MINERALS AND ENERGY BRANCH

OVERVIEW OF BEDROCK AGGREGATE POTENTIAL IN THE HALIFAX-DARTMOUTH METROPOLITAN AREA, NOVA SCOTIA

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NOVA SCOTIA
Natural Resources

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Overview of Bedrock Aggregate Potential in the Halifax-Dartmouth Metropolitan Area, Nova Scotia

G. Prime

Abstract

Continuing urban growth, land-use issues and environmental concerns in the Halifax-Dartmouth region have had a significant impact on the ability to access local aggregate resources. The demand for materials is increasing, but the availability of resource land for extractive purposes is declining. Current land-use policies and zoning practices in the municipality have contributed to the sterilization of prime aggregate deposits in the Metro area. If present trends continue without intervention, the local resource base may disappear in the future. This would result in reliance on distant sources to meet market demands. Any increase in haulage distance of these high tonnage, low cost materials would significantly increase the price of the delivered product and ultimately impact on the costs of construction. This could have serious implications for the cost of future growth and development of the Metro community.

To address these concerns, the Nova Scotia Department of Natural Resources conducted this study to assess the bedrock aggregate resource in the Metro area. Its primary goal is to define the resource to help protect it for future use. A field examination of the regional geology and testing of representative samples indicate that the rock types with the best aggregate potential are Goldenville Formation quartzite and Devono-Carboniferous granite.

Quartzite (formally termed metagreywacke) is a very durable stone which makes excellent aggregate. One exception is use in weather-exposed concrete products, where alkali-aggregate reactivity associated with some of the quartzite could cause premature failure of the concrete. However, this can be mitigated by the use of low alkali cements or the addition of supplementary cementing materials to the concrete. The presence of slate and siltstone interbeds significantly reduces the quality of a quartzite deposit because of problems with durability and particle shape. Calculations prepared in this study suggest that a high quality quartzite deposit should contain no more than 5% slate.

Granite is generally acceptable for most aggregate purposes. The quality of granite as aggregate appears to be related to grain size and microfracturing, although mineralogy can be a contributing factor. Aggregate test results indicate that fine- and medium-grained granite makes excellent all-purpose aggregate. Coarse-grained stone is consistently less durable, although most deposits will pass materials specifications. Preliminary results of this study also suggest that the coarse-grained rocks can be further weakened by pervasive microfractures. Sheared or weathered granite should be avoided for quarrying purposes. The presence of excessive amounts of platy or clay minerals (e.g. mica or kaolin) in either granite or quartzite should be avoided because of a tendency to reduce the hardness of the stone.

Halifax Formation slate and Windsor Group sedimentary rocks in the Metro area are unsuitable for high quality aggregate. These rock types generally lack durability and are susceptible to premature breakdown when exposed to moisture and freeze-thaw cycles. An abundance of sulphides in some of the slates can result in environmental damage to water courses if the sulphides are exposed by quarrying.

Subsequent investigations of similar rock types outside the Halifax-Dartmouth area support the conclusions of this study. Therefore, the results discussed here can generally be applied to comparable bedrock throughout the southwestern half of the province (Meguma Zone).

Acknowledgments

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Any errors or omissions in this report are the sole responsibility of the author.

Introduction

Sand, gravel and crushed stone aggregate are fundamental structural materials widely used in modern societies. From basic functions such as filling holes to specialized applications such as high strength concrete, aggregate plays a key role in the development, maintenance and day-to-day functioning of our communities. The aggregate industry makes significant contributions to local economies. In Nova Scotia, aggregate operators and road builders produce 10-12 Mt (million tonnes) of stone annually (Fig. 1) worth at least $50 million. It is a stable industry which directly employs more than 500 people throughout the province. Other companies, such as ready-mix producers and excavating firms, are dependent on the availability of aggregate for their livelihood.

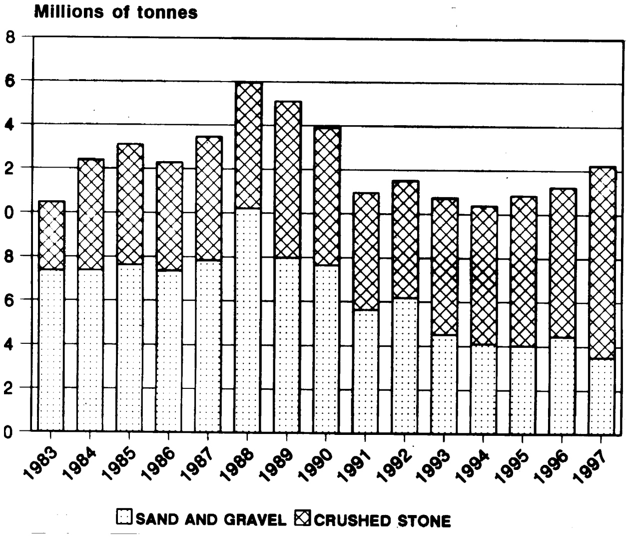


Figure 1. Nova Scotia aggregate production, 1983-1997 (data from Registry of Mineral and Petroleum Titles).

The demand for aggregate is largely a reflection of population, primarily due to the large volume requirements of urban centres for infrastructure (roads, sidewalks and water/sewage lines) and residential and commercial development. The Halifax-Dartmouth area is the largest population base in Atlantic Canada, with approximately 300 000 people in the two cities and associated communities (estimated here using 1994 Nova Scotia Department of Finance figures). Commonly referred to as Metro, it is the largest aggregate market in the province with more than 3 Mt of processed stone used annually. Approximately 33% of the total aggregate production for Nova Scotia is used in an area that represents less than 2% of the provincial land mass.

The overwhelming bulk of aggregate material used in Metro is extracted from a series of bedrock quarries which rim the Halifax-Dartmouth area (Fig. 2). This includes coarse aggregate (crushed stone) and manufactured fines. Natural sand and speciality gravels are trucked from distant glacial deposits in areas such as Coldbrook, Kings County, and Nine Mile River, Hants County. Local sources of aggregate are used whenever possible because of the high transportation costs associated with these bulk materials.

Resource Concerns

The aggregate industry has historically thrived in the Metro area, with adequate aggregate supplies to meet market demands. However, there are challenges facing the aggregate resource which make the future less certain. Concerns largely stem from recent urban and industrial growth, which have led to the aggressive development of the land base at the expense of the aggregate resource. Residential development, for example, is continuously encroaching on resource land. Because blasting guidelines for quarries require a minimum setback distance of 800 m from the nearest occupied dwelling (NSDOE, 1988), not only the land underlying the development is sterilized but large blocks of adjacent property are affected as well. Construction of one new house can eliminate as much as 2 km^2 of land (area $=\pi r^2$, where $r = 0.8$ km) from potential resource use.

The aggregate resource is continually being impacted by environmental protection measures such as the *Pit and Quarry Guidelines* (NSDOE, 1988) and restrictions on acid-generating rock (NSDOE and Environment Canada, 1990). Many former sources of aggregate can no longer be mined because of the environmental implications to their use.

Materials specifications for construction aggregates are continually being upgraded to ensure that structures such as highways, bridges and dams are constructed in a safe and cost-effective manner. Many former aggregate deposits will no longer meet the rigid standards demanded by the construction industry.

