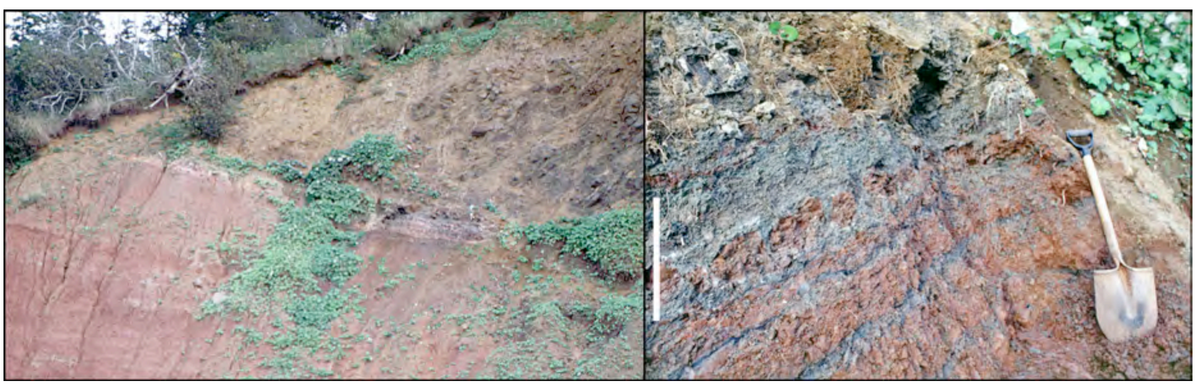


Figure 14. Triassic-Jurassic section at Partridge Island: left, view looking east towards cliff face with North Mountain Basalt above, the white-weathering bands of gray and black mudstone interbedded with red mudstone of the Partridge Island member of the Blomidon Formation, below and the underlying Whitewater member of the Blomidon Formation; right, close up of boundary section in the Partridge Island member – the contact with the North Mountain Basalt is at the upper left corner and the palynological Triassic-Jurassic boundary is within the span of the white bar (note gray-in-red mudcracks at lower part of white bar).

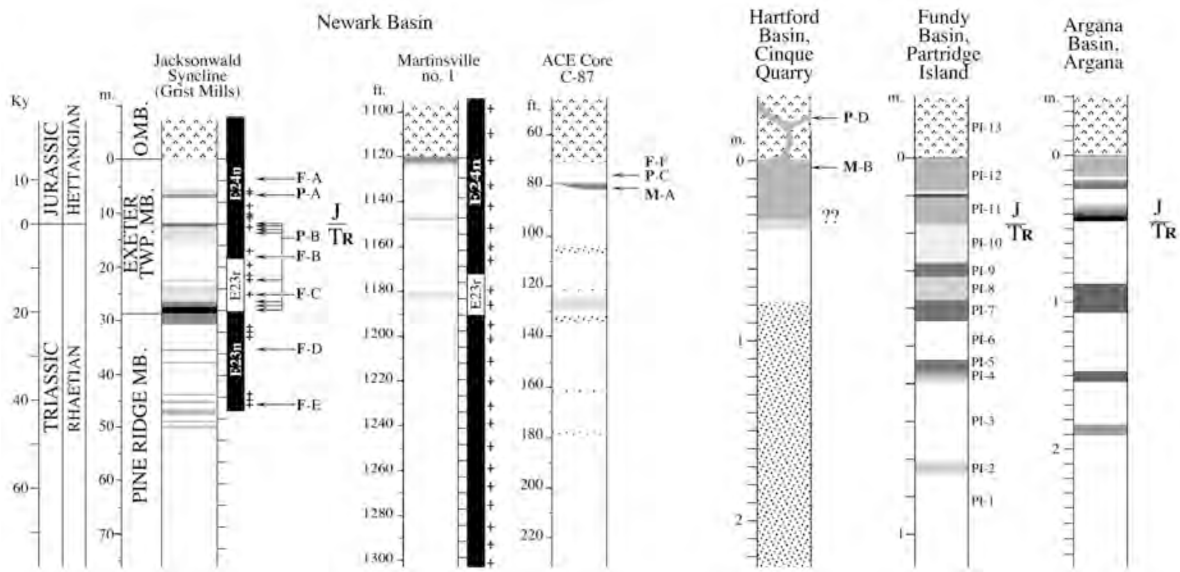


Figure 15. Comparison between Newark, Hartford, Fundy, and Argana basin boundaries (from Olsen et al., 2002b). Abbreviations: **F-**A, brontozooids only; **F-**B, *Batrachopus* cf. *B. deweyii*, *Rhynchosauroides*, and small brontozooids; **F-**C, last appearence new taxon B and *Brachychirotherium* and cf. *Apatopus*, also with *Rhynchosauroides* and small brontozooids; **F-**D, *Brachychirotherium*, new taxon B, *Batrachopus*, and small brontozooids; **F-**E, abundant *Brachychirotherium*, new taxon B, *Batrachopus*, and small to medium sized brontozooids; **F-**F, small to large brontozooids, including lowest occurrence of *Eubrontes giganteus*, also with *Batrachopus deweyii*, and *Rhynchosauroides*; **P-**A, lowest definitive Jurassic-type palynomorphs assemblage; **P-**B, palynomorph assemblages of Triassic aspect (lower) or dominated by spores (upper); **P-**C, palynomorph assemblage with *Corollina* only; **P-**D, palynomorph assemblage with *Corollina* only in matrix between basalt pillow; **M-**A, macrofossil plant assemblage dominated by *Brachyphyllum* and *Clathropteris*; **M-**B, macrofossil plant assemblage dominated by *Brachyphyllum*. *bg,* indicates position of "blue-gray sandstone" marker.

The lower 15 or meters of section at Partridge Island consists primarily of red mudstone. Sand patch cycles are not at all obvious. The upper 1.5 m of the section below the North Mountain Basalt consists of the red, purple, gray, and black thin beds that comprise the Partridge Island member. When not metamorphosed, this member is highly palyniferous, as it is here at the type locality of the informal member.

The Partridge Island section was first described by Fowell and Traverse (1995) who showed that the last appearances of a number of typical Triassic taxa occur in the uppermost 20 cm of the Blomidon. According to Fowell and Traverse (1995), the well-preserved palynofloras are dominated by the genus *Corollina.* The less common elements in the uppermost assemblages include species that are also present in earliest Jurassic assemblages from the Hartford basin. Palynomorph assemblages 30 cm downsection from the basalt contain rare specimens of the Late Triassic index species *Patinasporites densus* and a series of monosulcate grains shared with late Rhaetian assemblages from the Newark basin. Their analysis indicates that the Triassic-Jurassic boundary is within the uppermost few tens of centimetres of the Partridge Island member (Fig. 15).

A problem with this section, and indeed all low accumulation rate boundary sections in the Fundy basin and in Morocco (c.f., Olsen et al., 2003; Marzoli et al., 2004) is that there are often subtle low angle thrust and normal faults that distort the section in ways often very difficult to discern. Coupled with depositional lateral variations, including mud cracks (see Fig. 14), repeated attempts at measuring and sampling the same section are uncomfortably discrepant. Such repeated measurements provide an object lesson in stratigraphic precision, and strongly suggest analytical measurements should be done on the same samples collected in one sampling effort to assure registry among the data sets. One such section (by P.E.O.) was reanalyzed by Fowell (in Olsen et al., 2005) (Fig. 16) revealing the same basic pattern reported by Fowell and Traverse (1995), but with slightly different unit thicknesses.

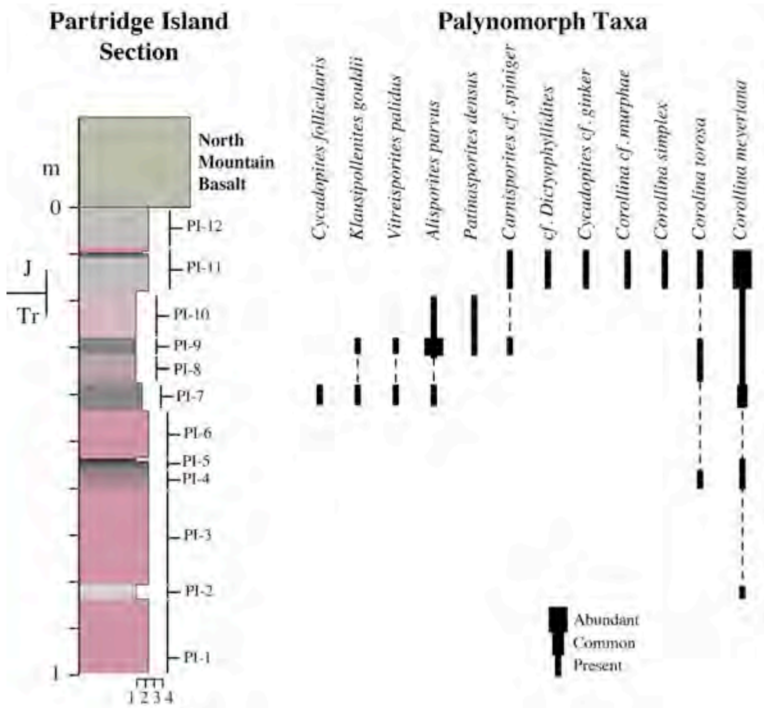


Figure 16. Boundary section from Paddy Island with pollen and spore data from Fowell (in Whiteside et al., 2005). These assemblages were recovered from channel samples that span the entire thickness of the sampled unit and therefore the boundary could be anywhere from the base of PI-10 to the top of PI-11, depending on which unit yielded the palynomorphs. Tanner and Kyte (2004) report an Ir anomaly from about 30 cm below the basalt.

There are several ways to estimate the accumulation rate at this section. One way is to use the magnetic reversal stratigraphy in the GAV-77-3 core (Kent and Olsen, 2000). Correlating to the Newark basin astronomically calibrated GPTS) (Fig. 4), it is clear that the accumulation rate is slowing through the history of the Blomidon Formation. Fitting an exponential curve to the all of the data, the best fit (Fig. 17) predicts an accumulation rate of 1.65 m / 100 ky for the top of the Blomidon Formation. If we use only the first possible magnetic polarity tie point (correlative of middle of E22r) and the base of the basalt, we get 0.76 m /100 ky. In the Newark basin the Triassic-Jurassic boundary is estimated to occur between 1 and 2 Van Houten cycles (20 to 40 ky) below the base of the North Mountain Basalt. Based on these two estimates, the Triassic-Jurassic boundary should be between 33-66 cm to 15-30 cm below the boundary. The observed position of the boundary between 20 and 30 cm below the basalt is certainly in line with these estimates.

