An Overview of the Industrial Mineral Potential of the North Mountain Basalt

G. Prime

Introduction

The Jurassic North Mountain Basalt is one of the youngest igneous rock units found in Nova Scotia. This hard, erosion-resistant rock underlies the North Mountain (Fig. 1), forming a protective cap that allows this upland to exist. The volcanic origin of the basalt has provided the rock with some unusual characteristics and mineralogy that make it suited to a variety of industrial applications. The hardness and impermeability of the rock permit it to be used for construction stone such as aggregate, rip rap and armourstone, all of which have played a significant role in the development of communities and the protection of coastal areas. The unusual joint patterns in the rock result in naturally shaped quarry blocks which can be used for building stone applications. A small local market for these products currently exists, but there may be greater opportunities in the export market. There is also the potential for research and development of other stone and mineral products for use in the environmental and sustainable agriculture industries. This report will review the body of research that has been conducted on the North Mountain Basalt in recent years and discuss it in the context of potential development opportunities.

Physiography and Geological Setting

The North Mountain is a prominent upland in western Nova Scotia which stretches for 200 km along the Bay of Fundy coast (Fig. 1). This cuesta generally rises steeply along the north wall of the Annapolis Valley and forms an escarpment which gently slopes north to the Bay of Fundy (Fig. 2). It has a maximum width of about 8 km in the east and tapers in the west to about 2.5 km. The mountain rises to a maximum of 225 m above mean sea level in the east and tapers to as little as 50-100 m high in the west. It has three topographic breaks that extend below sea level along its length at Digby, Tiverton and Freeport.

The mountain reflects approximately 250 million years of geological history, during which time significant tectonic movement, deposition and erosion took place. Deposition began in the Early Triassic when fissures developed along the eastern edge of North America while it was still part of the supercontinent Pangea. As the fissure system grew, a huge rift valley formed from the Gulf of Mexico to Greenland (Olsen *et al.,* 2005). Stretching and thinning of the crust at this time created a series of rift basins and sub-basins which became repositories primarily for continental sedimentary and volcanic rocks. The largest of these basins is the Fundy Basin where sediments and volcanic flows accumulated, followed by deep erosion. Today the vast majority of this remnant sedimentary basin underlies the Bay of Fundy. In Nova Scotia, however, the rim of the basin and its associated sub-basins are exposed on land along the North Mountain, the Annapolis Valley and various locations around the Minas Basin.

The oldest rocks that occur at the base of the North Mountain are redbeds exposed on its south side at locations such as Blomidon, Kings County, and The Seawall, Digby County. They comprise Triassic-Jurassic fluvial and lacustrine sedimentary redbeds composed of sandstone, siltstone, shale and conglomerate. Overlying these rocks are tholeiitic basalt flows which were deposited during a brief period in the Jurassic. Dated at 201 million years ago it is speculated that the entire 400 m thickness of volcanics was emplaced over a period of <0.5 million years (Kontak, 2003). Unconformably above the volcanic rocks is a veneer of terrestrial sedimentary rocks (limestone, siltstone and chert), which are exposed on the North Mountain in a very limited area between Baxters Harbour and Scots Bay, Kings County. Since the deposition of this more or less horizontal sedimentary/volcanic sequence, the strata

Prime, G. 2008: *in* Mineral Resources Branch, Report of Activities 2007; Nova Scotia Department of Natural Resources, Report ME 2008-1, p. 81-104.

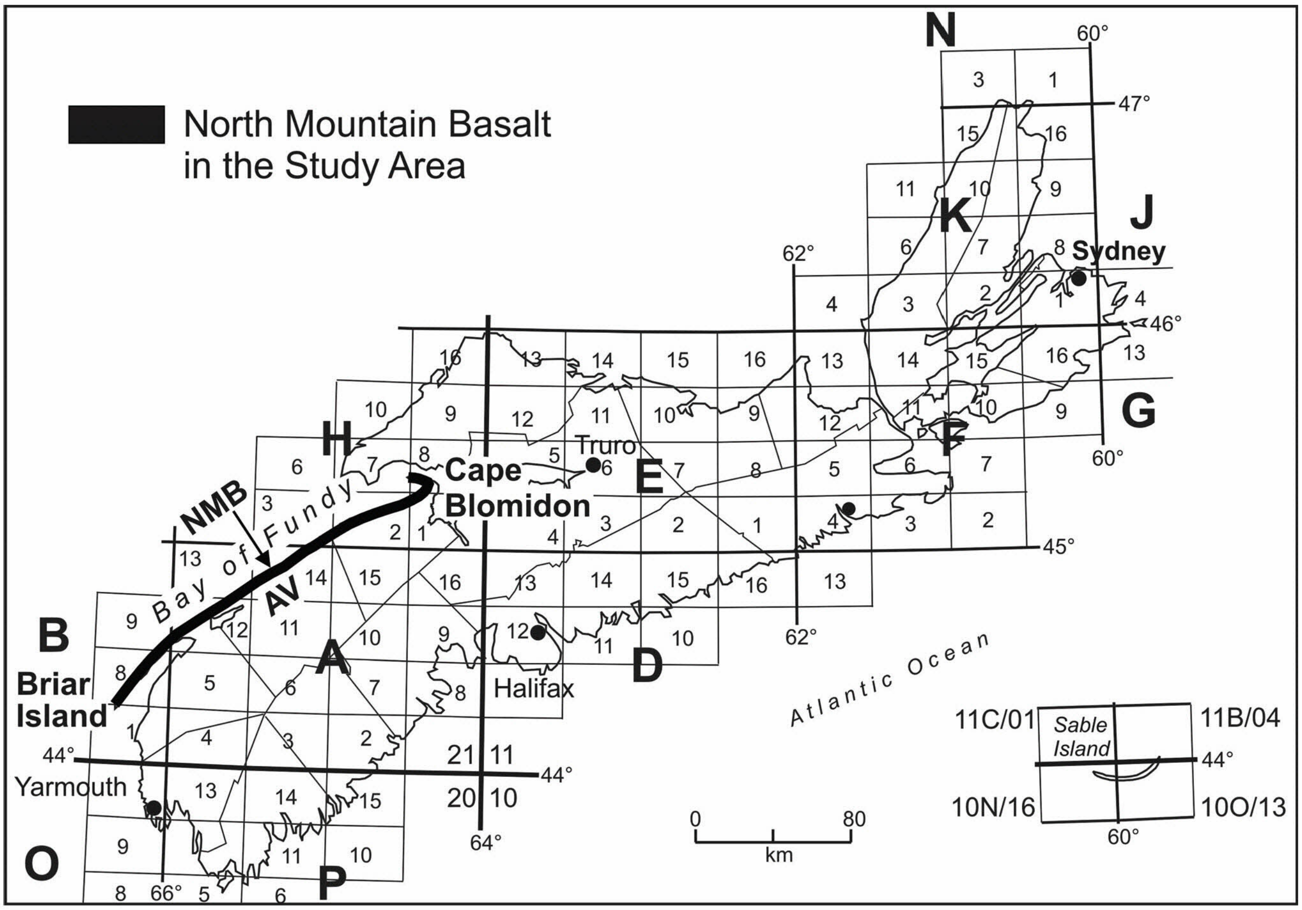

Figure 1. The North Mountain Basalt (NMB) underlies North Mountain between the Annapolis Valley (AV) and the Bay of Fundy.

