# Internal Stratigraphy of the Jurassic North Mountain Basalt, Southern Nova Scotia

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## Introduction

The Jurassic (201 Ma, Hodych and Dunning, 1992) North Mountain Basalt (NMB; also referred to as the North Mountain Formation) forms a prominent cuesta along the southern coastline of the Bay of Fundy. These continental, tholeiitic basalt flows have played an important role in the geological heritage of the province by: (1) hosting some of the earliest mineral resources exploited (e.g. Cu, Fe), (2) contributing to the character of zeolite mineralogy (e.g. type locality for mordenite; How, 1864), (3) forming part of the Fundy Rift Basin, an important part of the Mesozoic evolution of eastern North America, and (4) filling an important niche in the aggregate operations of the province. Despite the importance of the NMB there has been relatively little recent work devoted to defining and extending the stratigraphy of the basaltic flows along the length of the Annapolis Valley and addressing some important questions that are apparent from such work. This paper is, therefore, a summary of recent and continuing efforts to establish a working stratigraphy that may be applied to the NMB, and should be considered, as such, a work in progress.

## General Geology

The North Mountain Basalt (NMB) comprises an Early Jurassic (Hettangian) sequence of basalts that formed in the Fundy Rift Basin (i.e. failed aulacogen), part of the Newark Supergroup of 16 syn-rift basins of Middle Triassic to Early Jurassic age related to the incipient breakup of Pangea. The rocks underlying the NMB are red to pale green-grey, fluvial-lacustrine siltstone and shale of the Late Triassic Wolfville and overlying Blomidon formations, whereas the overlying rocks are lacustrine limestone of the Scots Bay Formation and time equivalent, fluvial-lacustrine red siltstone and shale of the McCoy Brook Formation. Whereas upwards of 250 m of McCoy Brook Formation sediments are exposed, only 9 m of Scots Bay Formation remain as remnant inliers along the Scots Bay coastline (De Wet and Hubert, 1989).

The NMB outcrops along the Bay of Fundy in southern mainland Nova Scotia and is exceptionally well exposed along the coastline and inland along river valleys (Fig. 1). Topographic relief of the area bounding the Bay of Fundy reflects the distribution of the underlying massive basalt flows. No more obvious is this than along the Annapolis Valley area where the west side of the valley is composed of massive, fresh basalt of the lower flow unit of the NMB. The proximity of the area on the north side of the Bay of Fundy to the east-west Cobequid-Chedabucto Fault Zone has resulted in structural modifications to the otherwise simple stratigraphy of the NMB. For this reason, studies were primarily confined to relatively undisturbed sections along the southern coastline of the Bay of Fundy in Nova Scotia.

## Methodology

The present study represents part of an ongoing examination of the nature of the NMB and associated zeolite mineralization (Kontak, 2000; DeWolfe *et al.,* 2001; Kontak *et al.,* under review). The area from Cape Split to Freeport (Fig. 1) has been examined in varying detail over the past three years and, in addition, drill core has been logged and detailed petrographic and petrological studies have been undertaken. Although not reported in detail here, integration of digital elevation modeling (DEM), using the provincial database, with field-based information appears to offer promise and is currently being explored further. Collectively, therefore, the study is focused at furthering our understanding of the nature of the NMB, the distribution of the different flow units, the characteristics of these units, and the mineral and aggregate potential of these rocks. In this paper the implications of continuing work are used to

