Bedrock Aggregate Potential of the Meguma Group

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Introduction

Bedrock Aggregate Potential

The primary focus of the Aggregate Program over the last decade has been the western half of mainland Nova Scotia (Fig. 1). This research has consisted of bedrock studies in the Halifax Regional Municipality (Prime, 2001; Prime and Bonner, 2007) and a bedrock and surficial study of the Annapolis Valley region (e.g. Prime, 2000, 2005). Most recently, a province-wide study has been initiated to evaluate crushed stone potential using a detailed geoscientific approach (Prime and White, 2004, 2006), with the initial work being conducted along the South Shore. Although all aspects of the aggregate resource have been examined during this period of time, detailed research has tended to focus on bedrock aggregate potential.

The focus on bedrock aggregate reflects a growing demand for quarried stone by the construction industry, and decline in the use of

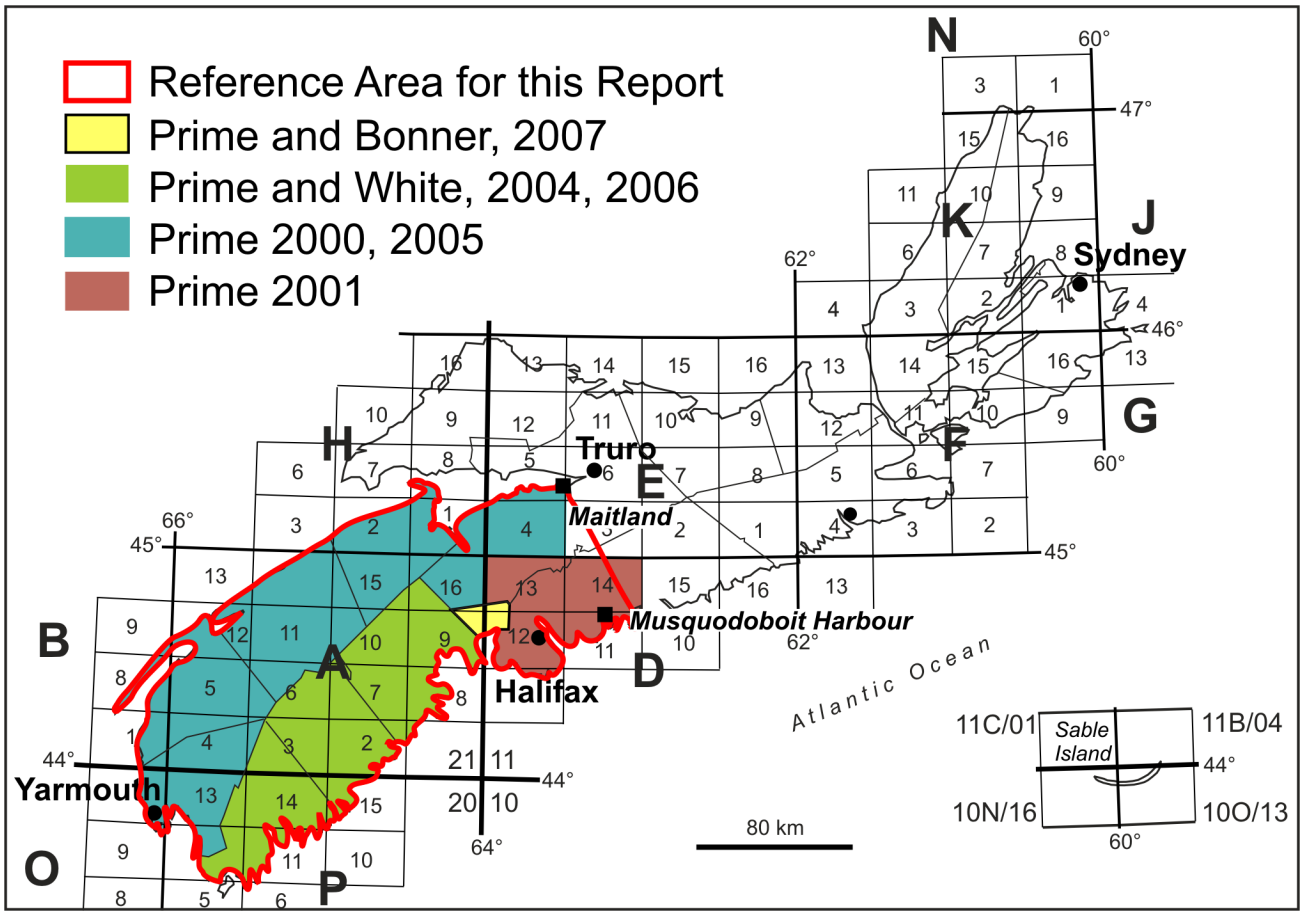

Figure 1. Recent bedrock aggregate studies by NSDNR in western and central mainland Nova Scotia. This report summarizes the Meguma Group component of this research.