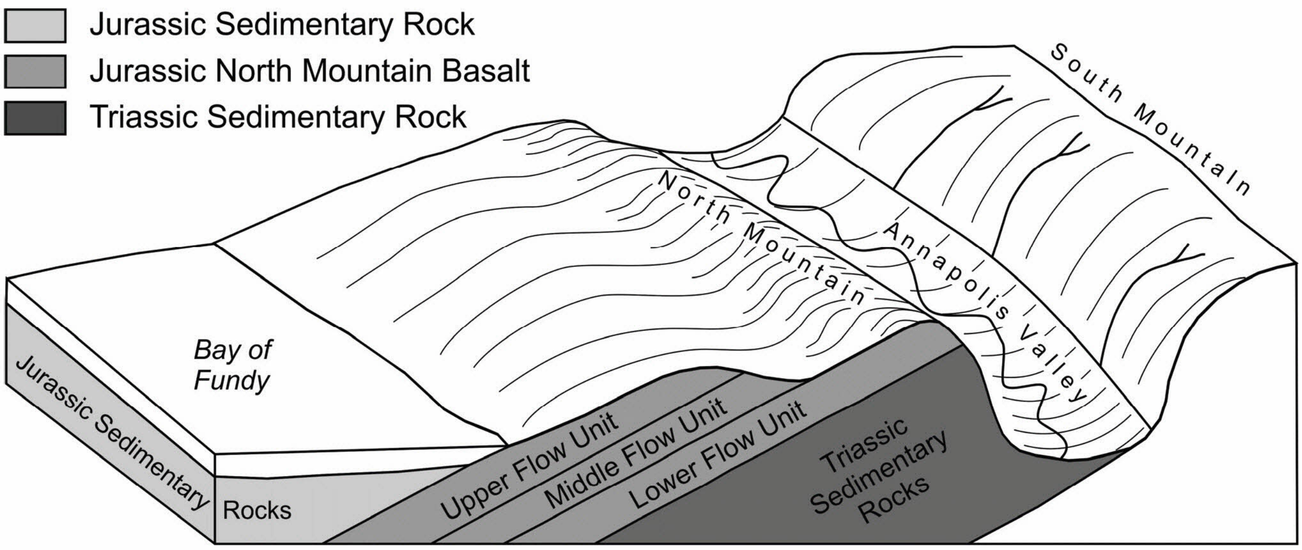

Figure 2. A schematic diagram illustrating the stratigraphy of the North Mountain Basalt. The Lower Flow Unit is exposed primarily on the south side of the mountain with the Upper Flow Unit occurring near the Bay of Fundy coast. The more easily eroded Middle Flow Unit, which commonly occurs as dips in the topography that can be detected and delineated using air photo interpretation and LiDAR DEM data (see Webster, 2005).

underlying the North Mountain have been tilted so that today they gently dip northward and under the Bay of Fundy (Fig. 2).

Although there is a major stratigraphic time gap above the Jurassic rocks on the North Mountain, the rock record elsewhere in the province, in the Bay of Fundy and on the Scotian Shelf, suggests that there may have been other periods of deposition on top of the Jurassic sedimentary rocks during the Jurassic, Cretaceous and Tertiary. The rock record on the North Mountain tells us, however, only that there has probably been a great deal of erosion in the area until relatively recent times. This wearing down of the landscape continued into the Quaternary with the activity of several episodes of glaciation over much of the last 2 million years. This erosion preferentially sculpted the landscape according to the susceptibility of the bedrock to wear.

At the end of the last glacial episode a covering of till was deposited unconformably over much of the bedrock. These unconsolidated sediments vary from a veneer to significantly thick deposits. Some areas have remained as glacially scoured bedrock surfaces to the present. During this final glacial melting more than 10 000 years ago, some of the rock debris and fines in the ice were incorporated into meltwater channels where they were sorted into sand and gravel. On land the sediments formed eskers, kame fields and outwash deposits. At the land/sea interface, deltaic and shoreline beach sand and gravel were deposited. Glaciomarine shoreline deposits that formed at sea level were subsequently uplifted following deglaciation as crustal rebound outpaced sea-level rise. This resulted in the formation of numerous raised beach deposits and erosional terraces along the Fundy coast. Over the last 10 000 years modern streams, sea-level rise and coastal erosion have modified the landscape to its present day appearance. For a detailed discussion of bedrock and surficial land form interpretation as delineated by high resolution laser altimetry, refer to the research of Webster (2005).

Geology of the North Mountain Basalt

The North Mountain Basalt consists of 400 m of continental tholeiitic basalt flows which have been mapped and divided into three units by Kontak (2003): the Lower Flow Unit, the Middle Flow Unit and the Upper Flow Unit (Fig. 2 and 3). During emplacement and solidification, these flows were subjected to variable rates of cooling, degassification and thermal contraction. In general the Lower and Upper flow units are very similar, each consisting of a thick, massive medium-grained flow which is characterized by columnar-jointed fracturing. When the molten magma was extruded and deposited as lava flows, relatively fast cooling produced contraction fractures around a series of cooling centres which have a polygonal pattern in plan view (Figs. 4a, b). As the cooling proceeded, solidification and contraction deepened into the magma flows or in a direction perpendicular to the temperature gradient. As a result these tensional joints produced three-dimensional columnar structures or elongate blocks (Figs. 4c, d). In general the columnar-jointed pillars formed vertically and, due to subsequent tilting of the strata, are observed today in a subvertical orientation. There are numerous locations in the North Mountain Basalt, however, where the columnar joints occur in inclined to subhorizontal orientations (see Figs. 6d and 6g in Kontak, 2006). The columnar jointing can be divided into two types: closely spaced entabulature joints (<40 cm) and widely spaced collonade joints (<2.5 m). Kontak (2006) observed that some quarries in the Lower Flow Unit consist of one type while other sites are a complex mixture in terms of the size of the pieces and their orientation.

The Middle Flow Unit is different from the other two units in terms of flow architecture and physical properties. It consists of numerous thin sheet flows (>16 according to Kontak, 2003) characterized by zeolite-bearing amygdules throughout much of each flow. The flows vary in thickness from 12-15 m with zoned, classic basalt flow vesicle distribution. The vesicles were formed by gas bubbles entrapped in a lava flow. Gas, due to its low density, rose to the top as molten basalt flowed out over the landscape. The highest concentration of vesicles (30-50%) are found in the upper 1-3 m of each flow, and in bubble trains or pipes (cylinders) that acted as migration channels for the entrapped gas as it worked its way toward the flow top or surface. The empty gas vesicles were filled by zeolite minerals when mineralized fluid passed through the basalt flows over an

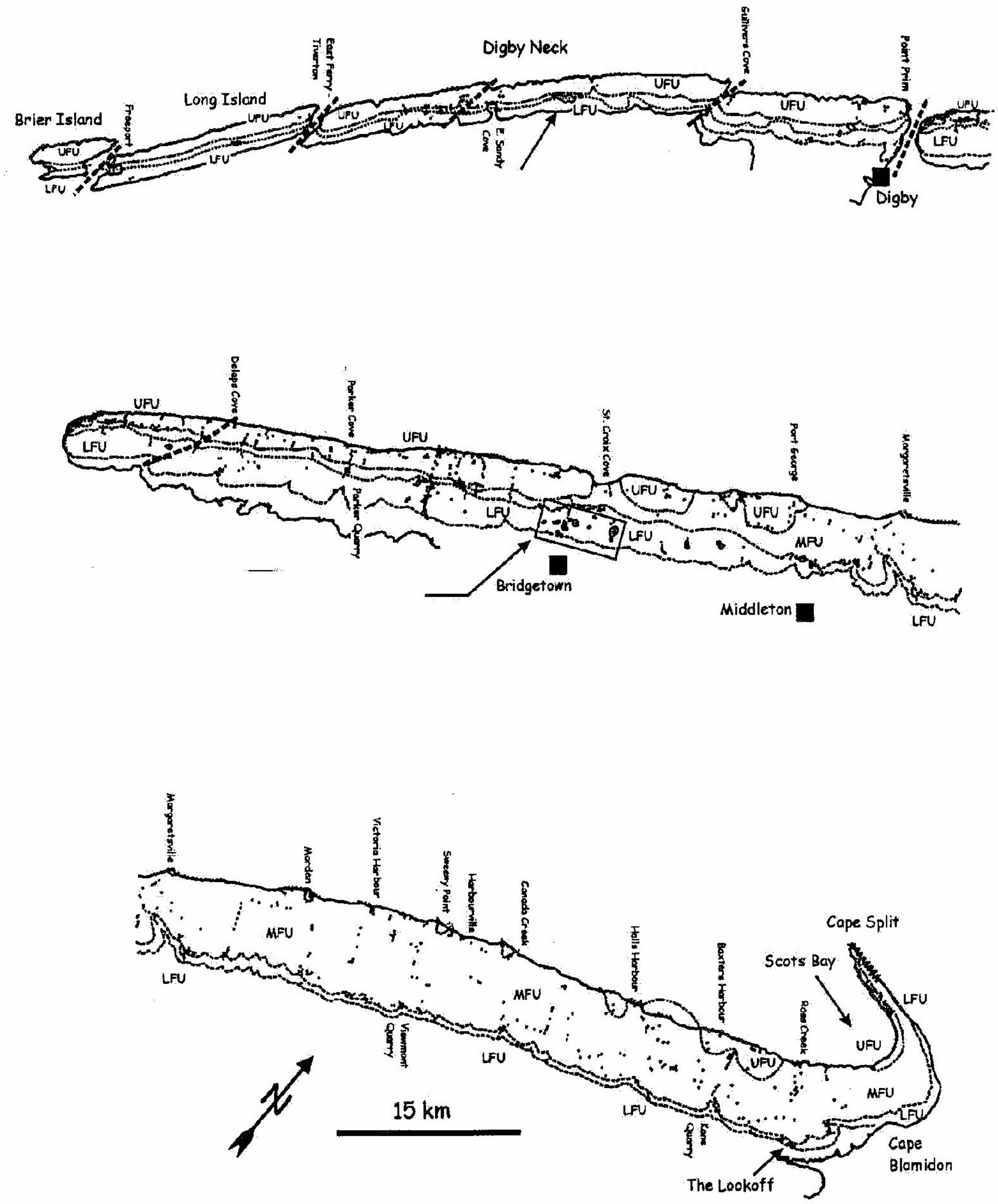

Figure 3. Geological map of the North Mountain Basalt, which is subdivided into the Lower Flow Unit (LFU), Middle Flow Unit (MFU) and Upper Flow Unit (UFU) (from Kontak, 2006).