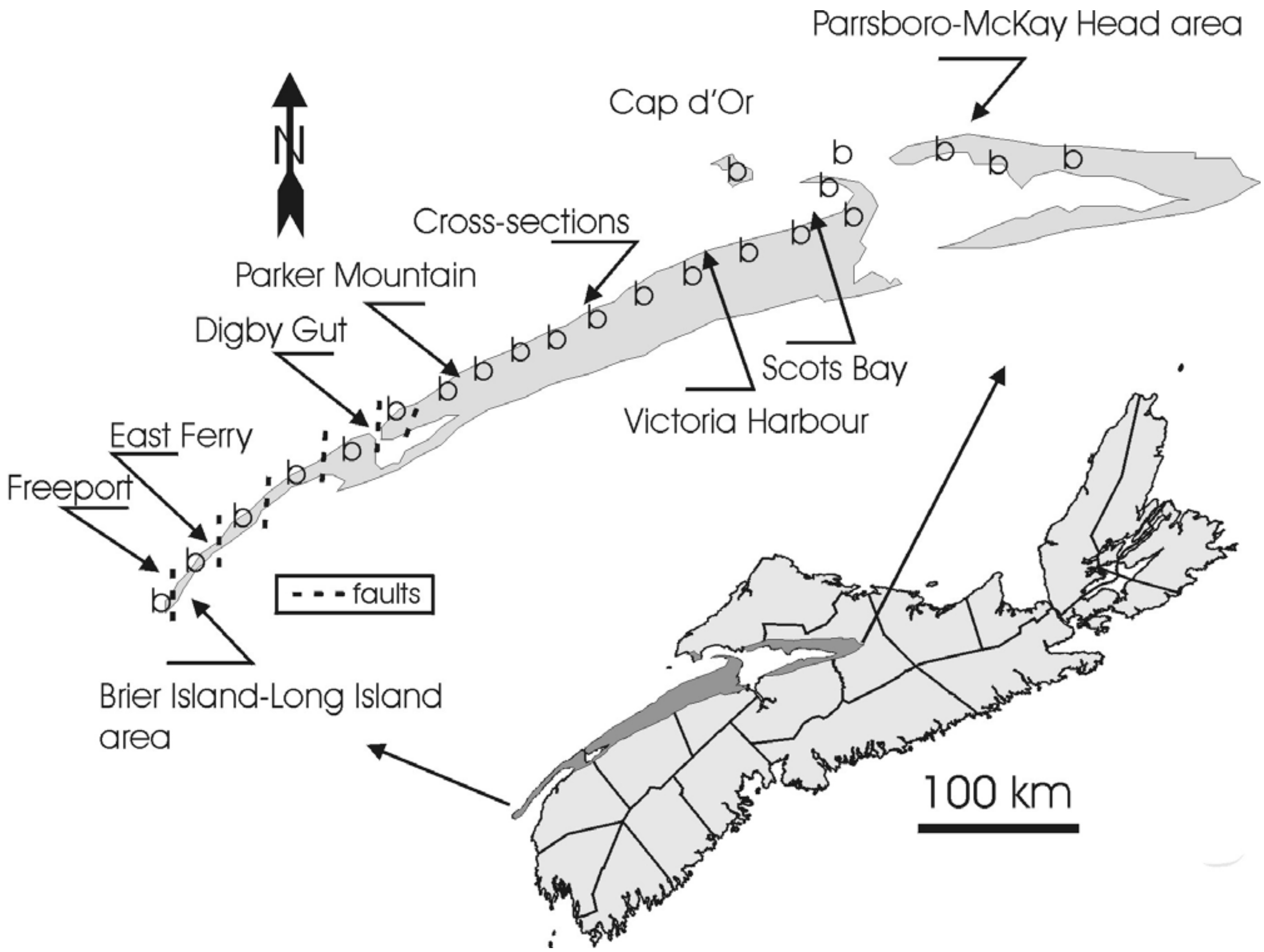


**Figure 1.** Map of Nova Scotia showing the outline of the Triassic-Jurassic rocks, with the North Mountain Basalt indicated as b symbol. The locations of relevant areas referred to in the text are indicated for reference.

examine the internal stratigraphy of the NMB, which may form a basis for further, more detailed geological studies in other parts of the unit.

## Previous Work

The regional mapping of Hudgins (1960), extending from Digby Gut to Scots Bay, provided the first detailed modern account of the internal stratigraphy, albeit based in part on earlier workers. Hudgins (1960) recognized the following stratigraphy (Table 1) for the NMB, mostly based on a measured section around the Digby Gut area.

The area west of Digby, in particular Long Island and Brier Island, was mapped by Lollis (1959) and Koskitalo (1967), with several diamond-drill holes part of the exploration work of the latter author. These authors both recognized that the NMB could be conveniently subdivided into three units based on the nature of the flows. Lollis (1959) named these units the South Shore member (SSM), Middle member (MM), and North Shore member (NSM) for, respectively, the lower massive flow, the amygdaloidal middle flows, and the upper massive flow(s). Assigned thickness were 185 m, maximum of 92 m, and 154 m, respectively, based on sections measured in the East Ferry area. More recently, Mallinson (1986) measured a section along the west end of Long Island at Freeport and integrated information from a diamond-drill hole (Koskitalo, 1967) to provide the following stratigraphy.

(1) SSM - 112 m of massive basalt.

(2) MM - four flows of 1.5 m to 2.5 m at Ronnie' Point, but seven flows of 3.3 m to 9 m in

**Table 1.** Stratigraphy of the North Mountain Basalt measured along a coastal section at Digby Gut (after Hudgins, 1960).

| Flow | Thickness | Comment |
|---|---|---|
| Top flow | 9+ m | greenish black to greyish black, columnar jointed |
| Second flow | 11+ m | greyish black, massive flow |
| Intermediate flows | 20+ m | varying thickness, fine grained, zeolite bearing |
| Intermediate flows | 51+ m | undetermined individual thickness, zeolite bearing |
| Bottom flow | 90+ m | greenish black to greyish black, columnar jointed |

drill core with maximum thickness of 41 m. This rapid change in flow number and thickness characterizes the MM, as also noted by Mallinson (1986) and observations of the writer.

(3) NSM - 61 m of massive basalt.

In addition, mapping by these authors, in conjunction with the impressive topographic profile of the land, indicated that the three-fold subdivision could be extended at least to the Digby area (Fig. 1). However, extrapolation of the stratigraphy eastward remained a problem and the present study is focused, therefore, on addressing this problem. In addition, the nature of the complex flows that constitute the MM is discussed.

The most recent mapping of the NMB was carried out by White *et al.* (1999) during regional mapping (i.e. 1:50 000 scale) of southwestern Nova Scotia. Due to the scale of this mapping, detailed subdivision of the NMB was not possible.

## Stratigraphy and General Features of the North Mountain Basalt

Based on the previous work discussed above, field observations of the writer, and additional work of Greenough *et al.* (1989), a proposed stratigraphic framework for the NMB is presented in Figure 2. In this diagram the terms lower, middle and upper flow units are used as proxies for the terms of Lollis (1959). With respect to this figure, the following points are noted, commencing from the base upwards.

(1) There is very little known about the relationship of the basal flow contact with the underlying sediments, either Triassic or older. Locally there are areas of intense bleaching and clay alteration (Hudgins, 1960; White *et al.,* 1999; D. Kontak, personal observations), but the extent and significance of such zones remains unconstrained and requires attention. An important aspect of the basement rocks to the NMB is their paleotopography at the time of basalt eruption. Given the fluvial-deltaic nature of the deposits, it is assumed that the overall landscape at this time was generally flat.