Opposition to quarrying has accompanied urban growth in the region. Concerns by residents usually focus on issues such as noise, dust, blasting, truck traffic and diminished property values. Several recent attempts to permit new quarries in the Metro area have been vocally denounced by residential interest groups. This is the largest single threat to the local resource. Even if a deposit meets all other conditions for development,

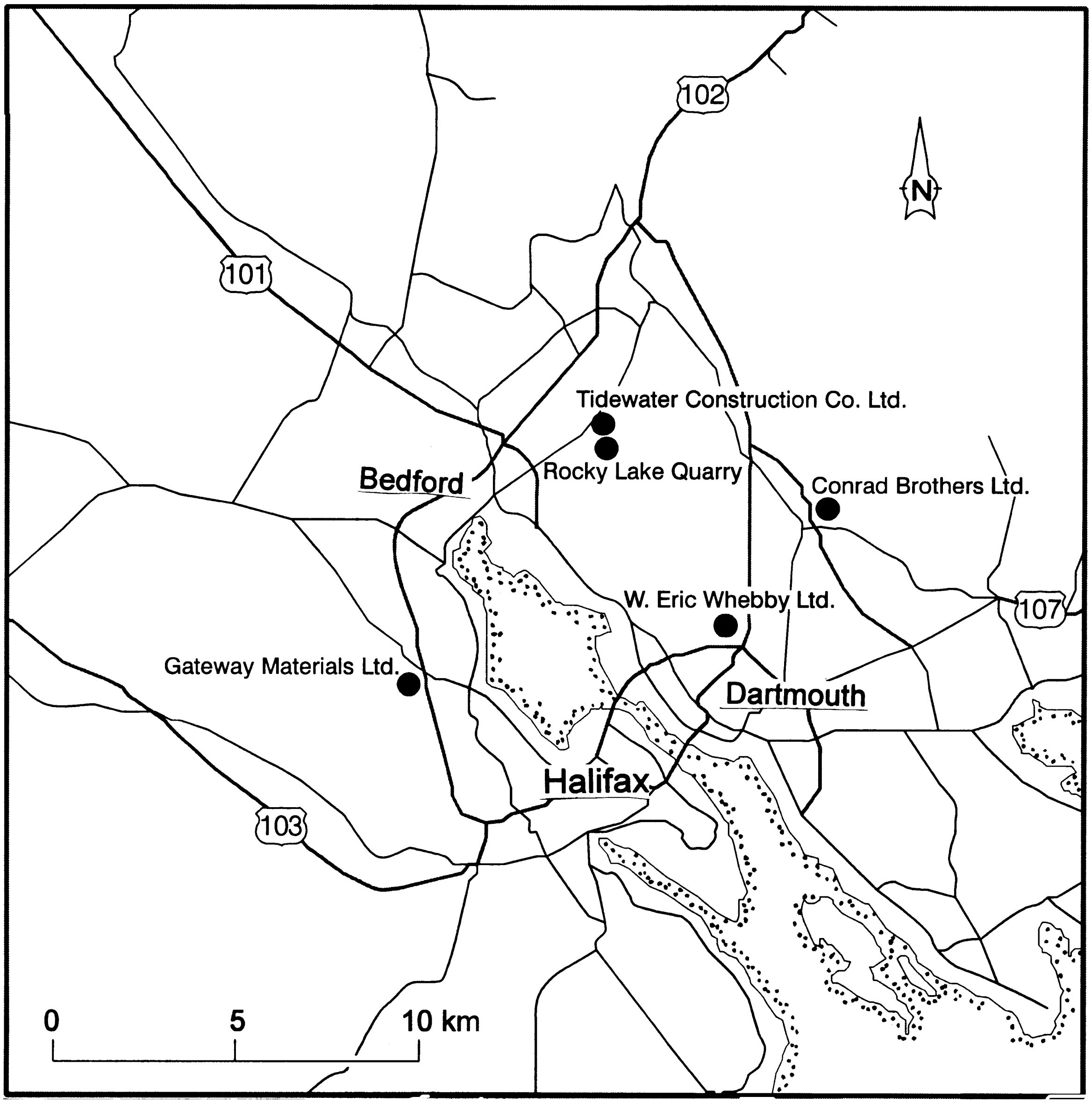


Figure 2. Location of aggregate quarries in the Halifax-Dartmouth metropolitan area.

public acceptance is critical for aggregate extraction to proceed.

Finally, there currently is no land-use legislation in the province which would protect the aggregate resource for extractive purposes. As a result, encroachment and sterilization of the resource land are proceeding unimpeded.

Collectively, these issues have had the effect of shrinking the aggregate resource base while the demand for high quality stone has continued to grow. If present trends persist, the Metro area will experience supply shortfalls in the future and ultimately the resource will disappear.

Purpose and Scope

Loss of the local aggregate resource would have a significant socio-economic impact on Metro. In recognition of this, the Department of Natural Resources initiated this study to assess aggregate potential in the Halifax-Dartmouth region. Its purpose is to provide an aggregate resource database which will (1) assist aggregate producers in finding high quality aggregate deposits, and (2) help develop an awareness of the importance of this dwindling resource to the Metro community.

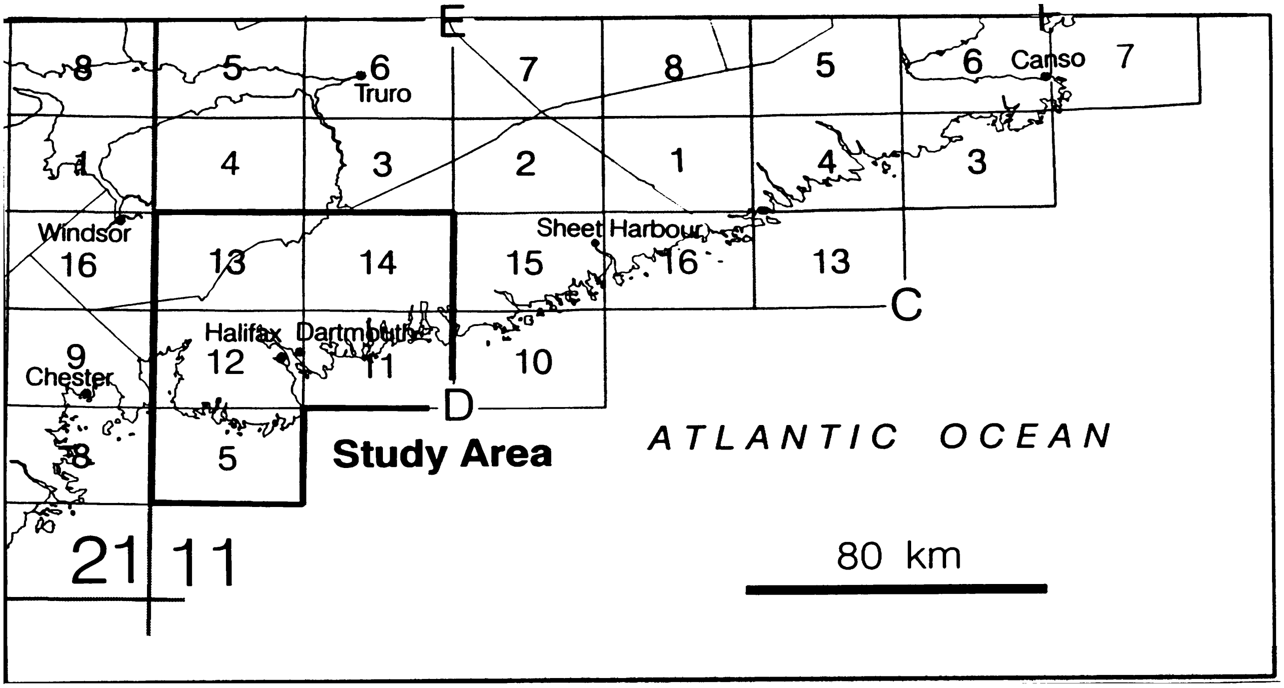


Figure 3. NTS map grid showing the study area location.

Due to a lack of sand and gravel deposits in the region (Fowler and Dickie, 1978) this study focuses on the bedrock geology for quarried aggregate. The study area (Fig. 3) was selected on the basis of what the author deemed a reasonable transportation distance to truck aggregate to the Halifax-Dartmouth metropolitan market for the foreseeable future (Table 1). An area encompassing a 35 km radius from The Narrows of Halifax Harbour was chosen for study. It comprises five 1:50 000 scale NTS map areas: 11D/05, 11D/11, 11D/12, 11D/13 and 11D/14. The study area, enclosing approximately 3200 km^2, is bounded to the east by longitude 63"00', to the north by latitude 45"00' and to the west by longitude 64"00'. The southern limit is the Atlantic coastline.