extended period of time following their emplacement and cooling (Kontak, 2006). The round or oval shape of the zeolite-filled vesicles, the light colour of the zeolite minerals, and their crystalline textures make it easy to identify the zeolite-enriched zones in the Middle Flow Unit. Although individual flow composition and characteristics are complex, Kontak (2006) has divided a sheet flow into five distinct zones based on the distribution and features of the amygdules and vesicles. In ascending order they are (1) the chilled base, (2) the core zone, (3) the vesicular cylinder zone, (4) the vesicle sheet zone and (5) the upper crust zone. Zeolite-filled amygdules are abundant in all of the zones except the core zone, which has a massive texture. Columnar joints are rare in the Middle Flow Unit and are generally observed in the core zone. Subhorizontal joints were also observed by the author in coastal sections of the core zone. For a detailed geological description and discussion of the North Mountain Basalt refer to Kontak (2000 and 2006).

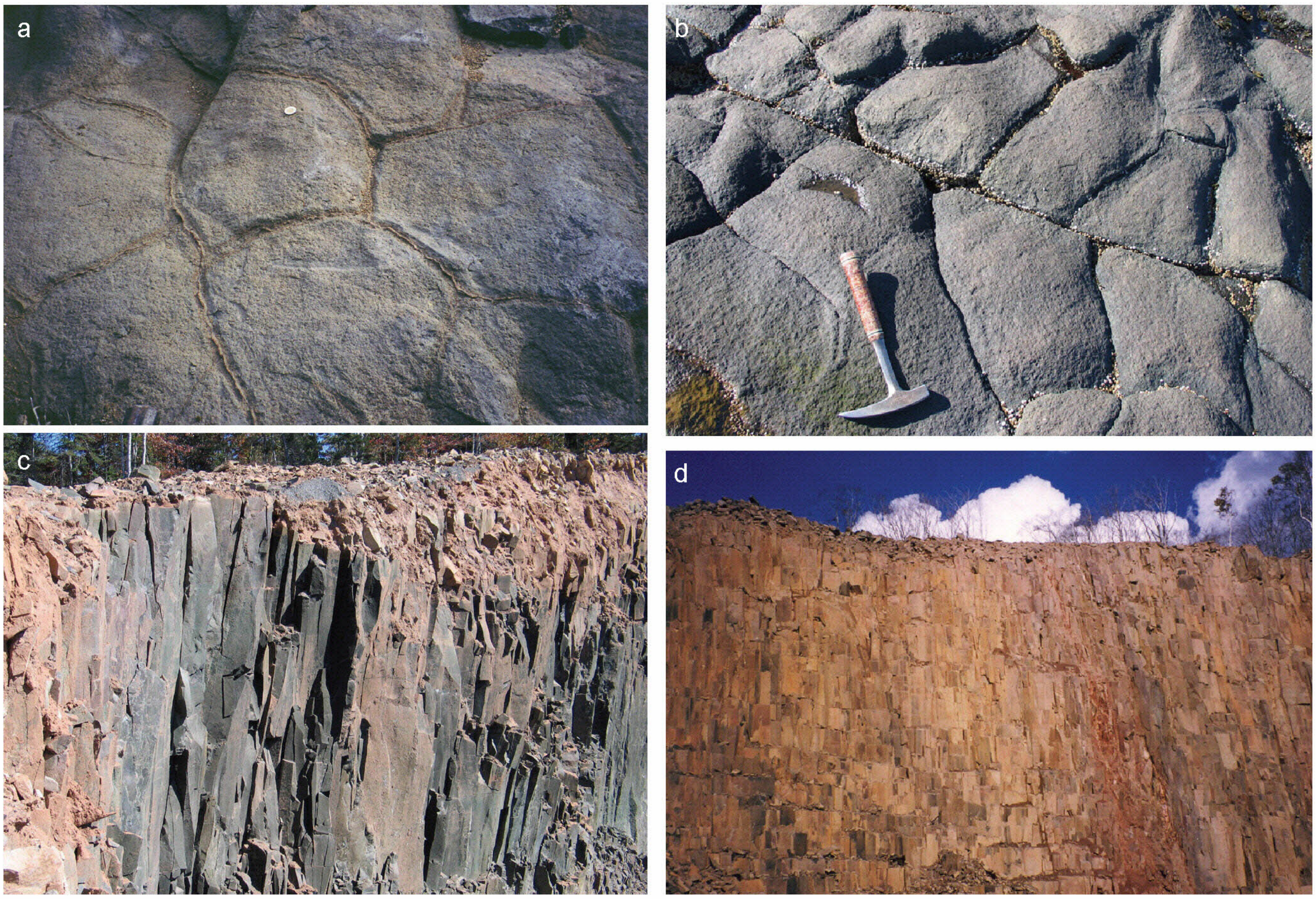

Figure 4a, b. Examples of basalt outcrop with columnar jointing in plan view. These 4-6 sided joint fractures project subvertically into the subsurface bedrock, producing polygonal-sided, elongate blocks or columns. Two dollar coin for scale in Figure 4a. **c.** A quarry face exposing approximately 6 m of columnar-jointed basalt in the Lower Flow Unit near Forest Glade, Annapolis County. Note there is no obvious subhorizontal fracture system in these rocks. **d.** Columnar-jointed basalt in the Lower Flow Unit with a subhorizontal joint fracture system. The quarry is located near Granville Ferry, Annapolis County.

Potential for Industrial Minerals

The depositional origin and composition of the North Mountain Basalt has resulted in properties that give the rocks a high stone resource potential. Depending on the flow unit this can include the uniform freshness (lack of significant alteration) of the rock, its massive fine-grained texture, its impermeability to water, the joint fracture system and an abundance of zeolite minerals. Products that have already been successfully used include bedrock aggregate, dimension stone and armourstone. Possible future uses for the basalt are zeolite products and soil amendments. Some aspects of the resource have been discussed previously by Kontak (2000 and 2006) and Prime (2005); this report will provide a broader overview of the stone resource and its implications for the future.

Aggregate Potential

Aggregate is a nonrenewable resource which is used for all aspects of construction and many specialty stone products. The primary applications include road base, bituminous concrete, Portland cement concrete and back fill. There are also many other uses, such as traction sand, mortar sand, roofing gravel, landscape stone, erosion control and pea gravel for playgrounds. Historically sand and gravel were the primary source of aggregate, which reflected the ubiquitous presence of glacial materials and their ease of extraction. Due to the depletion of glacial deposits and more demanding materials standards, however, bedrock aggregate production dominates the market today. In 2006 approximately 73% of aggregate in the province came from bedrock quarries (from Natural Resources Canada web site http://mmsd1.mms.nrcan.gc.ca/mmsd/production/2006/web06.pdf). The need for bedrock aggregate in the province will most likely continue to rise in the future.

The North Mountain Basalt is an important component of the bedrock aggregate resource. Commonly called trap rock by the industry, it has been used to produce crushed stone for several decades, as witnessed by the presence of numerous active and abandoned quarries along the mountain length. (Note: Many of these extraction sites are referred to by others as pits, but the author considers any site where bedrock materials are being extracted as a quarry.) Some of the quarries were operated by blasting the bedrock and many more sites were ripped using excavators and dozers. Under most circumstances aggregate quality can be determined by the method used to loosen and extract the stone. As a rule of thumb, bedrock that can be ripped is unsuitable for high quality aggregate because there are characteristics in the rock that cause it to be structurally weakened (e.g. abundant fracturing, soft alteration minerals or a metamorphic fabric). Conversely, rock that has to be blasted is commonly hard and durable, characteristics that are desirable in construction stone today.