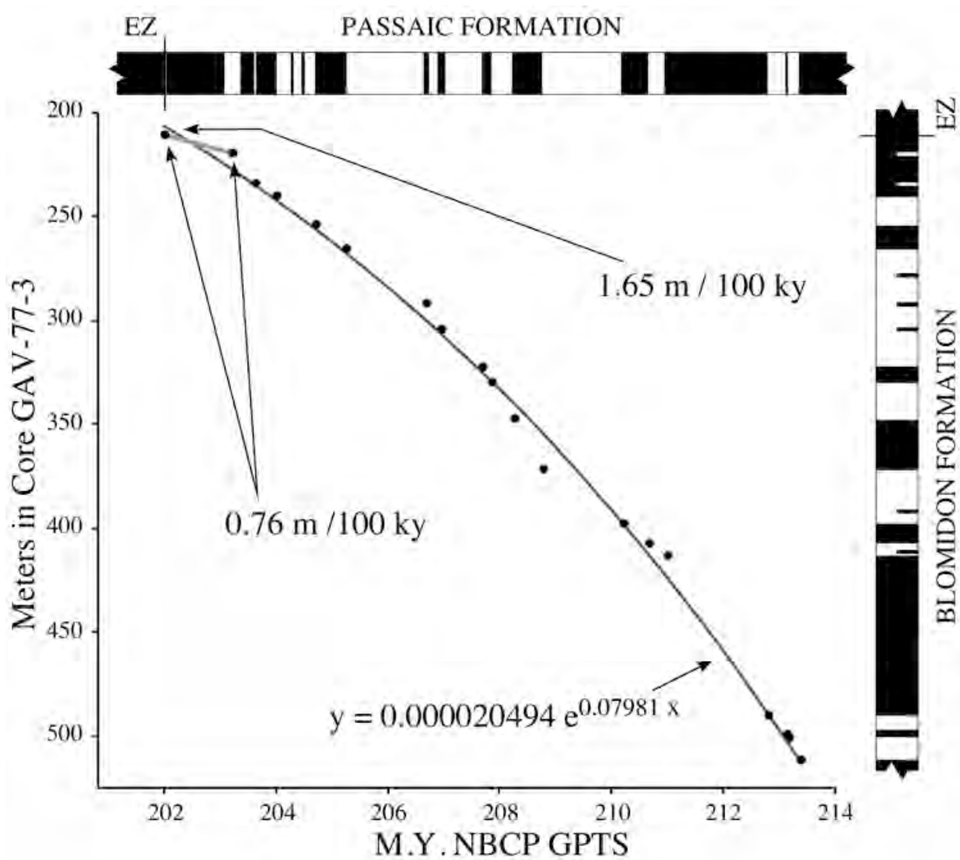


Figure 17. Correlation between Newark Basin Coring Project Astronomically Calibrated Geomagnetic Polarity Time Scale (Kent and Olsen, 1999) with the GAV-77-3 core of the Blomidon Formation and North Mountain Basalt (Kent and Olsen, 2000), and calibration of accumulation rates in the Fundy basin boundary section.

Another way to estimate the accumulation rate is to correlate the cyclostratigraphy of Partridge Island member and the Newark basin independent of the magnetostratigraphy. Assuming that the Partridge Island member correlates overall to the Exeter Member of the Newark basin section, there is a fairly good match between the individual Van Houten cycles (Fig. 15). Thus estimated, the accumulation rate is between 20 to 35 cm per 20 ky cycle. An estimate of 20 cm / 20 ky was derived this way by Olsen et al. (2002b).

Thus, independent, non-biostratigrahic, estimates of accumulation rate suggest that the palynological extinction level and boundary cyclostratigraphies in the Newark and Fundy basins are correlative. This is important because there are a variety of other possible proxies of environmental change that are shared between the two basin sections across the boundary that will be discussed at the outcrop.

Repeated sampling has resulted in an emerging picture of correlated environmental changes. First, the palynological transition in the Fundy basin is marked by an Ir anomaly of up to about 300 ppt (Tanner and Kyte, 2004; pers comm.). An Ir peak of the same magnitude is also seen in the Newark basin section exactly at the palynological transition (Olsen et al., 2003a; Whiteside et al., 2003). There are also new exciting carbon isotopic data that will discussed on the outcrop. Given the consilience of the accumulation rate and cyclostratigraphic information, and the parallel palynological, Ir and other chemostratigraphic data, a regional if not a global set of processes are plausibly responsible. The details of these observations will be presented with data in the field.

Another boundary section showing different but related phenomena is at Central Clarence, Nova Scotia, within the Partridge Island Member. This is the only macrofossil plant locality in the Blomidon Formation, and the identifiable floral assemblage consists entirely of the fern *Cladophebis* (Baird in Carroll, 1972). A potential Ir anomaly is associated with this section (Orth in Mossman, 1998). Although the contact with the North Mountain Basalt is covered, the fern horizon and Ir peak and may represent another example of a "fern spike" similar to that seen in the Newark basin (Olsen et al., 2002a,b).

The Central Clarence section is much coarser than at the Partridge Island section. This is part of a general trend within the Partridge Island member along strike of the basin, from Partridge Island to Digby Gut. Facies and thicknesses within the Partridge Island member are basically similar from Partridge Island to Cape Blomidon to the GAV-77-3 core. But from there to the west, the member coarsens and thickens dramatically, so that at Digby Gut, it is a gray conglomerate. Since no conglomerate is present in the position of the Partridge Island member within the Cape Spencer or Chinampas wells or at Grand Manan Island, we presume that this indicates a source of coarse sediment to the south from the hinge margin, consistent with accelerated tilting just prior to the extrusion of the North Mountain Basalt.

Olsen et al. (1987, 1990, 2002a, 2002b) have argued that the available data are consistent with the impact of a bolide, in a scenario similar to that of the K-T boundary. Indeed the parallels are impressive: extinction level (Cornet, 1977; Fowell and Olsen, 1993; Fowell and Traverse, 1995), Ir anomaly (Olsen, 2002a; Tanner and Kyte, 2004), fern spike (Fowell et al, 1994), negative $\delta^{13}C$ excursion (Hesselbo et al., 2002; Ward et al., 2004), and CO_2 anomaly inferred from stomatal density changes (McElwain et al., 1999; Beerling and Berner, 2004). Shocked quartz has been reported as well (Bice et al., 1992), although not corroborated by the others. However, the temporally close CAMP basalt flows, analogous with the Deccan Traps of the Cretaceous-Tertiary boundary and the Siberian Traps of the Permo-Triassic boundaries, suggest another hypothesis.

In contrast with the bolide hypothesis, the currently popular argument is that the CAMP eruptions, a portion of which is the North Mountain Basalt, somehow triggered a catastrophic change in climate, perhaps to a super-greenhouse (McElwain et al, 1999), with the release of methane from clathrates (Hesselbo et al., 2002; Beerling and Berner, 2004), or fatally cold climes via sulfate aerosols (McHone and Puffer, 2003). In any case the correlation between flood basalts and extinctions appears compelling (c.f., Rampino and Stothers, 1988; Rampino and Haggerty, 1996; most Hames et al., 2003), and the Ir anomaly is easily matched by basaltic ashes (Schmitz and Asaro, 1996), but at least for the Triassic-Jurassic boundary, there is no compelling evidence of any basalt extrusion prior to or at the time of the extinctions of the associated negative $\delta^{13}C$ anomaly. All of the places in which the CAMP flows can be seen in the same section as the extinction level or earliest Jurassic strata, CAMP flows occur above – never below. However, recently Marzoli et al. (2004) and Knight et al. (2004) have argued that a significant fraction of the basalts in Morocco predate the boundary. The Fundy basin is particularly germane to these arguments because most of the Moroccan basins have stratigraphies and basalt geochemistries remarkably similar to the Fundy basin.

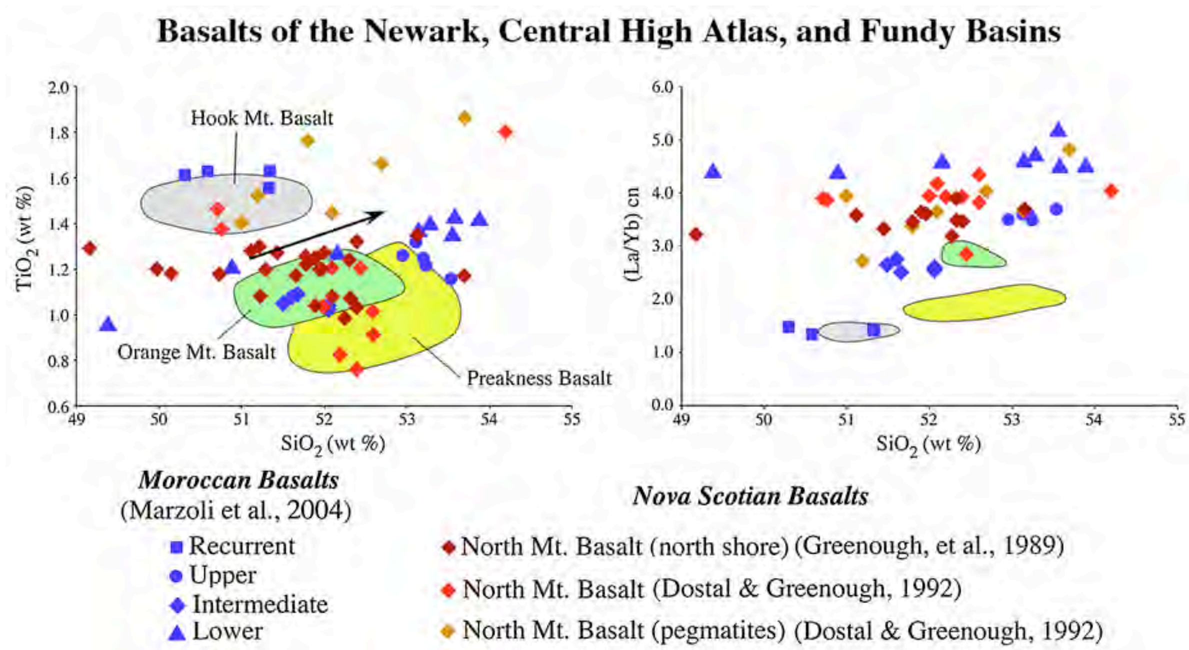


Figure 18. Aspects of the geochemistry of the Newark basin and Moroccan Basalts showing the similarity between the North Mountain Basalt (red, orange, and yellow) and the lower and intermediate basalts of Morocco (from Whiteside et al., 2005).

One set of data used by Marzoli et al. (2004) to support the existence of pre-boundary basalts is geochemical data from the basalts. Marzoli et al. (2004) and Knight et al. (2004) argue that that the lower basalt unit of the Central High Atlas Mountains (CHA) of Morroco has higher silica and chondrite normalized La/Yb (Boynton, 1984) ratios than any of the Newark and Hartford basin flows (Fig. 5). Marzoli et al. (2004) argue that because the Tr-J boundary is so close to the base of the Orange Mountain Basalt, the lower unit of the Central High Atlas sequence should predate the boundary. They argue that this reflects a temporal sequence of magmatic events that can be used to correlate laterally. However, the North Mountain basalt of the Fundy basin is much closer geographically to the High Atlas basin than it is to the Newark or Hartford basins, and thus it might be expected to be more geochemically similar to Moroccan basalts. Indeed this is the case. The silica content and chondrite normalized La/Yb cn ratios of the North Mountain Basalt overlap those of the CHA lower unit (Fig. 18; Whiteside et al., 2005). Based on their own geochemical methodology, the North Mountain Basalt correlates with at least the lower basalt unit of the CHA series. However, the extinction horizon is represented in the strata immediately below the North Mountain Basalt, in the Partridge Island member that is in obvious conflict with their hypothesis.