Methods

A field program was conducted from 1989 to 1992 under the Canada - Nova Scotia Cooperation Agreement on Mineral Development. The research focused on reconnaissance field work, bedrock sampling and laboratory analysis.

Preliminary work consisted of discussions with local aggregate producers and an examination of several quarries in the area to determine the geology and rock types that have proven successful for aggregate production. This was followed by reconnaissance field work using available bedrock geology maps (Fig. 4) to gain insight into the variety of rock types present in the study area. A more detailed geological examination was subsequently conducted in selected areas. See Appendix 1 for definitions of geological terms. National Topographic Series (NTS) maps (1:50 000 scale) were used as base maps.

A sampling program was conducted over the study area to collect representative samples for laboratory analysis. The selection of sample sites was based on the following criteria: (1) obtaining representative samples of selected rock types, (2) finding easily accessible sites where fresh samples could be collected, and (3) finding sites where the rock is undisturbed by weathering or structural deformation. (Note: sample sites were not selected on the basis of their potential for quarrying). Some of the samples were collected using a sledge hammer and chisels; however, most were obtained using a gasoline-powered rotary/impact drill and wedges (Fig. 5).

Sample preparation and laboratory analysis were carried out on all samples at the Technical University of Nova Scotia, Geocon Atlantic Limited (formerly Warnock Hersey Professional Services Ltd.) and Jacques Whitford Ltd. Testing consisted of Los Angeles abrasion loss, magnesium sulphate soundness loss, petrographic number analysis, absorption and Micro-Deval abrasion loss. A discussion of the tests is provided in Appendix 2. Specifications for road materials and concrete are described in Appendix 3.

Table 1. Nova Scotia Department of Transportation and Public Works haulage rates (1996).

For trucks hauling asphalt add 13 cents per tonne.							
km	$/tonne	km	$/tonne	km	$/tonne	km	$/tonne
1	0.84	28	5.05	55	6.76	82	8.43
2	1.00	29	5.21	56	6.84	83	8.51
3	1.14	30	5.37	57	6.89	84	8.57
4	1.32	31	5.52	58	6.96	85	8.62
5	1.47	32	5.69	59	7.01	86	8.68
6	1.63	33	5.79	60	7.08	87	8.76
7	1.77	34	5.90	61	7.14	88	8.82
8	1.94	35	6.02	62	7.20	89	8.87
9	2.08	36	6.12	63	7.26	90	8.94
10	2.26	37	6.23	64	7.33	91	9.00
11	2.40	38	6.35	65	7.39	92	9.06
12	2.57	39	6.46	66	7.46	93	9.12
13	2.71	40	6.57	67	7.51	94	9.19
14	2.87	41	6.58	68	7.56	95	9.24
15	3.03	42	6.59	69	7.64	96	9.29
16	3.17	43	6.60	70	7.71	97	9.39
17	3.35	44	6.63	71	7.76	98	9.44
18	3.50	45	6.64	72	7.81	99	9.49
19	3.66	46	6.65	73	7.88	100	9.54
20	3.80	47	6.66	74	7.94		
21	3.97	48	6.67	75	8.01	+6.20 cents per tonne over 100 km	
22	4.12	49	6.68	76	8.07		
23	4.27	50	6.69	77	8.13		
24	4.43	51	6.70	78	8.19		
25	4.60	52	6.71	79	8.25		
26	4.76	53	6.73	80	8.33		
27	4.89	54	6.75	81	8.38		

Following completion of the field work and sample analysis for this study, changes were made to aggregate specifications by Nova Scotia Department of Transportation and Public Works (NSDOTPW). The result is the mandatory testing of highways materials for Micro-Deval abrasion loss (Appendix 2 and Appendix 3). To reflect the new testing requirements, sample data from subsequent aggregate research are included here. The data, representing samples taken from comparable rock types to the west of the study area, can be used as a general guide for Metro area geology.

Previous Work

The earliest detailed mapping of bedrock geology in the study area was conducted by Faribault (1906a, b; 1907a, b, c; 1908a, b, c, d; 1909a, b) (Fig. 4). The focus of Faribault's work was metasedimentary rocks of the Meguma Group and the associated gold districts. Ham (1999a, b) has recently mapped the bedrock geology of the Musquodoboit Batholith. Coolen (1974) produced an unpublished map of the Kinsac Pluton to the north of Fall River as part of a B.Sc. honours thesis. To the west of Bedford Basin, mapping of the South Mountain Batholith was completed by Nova Scotia Department of Mines and Energy in the 1980s (MacDonald and Horne, 1987; Corey, 1987).

The first systematic surficial geology mapping in the area was carried out by the Nova Scotia Research Foundation as part of a province-wide identification of glacio-fluvial deposits and drumlins (MacNeill, 1956). This was followed by soils mapping for Halifax County by Agricultural Canada (MacDougall *et al.,* 1963). In the 1970s a province-wide granular aggregate study by the Nova Scotia Department of Mines and Energy delineated sand and gravel deposits on 1:50 000 scale maps (Fowler and Dickie, 1978). During the late 1970s and 1980s, surficial geology maps for central Nova Scotia and the Eastern Shore were produced by Nova Scotia Department of Mines and Energy (Stea and Fowler, 1979, 1981). The focus of these 1:100 000 scale maps was till geology and geochemistry. Later, 1:50 000 scale surficial geology