The basalts are an anomaly to these rules because some of the rock that can be ripped makes durable aggregate products. This is a result of the very regular, closely spaced, columnar jointing present in some of the flows. In places where the fracture system is open, the rock is loose enough to remove using heavy equipment. This can probably only be successfully accomplished along steep slopes, such as the ridge along the south side of the North Mountain or along the flanks of deeply incised stream valleys. Although the reasons for this are beyond the scope of this report, the author speculates that this is probably related to the opening of joint fractures, which are commonly sealed by iron or silicate minerals. The edges of these ridges were probably vulnerable to the opening of the near-surface joint fractures because of the continuous pressures and vibration of ice movement along the edge of this topographic high during periods of glacial advance. Near-surface groundwater fluctuations, freeze-thaw cycles and the periodic effects of permafrost over hundreds of millennia probably also contributed to the opening of the fractures. Evidence for looseness of this rock along exposed ridges is observed in the common presence of major talus slopes (Fig. 5) along the south margin of the columnar basalts (see map of Stea *et al.,* 1992). Conversely the more gently sloping topography to the north (and away from the stream valley walls) was less exposed to the glacial forces and remained solid near the surface.

In general, the rock on the North Mountain that can successfully be used to make high quality construction aggregate is found in the columnar-jointed basalt of the Upper and Lower flow units. The qualities in the rock that make it suited to aggregate are the relatively fine grain size (medium grained or finer), massive texture and generally fresh (unaltered) mineral composition. These characteristics make the rock reasonably hard, durable and resistant to water entry and freeze-thaw cycles. Although the presence of alteration minerals can negatively impact aggregate quality, they are typically limited in the basalt to narrow zones along the columnar joints. Kontak (2006) observed that they are restricted to a 4-5 mm zone and suggests that they may consist of "silica and a red-brown alteration selvage." When columnar-jointed rock is crushed for aggregate, such a thin zone of altered materials would proportionately represent a very minor component of the materials. Furthermore, many alteration minerals are not harmful to aggregate potential. Silica minerals would most likely be hard and not have a negative impact on aggregate quality. The author speculates that the best areas to obtain the highest quality columnar-jointed rock are on top of the mountain and away from steep slopes. The rock is probably freshest in these locations, although it is acknowledged that sloped locations are currently preferred due to the economics of market proximity.

The Middle Flow Unit, on the other hand, is generally unsuitable for construction grade aggregate. This reflects the abundance of zeolite-bearing amygdules that are found in these comparatively thin flows. Although most of the

Figure 5. Basalt scree slope beside a deep stream-cut valley in the North Mountain near Melvern Square, Annapolis County. The angular stone blocks are 0.5-1 m wide.

vesicles are filled, there are also partially filled and empty vesicles as well. Collectively the abundance of amygdules causes the rock to be mechanically weakened with a propensity for water entry and susceptibility to freeze-thaw cycles. The dull to earthy appearance of some of the zeolitic rocks can also be an indicator of rock softness and poor performance as construction aggregate. These characteristics would suggest that the Middle Flow Unit is only suitable for applications where quality considerations are minimal, such as the construction of woods access roads. The exception may be the Middle Flow Unit flow sheets where the massive-textured core zones are unusually thick (5-10 m) and can be quarried without encountering the less durable vesicular/amygdular rock. It remains to be determined, however, through sampling and testing in 2008 whether or not the massive rock in the core zone is acceptable for the production of high quality aggregate. Extraction in most of the zeolitic basalt quarries has been accomplished by ripping equipment which, unlike the majority of the columnar basalt, indicates a very friable rock. The shallow nature of the quarries suggests that near-surface weathering is a significant contributor to the weakening of the stone. At 2-3 m depths the rock is relatively solid but unlikely suitable for construction aggregate. This does not apply to the massive texture zones in the Middle Flow Unit which the author speculates would, generally speaking, be quite solid and durable even at the surface. The competence of this rock in combination with a low frequency of joints and fractures would probably require blasting to quarry.

A primary concern in rock being considered for construction aggregate is the presence of the weathered zones in the North Mountain Basalt

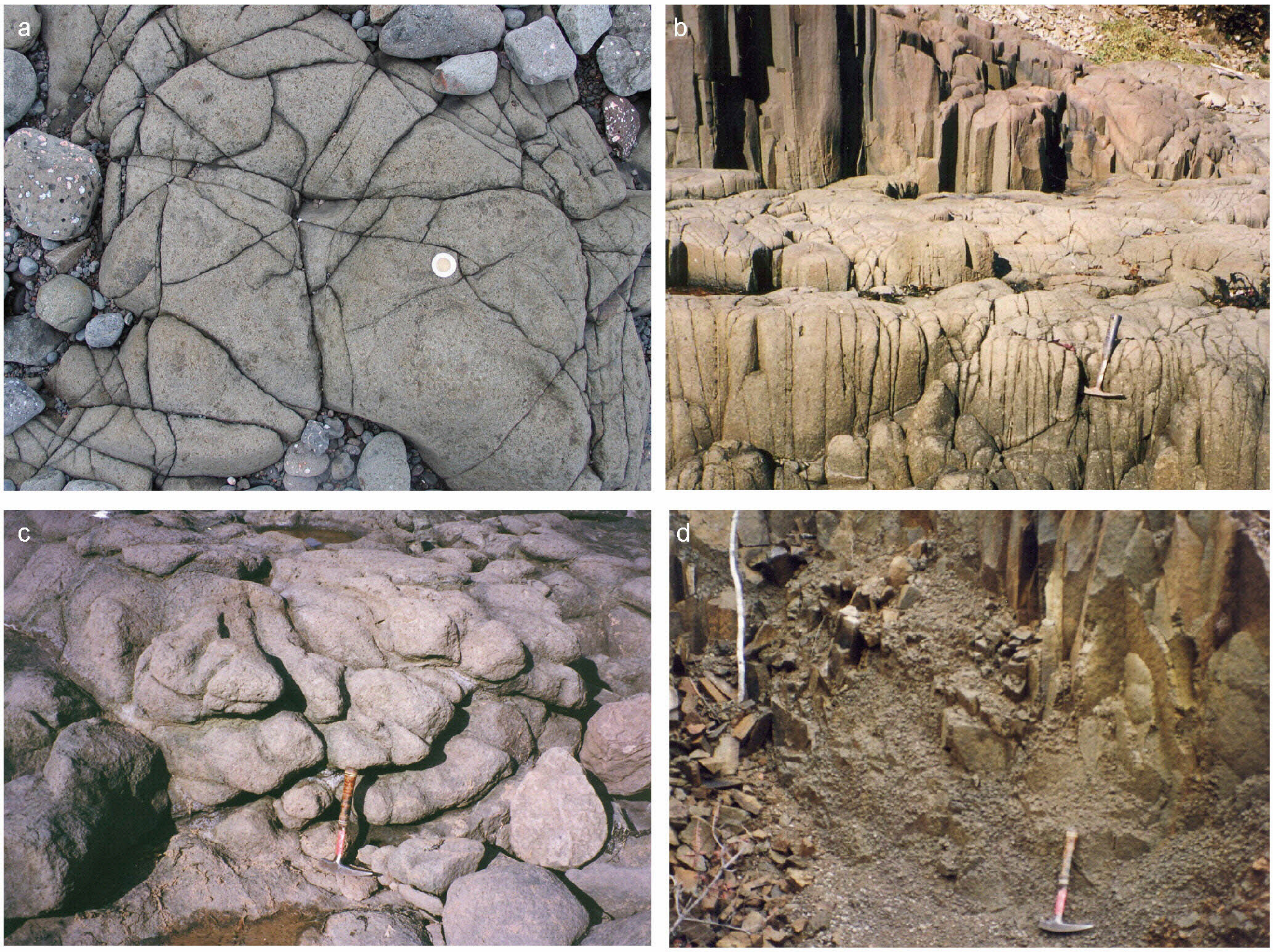

Figure 6. Various stages of weathering and precursors to weathering in the North Mountain Basalt. The precise mechanism of weathering is unknown, but it appears to be primarily related to profusely fractured rock and the voluminous water entry along those pathways. The actual weakening and disaggregation of the rock probably is a combination of the chemical breakdown of the constituent minerals and mechanical pressures such as freeze-thaw cycles over the millenia. **a, b.** Examples of highly fractured, columnar-jointed basalt in plan and side views. This rock is susceptible to water entry and weathering. **c.** Fracture-related weathering observed in the tidal zone bedrock at Cottage Cove Provincial Park, Annapolis County. The rock has been sculpted into rounded stone that eventually separates from the outcrop and produces boulders (lower right). **d.** Example of weathered columnar-jointed basalt on Long Island, Digby County, where some of the rock is very friable whereas adjacent rock appears solid.

which contain weakened stone that is friable and prone to water absorption. These characteristics negatively impact stone in most construction aggregate applications, causing the structures (e.g. highways) to perform poorly and fail prematurely. Highly weathered zones or saprolites were observed by the author in all three flow units and at numerous locations along the length of the mountain. The intensity of the weathering varies from minor effects in highly fractured but intact bedrock (Figs. 6a, b), to rock with significant weathering along fracture planes (Fig. 6c), to very friable bedrock (Fig. 6d), to classic corestone and grus deposits where the most of the rock consists of disaggregated materials lacking original bedrock features (Fig. 6g). Some of the most highly weathered bedrock observed by the author was found on Long Island and Briar Island.