Whiteside et al. (2005) hypothesize that the high La/Yb cn ratios of the North Mountain and initial Central High Atlas basalt are a consequence of crustal contamination derived from long distance lateral transport from dikes emanating from then adjacent regions of the southeast United States and Senegal. This hypothesis is supported by magnetic anisotropy data of Ernst et al. (2003) and de Boer et al. (2003) who argue for long distance lateral transport of magma over 1000 km. We hypothesize that the Orange Mountain Basalt and its correlatives in the southeastern and northeastern United States are contemporaneous with the North Mountain Basalt of the Fundy basin and the lower and intermediate flows in the

Argana and Central High Atlas basins, and that the lower La/Yb cn ratios are a consequence of erupting closer to the source of the magma, which de Boer et al. (2003) suggest was in the Blake Plateau region.

Marzoli et al (2004) and Knight et al. (2004) also argue that they can find no Jurassic strata below the Moroccan basalts. However, all the sections they figure and describe are deformed at the contact. In all the cases we have examined, there is a unit virtually identical to the Partridge Island member below every basal basalt sequence (Olsen et al., 2002b; Whiteside et al., 2004). This relationship suggests a simple test of their hypothesis. The prediction of the Marzoli et al. (2004) and Knight et al. (2004) hypothesis is that the High Atlas basalts were extruded *during* the carbon cycle perturbation reflected in the initial negative δ^{13}C anomaly of Hesselbo et al., 2002) and precludes the presence of a negative δ^{13}C anomaly beneath the basalts. These specific and distinct predictions are directly testable by additional sampling and analysis that we will discuss on the outcrop. While we find the correlation between large igneous provinces and extinctions compelling, we find there is still no direct evidence of a temporal sequence of events that allows or demonstrates causation.

It may be indeed that flood basalts and bolides produce similar effects on the Earth System. The Triassic-Jurassic boundary would seem to be an ideal venue for examining this possibility. Parsimony suggests, however, that one unifying rather than two different explanations should explain the same phenomena.

STOP 3: Wasson Bluff: Rhaetian to Hettangian

Units: Upper Blomidon Formation, North Mountain Basalt, McCoy Brook Formation

Main Points: Outcrop of the Triassic-Jurassic boundary; synfaulting sedimentation; earliest Jurassic tetrapod skeletal assemblages known; dinosaurs.

Park at pull off for Wasson Bluff Special Place and walk down dirt road to beach. All collecting is prohibited by law at the protected Special Place. Do not use rock hammers anywhere on these outcrops, even if you see no fossils. Outside the protected site, it is still against the law to remove or disturb any fossil in the bedrock. All fossils in Nova Scotia have this legal protection. Make sure you wear a hard hat. It will not help much with a big rock fall, but small rock falls occur often and P.E.O. has been hit several times.

Geologically, Wasson Bluff was first illustrated by William Dawson in 1855 in his depiction of cliffs east of Swan Creek to Wasson Bluff (Fig. 19). It was briefly described by Powers (1916) and Klein (1960) and developed a well-deserved reputation as a mineral locality, especially for zeolites (Dawson, 1891). The spectacular exposures at Wasson Bluff reveal the interplay between tectonics, sedimentation, and taphonomy described by Olsen et al. (1987, 1989) and Olsen and Schliche (1990).

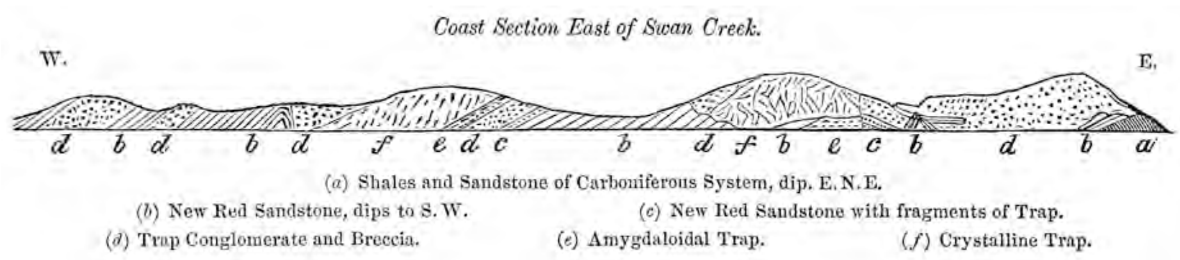
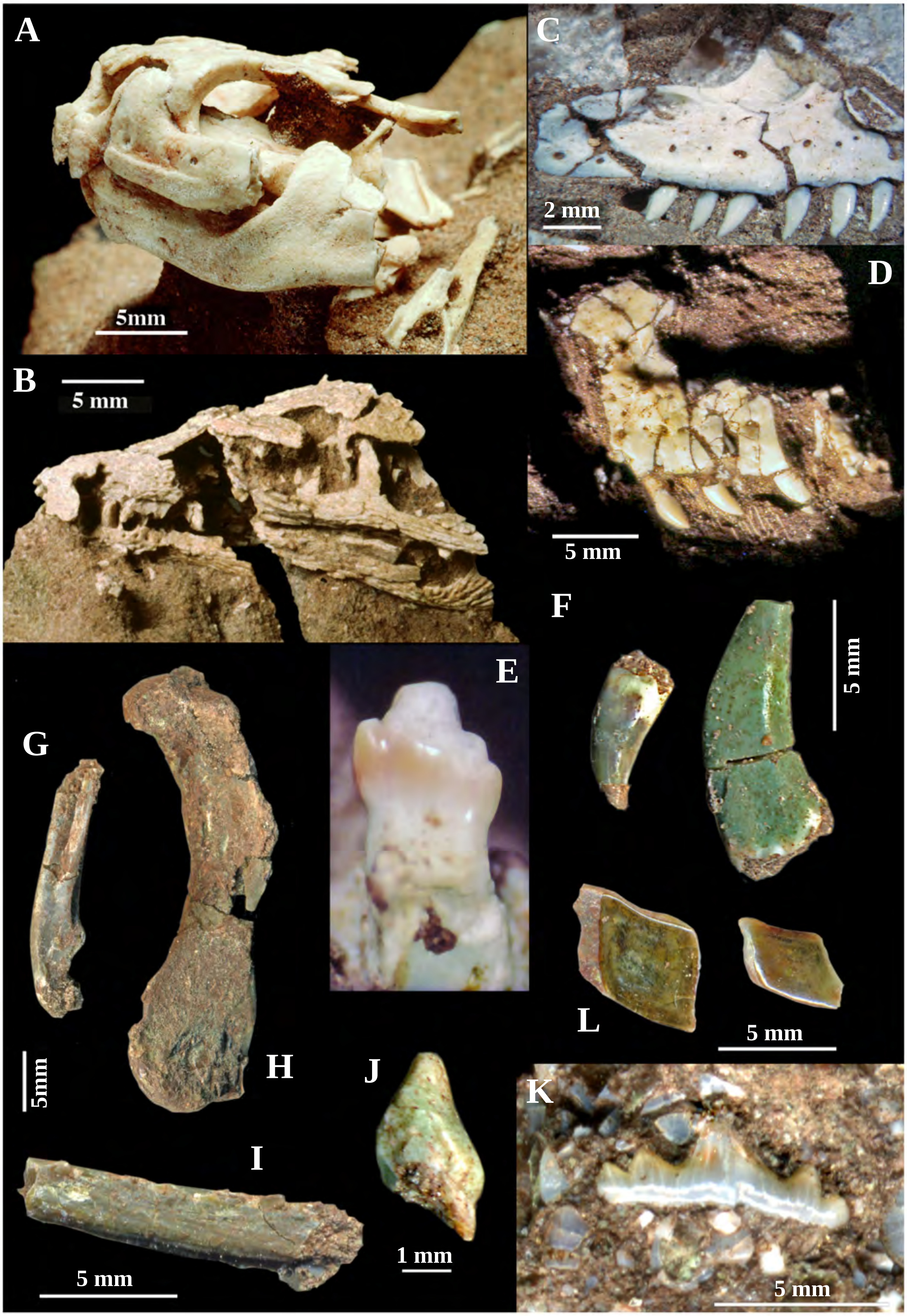


Figure 19. Dawson's (1855) depiction of the cliffs from Swan Creek (left) to Wasson Bluff (right). The Partridge Island member of the Blomidon Formation in contact with the North Mountain Basalt (Station 1 of Stop 3) is shown at the first "b" on the right. Station 12 (basalt cobble debris flows) is the first "d" on the left. Compare with the drawings in Figure 22.

Both professional and amateur paleontologists have made significant discoveries of dinosaur fossils in the McCoy Brook Formation over the past thirty years. As far as we know, vertebrate fossils were first found at Wasson Bluff by P.E.O., mapping the outcrops on a rainy day, August, 11, 1976. The first remains found were scraps of an elongate cervical vertebra of a prosauropod dinosaur, the oldest definitive dinosaur skeletal remains in Canada. P.E.O., although alone on that day, was traveling with Donald Baird and John (Jack) Horner (at that time from Princeton University), who joined P.E.O. for further collecting at Wasson Bluff the following days. Additional dinosaur remains were collected including a partial femur and other bones. Fragmentary fish were collected from the adjacent outcrop of the Scots Bay Member. Subsequent trips revealed additional remains from the same levels as the previous bones. During causal reconnaissance in 1984, P.E.O. found a beautifully preserved skull of a sphenodontian (*Clevosaurus bairdi*, Fig. 20) from a lower horizon within the McCoy Brook. The discovery of this skull prompted a colleague, Neil Shubin, then a graduate student at Harvard, to develop with P.E.O. an ultimately successful grant proposal to National Geographic. From 1985 to 1987 joint teams from Columbia and Harvard universities. In addition to P.E.O. and Shubin, the parties consistently included Hans Sues, William Amaral, Steven Gatesy, and Roy Schlische, as well as many others. As a result of their efforts, the amazingly prolific talus slope breccias were discovered, along with numerous other important additions to the Wasson Bluff faunal assemblage (Olsen et al., 1987). On March 1, 1990, in acknowledgement of the importance of the site, it was declared a Special Place under the terms of the Special Places Protection Act.

Triassic formations vary markedly in thickness in this area. At Wasson Bluff proper the Wolfville Formation and nearly all of the Blomidon Formation are absent and only a veneer of conglomeratic Blomidon Formation is present. The Early Jurassic McCoy Brook Formation fills fault-bounded wedge and trough-shaped basins developed on the faulted upper surface of the North Mountain Basalt (Fig. 21). Paleo-fault talus slope deposits and slide blocks are common in these sub-basins. McCoy Brook Formation debris flows consist exclusively of North Mountain Basalt clasts, testifying to the localized uplift of the lava flows (Tanner and Hubert, 1991). Left-lateral strike-slip and normal faults cut formations of all ages, and hydroplastic slickensides probably formed in incompletely lithified sediments. Neptunian dikes are common in the North Mountain Basalt and reveal important kinematic information. We shall examine all of these features on our trek along Wasson Bluff. The following discussion is based on Olsen et al. (1989) and is tied to the sketches of the Wasson Bluff outcrops with a series of stations numbered from east to west (Fig. 22).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Station 1: At the immediate eastern end of the exposure and just to the west of the small stream, the unconformity between Blomidon strata and Carboniferous basement is locally exposed in the modern talus slope. The Blomidon Formation is dipping towards the beach (i.e., southward) and consists mostly of gray, red and purple conglomerate and sandstone. The upper two meters, however consist of well bedded gray, red and purple sandstone and mudstone with some hopper cast-bearing gray claystones of the Partridge Island member. The contact between the Partridge Island member and the North Mountain Basalt is step-faulted. Hexagonal cooling joints are well developed immediately above the contact.