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glacial sand and gravel throughout the province. A comparison of the Mineral Resources Branch's most recently published annual production data (for 2003) with data from two decades earlier dramatically illustrates this shift. In 1983 sand and gravel represented 70% of total aggregate production (Nova Scotia Department of Mines and Energy, 1984) whereas the 2003 data show the trend to be completely reversed, with 66% of production coming from quarries (Nova Scotia Department of Natural Resources, 2006). This shift reflects a number of factors, but the primary considerations are: (1) depletion of glacial deposits in many areas of the province, (2) tightening of materials specifications, and (3) only quarried stone will meet these increasingly demanding standards.

Meguma Group Bedrock Aggregate Research

An important component of the bedrock research discussed above has been the evaluation of rocks in the Meguma Group. This reflects the ubiquitous presence of this rock unit in the western half of mainland Nova Scotia and the significant role that it has played in aggregate quarrying. This report summarizes aggregate potential for the Meguma Group. The focus of the discussion will be the area to the west of Maitland, Hants County, and Musquodoboit Harbour, Halifax County (Fig. 1). The conclusions, however, are applicable to all Meguma Group rocks.

What Makes Good Crushed Stone Aggregate?

Before reviewing the aggregate potential of rocks in the Meguma Group, the following discussion will briefly examine the characteristics that tend to make high quality aggregate. In general, rock produces good construction stone if it is competent, durable and resistant to weathering. Competence and durability refer to the aggregate particles' resistance to mechanical stresses, such as impact forces, compression and abrasion. This relates to the internal strength or cohesiveness of the rock generally attributed to bond strengths between mineral crystals or the cements binding the grains (e.g. sedimentary rocks). Other features that can affect the strength of the rock include vugs, microfractures, bedding plane weaknesses and metamorphic fabrics. Durable rock resists impact forces and abrasion associated with the grinding of adjacent stone particles. An example would be a highway where there is a high frequency of heavy truck traffic continually stressing the flexible asphalt pavement surface and the unbound stone of the roadbed below. These loads transfer tens of tonnes of weight from a loaded truck to the road via the small surface area of 10 or more tires contacting the pavement. If the rock lacks durability the repeated load forces and abrasion will eventually cause the structural breakdown of the asphalt and/or the road bed.

Resistance to weathering is a measure of characteristics that prevent water entry and the expansion and contraction associated with freeze-thaw cycles. This includes properties such as porosity, permeability and absorption. Features such as void spaces between sedimentary grains, vugs, microfractures, bedding plane weaknesses and metamorphic cleavage planes can be conduits to water entry and cause volume changes in the stone during freeze-thaw cycles. Soft clay minerals, such as kaolinite, can also soak up and retain water. Repeated expansion and contraction of susceptible stone during the freeze-thaw cycles can cause the premature weathering or breakdown of the aggregate particles. In the surface layers of asphalt or Portland cement concrete, the aggregate particles can disintegrate or become dislodged from the pavement as 'popouts' during episodes of stone expansion. The voids created in the pavement become areas of structural weakness which can cause it to ravel (i.e. break apart one piece at a time) and produce pot holes.

Collectively these physical characteristics determine whether or not the rock will be satisfactory for construction aggregate. If negative characteristics cause the rock to yield to these mechanical forces, the aggregate products break down and the structure has to be repaired or replaced prematurely. Public works agencies are very aware of the costs associated with the reduced life span of structures such as highways or concrete overpasses.

Chemical reactivity in aggregate stone is another concern in products such as Portland cement concrete and asphalt. The two most

common problems are alkali aggregate reactivity in Portland cement concrete and stripping in asphalt. Alkali aggregate reactivity occurs when certain aggregate rock types react with the alkalis in the Portland cement over time to cause premature deterioration of the concrete. In Nova Scotia it occurs as an alkali-silica reaction associated with the silicate minerals in specific rock types. When the silicates of the stone come in contact with alkalis of the cement in the presence of water, a reaction occurs at the surface of the aggregate particle to produce a silica gel reaction rim. Repeated wetting of the concrete causes the rim to grow, followed by pressure and cracking of the concrete. Further damage is caused by freeze-thaw cycles associated with water in the cracks. The result is a slow deterioration of the concrete over many years. In certain environments the presence of de-icing salt or sea water can accelerate the problem. The reaction is of particular concern in exposed concrete structures such as bridges, hydro power dams and wharves where premature failure of the structures is very costly. Stripping in bituminous concrete (asphalt) can occur when certain rock types exhibit an affinity for water at the surface of the aggregate particle so that the liquid asphalt cannot adhere to the stone. The result is that the asphalt is stripped from the aggregate over time, eventually causing the deterioration of the pavement surface by ravelling in the areas of weakened bonding.