(2) The basal or LFU varies in thickness from 40 to 185 m. As will be discussed below with reference to cross-sections, this variation is real and probably very abrupt, and must relate to pre-flow, possibly structurally controlled topographic variation, despite what the nature of the basement sediments may imply in general. All previous workers have inferred that the LFU represents a single homogeneous unit. The LFU is completely exposed at Parker Mountain quarry near Annapolis Royal, where the unit appears as a uniform textured, massive, holocrystalline basalt with well developed columnar jointing and without any apparent break in the exposed section. Well exposed sections of the LFU at East Ferry (Figs. 3, 4 of Lollis, 1959) and McKay Head (Greenough *et al.,* 1989; Greenough and Dostal, 1992) display mafic pegmatite (dolerite of Lollis, 1959) and rhyolite bands in the upper part of the unit.

(3) The MFU varies in total thickness, number of flows, and thickness of the individual flows along the strike length of the NMB. In the McKay Head-Parrsboro area, the flows are consistently thicker than in the Annapolis Valley, but there are fewer

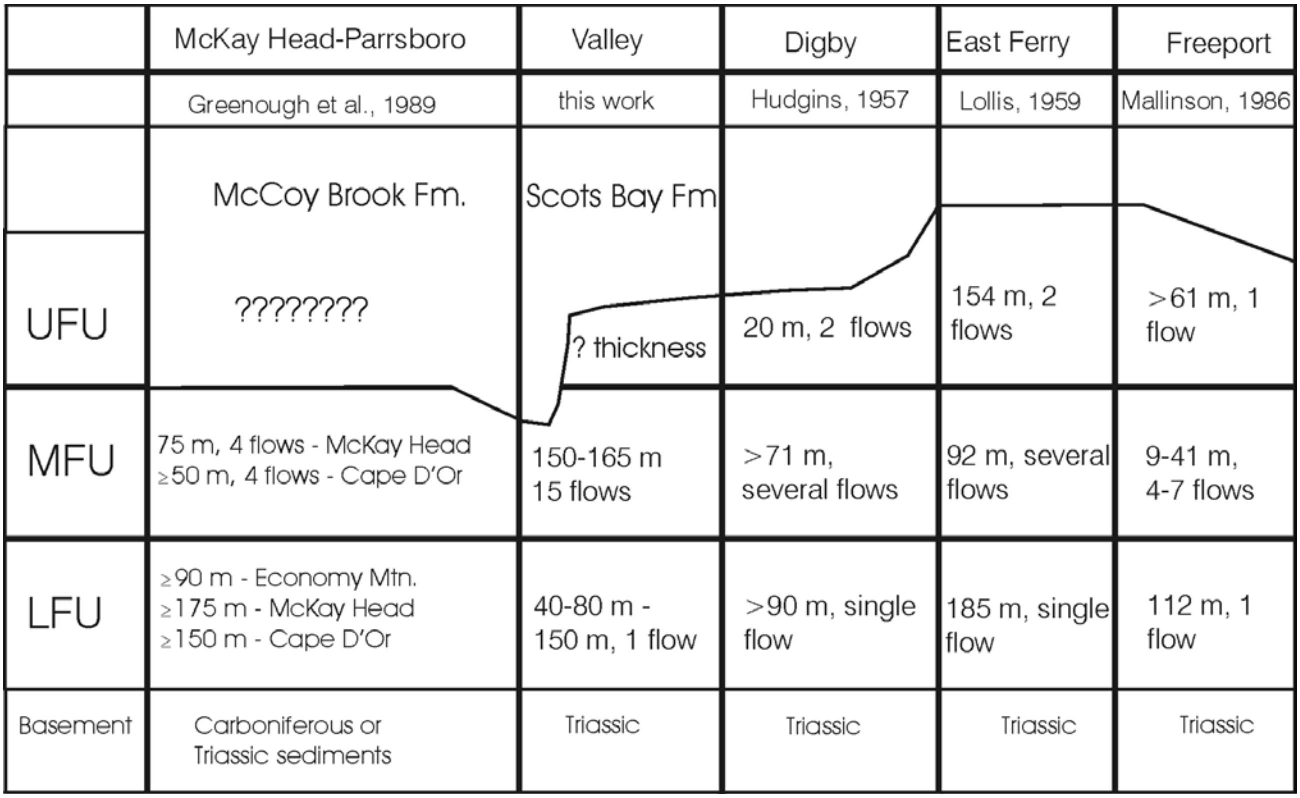


**Figure 2.** Summary of stratigraphy of the North Mountain Basalt around the Bay of Fundy coastline from Parrsboro to Freeport. Source of information for each area is indicated on the top of the section.

flows. There appears to be a thinning of the MFU toward the southwest in the Freeport-Brier Island area. The internal complexity of this unit is addressed in more detail below.

(4) The UFU is best exposed west of Digby, where the prominent ridge along the north side of Long Island and Brier Island is underlain by this unit. Exposure of this unit may relate to dextral offset along northeast-trending faults at several locations between Brier Island and Digby Gut (Fig. 1). This unit can be subdivided into a lower and upper part based on the presence of columnar jointing in the base and a more massive textured upper part with a honeycomb network of silica veins. This subdivision has been variably interpreted to represent a single flow with internal variation or two separate flows. Further work is required to reconcile this problem.