Station 2: The bulk of the North Mountain Basalt from here westward to the eastern sub-basin is mostly tectonized or "rubblized" basalt similar to what we have seen at Stop 1. Schlische in Olsen et al. (1989) hypothesized that this extensive zone of "rubblized" basalt marks a wide, predominantly left-lateral fault zone. This same fault zone apparently places the McCoy Brook Formation against Carboniferous rocks to the east of these outcrops. Splays of this fault zone trending at a higher angle to the cliff face are present. The degree of rubblization increases towards these splay faults, and many are marked by narrow, chlorite-fiber slickensides. Again, we hypothesize that the "rubblized" basalt formed as a result of faulting under near-surface but not exposed conditions; the mineralized faults probably formed at greater depth as a result of burial.

In between some zones of "rubblized" basalt are what we interpret as rotated basalt columns, much like those seen at Five Islands (Stop 1, Station 1). Stevens (1987) interpreted these rotated columns as portions of a dike. However, as at Five Islands (Stop 1), chill margins are absent, rotation of the columns is variable, and the sense of rotation is appropriate for down on the south motion of the bounding faults. Metamorphism and intrusive apophyses are also absent.

Station 3: A fault-bounded block of paleo-fault talus slope deposit marks the eastern end of the first sub-basin. This sub-basin is easily recognized by the distinctive deposits consisting of angular clast-supported basalt breccia in a matrix of sandstone or mudstone. Large blocks of basalt are common, many of which are themselves broken into smaller blocks with very small amounts of lateral movement. Sediment-filled voids among the basalt clasts show stratification that has yielded consistent bedding orientations throughout the outcrop, indicating deposition of the matrix after the accumulation of the basalt clasts. The matrix often yields abundant reptile bones. These deposits at Wasson Bluff are invariably associated with faults and have all the characteristics of talus slope accumulations (Tanner and Hubert, 1991).

Much like the talus slopes forming today on this beach, these McCoy Brook talus slopes contained many large empty spaces in which small animals could live. In order of

Figure 20. Small vertebrates from Wasson Bluff, Stop 3; A-B are from fluvial sandstone at Station 7, C-E, are from the talus slope breccias at Station 3, F-K are from the gravel bed of the Scots Bay Member in contact with the North Mountain basalt at Station 7: A, partial skull of sphenodontian *Clevosaurus bairdii* (type specimen); B, partial skull of protosuchian crocodyliform *Protosuchus micmac*; C, maxilla of undescribed sphenosuchian crocodylomorph (H.-D. Sues, pers. comm., 2005); D, partial maxilla of *Protosuchus micmac*; E, molariform tooth of advanced cynodont *Pachygenelus* cf. *P. monus*; F, two teeth possibly of a small theropod dinosaur; G, left, ulna of an advanced synapsid, possibly *Pachygenelus*; H, humerus, possibly *Pachygenelus*; I, dorsal fin spine of hybodont shark; J, tooth of ornithischian dinosaur; J, tooth of hybodont shark, cf. *Hybodus* sp., K, scales of *Semionotus* sp.

abundance, the taxa found so far include the protosuchid crocodyliform *Protosuchus micmac* (Sues et al., 1996), the very mammal-like trithelodont synapsid *Pachygenelus* cf. *monus* (Shubin et al., 1991), the sphenodontian *Clevosaurus bairdi* (Sues et al., 1994), a small probable ornithischian dinosaur resembling *Lesothosaurus* from southern Africa, and fragments of a small probable theropod dinosaur (Fig. 20). Most material is dissociated, but some articulated material is present. Unfortunately, most bones and skeletons are truncated at one end or another by small faults, and much material appears chewed. Bone-bearing coprolites occasionally occur, suggesting that at least some of the remains may have been dragged into the talus piles by a predator or scavenger. Tetrapod bones may be more abundant in this talus slope breccia than anywhere else in eastern North America. At this site aquatic fossils are completely absent.

Station 4: A high-angle reverse fault separated the talus slope deposits from the vertical Carboniferous basement rocks to the immediate northwest, which are unconformably overlain by the Blomidon Formation, in turn overlain by North Mountain Basalt (Fig. 22). This is an extension of the same contact surface seen at Station 1. South of the talus slope deposits are a series of north-dipping normal fault-bound "dominoes" of North Mountain Basalt (Figs. 21, 22). Basins that developed in these fault blocks are filled with McCoy Brook Formation, which consists of brown, at least partially eolian, sandstone. The southernmost outcrop of basalt adjacent to the "dominoes" is overlain by the lithologically-distinct Scots Bay Member. Lithologies typical of the Scots Bay Member are not present within the exposed dominoes to the north and the pink and white carbonate and green sandstone project on top of the units to the north. Therefore the sediments within these blocks should be basal-most Scots Bay Member (Fig. 21). Note that if the Scots Bay beds are rotated to horizontal, the reverse fault adjacent to the talus slope deposits becomes a normal fault, and the normal faults associated with the "dominoes" are antithetic to it (Fig. 21). Hence, the talus-slope deposits probably accumulated on the downthrown side of a normal fault. At the western end of this sub-basin, the talus slope deposits are faulted against North Mountain Basalt. This north-striking fault (Fig. 21) is probably a transfer fault because it terminates against the "reverse" fault, and dies out to the south in the zone of "dominoes".

Station 5: The top of one flow, another thin flow, and a third upper flow of the North Mountain Basalt are visible in the next stretch of outcrops. Here, the basalt is mostly massive and disturbed only by small faults. The green, red, and gray flows are each separated by vesicular horizons. This particular stretch of outcrop also contains numerous Neptunian dikes (Schlische and Ackermann, 1995), formed by the active extension of the North Mountain Basalt and filled with sediment from above. The dikes often follow pre-existing fractures, such as cooling columns in the basalt, or are sinuous. Schlische and Ackermann (1995) showed that the dikes in this region are preferentially oriented NE-SW in line with the regional extension direction inferred from the trend of the Shelburne dike.

Station 6: The basalt flows in the region dip to the southwest. The thick uppermost gray basalt flow is overlain by the Scots Bay Member, which can be excavated in the beach. The Scots Bay Member and other strata of the McCoy Brook Formation strike directly into the North Mountain Basalt in the cliff face, along which an east-west striking fault runs. The

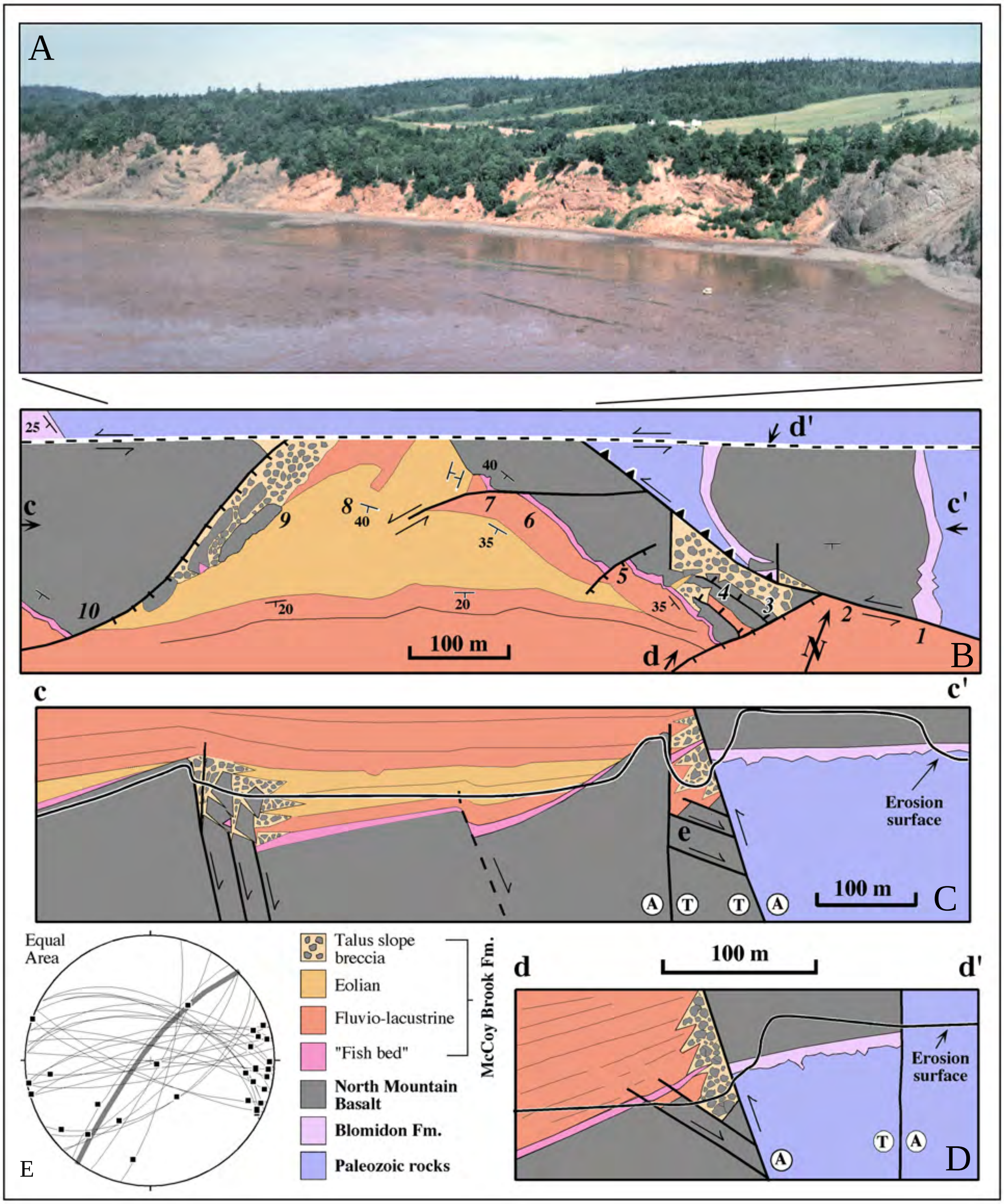


Figure 11. Wasson Bluff area, Stop 3: A, helicopter photo of middle segment of the Wasson Bluff transect; B, bedrock geological map of eastern 3/4 of Stop 3 transect (1-10 are Stations); C. cross-section c-c'; D, cross-section d-d'; E, equal area lower hemisphere stereographic projection showing attitude of faults (thin great circles), slickenlines (boxes), and average orientation of Neptunian dikes (shaded great circle) on west side of Wasson Bluff area, all consistent with northwest-southeast extension.

fault has offset the North Mountain Basalt—Scots Bay Member contact by approximately 25 m (Fig. 22). The fault zone is marked by a mineralized, slickensided plane with subhorizontal slickenlines. The basalt on either side of this plane is clearly rubblized, indicating the fault origin of the "rubblized" basalt. The upper surface of the basalt contains numerous neptunian dikes, the offset of which shows the motion to be almost pure strike-slip, agreeing with the slickenline directions.