Other characteristics of note are the shape of the stone, rock specific gravity and the presence of potentially harmful minerals. A variety of geological features such as bedding, metamorphic fabric and fracture patterns can influence stone shape. Tabular or platey clasts, which are typical of a slate or schist, can weaken products such as the surface course of asphalt. Specific gravity can be important if, for example, the materials are trucked long distances or there are issues regarding weight restrictions. The difference between a specific gravity of 2.4 and 2.6 could have significant fuel consumption costs for these bulk materials, particularly if they are hauled long distances. Minerals containing lead, arsenic, uranium or asbestos can be hazardous for human health and the environment, and are always a concern when they are found in aggregate.

Regional Geological Setting

The study area lies within the Meguma Terrane of southern Nova Scotia, which is separated from the Avalon Terrane by the Cobequid-Chedabucto Fault System (Fig. 2). These terranes are fault-bounded components of the northern Appalachian orogen or mountain chain of eastern North America (Hibbard *et al.,* 2006). Unlike most other terranes, the Meguma Terrane has no known equivalents elsewhere in the Appalachian belt. This is because the Cambro-Ordovician sedimentary rocks of the Meguma Group lie at the base of the terrane. The geological record of the Meguma Terrane represents approximately the last 550 million years, with periods of sedimentary and volcanic deposition, igneous intrusion, deformation and erosion. The bedrock that remains exposed today spans the period from the Cambrian to the Cretaceous, with the most recent ~100 million years missing from the rock record. Overlying the bedrock are Quaternary glacial deposits and post-glacial alluvial deposits.

Meguma Group

The Cambro-Ordovician Meguma Group is a thick succession of metamorphosed sedimentary rocks found at the base of the Meguma Terrane. It has been traditionally subdivided into two formations, the lower Goldenville Formation and the overlying Halifax Formation, which are defined on the basis of abundance of slate, metamorphosed siltstone (metasiltstone) and metamorphosed sandstone (metasandstone). The Goldenville Formation consists predominately of metasandstone and the conformably overlying Halifax Formation is predominately slate. Stratigraphic sections of bedrock in the Meguma Group, however, can be found in almost any proportion of interbedded metasandstone and slate. A ‘transition zone’ consisting of interbedded slate, metasiltstone and metasandstone, in approximately equal amounts, occurs between the two formations. Although included in the Halifax Formation, recent mapping and geochemical studies have shown that it is more closely linked with the Goldenville Formation (White, 2006, 2007).