(5) There is an apparent absence of UFU basalt along the north shore of the Minas Basin and, at present, the reason for this is not really known. The presence of a disconformity at McKay Head, with a weathered veneer (<1 m), of angular blocks of amygdaloidal basalt in a silty matrix sitting immediately below McCoy Brook Formation sediments, indicates neither a structural hiatus nor an extended period of uplift and erosion prior to deposition of the overlying sediments. Thus, it is possible that UFU basalt was never present along this part of the Fundy Basin.

(6) The MFU is overlain by Jurassic sediments of the Scots Bay Formation in the Annapolis Valley area and McCoy Brook Formation sediments along the north side of the Bay of Fundy. Interestingly, in the latter area there are abundant interflow sediments and sedimentary dykes within the MFU, whereas such features are much less abundant in the MFU along the Annapolis Valley.

## Cross-sections of the North Mountain Basalt Formation

Several cross-sections (Fig. 3) traversing the North Mountain have been prepared using:

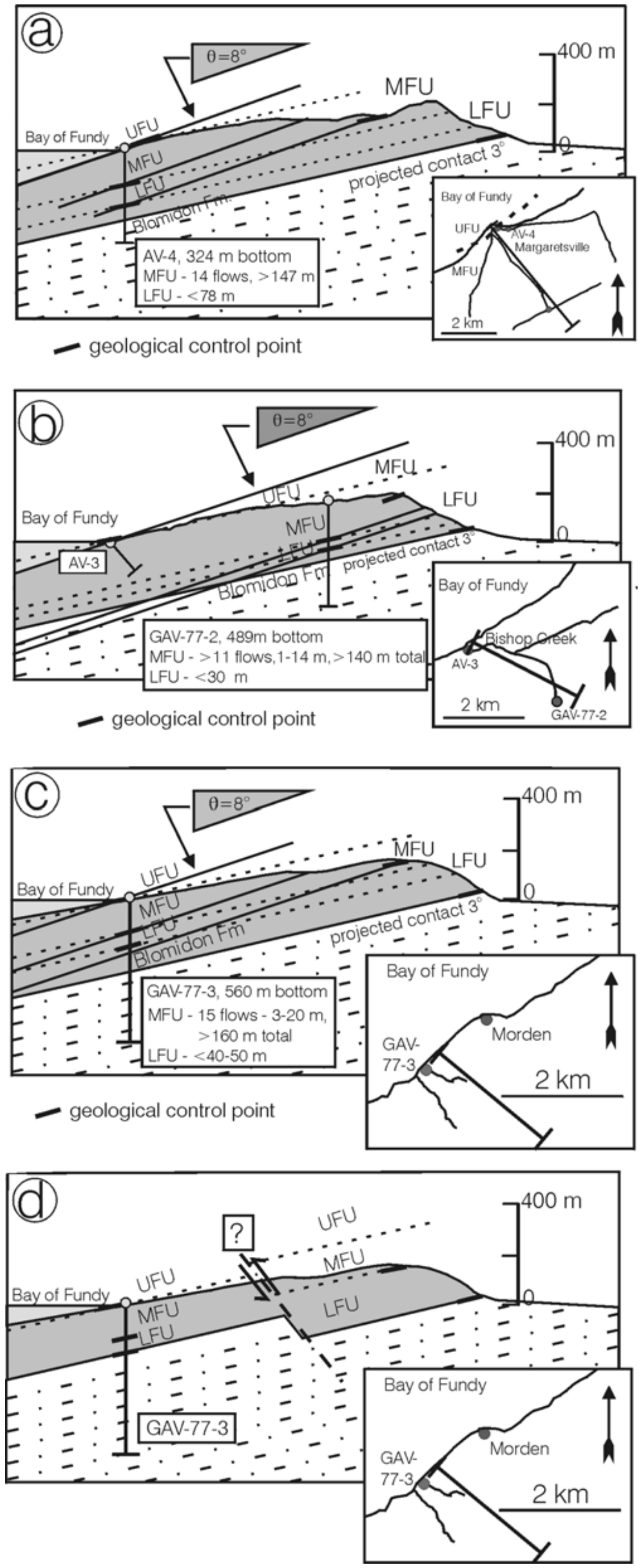


**Figure 3.** Cross-sections across the central part of the North Mountain Basalt in the Annapolis Valley area. Small inset diagrams locate the sections; see Figure1 for general locations. Sections constructed using the distribution of Triassic sedimentary rocks, outcrops along road traverses, and information from diamond-drill holes (AV-3, 4, GAV-77-2, 3). Note that the control points are indicated with short bold lines. The dip angles of 8° and 3° are used for purposes of discussion and inferring extent of the geology. Figure 3d is an interpretation of the geology of Figure 3c; note that there is presently no field evidence for the fault that is suggested as one possible interpretation of the geology.

(1) several drillholes collared in the MFU from exploration work in the 1960s and 1970s (Koskitalo, 1967; Comeau, 1978). These provide the best constraints on the regional dips of the basalt-sediment contact and internal dips between the flow units (LFU-MFU); and

(2) contacts between the UFU and underlying sediments, and between the different units of the NMB, as inferred from field relationships.

On these sections two dips have been used for extending contacts, 8° and 3°. The former dip represents a maximum for the range of 5-8° commonly quoted from observations of the flows themselves (e.g. Hudgins, 1960; Lollis, 1959; Mallinson, 1986), whereas the shallower dip of 3° is based on assumptions made from interpretation of the sections.