Station 7: The eastern end of the western sub-basin is marked by the onlap of the Scots Bay Member onto the upper surface of the North Mountain Basalt. Stratigraphically-higher strata onlap boulders of North Mountain Basalt, which in turn rest against a high-angle wall of massive vesicular basalt (Fig. 22). The western edge of the basalt wall is truncated by onlapping fluvial sandstone. Thin layers of basalt rubble are interbedded in the sandstone adjacent to the basalt. It is possible that the surface of the basalt was terraced by the lake that deposited the deeper water parts of the Scots Bay Member, producing the evident paleorelief.

Onlap of the Scots Bay Member onto the basalt is marked by a gravelly mudstone very rich in disarticulated fish and small tetrapod bones (Fig. 20). The most abundant faunal element is disarticulated remains of *Semionotus* sp. that can comprise a coquina of scales. Second are teeth and spines of a hybodont shark close to *Hybodus*, followed by scale and skull bones of an undetermined redfieldiid fish. Tetrapod bones are surprisingly common; no particular taxon is seemingly dominant. Isolated elements include protosuchid girdle elements and osteodems, small theropod dinosaur teeth similar to *Syntarsus* (or *Coelophysis*), small ornithischian teeth, vertebrae, and limb elements, and probable trithelodont postcranial elements (Fig. 20). This gravelly unit is probably a wave-sorted lag that accumulated between cobbles along the Scots Bay lake shore.

The upper portions of the lacustrine sequence consist of red mudstone and sandstone beds. The latter contains well-preserved reptile remains, some of which are articulated, but as yet no aquatic elements. This unit dips steeply at the outcrop of the Scots Bay Member, but it flattens out and reappears in the beach a few meters to the west. The most common taxon is *Clevosaurus bairdi* and the latter locality was the source of the type skull (Fig. 20). Since that discovery a series of articulated partial skeletons, skulls, and abundant isolated elements of *Clevosaurus* have been found. The second most common taxon is *Protosuchus micmac*, represented mostly from abundant isolated elements but an articulated if fragmentary skull has also been found (Fig. 20). Third are isolated elements of the trithelodont *Pachygenelus* cf. *monus*. Last are possible dinosaurian remains, the most notable is a possible articulated yearling prosauropod skeleton found by Neil Shubin, Hans-Dieter Sues and Bill Amaral in 1986. This specimen (FGM000GF18) includes vertebrae centra and significant portions of the left pelvis and hind limb. Detailed examination of the material (by T.F.) suggests the specimen does not represent a prosauropod dinosaur, but rather the postcranial remains of an adult *Protosuchus*.

Station 8: This area lies near the center of this triangular sub-basin and the cliffs in front of us (Fig. 22) are representative of most of its fill. Most of this fill consists of a NW- to SW-dipping largely eolian dune sandstone. According to Hubert and Mertz (1984), at least 48 m of dune sand are present in this basin which yield paleo-wind directions towards 241°. Toward the western end of the sub-basin, basalt clasts within the dune sands become more abundant and larger and at the western end of the sandstone outcrops (Fig. 22), eolian dune sands abut against a large slide block or domino of relatively intact basalt, producing an 8-m-high paleocliff with adjacent talus cones (Hubert and Mertz, 1984). According to these authors, successive first order surfaces in the eolian sandstone are veneered with basalt boulders (some larger than 1 m) that rolled down-slope and were buried by advancing barchan dunes and barchoid ridges. As the northwestern normal fault boundary of the sub-basin is approached, eolian dune sands interfinger with paleotalus slope deposits and another slide block of tectonically-disrupted basalt. These relationships indicate that the faulting responsible for sub-basin formation and sedimentation were coeval.

Directly in front of us is the site of the first discovery of bones at Wasson Bluff, dubbed the Princeton Quarry. In the first years after the initial discovery, several disarticulated sauropodomorph dinosaur vertebrae and appendicular bone fragments were uncovered. Based on the robustness of the elements, the specimens were attributed to *Ammosaurus* cf., a small sauropodomorph dinosaur from the Early Jurassic (Pliensbachian) Portland Formation of the Connecticut Valley. Subsequent work and discoveries have demonstrated the skeletal material is associated with abundant thin micaceous mud-drapes, mud-cracks, ripple surfaces, as well as a thicker (~5 cm) layer of fluvial mudstone, suggesting these dinosaurs were preserved in a localized fluvial deposit within an interdune area.

While leading a GAC field trip in 1992, Bob Grantham found several fragments of dinosaur bone at the original Princeton quarry. This resulted in the collection of a nearly complete and articulated sauropodomorph dinosaur over the following two years. George Hrynewich, a private fossil collector in Nova Scotia, and Ken Adams, the Curator of the Fundy Geological Museum, collected the specimen (FGM994GF69), which includes a nearly complete representation of the skeleton except for the skull. The specimen is small (femur size < 30 cm) in comparison to the larger Princeton specimen (femur length ~ 45 cm), and comparatively well preserved.

In 1997, T.F. began the preparation and study of 94GF69. Inspection of the site at this time led to the discovery of another dinosaur specimen (FGM998GF9) from the Princeton quarry. Many elements from this large (femur size ~50 cm) disarticulated specimen have been recovered from subsequent excavations; including a left complete femur, tibia, and fibula, distal end of the right femur, several vertebrae, nearly complete articulated ischium, and several forelimb elements.

In 1998, yet another large, but articulated specimen was discovered (FGM998GF13_I), and during excavations of this material over the past six years another two specimens (GF13_II and GF13_III) have been recovered, including articulated vertebrae columns and pelvic girdles, as well as seven articulated anterior-most cervical vertebra and a nearly complete but disaggregated skull.

With more specimens likely to come from this interval, which can be justifiably called a bone bed, the McCoy Brook Formation is the richest site in North America for Early Jurassic sauropodomorph dinosaurs. While the bone material is typically deformed by syndepositional faulting, recently collected material is well preserved and relatively undeformed. The sauropodomorph bone bed shows alternations between thin laminated mud layers, and micaceous sandstones, with some thicker mud stone units containing large basalt boulders, all of which suggests a quick burial of the articulated skeletons by fluvial deposition.

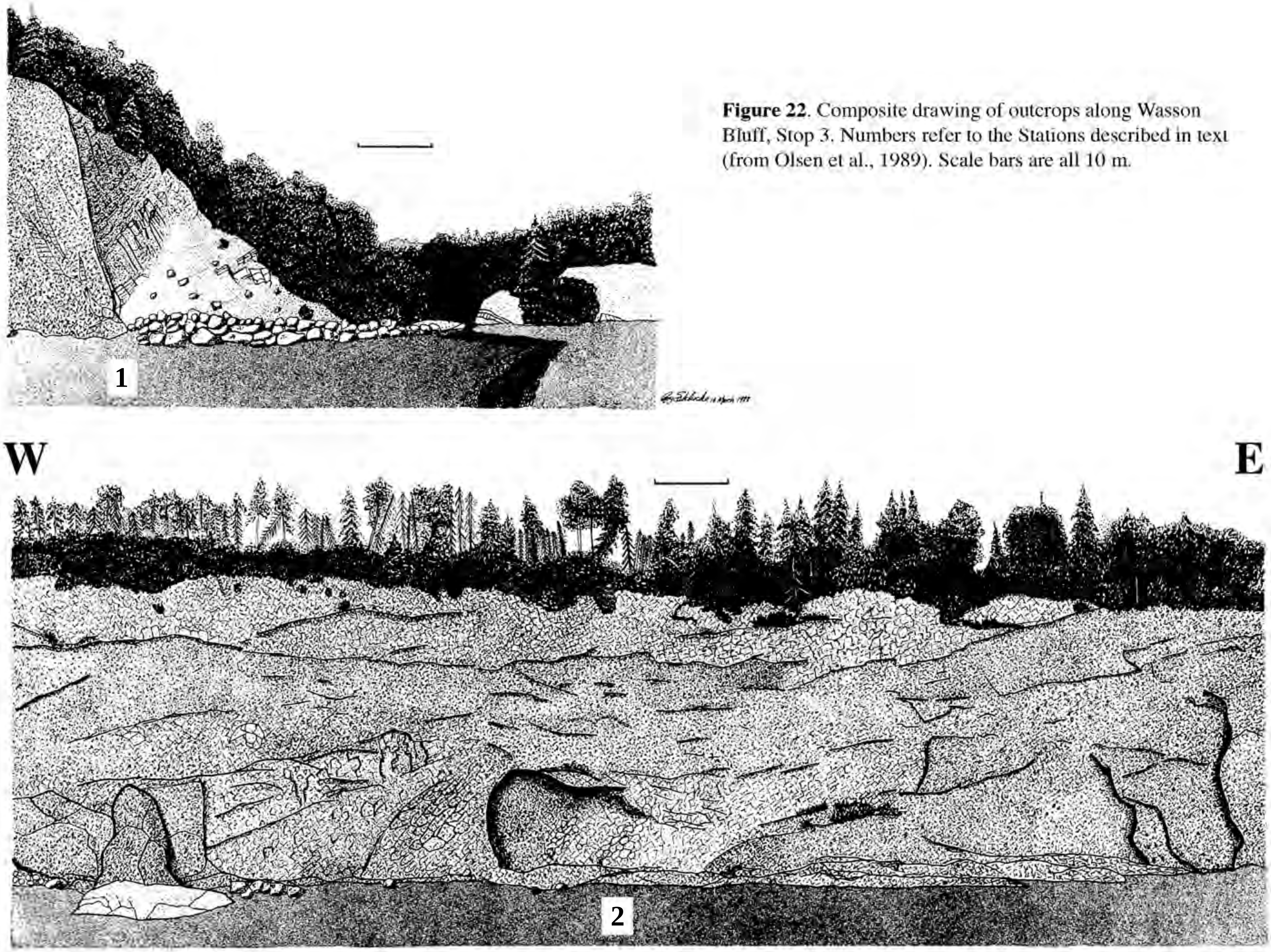
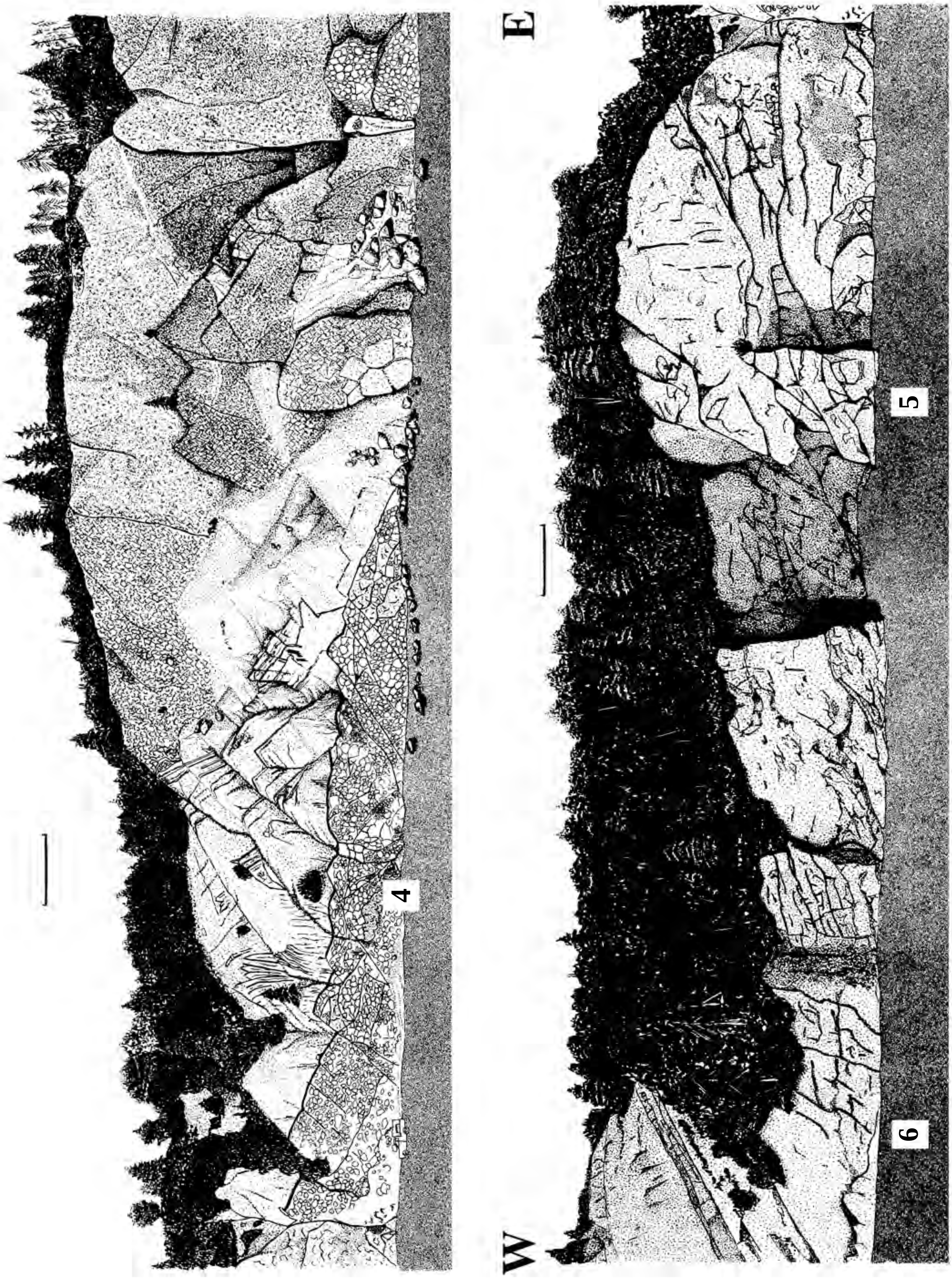