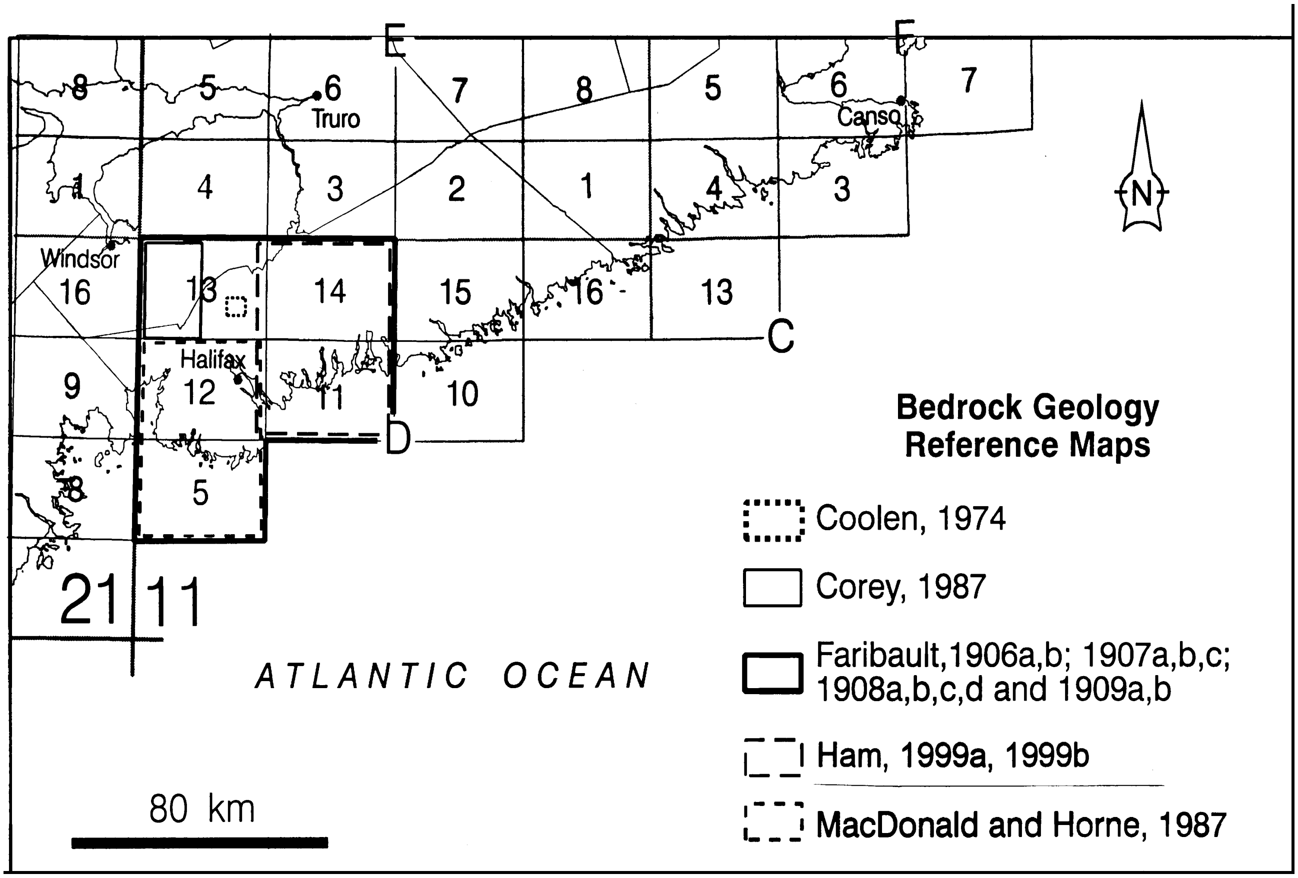


Figure 4. Study area location map showing areas previously mapped.

maps describing glaciology and till clast composition were produced for the Mount Uniacke and Halifax/ Sambro areas (Finck and Graves, 1987a, b; Graves and Finck, 1987a, b).

Recently mineral resource land-use maps covering the Metro area were produced by the Nova Scotia Department of Mines and Energy (Hopper and Dobson, 1988). The purpose of these maps is to provide a comprehensive database of mineral resource and land-use information. A variety of bedrock aggregate studies, with similar goals to this study, have been done across Canada (e.g. Webb, 1993; Ontario Geological Survey, 1991).

Geological Setting

The study area lies within the Meguma Zone, one of two tectonic terranes (refer to Appendix 1 for definitions) of the Appalachian Orogen which constitute mainland Nova Scotia (Fig. 6). The Meguma Zone, which lies to the south of the Cobequid-Chedabucto Fault Zone, consists of rocks ranging in age from Precambrian to Cretaceous, and is defined by a thick succession of Cambro-Ordovician metasedimentary rocks. The geology of the study area (Fig. 7), which is situated in the south-central area of the Meguma Zone, is composed of the Cambro-Ordivician metasedimentary rocks, Devono-Carboniferous intrusive rocks and Carboniferous sedimentary rocks.

The oldest rocks in the study area, Cambro-Ordovician rocks of the Meguma Group, consist of Halifax Formation slate and Goldenville Formation metagreywacke. These metasedimentary rocks were intruded by several phases of Devono-Carboniferous rocks. Carboniferous sedimentary rocks were subsequently and unconformably deposited on the metasedimentary and intrusive rocks. They are the youngest bedrock units in the area. Unconformably overlying the bedrock are unconsolidated Pleistocene deposits of till, minor glacial meltwater deposits, and modern stream deposits. For a more detailed discussion of the geological history of the study area, please refer to Appendix 5.

Figure 5. The primary method for collecting fresh samples involved use of a small gasoline-powered drill, wedges and feathers.

Results

The following is a discussion of the findings in this study. It is organized by groups, formations and intrusive complexes, from oldest to youngest. Each of these categories represents a distinct, mappable unit of rock or related group of rock types which can be distinguished from other rocks in the region on the basis of age and lithology. The order does not reflect the quality of the rock. Descriptions of the sample locations and analytical results are found in Appendix 4 and Table 2 respectively.

Meguma Group (Quartzite/Slate)

The Cambro-Ordivician Meguma Group was named and described by Woodman (1904a, b). It consists of two formations, the lower Goldenville Formation and the upper Halifax Formation. The formations are defined on the basis of relative abundance of slate and quartzite (i.e. metagreywacke) in the rock. The Goldenville Formation consists predominantly of quartzite and the Halifax Formation is predominantly slate. A narrow, unmapped transition zone comprises interbedded slate and quartzite in approximately equal amounts and commonly occurs between the two formations. The Meguma Group strata are folded and metamorphosed to varying degrees.

Goldenville Formation (Quartzite)

The Goldenville Formation consists of metagreywacke with interbedded layers of slate and metamorphic siltstone (referred to hereafter as 'siltstone'). Although the term 'metagreywacke' is the proper geoscientific term to describe this metamorphic sandstone, the name most commonly used by industry, the public and many geoscientists is 'quartzite'; therefore, the term quartzite will be used throughout the remainder of this discussion and on the accompanying maps (pocket). Quartzite predominates in the Goldenville Formation and commonly consists of stacked layers which are uninterrupted for several metres to tens of metres in thickness (Fig. 8). The layers are generally of uniform thickness and laterally continuous over several hundred metres. Colour is quite consistent in the rocks, varying from medium-grey to green-grey. Grain size in the quartzite generally varies from fine- to medium-grained sandstone and rarely coarse-grained, pebbly sandstone to conglomerate (outside the study area). Intraclasts of siltstone and mudstone are locally common in the quartzite units. The quartzite is blocky when broken and may or may not have visible bedding. The slate or siltstone layers are a mixture of silt- and clay-sized particles and are well laminated. The siltstone layers can technically be defined as the fine member of the quartzite unit. Regional and contact metamorphism associated with the emplacement of the South Mountain Batholith have resulted in low grade (greenschist to amphibolite facies) metamorphism in the fine-grained units and varying degrees of recrystallization in all of the strata. A foliation cleavage occurs throughout the fine-grained rocks, usually at an angle to the lamination. Sulphides are common in small amounts (generally < 1%), usually in the form of pyrite (Fig. 9).

Quartzite rocks of the Meguma Group have been a primary source of aggregate in Nova Scotia for many years. Quartzite has consistently proven highly satisfactory as a construction material, especially in highway applications. In Metro, quartzite has been the quarried aggregate of choice for several decades. There are many abandoned quartzite quarries in the Metro area.