Mafic rocks such as basalt appear to be particularly susceptible to weathering. Basalt clasts in till and gravel commonly have a single exfoliation shell such as observed in Figure 6h. Given that this was not observed in any other rock types in the till, it suggests that basalt is one of the

Figure 6. (cont'd).
e. Exfoliation shells in this basalt outcrop near Blomidon, Kings County, appear to be the early stages of weathering in tightly fractured bedrock. Eventually the outer portion of this rounded rock will break down to produce a small corestone similar to those observed in zeolitic basalt near Ross Creek, Kings County, in Figure 6f. **g.** Corestone and grus which appears to be in highly weathered columnar-jointed basalt of the Upper Flow Unit on Long Island, Digby County. Weathering is so pervasive that none of the original bedrock characteristics, such as fractures, remain. **h.** Exfoliation shell of a basalt clast in till. These shells are common in till and gravel basalt clasts and appear to indicate that basalt is more susceptible to weathering than other igneous rocks.

most weathering-prone igneous rocks in the province. It must be emphasized, however, that this outer rim weathering process occurs on the order of hundreds or thousands of years and would not affect an aggregate clast during its normal life span.

The cause for the weathering that produces these very friable rocks is beyond the scope of this report; presumably it is related to a combination of water access to highly fractured rock and freeze-thaw cycles. Areas of significant weathering should be avoided when looking for construction aggregate deposits. Areas of topographic breaks in the basalts should be approached with caution because the preferential erosion that has occurred there in the past can be a sign of soft rock. Similarly, many areas where the pit/quarry extraction has been accomplished by ripping may be an indicator that friable rock is present. Examining the geology of these sites for weathered stone should be a priority.

The author is currently conducting a bedrock aggregate sampling program of the North Mountain Basalt. Several samples have been tested for aggregate quality to date and the final samples will be collected for analysis in 2008. It is anticipated that the analytical results will be published in 2009.

Figure 7a. Secondary sets of hairline fractures are commonly found in the columnar-jointed basalt. **b.** The large piece of columnar-jointed rock that is positioned diagonally across the photo contains two hairline fractures: one to the left of the hammer point and the other near the right edge of the piece of rock. **c.** Plan view of columnar-jointed basalt with pervasive secondary fracturing on Briar Island, Digby County. The fractures would project subvertically into the bedrock and sub-parallel to the long axis of the column block. This degree of fracturing would be unacceptable for dimension stone applications. One dollar coin for scale. **d, e** and **f.** (facing page). Examples of the tabular, blocky, prismatic and flagstone rock that were shaped by fracture systems.

Dimension Stone Potential

Dimension stone can be defined as rock that has been quarried, shaped and finished for a variety of construction applications. This includes products used in a structural capacity, such as load-bearing walls and foundation courses, or in high end finishes where the stone is polished for products such as flooring, wall cladding and kitchen counter tops. Cut and polished stone for monuments is another important use of dimension stone. A great deal of stone is also shaped for landscape purposes such as flagstone walkways, retaining walls and stone fences. Most types of rock in the province have been used for dimension stone purposes. The ability of the rock to suit an application depends on the material specifications of the product and the knowledge of the stone mason. Desirable or required characteristics can include mechanical strength, colour, shape, texture, resistance to weathering and an absence of sulphides.

Columnar-jointed basalt, primarily from the Lower Flow Unit, has been used for many years as building stone and decorative landscape stone. Most of the dimension stone has been used in the Annapolis Valley region because of its proximity to the basalt quarries. Applications observed by the author include dry-stone (no mortar) retaining walls and fences, mortared walls and fences, fire places, chimneys and building foundations.

Although demand for the basalt as dimension stone is currently quite limited, it is the author's opinion that the market for these materials could be larger. There are several characteristics of the stone

that make it suited to the construction of stone walls and fences. First, the columnar fracturing in the rock produces elongate, polygonal shaped stone which is typically 4-6 sided (Figs. 4b, c). Between the columnar joint fractures are other heat-related fractures (Figs. 7a, b, c), which can break the columnar blocks into other shapes such as prismatic-shaped wedges, rectangular to tabular blocks (Fig. 7d, e) and thin, more or less parallel-faced flagstone (Fig. 7f). One stone mason indicated to the author that the basalt is very easy to work with in constructing stone walls. The tabular-shaped pieces and flagstone are suitable for wall corners and ends as well as laying a flat-surfaced top (Fig. 8a). Another feature of the columnar basalt that is important to building stone is that the columnar jointing commonly produces elongate blocks (>1 m in length) which can be used for tie stone. These pieces of rock are normally required when stone walls are constructed with two finished faces, separated by a space filled with waste rock or concrete rubble (Figs. 8a, b). If measures are not taken to provide a connection between the inner and outer wall, it is structurally weakened and prone to failure over time. Tie stones or bond stones placed at regular intervals are used to bridge or join the entire thickness of a wall and connect the faces along its length. These pieces not only provide structural integrity to the wall but also act as facing stone on both sides of a wall. Another appealing characteristic of the basalt is the variation in colours. The colours, including stained fracture faces and fresh stone, vary from buff to dark brown to green-black to brown-black. A quarry typically contains more than one colour of stone, which is ideal for producing visually interesting and attractive structures (Fig. 8c). Finally, the rock rarely contains sulphides, such as pyrite or pyrrhotite, which can cause unsightly rust-coloured staining in weather-exposed applications.

Although the existing market for the stone is small, there may be an opportunity to expand it in the future. This might include greater promotion in the Metro area or to the landscaping companies throughout the province. Because the basalt is unusual there may be opportunties to export the stone to other provinces or the eastern seaboard of