Figure 22. Composite drawing of outcrops along Wasson Bluff, Stop 3. Numbers refer to the Stations described in text (from Olsen et al., 1989). Scale bars are all 10 m.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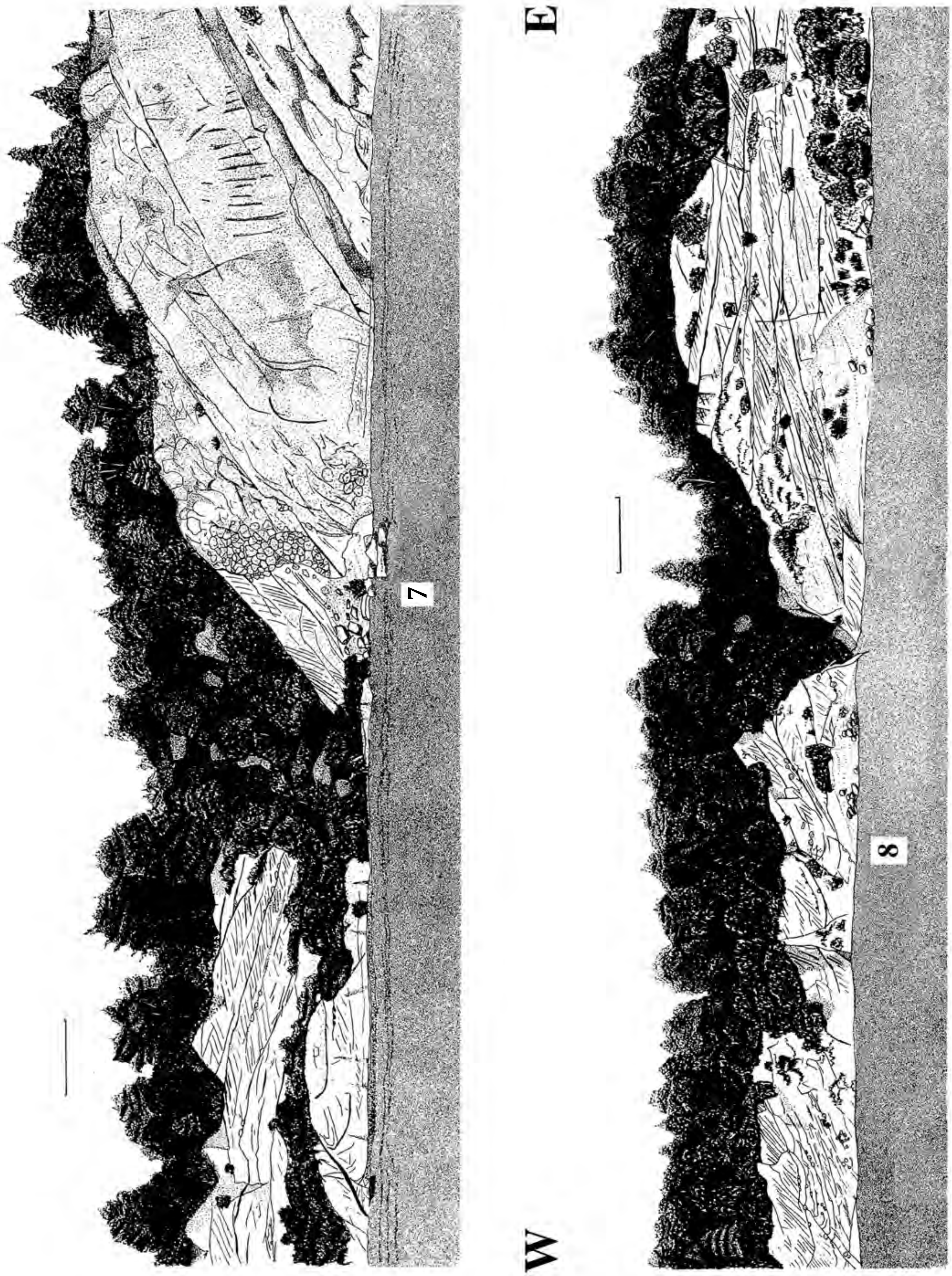
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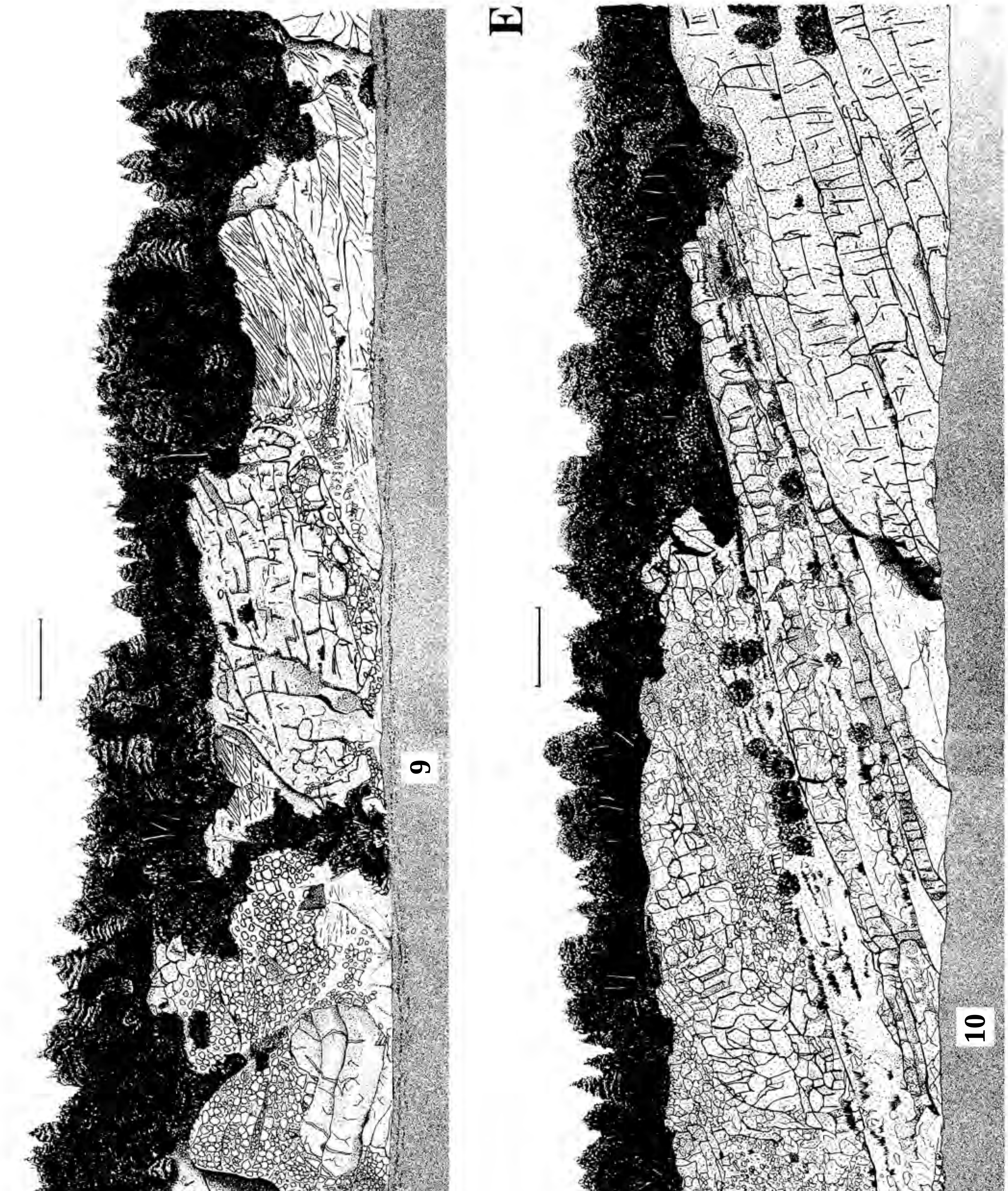
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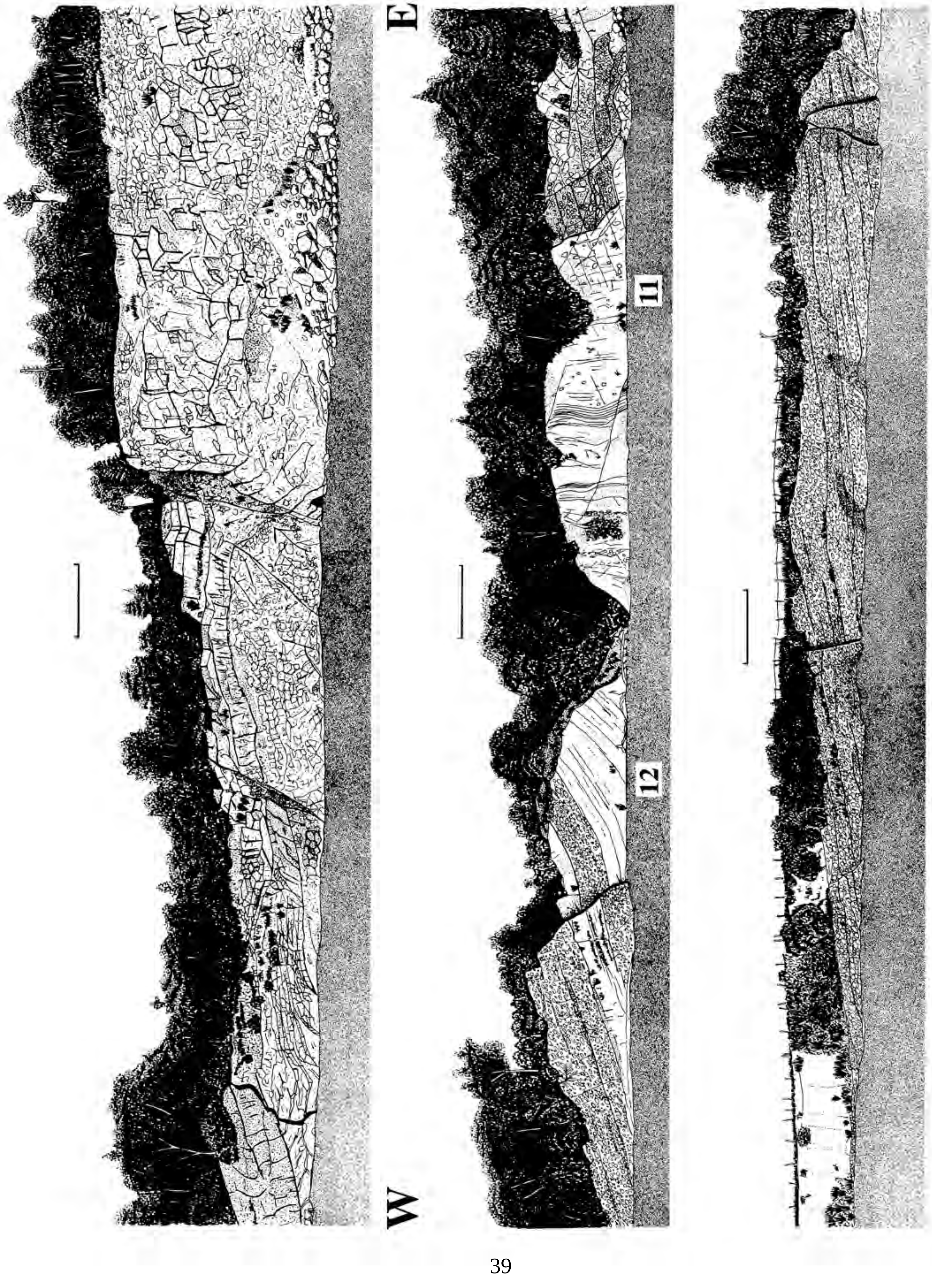
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Finally, looking south, laterally persistent beds of apparently ripple cross-laminated, water-laid, reworked eolian sandstone are found in the tidal flat at the top of the eolian sandstone wedge in the main half graben. These sandstones contain poorly preserved but abundant brontozooids including *Eubrontes* (*Anchisauripus*) cf. *sillimani* and *Batrachopus* sp. tracks.