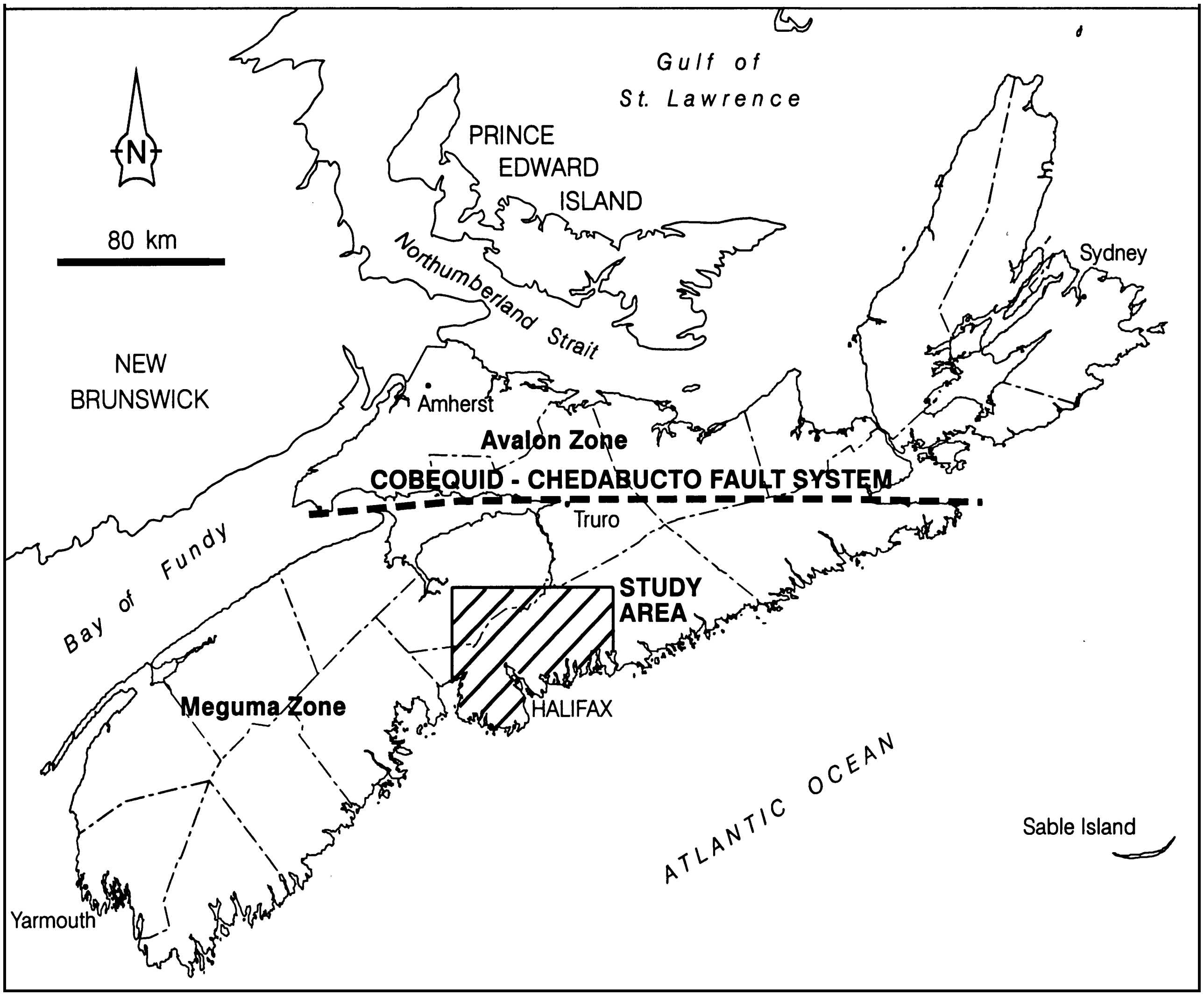


Figure 6. Simplified map of Nova Scotia showing the Cobequid-Chedabucto Fault System, which divides mainland Nova Scotia into the Avalon Zone to the north of the fault and the Meguma Zone to the south.

Quartzite performs well within maximum limits for aggregate products on all of the aggregate tests and consistently better than the other rock types sampled in the study area (Table 2). Los Angeles abrasion loss varies from 17.2 % to 19.4%, magnesium sulphate soundness loss from 0.6% to 9.9% and petrographic number from 100.0 to 100.6. When slate or schist were components of the sample (HC-20 and HC-23), the quality of the stone deteriorated significantly. This is due primarily to the high petrographic numbers, 344.4 and 237.5 respectively. These poor results are probably the result of softness imparted by clay minerals in the stone during the scratch test.

As previously discussed, samples taken from the study area were not tested for Micro-Deval abrasion loss. However, samples of similar quartzite from the Goldenville Formation outside the study area were tested as part of a subsequent study (Table 3). Two of the samples, AV-13 and AV-14, contained at least 20% siltstone. The percentage of weight loss for the samples was 10.7% and 8.6% respectively. A third sample (AV-15), containing very minor siltstone, had a percentage weight loss of 6.6%. These results are well within allowable limits for Nova Scotia Department of Transportation and Public Works (NSDOTPW) highways specifications (Appendix 3).

Quartzite/Slate Ratio

It has long been recognized by the aggregate industry that the presence of slate in quartzite deposits is detrimental to their performance in high quality aggregate applications. Although some slate is present

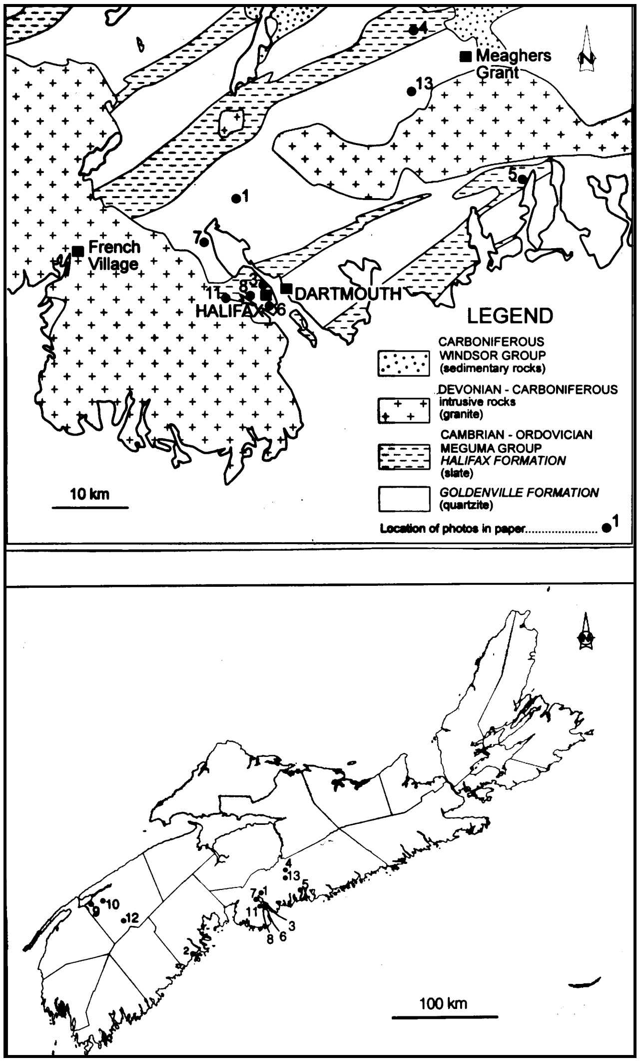


Figure 7. (7a) General bedrock geology of the study area showing locations of the photos used in this paper. (7b) Locations of photos (2, 9, 10, 12) taken outside the study area.

in all quartzite deposits, producers have always searched for sources that contain a minimum of these deleterious rocks. Observations made in this study verify that a high percentage of quartzite in the bedrock is desirable for an aggregate quarry. Visual estimates of slate in the Metro quartzite quarries by the author and other geologists (R. J. Horne and R. J. Ryan, personal communication) indicate that they typically contain less than 10% slate. However, the common presence of siltstone (an intermediate rock type containing clay and sand-sized grains) in the deposits further complicates aggregate potential because the grain size distribution of this rock type results in performance properties falling somewhere between slate and quartzite.

Determining acceptable limits for the amount of slate in Goldenville Formation quartzite for aggregate applications was beyond the scope of this study. However, the petrographic number test (described in Appendix 2) is a numerical way of approximating the minimum quartzite/slate ratio that would be acceptable at a proposed high-quality site. In using this method the following assumptions must be made regarding a hypothetical deposit and quarrying methods. (1) The deposit is composed entirely of the end member lithologies, slate and quartzite. As such, all stone extracted and processed from the deposit for the petrographic number test can all be assigned to Factor 1 (good) for quartzite and Factor 10 (deleterious) for slate. (2) There is an even distribution of interbedded slate in the quartzite. (3) Extraction methods in the deposit do not permit separating out or 'high grading' the quartzite units to improve the grade of the aggregate.

In order to determine an acceptable quartzite/slate ratio, a Petrographic Number (PN) was selected as an upper limit for high quality aggregate. For this study a PN of 35, the specification used by NSDOTPW for stone used in asphalt concrete (Appendix 3), was chosen as a maximum number (remembering that low PN values indicate the best stone). Using this numerical value as a benchmark, petrographic numbers for several quartzite/slate ratios were calculated (Table 4). It could then be determined that the minimum acceptable quartzite/slate ratio is approximately 24:1 or 4% slate.