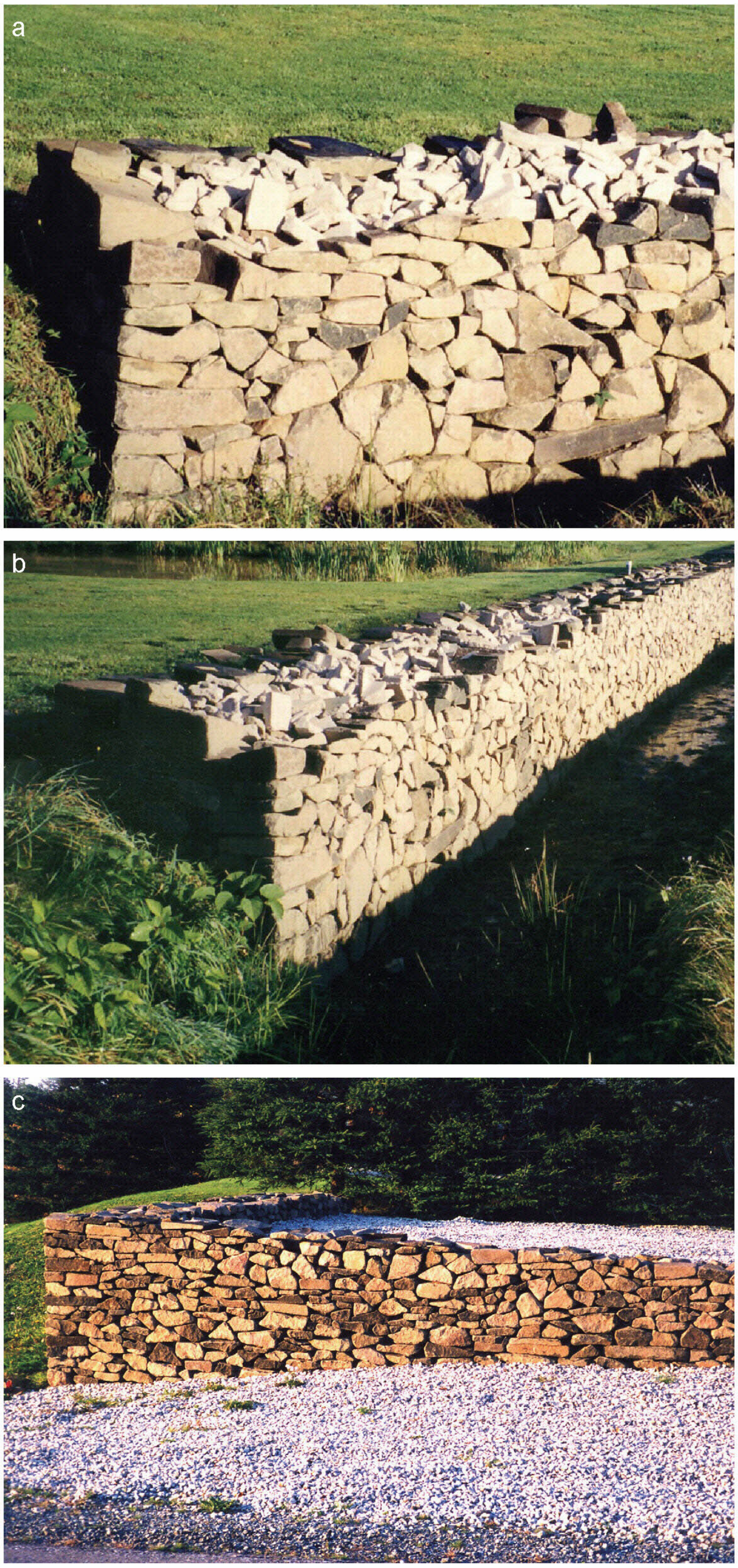

Figure 8a, b, c. Examples of columnar-jointed basalt stone walls. Figures 8a and b show a free standing dry-stone fence (in progress) with two finished faces and a centre filled with rubble. Note the rectangular shape of the corner stone and flat pieces being placed for the top course. Figure 8c is a retaining wall supporting a raised driveway. Notice the variety of stone shapes and colours in this wall as well as the rectangular-shaped corner blocks.

the United States. Many areas in the United States and Ontario, for example, only have limestone as a local product. Transportation of the rock could be accomplished by (1) trucking, (2) trucking to a rail line or (3) possibly trucking the stone to existing wharf/port facilities for barging. Because there are several quarries along the south side of the North Mountain that have the capability of providing this product, it is readily available at the present time to test these markets. A cautionary note about hauling this rock is its high specific gravity (2.8-3.0) compared to other rocks such as granite (2.6) or quartzite (2.7). This increased weight per volume of stone would add significant fuel costs to each truck load of materials. Highway weight restrictions in some jurisdictions might result in a truck not being loaded to maximum capacity.

Armourstone

Armourstone consists of large blocks of stone that are primarily used in the construction of marine and coastal defence structures. This includes shoreline erosion control, the protection of marine structures and dike lands, and providing sheltered harbours for coastal communities. There are also a wide variety of inland applications such as retaining walls, dam structures, erosion control along water courses and the protection of bridge piers and abutments. The size and shape of the blocks vary according to the application, but the large tandem and triaxle dump trucks usually only carry 2-3 boulders. Although there doesn't appear to be a standard definition for block size, according to Smith (1999) the minimum size is 0.25 tonnes(t), with some blocks as large as 20 t. The lower limit overlaps with smaller stone, which is referred to by industry as rip rap, although this term is used to describe larger blocks as well. The upper limit is largely established by geological constraints such as joint fracture spacing, although there are haulage equipment limitations as well. The blocks are typically 5-10 t for most applications. The shape of the rock can also vary from blocky to rounded, depending on the project requirements and stone availability.

Although just about any type of rock has been used for armourstone in the province, this does not mean that all rock is suited for this purpose. Many structures fail prematurely because deleterious rock was used in situations where a high quality product was needed. Finck (2007) identified stone quality as one of the primary causes for premature failure of stone retaining walls used to prevent coastal erosion. Unmetamorphosed sedimentary rocks and foliated metamorphic rock are examples of rocks that lack strength and are prone to water entry and freeze-thaw cycles. Applications where the rock is exposed to the rigours of weather and hydraulic influences, such as the tidal zone or along a river embankment, require special attention to stone quality. Marine structures in particular require rock that "must be able to withstand rapidly fluctuating and severe hydraulic pressure changes, impact due to movement, abrasion and attrition, wetting and drying, thermal cycling, and possibly freeze/thaw, salt and solution damage" (Smith, 1999, p. 293). Rocks that tend to meet these criteria are igneous and metamorphic rocks that don't contain metamorphic fabrics, pervasive fracturing or other structural weaknesses. Metamorphosed sandstone, igneous intrusive rocks and volcanic rocks are the primary sources of high quality rock.

Although not a primary source of large stone blocks in the province, the North Mountain Basalt has been used for coastal armourstone applications, such as breakwaters (Fig. 9), and preventing erosion of the dyke land (Fig. 10). Characteristics of the basalts that make them suited to the production of this product are durability and impermeability. The Upper and Lower flow units contain rock that is relatively fresh, fine-grained and impermeable to water penetration. These features permit the rock to be resistant to weathering, freeze-thaw cycles, impact forces and abrasion. Conversely, the zeolitic basalt of the Middle Flow Unit lacks durability, is quite fractured in places, and appears prone to water entry and weathering. The exception might be locations where the core zone is uncommonly thick (5-10 m). Rock falls associated with this massive-textured rock in coastal exposures suggest that the joint/fracture system may be conductive to the production of large, competent blocks. These thick core zones are apparently rare and would require expensive exploration and diamond-drilling to locate the test for armourstone potential. Although the Upper and Lower flow units have favourable mineralogical characteristics and grain textures for armourstone, the close spacing of the columnar

Figure 9. A recently constructed breakwater made from basalt armourstone at Tiverton, Digby County.

joint fractures would render much of the rock incapable of producing large blocks of stone. In general, most of the quarries of the Lower Flow Unit tend to produce stone that breaks into small elongate blocks. Conversely, the Upper Flow Unit, in spite of similar fracture systems, has been extensively used to produce large blocks for armourstone purposes.

The reason for the difference between the two units is beyond the scope of this report, but the author speculates that it may have to do with the location of the quarries in the flow units or the size of the columnar-jointed rock they contain. Quarries in the Lower Flow Unit primarily occur along the south edge of the mountain where, for reasons discussed previously, there is loosened, columnar-jointed rock along steep mountain slopes. Conversely, quarries in the Upper Flow Unit generally occur on the opposite side of the mountain where it commonly slopes gently to the Bay of Fundy. Possibly the near-surface bedrock in this area was more protected from ice, water and weather during the Pleistocene and post-glacial times. As a result, the rock encountered near the surface is less fractured and commonly produces larger, solid blocks. Another unexplored possibility is that the Upper Flow Unit contains more widely spaced columnar jointing than the Lower Flow Unit, which may positively affect the size of the blocks that can be produced. According to Kontak (2006) the widely spaced joints can be as much as 2.5 m apart. Basalt deposits containing the largest columns would most likely be the best choice for producing solid, weather-impervious armourstone.

It is not clear if high quality armourstone can be produced from closely spaced columnar-jointed rock. Due to the hazardous conditions where much of the basalt armourstone is placed, it could not be assessed for the presence of internal columnar jointing in individual blocks or examined for post-emplacement stone deterioration. The author has observed several large quarry blocks and glacial boulders, however, that contain closely spaced columnar jointing (e.g. Fig. 11). Whether or not these columnar joints in tidal armourstone would progressively open, absorb water and cause a

Figure 10. Basalt armourstone used to protect a dyke from erosion at the head of St. Marys Bay near Roxville, Digby County.

breakdown of the rock over time due to freeze-thaw cycles is unknown. The fact that at least some of the tightly jointed glacial boulders survived the forces of glaciation and post-glacial weathering suggests that closely spaced columnar-jointed blocks can be quite durable. This durability would certainly be tested by the extreme forces associated with a marine breakwater in a temperate climate. Any examination of a basalt deposit for armourstone potential should include an evaluation for tightly spaced columnar jointing and the implications it could have on the armourstone product.

Zeolites

Zeolites are crystalline, hydrated alumino-silicates that are classed along with quartz and feldspar as tectosilicates. This group of minerals consists of a three-dimensional framework or lattice of silicon-oxygen tetrahedra, where all four corner oxygen atoms of each tetrahedra are shared with the adjoining tetrahedra. Although the framework structures of quartz and feldspar are dense and tightly packed, zeolite structures are remarkably open, with significant void volumes that give them the capability of functioning as ‘molecular sieves’. This permits the selective capture of cations (based on their molecular dimensions) in lattice channels or tunnels. Cations such as Na^{+}, NH^{4+}, K^{+}, Ca^{2+} and Mg^{2+} can be loosely held in the molecular structure of the lattice and later released or exchanged for other cations.