The vertebrate assemblages from Wasson Bluff are critical to the debate on the structure and origin of the Triassic-Jurassic mass extinctions. Compilations of latest Triassic assemblages from other portions of the Newark Supergroup and other parts of the world (Olsen and Sues, 1986; Olsen et al., 1987; Benton, 1995) demostrate that all of the families present in the Early Jurassic McCoy Brook assemblages were already present during the latest Triassic. However, despite the fact that the Jurassic Nova Scotian assemblages come from a variety of facies, from fully aquatic to fully terrestrial, and the fossils are very common, the dominant late Triassic families of reptiles and amphibians are absent. This is also true of intra- and post-extrusive deposits from the rest of the Newark Supergroup. Thus, the McCoy Brook assemblages represent survivors of the massive Triassic-Jurassic extinction event, in which 43% of all terrestrial vertebrate families went extinct.

The McCoy Brook assemblages occur directly on top of the North Mountain Basalt, which based on geochemistry is probably the temporal equivalent of the Orange Mountain Basalt, and therefore the assemblage is plausibly correlated with the Midland Formation of the Culpeper basin, the Feltville Formation of the Newark basin and the Shuttle Meadow Formation of the Hartford basin. Based on the geochemical similarity of the North Mountain and Orange Mountain-Talcott basalts (Puffer et al., 1988) and the cyclostratigraphy of the upper Blomidon and lower Scots Bay Formation, the McCoy Brook assemblages is less than 100,000 years younger than the Triassic-Jurassic boundary (Olsen et al., 2002b; 2003; Whiteside et al., 2005). The extinctions must have taken place prior to this time suggesting an abrupt extinction event.

<u>Station 9:</u> A complex mix of very large basalt blocks (+5 m), sandstone and talus breccia marks the west end of this sub-basin, just east of its bounding fault. A fragmentary but partially articulated prosauropod dinosaur skeleton collected by the Harvard team in 1986 includes a partial gastralia basket and associated group of gastroliths (NSM 005GF009.001). This is the only North American prosauropod known with gastroliths. They are especially interesting because clasts of this type are not found in the Wasson Bluff outcrops, so the dinosaur must have traveled some distance to get them. Elements from this specimen were included in a study of dinosaurian gastroliths (Whittle and Onorator 2000), and a sphenodontian mandibular ramus located several centimetres from the gastrolith pile has been used to suggest prosauropods may have been omnivorous (Barrett, 2000). It should be noted, however, that phosphorus is limiting in most environments and it is normal for otherwise herbivorous tetrapods to chew or ingest bones and bone fragments. In 1988, Kevin Murphy, a grade nine student (Ellenvale Jr. High School, Dartmouth, NS) found a fragment of dinosaur bone during a high school geology trip at this site. The specimen (NSM 989GF6.1) was accessioned as “a vertebra fragment”, however subsequent preparation and study have shown the material is a portion of the frontal/parietal area of an as yet undetermined dinosaur. It may be the same individual as the gastralia. Further excavation at this site by a team led by Bob Grantham, then Curator of Geology (Nova Scotia Museum of Natural History) collected another specimen (FGM000GF46), including part of a pelvis and several vertebrae, badly broken prior to fossilization and deformed from syndepositional

faulting that commonly affects vertebrate fossils from this formation. A structural inference can also be based on the gastroliths and the skeletal deformation; faulting took place under low confining pressures in the relatively incompetent, probably incompletely lithified sandstones. None of these intra-dinosaur faults are mineralized. Parts of this specimen are on display at the Fundy Geological Museum.

The southeast corner of the large multi-flow basalt block between sandstone on the east and massive basalt flows on the west is notched and filled with Scots Bay Member, containing its characteristic fauna, apparently in gross unconformable contact. We interpret this notch as a cavity produced by (wave?) plucking of a basalt boulder followed by onlap of the Scots Bay. The Scots Bay Member is truncated to the immediate southeast by a healed fault, the south side of which is orange sandstone and basalt breccia. Again this series of contacts shows that faulting, erosion of the uplifted blocks, and sedimentation were contemporaneous.

The normal fault (as revealed by slickensides) at the northwestern edge of this sub-basin is typical of faults at Wasson Bluff. It consists of an upward-widening fault zone of (basalt) breccia in a matrix of sandstone and mudstone. The degree of brecciation and volume of sedimentary matrix increase toward the fault. This fault breccia is welded to the hanging wall and partially to the footwall, and is cut by a narrower zone of red fine-grained material, which is probably gouge, but resembles the infill of Neptunian dikes. This red material is then cut by narrow, mineralized, slickensided surfaces. We hypothesize that the matrix-rich breccia formed in a wide fault zone that was open at the surface. The red gouge and mineralized slickensides formed at greater depths as a result of additional burial. It therefore appears likely that fault zones narrow with depth (within the brittle field), with cataclasis becoming more confined, and with eventual mineralization.

Station 10: Westward of the sub-basin are extensive exposures of middle and upper North Mountain Basalt. Several thin flow units are overlain by the thick and massive upper flow sequence of the basalt, all of which dip to the southwest. Some evidence of faulting during extrusion of the North Mountain Basalt includes a left-lateral offset in a wrinkle or flexure at the top of one thin flow, filled by the succeeding next thin flow. The cooling rims in the infilling flow suggest that the offset occurred before the extrusion of the upper flow.

Hexagonal cooling joints are well developed in some of the flow units at the western side of this station. Many of these joints have served to localize the Neptunian dikes. In one example described and figured by Schlische and Ackerman (1995), we see that the cooling joints oriented normal to the regional extension direction formed the widest Neptunian dikes.

In this same area, a sinuous 20- to 30-cm-wide vesicular basalt dike with clearly chilled margins cuts a flow. Its relationship to the surrounding units is completely obscure and it may represent no more than an injection of the last fluid material from the interior of a cooling flow into its already chilled upper surface.

Station 11: A basalt-clast fault-related breccia with abundant sediment matrix crops out at the contact between the upper North Mountain Basalt and sedimentary strata to the west. Its bedding attitude is obscure. It is bound on its southwest by a high-angle fault striking WNW with subhorizontal slickenlines. Immediately to the west of this fault, strata within the McCoy Brook Formation, including thinly-bedded purple-gray-brown lacustrine units, have vertical bedding (Fig. 22). The fault zone between the vertical McCoy Brook Formation and the basalt contains phacoids of purple basalt gravel. A less-disturbed, similar-appearing gravel is present in the adjacent mud flat directly along strike, in conformable contact with the North Mountain Basalt, and is apparently the local expression of the Scots Bay Member. This region of upturned strata is due to later Jurassic compression during inversion (Withjack et al., 1995).

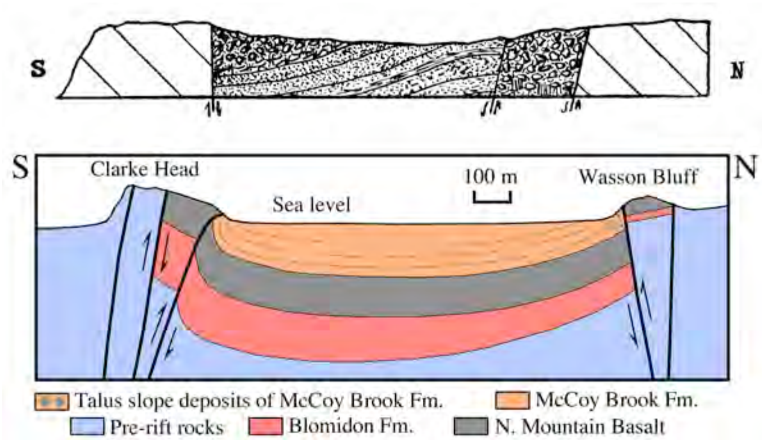
The meter-scale laminated and thin bedded vertically oriented purple-gray-brown interval appears to be a lacustrine interval above the Scots Bay Member. Its stratigraphic position in the section at Station 7 seems to be just above the fluvial sandstone capping the Scots Bay Member. Thus far it has produced only very rare ostracodes, conchostracans, and *Semionotus* scales. From this station, and perhaps as far west as Swan Creek, is another small sub-basin developed on the syndepositionally faulted and tilted North Mountain Basalt with its own distinctive local facies of the McCoy Brook Formation.

The small creek that comes down from the north at this station follows the strike of the steeply dipping McCoy brook until it crosses a fault and passes into the Blomidon Formation. The Blomidon Formation is much thicker here than at Stations 1 and 2 and looks much more like it does at Partridge Island, demonstrating thickening of the formation towards the Clarke Head area (see below).