Because fine-grained quartzite and siltstone interbeds are commonly found in most exposures of the Goldenville Formation, Factor 3 and Factor 6 stone can also be expected in the quarry. These rocks typically have platy minerals and cleavage planes, which reduce the mechanical strength of the aggregate particles and their hardness in the scratch test. This would cause the acceptable quartzite/slate ratio to be even higher. However, most quartzite quarries can be selectively mined to extract the better materials for high-end uses, permitting a greater amount of slate and siltstone in the deposit, provided they can be cost-effectively worked around. The presence of some thinly interbedded slate/ quartzite units (Fig. 10) can also be a benefit because they result in tabular or brick-shaped pieces of stone which can be used for dimension stone, such as the construction of walls (Fig. 11).

Project time constraints, inadequate bedrock exposure and a lack of stratigraphic subdivision made resource mapping of the Goldenville Formation at a detailed level impossible. Departmental staff currently

Table 2. Summary of analytical results.

Sample Number	Rock Unit	% Grain Size Distribution of Crushed Sample (+4/-4 to +200/-200 mesh)	Los Angeles Abrasion Loss (%)	Magnesium Sulphate Soundness Loss (%)	Relative Mass Density (oven dried)	Absorption % of Mass Density (oven dried)	Petrographic Number
HC-1	Monzogranite	79.9 / 19.0 / 1.2	43.5	12.7	2.627	0.91	-
HC-2	Monzogranite	80.3 / 17.9 /1.8	37.6	5.4	2.607	0.72	-
HC-3	Leucogranite	85.5 /12.6 / 1.9	31.9	2.7	2.544	1.33	100.4
HC-4	Granodiorite	81.0 / 17.9 / 1.1	41.0	15.6	2.586	1.12	-
HC-5	Monzogranite	83.6 / 15.3 / 1.1	45.8	7.5	2.543	1.30	100.0
HC-6	Granodiorite	74.1 / 24.5 / 1.3	61.5	23.6	2.560	1.37	-
HC-7	Leucomonzogranite	82.8 / 15.5 / 1.6	33.1	4.0	2.586	0.84	100.4
HC-8	Monzogranite	84.7 / 13.8 / 1.4	35.6	8.0	2.621	0.83	-
HC-9	Granodiorite	80.7 / 18.5 / 0.9	47.7	13.4	2.610	1.31	-
HC-10	Leucomonzogranite	84.1 / 14.4 / 1.7	31.3	9.0	2.553	1.36	102.2
HC-11	Quartzite	93.0 / 6.1 / 0.8	19.1	2.6	2.672	0.56	-
HC-12	Quartzite	89.9 / 8.9 / 1.4	17.2	9.9	2.673	0.53	-
HC-13	Quartzite	89.1 / 9.2 / 1.6	18.3	2.0	2.650	0.63	100.0
HC-14	Granodiorite	86.9 / 11.9 / 1.3	32.3	7.6	2.682	0.80	134.0
HC-15	Quartzite	72.9 / 23.5 / 3.5	19.4	1.3	2.631	0.54	-
HC-16	Quartzite	90.0 / 9.0 / 0.9	18.3	1.7	2.680	0.45	-
HC-17	Quartzite	90.5 / 8.7 / 0.9	17.2	0.8	2.696	0.43	100.6
HC-18	Quartzite	86.4 / 12.1 / 1.5	17.3	0.8	2.684	0.41	-
HC-19	Quartzite	89.5 / 8.9 / 1.6	18.5	2.2	2.668	0.56	-

Table 2. Continued

Sample Number	Rock Unit	% Grain Size Distribution of Crushed Sample (+4/-4 to +200/-200 mesh)	Los Angeles Abrasion Loss (%)	Magnesium Sulphate Soundness Loss (%)	Relative Mass Density (oven dried)	Absorption % of Mass Density (oven dried)	Petrographic Number
HC-20	Quartzite	81.7 / 16.0 / 2.3	30.5	20.7	2.684	1.26	344.4
HC-21	Quartzite	86.0 / 11.7 /2.4	17.9	0.6	2.697	0.45	100.0
HC-22	Granodiorite	85.4 / 13.2 / 1.3	39.8	8.1	2.615	1.01	-
HC-23	Quartzite/Schist	87.9 / 10.01 / 2.2	20.6	2.9	2.745	0.73	237.5
HC-24	Granodiorite	77.1 / 22.0 / 1.0	48.3	15.1	2.631	1.03	347.0
HC-25	Granodiorite	75.8 / 22.8 / 1.3	57.0	37.4	2.604	1.38	-
HC-26	Leucogranite	85.3 / 13.3 / 1.5	28.8	2.4	2.593	0.79	100.0
HC-27	Granodiorite	79.4 / 19.1 / 1.4	35.9	8.0	2.643	0.80	-
HC-28	Leucomonzogranite	85.7 / 13.9 / 0.4	43.6	8.8	2.609	0.69	150.00
HC-29	Leucomonzogranite	82.9 / 15.7 / 1.4	42.8	17.6	2.599	0.71	111.2
HC-30	Leucomonzogranite	83.4 / 15.4 / 1.3	36.2	10.3	2.597	0.79	-
HC-31	Leucomonzogranite	78.5 / 18.8 / 2.5	32.3	4.2	2.595	0.75	-
HC-32	Leucomonzogranite	78.3 / 19.6 / 2.2	32.6	8.0	2.605	0.68	106.0
HC-33	Leucomonzogranite	82.7 / 15.3 / 1.9	36.3	9.2	-	-	-
HC-34	Fossiliferous Dolostone	78.6 / 20.1 / 1.2	43.7	40.1	2.649	2.18	369.0
HC-35	Leucomonzogranite	75.9 / 22.3 / 1.8	39.9	3.9	2.588	0.86	109.0
HC-36	Leucomonzogranite	82.0 / 16.8 / 1.3	48.2	5.7	2.597	0.72	144.0
HC-37	Monzogranite	83.3 / 15.2 / 1.5	46.8	6.9	2.597	0.85	110.0
HC-38	Leucomonzogranite	86.4 / 11.8 / 1.8	44.7	7.5	2.601	0.66	105.0
HC-39	Leucomonzogranite	72.0 / 26.0 / 2.1	43.9	8.7	2.601	0.71	195.0

Table 2. Continued

Sample Number	Rock Unit	% Grain Size Distribution of Crushed Sample (+4/-4 to +200/-200 mesh)	Los Angeles Abrasion Loss (%)	Magnesium Sulphate Soundness Loss (%)	Relative Mass Density (oven dried)	Absorption % of Mass Density (oven dried)	Petrographic Number
HC-40	Leucomonzogranite	88.9 / 10.1 / 0.8	30.6	1.7	2.604	0.66	100.0
HC-41	Monzogranite	83.7 / 15.1 / 1.3	38.1	1.1	2.637	0.60	110.0
HC-42	Leucomonzogranite	75.8 / 22.3 / 2.0	40.9	3.1	2.613	0.66	105.0
HC-43	Leucomonzogranite	75.8 / 22.7 / 1.5	48.9	9.7	2.596	0.72	153.0
HC-44	Leucomonzogranite	81.4 / 17.2 / 1.6	43.8	4.0	2.609	0.57	174.0
HC-45	Leucomonzogranite	84.4 / 13.9 / 1.5	38.5	2.8	2.601	0.77	106.0
HC-46	Leucomonzogranite	84.2 / 14.5 / 1.3	43.0	4.2	2.597	1.00	151.0
HC-47	Leucomonzogranite	83.0 / 15.9 / 1.1	41.9	4.3	2.606	0.70	125.0
HC-48	Leucomonzogranite	88.1 / 10.0 / 1.7	31.7	2.0	2.576	1.02	100.0
HC-49	Leucomonzogranite	90.6 / 8.1 / 1.2	30.2	2.9	2.579	0.90	100.0
HC-50	Granodiorite	81.1 / 17.2 / 1.5	39.0	4.9	2.654	0.72	115.0
HC-51	Monzogranite	83.8 / 15.1 / 1.0	46.3	5.4	2.624	0.63	106.0
HC-52	Leucomonzogranite	83.8 / 14.6 / 1.5	42.9	4.9	2.610	0.44	102.0
HC-53	Leucomonzogranite	88.5 / 10.4 / 1.2	28.0	1.2	2.583	0.80	103.0
HC-54	Monzogranite	81.2 / 17.1 / 1.7	42.2	5.1	2.621	0.48	106.0
HC-55	Monzogranite	78.6 / 19.7 / 1.6	44.4	8.6	2.605	0.61	121.0
HC-56	Leucomonzogranite	81.9 / 16.3 / 1.6	39.4	5.3	2.610	0.67	103.0
HC-57	Leucomonzogranite	82.8 / 15.8 / 1.4	36.1	2.9	2.601	0.60	114.0
HC-58	Monzogranite	79.7 / 19.7 / 0.6	40.7	6.0	2.616	0.71	113.0