The following features are highlighted from the cross-sections in Figure 3.

(1) The regional dip of the NMB-sediment contact and flow unit contacts is close to 2-3°, which is much less than what is observed locally for flows themselves (see below).

(2) There is an inconsistency in the thickness of the LFU based on the inferred thickness of the exposure along the escarpment of the North Mountain (ca. 200 m) versus that determined from the drillholes (30-80 m). This inconsistency is apparent on all three sections suggesting, therefore, that there is a real variation of the unit thickness. This lateral change in thickness of the LFU on this scale was not previously recognized.

(3) The present relief of the North Mountain is attributed to the fact that the LFU is a massive, holocrystalline basalt. Had the LFU been composed of multiple amygdaloidal flows like the MFU, then the North Mountain would not be a prominent topographic feature due to its likely erosion, as has been the case for the MFU.

In order to accommodate the apparent regional variation in thickness of the LFU a preliminary interpretation of the Morden cross-section is presented in Figure 3d. It is proposed that pre-eruption faulting may have created a topographic depression of ca. 100-120 m, within which the LFU was deposited, thus accounting for its unusual thickness and textural uniqueness compared to the MFU and UFU (i.e. holocrystalline and lacking mesostasis). The extent of this northeast-trending fault feature is not known and there is no known manifestation of this in the field, or at least none that the writer is aware of. However, the presence of the fault relates to assuming that the overlying MFU is of uniform thickness to the southeast, which may in fact not be the case. If the MFU thinned out to the southeast, then the inferred displacement of the basement fault would not be required. Clearly, further work is required to resolve this dilema.

## Internal Features of the Middle Flow Unit

Mapping of semi-continuous outcrop of the NMB along the southern Bay of Fundy coastline has indicated that the MFU has a complex internal stratigraphy and flow architecture. Given that the continuity of flows is important when trying to delineate a contained resource (e.g. zeolites), several areas have been examined in detail to demonstrate this complex architecture. A view of part of such a section of the MFU at Victoria Harbor is shown in Figure 4 where several important features are noted, namely: (1) the irregular contact between flows 1 and 2; (2) the pinching out of flow 2 against flow 1; and (3) the regular dip and thicknesses of both flows 3 and 4.

The results of mapping a multi-kilometre long section of MFU basalt from northeast of the wharf at Margaretsville (Fig. 3a for location) are summarized in Figure 5. From this section the following features are noted.

(1) Five flows can be followed along strike for 3.6 km. These same flows also continue to the southwest on the other side of Light House Point.

(2) The five flows are very irregular along strike, with pinch and swell features common. In some cases, the flow pinches out completely only to later re-emerge. Flow 3 in particular does this (point 1).

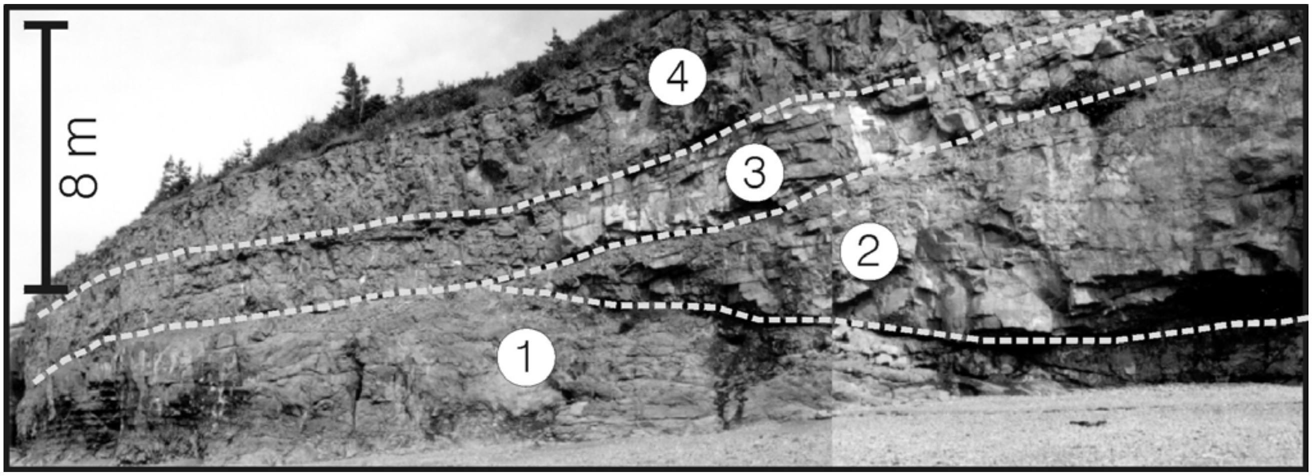


**Figure 4.** Photo mosaic of MFU flows at Victoria Harbour (facing southeast) showing occurrence of four basalt flows (numbered 1-4). Note that flow 2 pinches out to the northeast, but that it re-appears along the section.

(3) The presence of lava tongues between flows 2 and 3 (point 2) may indicate the presence of yet another flow not fully exposed in this section. These lava tongues are quite large, some 20-25 m width and 6-8 m high.

(4) Within the flows more complexity occurs, but on a smaller scale. This is best illustrated at point 3 of flow 4 where multiple thin flows constitute the unit (Fig. 6). Note that along strike this flow becomes a single, homogeneous flow with the same zonal distribution of vesicles noted in other flows (Kontak, 2001).