The ability to exchange some of their constituent elements without major change of structure makes zeolites effective absorbents and ion exchangers. They are widely used today for applications such as water softeners, water purifiers, detergents, slow-release fertilizers, odour suppressants, feed additives to prevent animal disease, lightweight concrete, catalysts in the petrochemical industry, and pozzolanic materials to prevent alkali aggregate reactivity in concrete. The materials for these applications are obtained

Figure 11. A large block of closely spaced columnar-jointed basalt that could be used for armourstone. It is unknown if this piece of rock would withstand the long term rigours of a marine tidal application. Would water eventually enter these sealed fractures, causing the rock to break down over time as a result of freeze-thaw cycles? Perhaps the placement of this type of rock in a structure such as a breakwater should be avoided because of the potential of premature failure.

(1) from mines where they are extracted and processed from natural mineral deposits, and (2) as a synthetically manufactured product. Naturally occurring zeolite deposits contain a mixture of zeolite and other minerals. Separating the different minerals in natural deposits is often not possible, so companies have devised methods to synthesize specific zeolite minerals that have the properties and very high purity required for some zeolite products. Synthetic zeolites are expensive to produce, however, so natural zeolites are used in market applications where purity tolerances permit their use.

Zeolite minerals (Figs. 12, 13a, b) have been found in the North Mountain Basalt by mineral collectors for more than a century. In 1864, one of these collectors, Professor Henry How, discovered the new zeolite mineral Mordenite, which was named after the village of Morden, Kings County, where the discovery was made. Scientific interest in the zeolites has spanned more than four decades (e.g. Aumento, 1966; Donahue *et al.,* 1992; Pe-Piper and Miller, 2002; Kontak, 2000 and 2006). In the 1990s, prospector Ian Booth looked at the zeolites from a commercial, industrial mineral perspective. Ultimately his research and promotion of these minerals (e.g. Booth, 1994) encouraged C_2C Mining Corporation to stake ground and conduct an exploration program on the North Mountain. The company's work, which focused on several areas of the Middle Flow Unit, included geological mapping, diamond drilling and outcrop

Figure 12. Specimen of stilbite, a common zeolite in the North Mountain Basalt and Nova Scotia's official mineral.

sampling surveys. Quarried rock and drill-core samples were processed at local labs to separate the zeolite fractions for mineral identification and cation exchange capacity (CEC) tests. The CEC tests, which quantify how well the zeolites perform at exchanging cations, consistently showed higher levels than expected based on the visual estimate of zeolite concentrations in the basalt hand specimens. This perplexing result was examined and explained by Kontak (2000), who found that a significant component of the basalt mesostasis glass and matrix feldspars are altered to zeolite. This discovery enhances the potential of the Middle Flow Unit for future development of this industrial mineral resource. Kontak's (2006) detailed evaluation of zeolite distribution in the Middle Flow Unit will also be beneficial for quantifying the resource.

Although C_2C Mining's work resulted in a mining permit for their Stronach Mountain property, the site has not been developed to date. Recent exploration and scientific studies of zeolites on the North Mountain, however, have encouraged Department of Natural Resources geologist Garth DeMont to re-evaluate zeolite potential from the perspective of small-scale mining to address some of the environmental issues facing Nova Scotians. Possible applications include products that can be used to clean polluted waste water, to suppress unpleasant odours associated with farms and compost bins, to reduce the quantity of water required to irrigate farm fields, and to cleanse heavy metals from sewage sludge so it can be used safely as a source of fertilizer. In order to examine the potential of the North Mountain zeolites in terms of product opportunities, however,

Figure 13a. Hand specimen of zeolitic basalt typical of the Middle Flow Unit.

significant research is required. One concern that needs to be addressed is the often complex mixture of zeolite minerals that are present in the rock. Several zeolite minerals have been identified in the basalt, each of which has its own unique crystal structure, and hence its own physical and chemical properties. Characterization of the zeolite minerals in each deposit is key to describing the marketable properties of the zeolite deposit. This proposed evaluation of the resource would involve techniques such as geological field mapping, trenching and diamond-drilling surveys in order to determine the quality and quantity of zeolites available in each of the defined areas. Laboratory research would be done concurrently to characterize the zeolite minerals. This would be followed by collecting small bulk samples for use in the zeolite application field trials. Currently there are discussions between DNR and an outside research agency regarding a strategy to carry this research forward (DeMont, personal communication, 2008). If successful, these studies could have important implications for the environment as well as providing other small-scale business opportunities in the region.

Rock Dust as a Slow-release Fertilizer

For millennia traditional methods of farming used a combination of organics and other naturally occurring materials to grow crops and control pests. This changed in the Twentieth Century with the development of mechanization, chemical fertilizers and pestcides, which have permitted intensified farming and dramatic improvements in crop yields. As a result synthetic fertilizers

Figure 13b. Outcrop of zeolitic basalt typical of the Middle Flow Unit.

effectively replaced the traditional methods of fertilization. Unfortunately, there have been environmental consequences such as soil degradation and water contamination in many areas. Recognition of these concerns by environmental organizations and a growing desire by consumers to eat healthier foods has seen a resurgence of more natural ways of farming with the result that the organic farming movement has taken hold in the last few decades.

One aspect of this movement that was brought to the author's attention by an organic gardener in the early 1990s is the use of finely crushed stone powder as a soil amendment. For several decades a small group of organic farmers and gardeners have used rock dust to add nutrients to the soils for the purpose of improving crop growth while maintaining a healthy soil. The premise for these claims is that certain rock types, when finely ground and mixed with soils, slowly release elements into the soil that can be later used by the plant crops as nutrients. Although agricultural science has proven that rock dusts such as limestone, gypsum and dolomite improve soil productivity, these rock types are composed of reasonably water-soluble substances that readily break down into usable constituents in a relatively short time. The concept of using ordinary rock types (e.g. granite or basalt) for this purpose has largely been dismissed by soil scientists as 'wishful thinking'. Issues such as the low solubility of the materials and the unlikely availability of their component nutrients to the plants are some of the arguments against this idea. But proponents of the efficacy of rock dust argue that intensive farming practises using modern synthetic fertilizers only add a few macronutrients to the soil while ignoring the importance of micronutrients in plant growth and development. Decades of using super fertilizers and repeated monoculture plantings have achieved high crop yield at the expense of the soils. Through the continuous seasonal removal of biomass by harvesting the crops, there has been a selective depletion of the micro-nutrients naturally present in the soil. It has been purported that this intensive farming has depleted the nutrients to the point that some farm soils are no longer productive. In other soils it is suggested that the nutrients are naturally deficient because of the natural composition of a particular glacial deposit. By applying the dust over many years, perhaps the depleted soils could be 'rejuvenated' and eventually make the land more productive and the crops more nutrient-rich.

Interest in these materials by organic growers has reached the point that a significant industry has developed around the production of rock dust products. At the time that the author was investigating this matter in the early 1990s, rock dust products were being marketed in 33 US states, three provinces, and several other countries around the world. Attendance at a geological conference in the US around this time coincidentally included a field trip to an aggregate operation where they had recently started producing rock dust products. The operations manager at the time said that they were seeing "exponential growth" in sales year to year. Imported products such as basalt have also been sold in local garden centres in the Nova Scotia for than more than a decade.

In terms of evidence of rock dust's effectiveness as a soil amendment, there have been numerous anecdotal claims that support this premise. There are also a variety of testimonials of rock dust producing large, flavourful vegetables filled with nutrients. In terms of scientific evidence a small number of studies have been conducted worldwide over the last century on plants such as coniferous trees, turfgrass, alfalfa and corn. The results generally indicate that rock dust is effective as a supplement to or replacement for synthetic fertilizer. Although the author was somewhat skeptical of these claims at the time, the scientific evidence was encouraging. Furthermore, there was a certain intuitiveness to this concept in terms of geological principles. It is well known that some of the most productive soils contain a high proportion of clay. The flood plains of deltas such as the Nile and Mississippi Rivers are some of the most fertile farming regions of the world. Similarly, it is well known that the eruption of very fine volcanic ash in volcanically active regions can result in productive farm land a short time later.