Figure 8. Exposure of Goldenville Formation quartzite in a road cut on Route 102 near Bedford (location #1, Fig. 7). The combined thickness of these units (dipping diagonally to the left) is approximately 12 m. Quartzite at this site is uninterrupted for several tens of metres.

remapping the Meguma Group in the Halifax area have not subdivided the Goldenville Formation and there is some debate as to whether this is possible at this time (R. J. Horne, Nova Scotia Department of Natural Resources, personal communication). In order to identify good stone potential in the Goldenville Formation field mapping must be combined with site-specific testing, such as trenching, diamond-drilling and geophysical surveys. Figure 12 is a schematic diagram demonstrating how areas with good exposure of quartzite may be deceptive in terms of aggregate potential. Factors such as preferential glacial erosion and till deposition can result in the selective burial of bedrock based on lithology and stratigraphy. In Figure 12 unacceptable amounts of deleterious slate present in the bedrock are hidden by overburden. The issue can be further complicated by the presence of siltstone with aggregate properties falling somewhere between quartzite and slate. Because of these complications it was not possible to map the Goldenville Formation according to aggregate quality and potential. The one exception to this is the transition zone between the Halifax and Goldenville formations where deleterious materials such as acid-generating sulphides and high proportions of slate have resulted in a low ranking for this zone. This loosely defined zone should be approached with caution or avoided when looking for a quarry site. The author recommends a minimum distance of 1 km away from the Halifax Formation contact in order to minimize deleterious materials in the quartzite deposits.

In summary, the Goldenville Formation quartzite is hard, durable and makes excellent aggregate for most applications. Stone with significant amounts of slate, siltstone, schist and sulphides should be avoided. With the exception of use in specific concrete applications, where alkali-aggregate reactivity can be a concern (discussed below), the quartzite performs better than all other rock types in the study area.

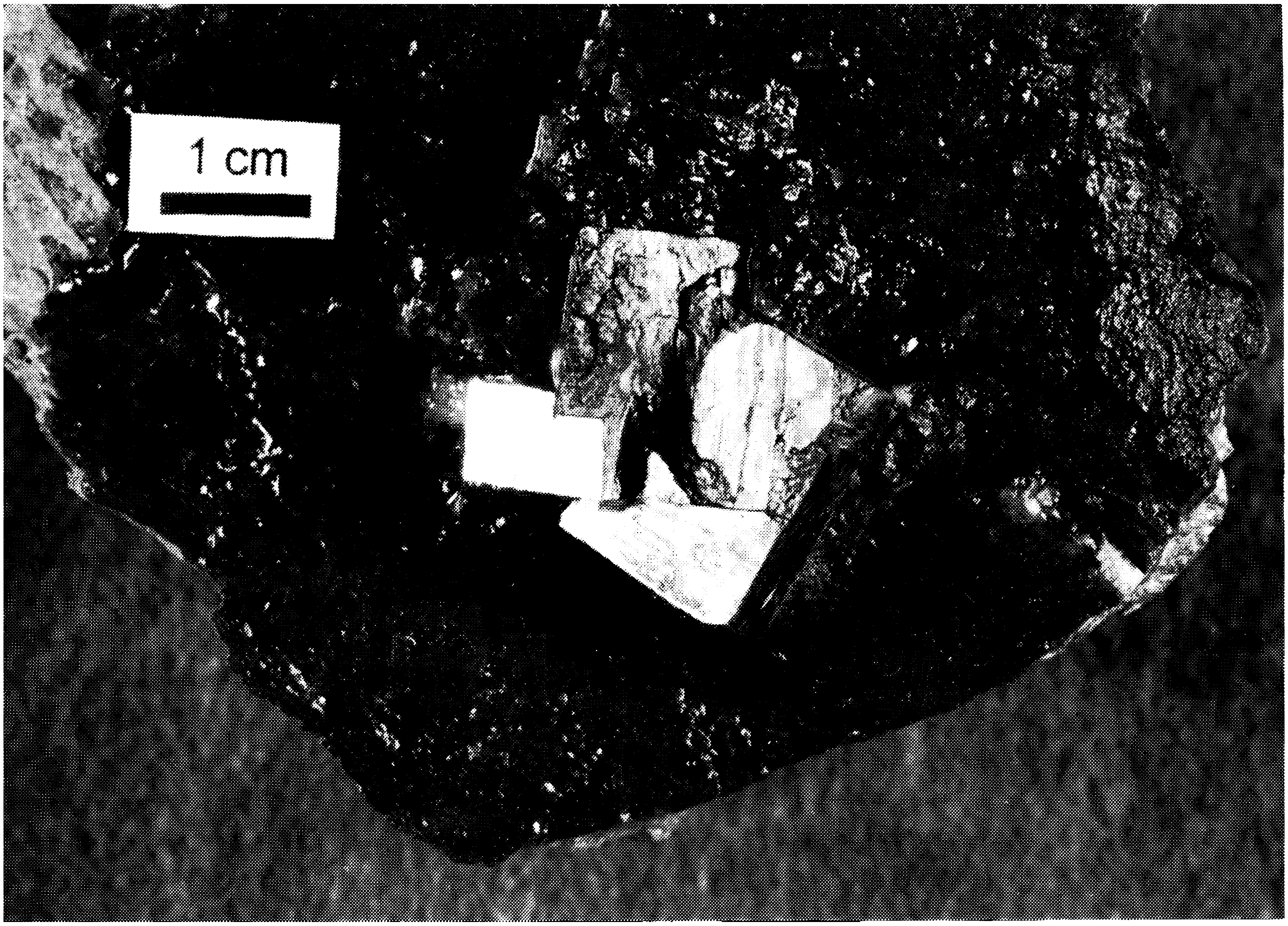


Figure 9. Pyrite is present throughout slates and quartzites of the Meguma Group. This pale yellow metallic mineral can cause acid drainage problems and produce rust-coloured stains on building walls.

Alkali-Aggregate Reactivity in Goldenville Formation Quartzite

Quantitative evaluation of the quartzite aggregate in terms of alkali-aggregate reactivity was beyond the scope of this study. However, it warrants general discussion because it is a potential concern in some concrete applications. The following is a brief description of the reaction and the implications it has for bedrock in the Metro area.

Certain aggregate rock types in concrete, when exposed to repeated wetting and drying, tend to react with the alkalis in Portland cement. This is known as alkali-aggregate reactivity or AAR. The reaction is complex and dependent on the mineralogy of the rock; however, the result is reaction rims that form around the aggregate clasts. Over time and in the presence of water, the rims expand. This causes pressure to build in the concrete and ultimately creates fractures, which continue to grow. 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. The presence of de-icing salts or sea water can accelerate the problem. The reaction is of particular concern in exposed concrete structures such as bridges, hydro power dams and wharfs.