(5) Flow dips may be irregular (point 4), which suggests that the best indication of the overall dip is derived from the sections, as prepared in Figure 3.

(6) The north end of the section is less complex, with a consistent thickness for flows 2 and 4 that continues for several 100 m to the end of the area mapped. This consistency is similar to what is observed southwest of Light House Point, thus indicating that the degree of complexity seen in the flows of Figure 5 may be anomalous.

(7) Within any one flow there is commonly present the systematic distribution of vesicles and amygdules described for the NMB flows by Kontak (2000).

(8) Although accessibility prevented examining flow 1 in detail, it may represent the lower part of the UFU.

# Discussion and Summary

The brief description and summary of the information presently available for the stratigraphy of the NMB indicates that there is much yet to be learned about this formation. In addition, there are several outstanding problems to be addressed, some of which follow.

(1) What is the origin of the LFU? Although it has been referred to as a ponded lava (Papezik *et al.,* 1988), are alternative origins likely and is a single outpouring of lava represented? Is the regional variation in thickness related to pre-flow faulting as a consequence of crustal thinning or extension? As indicated in the cross-sections (Fig. 3), there appears to be good reason to infer the presence of a northeast-trending fault within the basement to the NMB that may run parallel to the length of the valley for an unknown distance. Additional work using digital elevation data combined with imaging analysis may reveal if this feature does exist.

(2) The MFU is laterally variable with regard to the number of flows and their aggregate thickness. This is most clearly demonstrated in the McKay Head-Parrsboro area where only four flows are present, contrasting with the fifteen flows in the Annapolis Valley. Does this indicate separate vent sites?

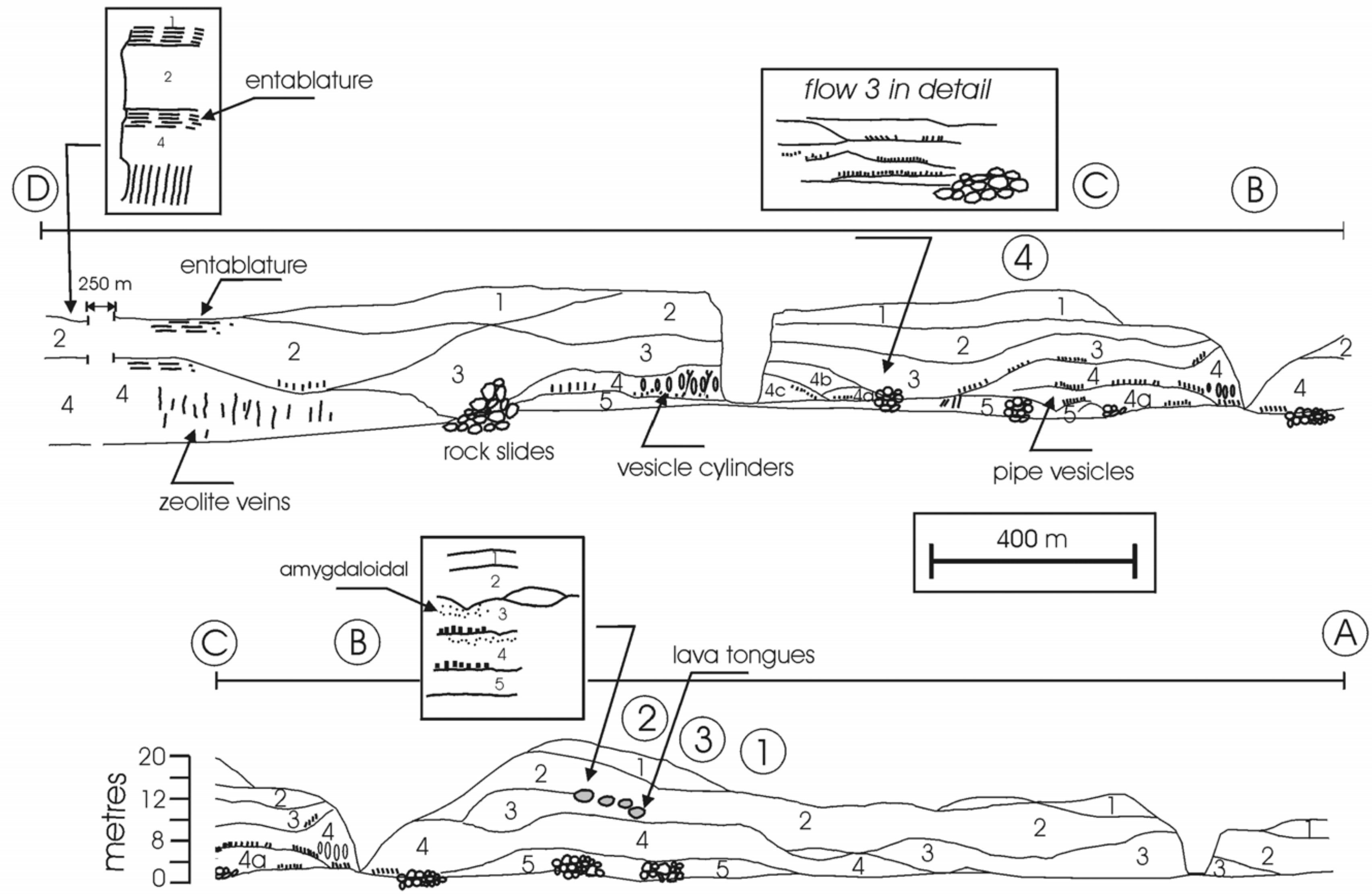


**Figure 5.** Long section parallel to the coastline from Margaretsville northeast towards Bishop Creek (between sections a and b in Figure 3) which shows flows of the middle flow unit of the North Mountain Basalt in the cliff section. Note that flow 5 outcrops extensively at low tide, but is not shown in the section. The section commenced northeast of Lighthouse Point past the wharf and a concrete retaining wall in front of a cottage. The section was generated by noting flow stratigraphy every 50-100 m along the traverse line parallel to the coastline. Note vertical exaggeration.