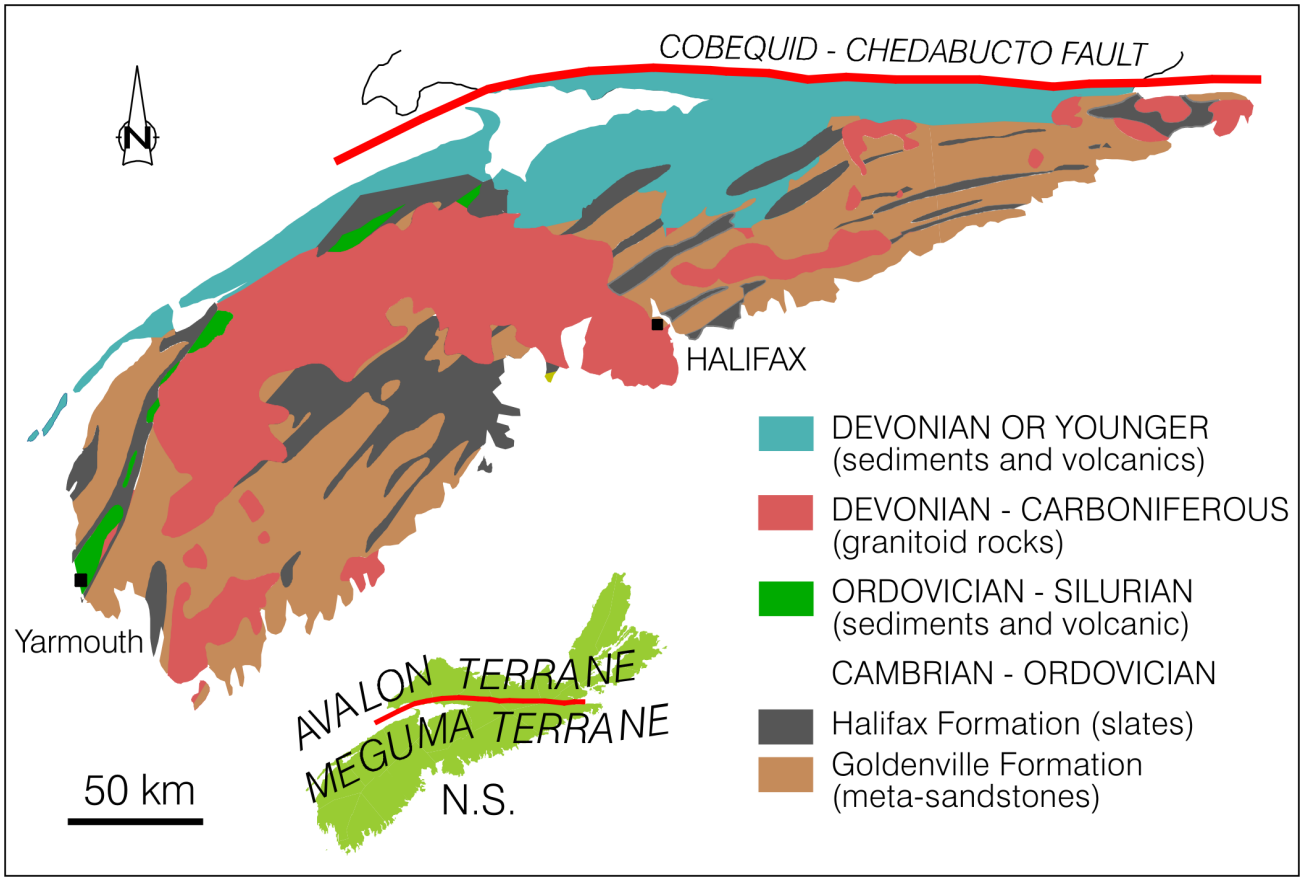

Figure 2. Geological map showing the Meguma Terrane, the Meguma Group and the plutonic rocks that intrude them.

The Meguma Group is interpreted to have been deposited in a deep marine environment where turbidity currents deposited sediments at the base of the continental slope on an abyssal plain (e.g. Phinney, 1961; Campbell, 1966; Harris and Schenk, 1975). Sandstone in the Goldenville Formation represents channel sand deposits, probably from the edge of a former continental shelf and transported to depth in submarine canyons during periods of shelf deposit instability. The channel deposits splayed onto the deep ocean floor where they interacted with mud and silt deposits of the abyssal plain. Repeated pulses of sand in the migrating submarine channels over millions of years resulted in a thick, repetitious sequence of sand, silt and clay several kilometres in thickness. The sediments eventually became lithified to form sandstone, siltstone and shale, respectively. Although the interbedding of metasandstone with slate suggests that the sand-dominated channel deposits of the Goldenville Formation were continuous with an adjacent (distal and lateral) deep water, clay-dominated environment (the Halifax Formation), there is no evidence of this lateral change from sandstone-dominated strata to slate-dominated strata. Rather, the Halifax Formation overlies the Goldenville Formation in all observed contact relationships, representing a vertical change to a restricted clay- and silt-dominated, deep water environment with the apparent abrupt end of turbidity current deposition. The clay- and silt-dominated deposition of the Halifax Formation also accumulated several kilometres thickness. Collectively, the Goldenville Formation and the Halifax Formation have a measured thickness of 10 km (Harris and Schenk,1975), but it may be substantially thicker as the base of the Meguma Group is not exposed and Meguma Group rocks located on the Scotian Shelf are not included in this measurement. A combination of sediment burial, deformation and metamorphism associated with the Neoacadian Orogeny and the emplacement of plutonic rock eventually produced the metasandstone,

metasiltstone and slate that constitute the Meguma Group today.

Goldenville Formation

The Goldenville Formation is defined by a predominance of metasandstone with lesser amounts of interbedded metasiltstone and slate. The sandstone commonly consists of stacked layers that are uninterrupted for several metres to tens of metres in thickness. There are locally uninterrupted sandstone units up to 150 m in thickness (Waldron and Jenson, 1985). The layers are generally of uniform thickness and laterally continuous over several hundred metres. Colour is consistent in the rocks, varying from medium grey to green-grey. Grain size in the metasandstone generally varies from fine- to medium-grained, and rarely coarse-grained pebbly to fine-grained conglomerate. The metasandstone is generally blocky and massive when broken, and may or may not have visible bedding or cleavage planes (Fig. 3). The metasiltstone is a fine-grained equivalent of the metasandstone, which is common in the Goldenville Formation (Fig. 4). It typically has a metamorphic fabric and may or may not contain bedding. Slate layers are generally a mixture of silt- and clay-sized particles and well laminated, but bedding is often obscured by the cleavage pervasive to the finer grained rocks. The proportion of metasiltstone and slate can vary from minimal to significant. Sulphides are common in small amounts (generally <1%), usually in the form of isolated pyrite crystals.