Perhaps a similar situation could be achieved artificially by applying crushed rock dust composed of micro-particles that collectively have a huge surface area and possibly an enhanced capability of releasing nutrients to the plants. As a result the author promoted the concept to industry which lead to in a federal-provincial funded study being conducted by Coastal BioAgresearch Ltd. (Termeer, 1996). The focus of the research was an examination of waste fines generated in pits and quarries to determine if they could be used for slow-release fertilizers. Three sources of rock from quarries in the western region of the province were selected for examination. The solid rock from granite, quartzite (formally called metagreywacke) and basalt quarries was ground into a powder of a texture similar to refined baking flour and added to soils under green house and field conditions. The dust was also mixed with compost to make a synthetic topsoil and tested under the same trial conditions. The results of the research are very encouraging. The report states: "Rock dusts have a very low level of extractable nutrients compared to conventional sources of fertilizer. Yet, this project clearly demonstrated that application of rock dusts to soils can increase crop yields." The report went on to say that "Unprocessed aggregate fines can be used to blend an 'artificial topsoil' by adding organic matter and sand, depending on the aggregate fines characteristics. Since aggregate fines tend to have a higher nutrient extractability than agricultural soils, topsoil produced from aggregate fines will have a higher fertility status" (Termeer,1996, p. 1).

Although this was a relatively small, short term research project, the author is encouraged by the results. Furthermore a survey conducted by the company of organic farmers at the time suggested that they were quite interested in this product and would use it if it was locally available. In order to prove that rock dust is effective as a soil amendment it is the author's opinion that it would take 5-10 years of research. This long term commitment would help determine if the soils are gradually improved over time, perhaps as a result of weathering and the further break down of the dust particles in the soil. The field trials might involve fines from several different rock types, different size fractions of the dust, several different crops and applications on more than one soil type.

Based on an examination of the research by others, mafic rocks such as diabase and basalt have been the primary choice for rock dust experiments. It is the opinion of the author that the North Mountain Basalt is the best choice in Nova Scotia for the continuation of this research. The columnar jointed rock was used in the Coastal BioAgresearch study, but zeolitic basalt, with its cation exchange capacity, may be an even better choice as a slow-release fertilizer. Although there is no rock dust research being contemplated at this time, the environmental benefits of such studies have intriguing possibilities. If some of the synthetic fertilizers could be replaced by more benign, natural replacements, there should be a reduction of contaminants in water courses and underground aquifers. This would have human health benefits and help mitigate the eutrophication of streams and rivers in intensely farmed regions. There is also the possibility of increasing yields and nutrient values in the crops. Application of the dust to marginal soils (e.g. coarse gravelly tills) may eventually upgrade the soils to more arable farm land for the future. It's possible that the long term use of these benign materials may also contribute to a more sustainable approach to farming in the province. There may also be small-scale business opportunities to manufacture fertilizer products for the local organic market and possibly as an export to the United States. It is conceivable that a line of rock dust products blended from a combination of rock types could be tailored for specific crops and soil conditions. Perhaps zeolitic basalt dust or coarser stone (sand-sized?) materials could be combined with synthetic fertilizers so that some of the nutrients of the chemical fertilizers could be retained and slowly released due to the cation exchange capacity of the zeolites. The possibilities of this simple concept are significant, but the research would be expensive and require a long term commitment to adequately determine if it has any merit.

Discussion

Quarrying on the North Mountain has been the topic of much controversy at various times over the last two decades. The most recent example was the failed attempt to establish an export quarry at Whites Point on Digby Neck. At issue were a number of concerns regarding the impact a quarry would have on tourism, the fishery, whale habitat, land values and quality of life. Press coverage suggested that the proposed quarry was "an assault on the physical integrity of Nova Scotia" (Surette, 2006). A Private Members Bill proposing the moratorium of aggregate export from Digby Neck was also introduced to the Nova Scotia legislature (Theriault, 2006). Interestingly, in spite of the relatively modest size of the development proposal (in terms of a mining operation), the controversy received national attention on the CBC radio show Ideas and in the magazine *The Walrus* (Richler, 2007). Ultimately the decision by the Federal-Provincial Joint Review Panel authorized by the Canadian Environmental Assessment Agency was to reject the quarry based on issues such as core community values and environmental concerns. The panel also recommended the implementation of a coastal zone management strategy and a moratorium on new quarry developments until a more comprehensive set of guidelines is in place.

Although the author is cognisant of the sensitivities of communities to heavy industry such as quarrying in the region, it also has to be recognized that mining is one of the cornerstones of the rural economy. During the fieldwork phase of this report the author listened to quiet support for the Whites Point project by area residents concerned about the state of employment in the region. Beyond the direct benefits to quarry employees there are many support industries that interact with, or benefit from, aggregate operations. This includes trucking, equipment sales and road builders, to name a few. Ensuring the continued viability and long term success of this industry should be a goal shared by the producers, governments and communities.

In addition to being contributors to the economic prosperity of the region, quarries also are the source of basic construction materials that are strategic to the growth and functioning of communities. High quality aggregate is necessary for all aspects of construction and infrastructure development. But much of the region, such as the lowland areas and Annapolis Valley floor, are underlain by soft sedimentary rock that is not suitable for the production of construction aggregate. Even the North Mountain Basalt contains a mixture of rock units, much of which will not meet high quality material standards. One might suggest getting the stone from elsewhere, but this can be impractical and costly for the community and the environment. Some of the rock on the South Mountain (to the south of the Annapolis Valley), for example, can also be used for aggregate and armourstone. But this is only effective and reasonable where these quarries are closer to a construction site than North Mountain Basalt quarries. This reflects the high haulage costs of these heavy, bulk materials, which must be obtained as close as possible to the site of their intended use. For an appreciation of the effects that haulage distance has on the price of the landed aggregate, refer to stone haulage rates paid by the province for highway work (Nova Scotia Department of Transportation and Infrastructure Renewal, 2007). Proximity of the source also has environmental implications because of the amount of fossil fuels consumed and air emissions per tonne of stone delivered. For a complete discussion of these issues refer to Prime and Bonner, 2007.

Many of the mining opportunities suggested in this report may benefit other aspects of communities, such as the environment. Perhaps research will show that zeolites can be used as an odour suppressant in composting and livestock farming, or for removing harmful metals from sewage sludge. If zeolitic basalt rock dust can be used as a slow-release fertilizer in organic farming, or as a partial substitute for synthetic fertilizers, it may make an important contribution in the direction of sustainable agriculture. A major research initiative would be required to determine the efficacy of these poorly understood or largely untested concepts.

If the new products are determined to be effective, there is the possibility of extracting and processing the materials using small-scale mining methods and confining the operation to a relatively small area (Garth DeMont, personal communication, 2006). Perhaps the zeolite and rock dust products could be produced from existing zeolitic basalt quarries in the Middle Flow Unit, thus minimizing the number of new quarries in favour of using historic sites where the land has already been disturbed. Garth DeMont (personal communication, 2006) suggested the possibility of combining zeolite and dimension stone or aggregate production from a site that occurs at the contact between the Middle Flow Unit and the Upper or Lower flow units.

In terms of aggregate, much of the rock of the Upper and Lower flow units of the North Mountain Basalt has properties that make it suited to the production of construction grade stone. From a geotechnical perspective the best materials may occur on top of the mountain, where the rock has a greater likelihood of being fresher near the surface than along the sloped mountain walls. Another advantage of these areas is a matter of view planes. One of the common complaints of communities throughout the province is the visual impact of quarries located on mountain slopes. In the interest of community acceptance, future quarry applicants may want to consider the benefits of a visual barrier to the quarry where possible. The siting of a quarry operation should always be done, if possible, with the neighbours in mind.

Rip rap and armourstone, which protects wharves and shorelines along the Bay of Fundy from storms, can only be produced from high quality stone found in upland settings such as the North Mountain. The soft sandstone, conglomerate and mudstone found in the lowlands would fall apart if quarried and used in a high energy, weather-exposed environment such as the shoreline. The need for the armourstone in the region will only increase as sea levels rise. Recently expressed concerns over the potential future flooding of historic Annapolis Royal and the need for infrastructure upgrades to prevent such a disaster (Flinn, 2008) highlight this need. If these preventive measures are taken, stone would most likely be the primary component of the work (e.g. aggregate, armourstone and concrete) and would have to be obtained nearby. So, ensuring future access to all of these vital construction materials should be part of the dialogue in any coastal protection and management strategy.

Finally, it should be emphasized that industry, communities and individuals have a shared interest in continued quarrying on the North Mountain. These stone resources are vital to the development of the communities, employment and tax revenue in the region. There is also a shared responsibility in ensuring that the extraction sites are kept clean and protected from the public. Although pit and quarry regulations adequately oversee recent quarry developments, there are a host of older sites where issues such as ponds and unstable quarry walls continue to be a problem in terms of public safety. Openly accessible sites also can become the receptacles for garbage and pollutants, which can quickly and permanently damage underlying aquifers. The same applies to the use of a former quarry by the land owner for storing derelict automobiles and other machinery. Proper protection of the sites from misuse and public access should be the goal of the entire community. The future of industrial mineral mining on the North Mountain will require thoughtful planning to ensure that these vital resources remain accessible for the public good.

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