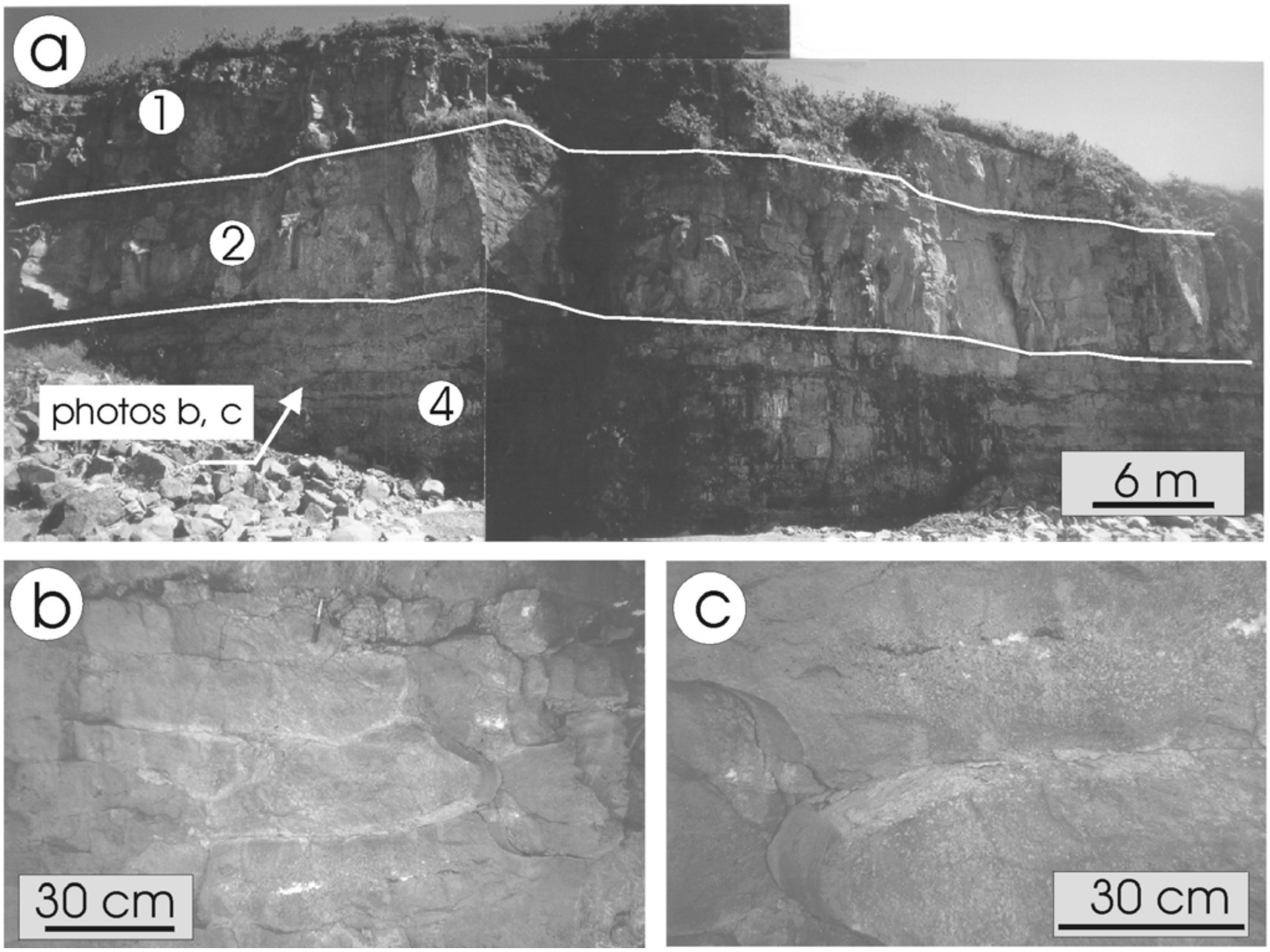


**Figure 6.** (a) Photo mosaic of MFU at point C, or station 18 along the section in Figure 5. Note the uniform thickness of flow 2 at this location. (b, c) Close up of flow 4 showing the presence of numerous, thin (i.e. 30-40 cm) flows.

(3) The amygdaloidal-rich nature of the MFU contrasts markedly with the massive and generally vesicle-free nature of the LFU and UFU. Is this feature a reflection of primary differences in melt chemistry (i.e. dissolved gas) or a consequence of different post-eruptive histories (i.e. rate of cooling, flow thickness, etc.)? If the former is correct, then it suggests multiple source magmas for the NMB.