Halifax Formation

The Halifax Formation, which overlies the Goldenville Formation, consists predominately of slate with minor interbedded metasiltstone and metasandstone. The slate is composed of clay- and silt-sized particles and commonly contains thin interbeds of metasiltstone to produce a laminated texture (Fig. 5). The metasiltstone layers are generally characterized by parallel layering or ripple crosslamination. The colour varies from black to blue-grey to pale green-grey. Contact metamorphism near granites has resulted in metamorphic grades in these fine-grained rocks varying from greenschist to amphibolite facies (e.g. White, 2006, 2007) and a well developed hornfelsic texture. Cleavage and schistosity associated with regional metamorphism and deformation are pervasive in the slates. Sulphides in the form of pyrite, pyrrhotite and arsenopyrite are common in specific units of the Halifax Formation.

Aggregate Potential

Goldenville Formation

Metasandstone of the Goldenville Formation has been a primary source of aggregate in the western mainland of Nova Scotia for many years. Its success is based on a long history where it has proven highly satisfactory as a construction material, especially in highway applications. This quality largely reflects the hardness and durability of the metasandstone, which has been subjected to metamorphism and recrystallization due to the annealing or partial melting of the original sedimentary rock. This permits the rock to test very well for abrasion resistence and durability. The recrystallization also makes the rock very ‘tight’ and resistant to water entry and weathering. The comparatively thin weathering rind at the surface of the metamorphosed sandstone outcrops (usually only a few millimetres thick) is a testimonial to this water resistence. The surface penetration of water in outcrops of most other rock types is typically far greater than that of the metasandstone.

Metasandstone, however, is not the only rock type found in the Goldenville Formation. Due to a range of depositional conditions at the time of burial, there are various amounts of metasiltstone and slate present as interbedded units, with compositions gradational between the two rock types. These fine-grained rocks are characterized by a metamorphic fabric (schistose or slatey cleavage) and associated soft, platy minerals (e.g. chlorite, muscovite and biotite). Figure 4 shows an outcrop of Goldenville Formation rock where surface weathering reveals the contrast between foliated siltstone and the coarser, massive sandstone. Note that the preferential weathering of the siltstone is most likely due to the presence of soft, micaceous minerals which were vulnerable to postglacial weathering. Cleavage planes of the finer

Figure 3. Block of massive metamorphic sandstone from the Goldenville Formation. This rock has no evidence of bedding or metamorphic cleavage, making it very durable as a source of crushed stone.

grained metasandstone and metasiltstone are commonly the only evidence of bedding observed in the weathered surface of Goldenville Formation outcrop. Platy minerals that define the metamorphic fabric in the metasiltstone form a plane of mechanical weakness associated with low bond strength between the micaceous layers. The metamorphic fabric also makes the aggregate particles vulnerable to water via microscopic openings along cleavage planes. The crushing of stone with a cleavage also results in the production of platy clasts, which can create voids in the asphalt mix during compaction of the road surface (Prime, 2001). Voids weaken the bond structure of bituminous concrete and also make it vulnerable to water entry and freeze-thaw cycles. The metamorphic fabric is also a plane of weakness in the stone that is vulnerable to compressional forces parallelling the cleavage direction.

Because interbedded, fine-grained rock is present in all Goldenville Formation strata, it is a major concern for aggregate quality. A rule of thumb to avoid problems is simply to pick the deposits that contain the least amount of slate and metasiltstone. In this respect, stacked sequences of channel sandstone (Fig. 6) would be the primary choice for quarrying because they contain a minimum of fine-grained rock. This is speculated to be a reflection of their more proximal locations in the depositional system, where less fines were initially deposited or were subsequently eroded away by the next pulse of channel deposition. This sedimentary environment typically contains sandstone units >1.0 m in thickness that are uninterrupted by fine-grained rock. In deposits that are more distally located in the depositional system, the percentage of fine-grained units can increase dramatically. Figure 7 shows subvertical units that are typically 0.5 m in thickness and separated by fine-grained rock, generally as the top of a fining-upward sequence. Channel flow during deposition at this location was subdued to the point

Figure 4. Surface exposure of the Goldenville Formation with massive sandstone (top half of photo) overlying foliated fine-grained sandstone or siltstone.

that erosion of the underlying units was minimal. These deposits contain enough fine-grained rock to potentially cause problems for stone quality in construction aggregate applications. Furthermore, because the deleterious rock occurs as repeating interbeds throughout the deposit, selective mining around the problem rock in a quarry would be impossible. In the apparent distal reaches of the depositional system, where fine-grained rock is abundant, the metasiltstone and slate occupy a significant proportion of the rock. Areas such as the contact between the Goldenville Formation and the Halifax Formation (Fig. 8) are unacceptable for high quality aggregate applications. These 'transition zones' should be avoided or approached with caution when looking for quarry site. In addition, this zone is characteristically enriched in metal content.