<u>Station 12:</u> As we walk to the west, dips in the McCoy Brook Formation quickly shallow. The remainder of the outcrop consists of debris flows of the McCoy Brook Formation, and interbedded and overlying red sediments. The clasts of the matrix-supported flows consist exclusively of North Mountain Basalt. Individual debris flows are only decimenters thick (J.P. Smoot, pers. com.). Tanner and Hubert (1991) have further described this distinctive but unfossiliferous debris flow sequence. Several WNW-striking, left-lateral(?) faults cut these debris flows. The interbeds of red clastics are paleosols riddled with abundant root mottles. Only a thin section of sedimentary strata overly the debris flows, but these appear to be normal McCoy Brook sand patch mudstones with gypsum nodules.

A view to the west and southwest shows a reverse fault throwing North Mountain Basalt over McCoy Brook Formation. Superficially, it appears as though the North Mountain Basalt is in conformable contact with underlying red beds, contributing, no doubt to the misinterpretation that the red beds at Wasson Bluff were Blomidon Formation and the basalt at Wasson Bluff (and McKay Head) were interbedded between the Blomidon and Wolfville Formations (e.g., Klein, 1962). Another fault to the south separates North Mountain Basalt from a tectonic mélange of Palaeozoic rocks, which include boulders of granulite-grade mylonite (Gibbons et al., 1996), developed within the most outboard exposed fault segment of the Minas fault zone. While Gibbons et al. (1996) ascribe the deformation to successive faulting events, the gypsiferous megabreccia exposed at Clarke Head finds a remarkably close match in breccias seen in outcrop along the shores of the Isles de Madeline in the Gulf of St. Lawrence. In this area, the breccias are due to salt diapirism, another deformational process that should be added to the mix of processes acting along this remarkable fault zone.

Figure 23. Cross-section from Wasson Bluff to Clarke Head. Above, Powers (1916) interpretation in which basaltic agglomerate (Powers' Five Island Volcanics) lies above Wolfville Fm. (Powers' Annapollis Fm.). Below, interpretation of Withjack et al. (1995) in which the stratigraphy is strongly modified by syn-sedimentary tectonics and there is a thick post-basalt unit (McCoy Brook Fm.)



An interpretive cross section from here to Clarke Head is shown in Fig. 23 (from Withjack et al., 1995). The synclinal shape of the overall structure is supported by measurements of McCoy Brook bedding attitudes in the beach. This synclinal structure bears a striking resemblance to structures seen in seismic lines along the projection of the Minas fault zone into the Bay of Fundy (Withjack et al., 1995; Wade et al., 1996). It is worth noting that the thickness of the Blomidon at Clarke Head is in excess of 100 m, showing a rapid increase in thickness from the Wasson Bluff area, presumably due to Triassic faulting and subsidence.

If we have sufficient time, we will be leaving Stop 3 by a road paralleling Swan Creek. As we follow Swan Creek inland, we will pass outcrops of the Scots Bay Member with fragmentary *Semionotus* and coprolites on the west bank of the creek where it intersects the North Mountain Basalt.

STOP 4: Fundy Geological Museum

Repository of most McCoy Brook fossils and fossils from much of Nova Scotia north of the Minas basin.

Main Points: Assemblages of dinosaur skeletons and other material from Wasson Bluff; other Jurassic skeletal remains; Triassic assemblages from Carrs Brook (Middle Triassic), Economy (Wolfville Formation, Carnian), and Paddy Island (basal Blomidon Formation, Norian).

The Fundy Geological Museum in Parrsboro, NS, provides public visitors with educational exhibits relating the geological significance of the surrounding area. Situated on the northern shore of the Bay of Fundy (Minas Basin), the museum is centrally located between the internationally significant fossil sites of Carboniferous (Joggins) and Triassic through Jurassic ages (Wasson Bluff, Wolfville Formation). The museum includes an exhibition gallery, lab space, a multi-purpose room, gift shop and administration offices. Officially opened in December 1993, the museum has averaged about 24,000 visitors a year, and is operated by the Cumberland Geological Society, as part of the Nova Scotia's Family of 25 Museums.

The Museum was born from the local interest and support that resulted from the discovery of the enormous cache of Early Jurassic small vertebrate remains at Wasson Bluff (Stop 3). The Museum continues to encourage ongoing discovery, with an active research lab, fossil preparation staff, and collaborations with local and international earth science researchers. Wasson Bluff and Joggins are now protected by provincial legislation that requires researchers to acquire provincial permits before conducting any excavations of palaeontological specimens.

At this stop, we will tour the public exhibits, and get a behinds-the-scenes look at the lab and collections. In particular, we will look at vertebrate assemblages within the collection from five intervals, from oldest to youngest:

1. Assemblage from the Economy member of the Wolfville Formation, Lower Economy, Cumberland County. This assemblage differs from all others of established Late Triassic age in being dominated by fragments of cyclotosaurid temnospondyl amphibians. Unfortunately, most of the material is very fragmentary and we must stress that none of the identifications are certain or the result of exhaustive analysis. However, some material has been at least tentatively identified, and these include the long-snouted trematosaurid amphibian *Cosgriffius* (Welles, 1993; S. Lucas, pers. comm.), large to small cyclotosaurid temnospondyls, cf. *Tanystropheus*, procolophonids, small and large fragmentary synapsids, and various fragmentary, probable archosauromorphs, including large serrated teeth most likely rauisuchian. The site also shows thick-shelled unionid clams and the burrow trace fossil *Scoyenia*. Absent are metoposaurid amphibians and phytosaurs, and this assemblage is decidedly different from any Late Triassic age assemblage in North America.The age of this assemblage has been interpreted as Anisian, by comparison to the Moenkopi in the western United States (Baird, 1986; Olsen et al., 1989). However, superficially similar assemblages are known from the Early Carnian age strata of Germany.

2. Assemblage from the middle to upper Wolfville of Economy Point. This assemblage, known only from a few teeth and bone scraps, is potentially important because it suggests that more may be found in these relatively unprospected sequences. Strata of the middle Wolfville on the south shore of the Minas basin has produced a diverse and important Carnian age assemblage, (e.g., Sues, 2003).

3. “Paddy Island” footprint assemblage. Marginal lacustrine or fluvial sandstones of the Red Head Member of the Blomidon Formation on the mainland just south of Paddy Island have produced a large assemblage of reptile footprints, many of which are in the collections of the Fundy Geological Museum. Most common is the probable dinosauromorph *Atreipus acadianus* and the probable lepidosauromorph track *Rhynchosauroides* sp. Good examples of the probable suchian (?rauisuchian) track *Brachychirotherium* cf. *parvum* and a new dinosaur-like bipedal genus are also present (Fig. 6). A skull and associated fragmentary postcranial elements and isolated cranial elements of the procolophonid *Hypsognathus* cf. *fenneri* have also been recovered (Fig. 6).

4. Five Islands to McKay Head assemblages. The Fundy Geological Museum has many examples of *Semionotus* from the McCoy Brook Formation of Five Islands. These include specimens brought in by amateurs as well as collections made over nearly 30 years by P.E.O. and other researchers. The largest articulated specimen is here as well. In addition, there are a number of slabs of tracks from the McCoy Brook Formation of the McKay Head and Blue Sac areas, including a handsome but isolated *Otozoum* pes collected by P.E.O. and Emma C. Rainforth in August 1998 from McKay Head and a slab of *Anomoepus* from Blue

Sac, the trackmaker of which patted its hands on the ground (Olsen and Rainforth, 2003) (Fig. 12).

5. Wasson Bluff Assemblage. The core of the collections at the Fundy Museum are the dinosaur and other fossils from Wasson Bluff. These comprise the largest (and possibly the only) assemblage of Hettangian age dinosaurs from North America including what seems to be multiple new species of sauropodomorph dinosaurs (prosauropods) originally shoehorned into previously known taxa, such as *Anchisaurus*, *Ammosaurus*, or *Massospondylus*, and possible theropods – all from Stop 3, Station 8. Also in the collections are partial skeletons of the sphenodontian *Clevosaurus*, the nice partial skull of *Protosuchus micmac* (all from the fluvial sandstone at Stop 3, Station 7), and numerous bones of *Protosuchus* and other tetrapods from the talus slope breccias of Stop 3, Station 3). These remains represent tetrapod assemblages that established themselves in the Fundy basin within 100 ky or so after the Triassic-Jurassic boundary and therefore represent the recovery fauna of one of the largest mass extinctions of the last 600 million years.

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Pre-conference Field Trips

A1 Contamination in the South Mountain Batholith and Port Mouton Pluton, southern Nova Scotia
D. Barrie Clarke and Saskia Erdmann

A2 Salt tectonics and sedimentation in western Cape Breton Island, Nova Scotia
Ian Davison and Chris Jauer

A3 Glaciation and landscapes of the Halifax region, Nova Scotia
Ralph Stea and John Gosse

A4 Structural geology and vein arrays of lode gold deposits, Meguma terrane, Nova Scotia
Rick Horne

A5 Facies heterogeneity in lacustrine basins: the transtensional Moncton Basin (Mississippian) and extensional Fundy Basin (Triassic-Jurassic), New Brunswick and Nova Scotia
David Keighley and David E. Brown

A6 Geological setting of intrusion-related gold mineralization in southwestern New Brunswick
Kathleen Thorne, Malcolm McLeod, Les Fyffe, and David Lentz

A7 The Triassic-Jurassic faunal and floral transition in the Fundy Basin, Nova Scotia
Paul Olsen, Jessica Whiteside, and Tim Fedak

Post-conference Field Trips

B1 Accretion of peri-Gondwanan terranes, northern mainland Nova Scotia and southern New Brunswick
Sandra Barr, Susan Johnson, Brendan Murphy, Georgia Pe-Piper, David Piper, and Chris White

B2 The Joggins Cliffs of Nova Scotia: Lyell & Co's "Coal Age Galapagos"
J.H. Calder, M.R. Gibling, and M.C. Rygel

B3 Geology and volcanology of the Jurassic North Mountain Basalt, southern Nova Scotia
Dan Kontak, Jarda Dostal, and John Greenough

B4 Stratigraphic setting of base-metal deposits in the Bathurst Mining Camp, New Brunswick
Steve McCutcheon, Jim Walker, Pierre Bernard, David Lentz, Warna Downey, and Sean McClenaghan

B5 Geology and environmental geochemistry of lode gold deposits in Nova Scotia
Paul Smith, Michael Parsons, and Terry Goodwin

B6 The macrotidal environment of the Minas Basin, Nova Scotia: sedimentology, morphology, and human impact
Ian Spooner, Andrew MacRae, and Danika van Proosdij

B7 Transpression and transtension along a continental transform fault: Minas Fault Zone, Nova Scotia
John W.F. Waldron, Joseph Clancy White, Elizabeth MacInnes, and Carlos G. Roselli

B8 New Brunswick Appalachian transect: Bedrock and Quaternary geology of the Mount Carleton – Restigouche River area
Reginald A. Wilson, Michael A. Parkhill, and Jeffrey I. Carroll

B9 Gold metallogeny in the Newfoundland Appalachians
Andrew Kerr, Richard J. Wardle, Sean J. O'Brien, David W. Evans, and Gerald C. Squires