(4) Why is the UFU absent from the north side of the Bay of Fundy? Is this a primary or erosional feature and what are the implications for both? As discussed above, it is suggested that this is a primary feature and may extend to the Scots Bay area where the Scots Bay Formation rests with slight discordance on zeolite-bearing basalts of the MFU. One obvious implication of this is that the feeder for the MFU would have to lie south of this area, which would be consistent with the apparent increase in its thickness towards East Ferry (Lollis, 1959; Fig. 2).

In order to address these problems additional field work is required, as well as integration of field studies with other techniques. For example, the extent of the MFU and UFU may be traced with the use of digital elevation model maps. The subtle changes in relief displayed in these images (Fig. 7) may relate to a change in nature of the basalt flows of the MFU, that is weathered versus fresh basalt as typifies, respectively, the red oxidized tops and more massive middle and lower parts. Similarly, it may be possible to trace out the contacts between the MFU, the LFU and UFU given the marked differences in the nature of the units. Following this work, it is hoped that a final map showing

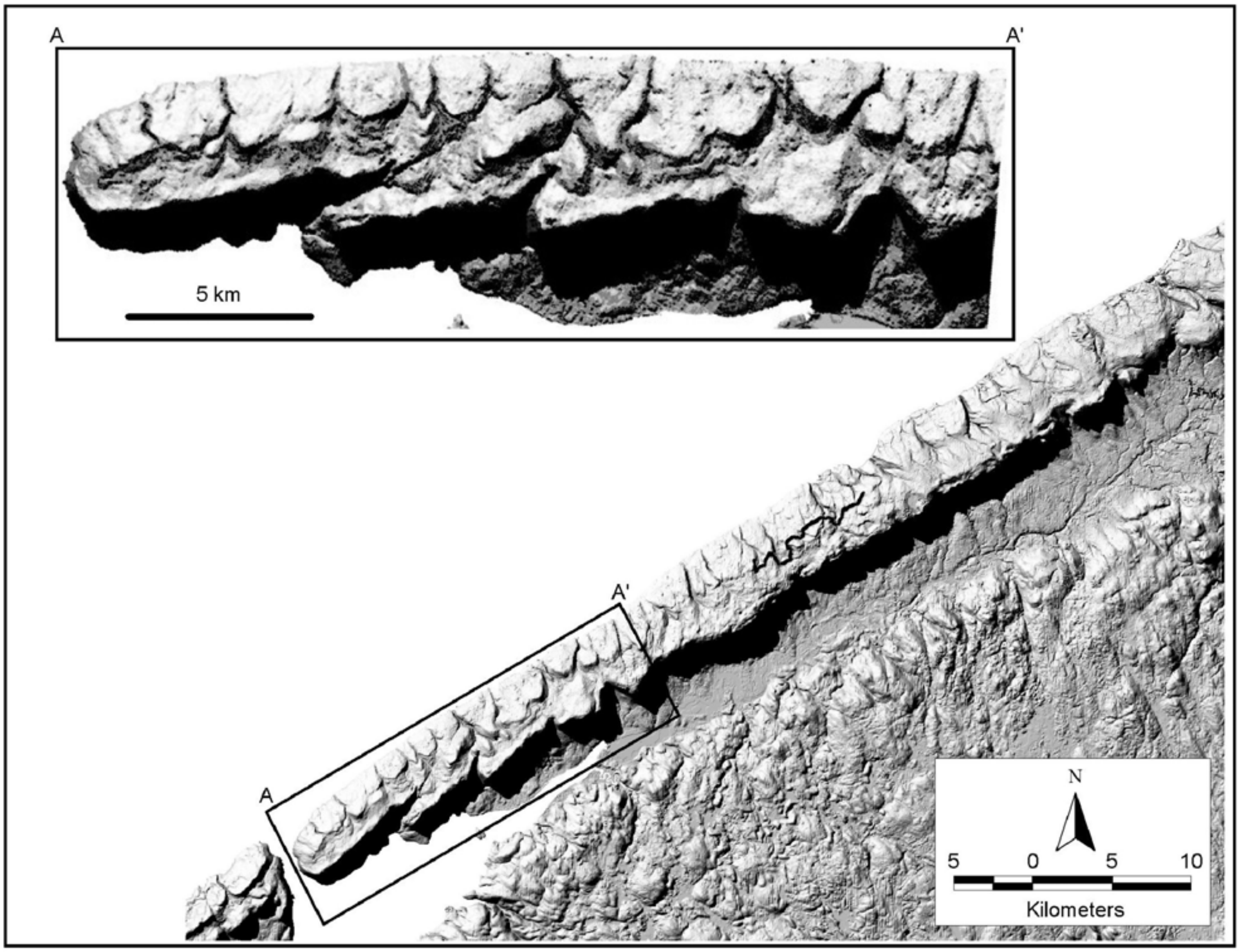


**Figure 7.** Digital elevation map with grey scale coloration of part of the Annapolis Valley region between Annapolis Royal and Digby. Note that the area northeast of Digby Gut has been enlarged to show detail. The North Mountain Basalt forms a prominent topographic feature that clearly indicates the extent of this unit. The enlarged area shows that the thick (i.e. ca. 150 m), lower flow unit is overlain by the middle flow unit and that multiple thin flows are recognizable and enhanced due to differential weathering of zeolitized flows.

distribution of the three units of the North Mountain Basalt, namely the LFU, MFU and UFU, can be produced which will have use in delineating favorable areas for occurrence of high-quality aggregate rock, zeolites, and metallic (Cu, Fe) minerals.

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