In summary, aggregate exploration in the Goldenville Formation should focus on the deposits that contain a minimum of metasiltstone and slate, which are considered deleterious for the production of high quality construction aggregate. As a general guideline, the focus of exploration should be on deposits where metasandstone units more than 1 m in thickness predominate. Determining where these deposits are is not simple. Recent detailed mapping of the Goldenville Formation in some areas (e.g. White, 2006, 2007) has permitted subdivision of the Goldenville Formation into members (mappable units). This refinement of the stratigraphy, which is partially based on relative bedding thickness, can be used as a general exploration tool to identify areas with potentially thicker sandstone beds. Much of the formation is not subdivided, however, and will require reconnaissance field work to determine where the thick bedded units are present.

Although the observance of thickly bedded units in the field may be an indication of high quality aggregate potential, it may also be a false indicator (Prime, 2001). Due to the effects of

Figure 5. Extensive exposure of laminated Halifax Formation slate where cleavage is more or less parallel to bedding.

glaciation, differential erosion can cause more competent sandstone bedrock to project higher in the landscape with a greater probability of being exposed as outcrop. Conversely, the more easily eroded siltstone and slate interbeds commonly occur as dips in the bedrock where they are typically covered with till. The result can be a visual bias in the field toward the more erosion-resistant bedrock, which may rarely give the false impression that the bedrock in the area is a better target than actually exists. The presence of thick metasandstone units with significant slate/siltstone interbeds, however, would be unusual in these rocks. Caution should be used in any exploration program to make sure that a deposit has been properly assessed. This may include trenching, a diamond-drilling program, or possibly a geophysical survey. For a detailed discussion of the implications of geology in aggregate exploration, refer to Prime and White (2004) and Prime and Bonner (2007).

Alkali Aggregate Reactivity

Research over the last thirty years has shown that alkali reactivity associated with an alkali-silica reaction is common in Nova Scotia (e.g. Duncan and Swenson, 1969; Langley *et al.,* 1993). When alkalis from the cement are exposed to silicate minerals of some aggregates in the presence of water, a reaction occurs at the surface of the aggregate particle to produce a silica gel reaction rim. The affinity of the silica gel for water causes the rim to grow and cracking to occur. For a detailed description of the reaction refer to Dolar-Mantuani (1983).

Examination of many concrete structures in Nova Scotia indicates that microcrystalline quartz and structurally altered quartz in certain rock types are reactive (Langley *et al.,* 1993). The data indicate that the Goldenville Formation metasandstone is reactive throughout the Meguma Terrane. Recrystallization of sandstone near

Figure 6. Thick units of Goldenville Formation metasandstone dipping diagonally to the left along Route 102 near Windsor Junction. These beds of several metres thickness are separated by thin metasiltstone and slate units.

intrusive contacts appears to dampen the alkali reaction. There appears to be an inverse relationship between proximity to granitic rocks and the intensity of reactivity. Although temperature increases associated with the emplacement of intrusives have clearly modified the quartz grains of these metasedimentary rocks, it is still uncertain what mechanism causes the reduction in intensity of the reaction. In spite of the reactivity of metasandstone in concrete there are measures that can be taken to reduce the problem. This includes the use of low-alkali cements, or the use of pozzolanic additives (e.g. fly ash) in the ready-mix.

The presence of small amounts of pyrite (and other sulphide minerals) in the Goldenville Formation is not an environmental concern, but sulphides can be significant in terms of aesthetic appearances. Even small amounts of pyrite can be a problem in exposed stone used in the construction of building exteriors, retaining walls or in weather-exposed concrete. Rain water very quickly can cause a rust stain to occur at the site of a pyrite crystal, creating a detractive discolouration of the structure.

Halifax Formation

Slate in the Halifax Formation has not been tested for aggregate quality because it is generally accepted that it is a deleterious stone, performing poorly in laboratory tests and product applications where high quality aggregate is required. Physical properties that negatively affect quality are stone softness, fissility, cleavage and platy shape of the aggregate particles (Fig. 9). These characteristics typically result in low durability in the stone, causing it to break down when subjected to a variety of stresses. In applications such as highways, for example, the soft, fissile aggregate produced from slate tends to cause early mechanical failure of the structure. Cleavage in the

Figure 7. Steeply dipping Goldenville Formation metasandstone beds which are typically 0.5 m in thickness. Metasiltstone and slate are common interbeds in this exposure.

stone makes the rock more susceptible to water absorption, freeze-thaw cycles and weathering. The result is that the aggregate particles tend to rapidly break down in applications where they are exposed to the weather. In bituminous concrete (asphalt) slate clasts tend to swell from water absorption and expand with freezing to cause popouts. The tabular, platy shape of slate clasts is also undesirable in bituminous concrete because a bridging effect tends to cause large voids requiring additional asphalt or creating areas of structural weakness (Prime, 2001). Degradation of any construction stone product using these materials would be expected to be premature. Thus, the Halifax Formation is dismissed as a potential source of construction aggregate.

It is important to recognize, however, that rocks of the Halifax Formation have been used extensively as aggregate in the western half of the province, especially in areas where other materials are scarce. In general the production sites consist overwhelmingly of slate, but interbeds of metasiltstone are common and minor metasandstone may be present. The materials have been very popular because they are easily ripped, requiring minimal equipment and cost to extract. The aggregate clasts have a platy shape, causing them to produce a reasonably durable road base and smooth surface in low traffic applications such as haulage roads and driveways. The Metro area contains numerous slate quarries, but these sites have been abandoned due to problems associated with inferior quality and acid rock drainage.

Acid Rock Drainage (ARD) in the Halifax Formation

A major problem using rocks of the Halifax Formation for aggregate purposes is acid rock drainage associated with sulphide-rich slates (e.g. King, 1985; Environment Canada, 1987; King and Hart, 1987; Lund *et al.*, 1987). Research indicates

Figure 8. Interbedded units of metasandstone, metasiltstone and slate in the contact zone between the Halifax Formation and Goldenville Formation. This zone is informally referred to as the 'transition zone'.

that when sulphide-rich slates are exposed to air and water through excavation, the sulphide minerals react with water to produce a weak sulphuric acid. The iron sulphide mineral pyrrhotite is even more reactive than pyrite. The reaction occurs mainly through quarrying when the protective overburden is removed. The problem is further exacerbated when the materials are extracted and crushed for aggregate, dramatically increasing the surface area of the slate and exposure of the sulphide minerals. Thus, acid generation occurs not only at the aggregate production sites but in all locations where the materials have been placed in an exposed manner (e.g. woods access roads). Acidic runoff can then leach heavy metals out of nearby mine tailings dumps, bedrock or soils, causing them to be mobilized into the water system. As the acidic waters enter a river or stream the natural pH of the waterway is lowered. Collectively, acidity and metal contamination cause lakes and streams to be stressed. Degradation of the water makes conditions unacceptable for much of the aquatic life and causes toxic metals to enter the food chain. Fish kills related to acid drainage have been well documented (Scott, 1961; Environmental Protection Service, 1976).

Environmental guidelines are now in place regarding the development of quarries in the Halifax Formation (Nova Scotia Department of Environment and Environment Canada, 1990). As a result the exposure or use of slates that exceed 0.4% sulphides (12.51 kg H_2SO_4/tonne) is now prohibited.

Conclusions

The aggregate potential of the Meguma Group depends on a number of geological variables that affect stone quality. Regardless of the parameters, only the Goldenville Formation is capable of producing high quality aggregate. This is a

Figure 9. Slate rubble is commonly used to produce woods roads due to ease of extraction and the smooth surfaces that these platy materials create.

reflection of the predominant rock type, metasandstone, which produces very hard, durable construction aggregate. This quality is subdued, however, by the presence of interbedded slate and metasiltstone which are considered to be deleterious rock types in these sedimentary deposits. Ideally a potential quarry site should contain a minimum of slate interbeds. The focus of exploration should be sites where the majority of individual metasandstone units are more than 1 m in thickness. This reflects the proximal location in the turbidity channel system where the least quantity of fines were deposited or remained following erosion. The thicker the individual metasandstone units are, the better they are for an exploration target. Regardless of the thickness of the metasandstone, however, the presence of slate beds should be carefully scrutinized due to their deleterious nature. Metasandstone and metasiltstone that contain an abundance of foliated rock should also be avoided if high quality material is the goal. One negative characteristic in metasandstone is its tendency toward alkali aggregate reactivity in concrete, but measures can be taken to mitigate the reaction by using low-alkali cements or adding pozzolans to neutralize the reaction.

Halifax Formation slate cannot be used for construction aggregate due to the metamorphic fabric and presence of soft minerals. These characteristics cause the rock to be friable and subject to weathering processes. These rocks have been used extensively, however, in parts of the region for applications such as woods roads and driveways due to their availability, economy and rock characteristics that make good road surfaces. One major environmental concern is the presence of acid-generating sulphides (pyrite and pyrrhotite) in some areas of the slate.

References

Campbell, F. A. 1966: Paleocurrent and sedimentation of part of the Meguma Group (Lower Paleozoic); unpublished M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Dolar-Mantuani, L. 1983: Handbook of concrete aggregates: a petrographic and technological evaluation; *in* Cooperation with National Research Council of Canada; Noyles Publications; 345 p.

Duncan, M. A. G. and Swenson, E. G. 1969: Investigation of concrete expansion in Nova Scotia; The Professional Engineer in Nova Scotia, v. 10, no. 2, p. 16-19.

Environment Canada 1987: Proceedings: Acid Mine Drainage, Seminar/Workshop; 617 p.

Environmental Protection Service 1976: A report on the causes of fish kills in the Shubenacadie River at Enfield; Nova Scotia Environmental Services Branch, Atlantic Region.

Harris, I. M. and Schenk, P. E. 1975: The Meguma Group; *in* Ancient Sediments of Nova Scotia, ed. I. M. Harris; Society of Economic Paleontologists and Mineralogists, Eastern Section Guidebook, p. 17-38.

Hibbard, J. P., van Staal, C. R., Rankin, D. W. and Williams, H. 2006: Lithotectonic map of the Appalachian Orogen, Canada-United States of America; Geological Survey of Canada, Map 2096A, scale 1:1 500 000.

King, M. 1985: Acid drainage and acidification of Nova Scotia waters; Water Planning and Management Branch, Inland Waters Directorate, Environment, Canada.

King, M. and Hart, W. 1987: Contribution of acidity and heavy metals to surface and groundwater by pyritiferous slates in the vicinity of the Halifax Airport; prepared by Centre for Water Resource Studies, Technical University of Nova Scotia, 121 p.

Langley, W. S., Fournier, B. and Malhotra, V. M. 1993: Alkali-aggregate reactivity in Nova Scotia; prepared by Canada Centre for Mineral and Energy Technology for Energy, Mines and Resources Canada, 36 p.

Lund, O. P., Vaughan, J. G. and Thirumurthi, D. 1987: Impact of acid drainage pollution from mineralized slate at Halifax Airport; Water Pollution Research Journal of Canada, v. 22, no. 2, p. 308-325.

Nova Scotia Department of Environment and Environment Canada 1990: Guidelines for development of the slates of Nova Scotia.

Nova Scotia Department of Mines and Energy 1984: Annual Report for 1983; Mines and Minerals Branch; ed. J. Szostak and K. A. Mills, 108 p.

Nova Scotia Department of Natural Resources 2006: Appendix 1: Mining industry activity in Nova Scotia 2003; *in* Mineral Resources Branch Report of Activities 2005; Report ME 2006-1, 200 p.

Prime, G. 2001: Overview of bedrock aggregate potential in the Halifax-Dartmouth metropolitan area, Nova Scotia; Nova Scotia Department of Natural Resources, Mines and Energy Branches, Economic Geology Series ME 2001-1, 74 p.

Prime, G. 2005: Aggregate program activities in 2004; *in* Mineral Resources Branch, Report of Activities 2004, ed. D. R. MacDonald; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 93-99.

Prime, G. and Bonner, F. 2007: Bedrock aggregate development potential in western Halifax Regional Municipality; Nova Scotia Department of Natural Resources, Mineral Resources Branch, Economic Geology Series ME 2007-1, 52 p.

Prime, G. and White, C. E. 2004: Potential granitic aggregate sources in the Halifax Regional Municipality area; Nova Scotia Department of Natural Resources, Open File Illustration ME 2004-1.

Prime, G. and White, C. E. 2006: Current bedrock aggregate research; *in* Mineral Resources Branch, Report of Activities 2005; Nova Scotia Department of Natural Resources, Report ME 2006-1, p. 137-142.

Scott, J. S. 1961: Toxicity of surface waters in part of the Shubenacadie drainage system; Geological Survey of Canada, Topical Report # 4.

Waldron, J. W. F. and Jenson, L. R. 1985: Sedimentology of the Goldenville Formation, Eastern Shore, Nova Scotia; Geological Survey of Canada Paper 85-15, Geological Survey of Canada; 31 p.

White, C. E., 2006: Preliminary bedrock geology of the Liverpool and Lake Rossignol map areas (NTS 21/02 and 21/03), southern Nova Scotia;

in Mineral Resources Branch, Report of Activities 2005; Nova Scotia Department of Natural Resources, Report ME 2006-1, p. 149-163.

White, C. E. 2007: Preliminary bedrock geology of Kejimikujik Lake map area (NTS 21A/06), southern Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2006; Nova Scotia Department of Natural Resources, Report ME 2007-1, p 159-170.