The problem was first observed in Nova Scotia in the early 1960s in hydroelectric plants where they were experiencing alignment difficulties with generators and turbines. Duncan and Swenson (1969) and Swenson (circa 1970) investigated and documented alkali reactivity in some aggregates in the province. By the mid-1980s it was identified as a major factor in the premature failure of concrete structures in the province. Recognition of the potential costs associated with this damage stimulated a substantial amount of research to evaluate the reaction and identify solutions to the problem. A summary of the results was reported by Langley *et al.* (1993).

Table 3. Micro-Deval analyses for quartzite and granite samples.

Sample Number	Rock Type	Sample Description	Micro- Deval	Los Angeles Abrasion Loss (%)	$MgSO_4$ Soundness Loss (%)	Average Specific Gravity	Absorption at SSD (%)	Petrographic Number
AVV-1	Morse Road Leucomonzogranite	Pink to buff, coarse grained, megacrystic, 6-8% biotite, some chloritization.	8.3	36.2	2.89	2.634	0.36	150
AVV-2	Scrag Lake Biotite Granodiorite	Blue-gray, medium -coarse grained, 10-12% biotite, megacrystic (5%) abundant iron staining on joint planes, common zenoliths.	7.2	24.9	1.17	2.705	0.38	110
AVV-3	Scrag Lake Biotite Granodiorite	White-gray, coarse grained, 5% biotite, megacrystic, subvertical weathered zones may be related to shearing.	8.6	34.7	2.26	2.678	0.35	132
AVV-4	Scrag Lake Biotite Monzogranite	Pale brown with maroon tinge, medium-coarse grained, 5% biotite, minor megacrysts, highly fractured, slickensides in fracture planes, pronounced weathering.	10.7	45.3	4.80	2.619	0.79	110
AVV-5	Sandy Lake Biotite Monzogranite	Buff-salmon coloured, medium-grained, 3-4% biotite, equigranular, minor pegmatites in samples (5%).	7.8	35.6	2.77	2.612	0.65	103
AVV-6	Sandy Lake Biotite Monzogranite	Medium gray monzogranite, pale pink and gray overtones, coarse grained, 7-8% biotite, 5-10% megacrysts,	10.0	33.0	3.45	2.646	0.57	125
AVV-7	Sandy Lake Biotite Monzogranite	Medium gray, pale pink and gray overtones, coarse-grained, 5-10% megacrysts, 7-8% biotite, aplite dyke present.	7.1	30.8	1.63	2.656	0.50	119
AVV-8	Sandy Lake Biotite Monzogranite	Medium gray monzogranite, pale pink and gray overtones, orange tinge, coarse grained, 5-10% megacrysts, 3-4% biotite, aplite dyke present, hematite and manganese staining on joint faces.	7.8	33.8	2.32	2.624	0.48	114
AVV-9	Panuke Lake Leucomonzogranite	Salmon colored, medium grained, equigranular, 4% biotite, 4% muscovite, pale green alteration pods, iron staining on joints.	6.3	26.7	1.02	2.618	0.57	115

Table 3. Continued.

Sample Number	Rock Type	Sample Description	Micro- Deval	Los Angeles Abrasion Loss (%)	$MgSO_4$ Soundness Loss (%)	Average Specific Gravity	Absorption at SSD (%)	Petrographic Number
AVV-10	Sandy Lake Biotite Monzogranite	Medium gray with pink-green tinge, coarse grained, megacrystic, koalinized feldspars, rock breaks easily, abundant shearing and oxidized zones, quartz veins in shears.	9.7	32.3	7.37	2.626	0.84	120
AVV-11	Sandy Lake Biotite Monzogranite	Pale salmon color, coarse grained granite with fine grained aplite dyke, strongly jointed, iron mineralization on joint faces, 3-4% biotite.	3.6	21.0	0.53	2.622	0.56	100
AVV-12	Sandy Lake Biotite Monzogranite	Pale salmon colored, medium grained, equigranular, iron staining on fractures, simular to AVV-9, 2-3% biotite, some pale green alteration of the feldspars (<1%), kaolinization present.	5.3	25.6	1.05	2.623	0.68	113
AVV-13	Goldenville Formation, Quartizte (Metagraywacke)	Quartzites with some siltstone; some slatey cleavage, minor pyrite on fracture planes and in pods as well, some layering of the finer units, sampled 80% quartzite and 20% siltstone.	10.7	17.7	0.46	2.729	0.31	141
AVV-14	Goldenville Formation, Quartzite (Metagraywacke)	Green-gray quartzite and siltstone, easily broken along fracture planes, some foliation.	8.6	14.1	0.73	2.703	0.28	120
AVV-15	Goldenville Formation, Quartzite (Metagraywacke)	Green-gray quartzite, minor slate, well defined thick units of quartzite (less than or equal to 0.3 m) separated by thin partings of slate and siltstone beds, quartzite (less than or equal to 3 m), small amounts of pyrite in quartzite (<1%).	6.6	16.1	0.75	2.732	0.29	105
AVV-16	West Dalhousie, Muscovite-Biotite Monzogranite	Medium gray with pale pink overtones, coarse grained, megacrystic, 8-10% biotite, pegmatitic, hematite staining present on fracture surfaces, staining of quartz grains, rock is quite durable.	9.8	46.3	1.96	2.627	0.49	129

Table 4. Semiquantitative method for determining an acceptable proportion of slate in a quartzite aggregate deposit. Using the Petrographic Number test procedure and a maximum PN=135 (for types A, B-HF and C-HF asphalt concrete), approximately 4% slate would be allowable in a high quality deposit. This method requires that the entire composition of the hypothetical deposits described in the table consist of Petrographic Test end members quartzite and slate or factors (1) and (10) respectively. In real Meguma Group quartzite deposits this is rarely the case. The presence of siltstone as factors (3) and (6) would significantly complicate the calculations above, and the allowable slate limits.

Quartzite Deposit/Slate Ratio	**% Quartzite (% x Factor 1)**	**% Slate + (% x Factor 10)**	**= Petrographic Number (PN)**
19 : 1	95 per cent (95 x 1)	5 per cent + (5 x 10)	equals 145
24 : 1	96 per cent (96 x 1)	4 per cent + (4 x 10)	equals 136
97 : 3	97 per cent (97 x 1)	3 per cent + (3 x 10)	equals 127
49 : 1	98 per cent (98 x 1)	2 per cent + (2 x 10)	equals 118
99 : 1	99 per cent (99 x 1)	1 per cent + (1 x 10)	equals 109
100 : 0	100 per cent (100 x 1)	____	equals 100

The research of the last 30 years has concluded that alkali reactivity in Nova Scotia is common and occurs as an alkali-silica reaction. When alkalis from the cement are exposed to certain silicate minerals (e.g. microcrystalline to cryptocrystalline quartz) in 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 silica gel for water causes the rim to grow and cracking to occur (Fig. 13). 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 reason appears to be increased surface area in the quartz where the reaction can take place. The data indicate that the Goldenville Formation quartzite is quite reactive throughout the Meguma Zone. Recrystallization of the quartzite near intrusive contacts appears to reduce the alkali reaction. There appears to be an inverse relationship between proximity to granitoid rocks and the intensity of the reactivity. Although temperature increases associated with emplacement of the 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 summary, research indicates that alkali reactivity is a concern when quartzite of the Meguma Group is the source of aggregate used in concrete. However, concrete products represent only 2-3% of total annual consumption of aggregate in the province, and of this, probably less than half of the materials would be structural concrete in an exposed or vulnerable position for the reaction. Furthermore, the reaction can be controlled in potentially reactive stone by using low alkali cements, limiting the alkali content of the concrete mixture, and using supplementary cementing materials such as fly ash to mitigate the problem (Langley *et al.*, 1993).

Halifax Formation

The Halifax Formation, which overlies and laterally interfingers with the Goldenville Formation, consists predominantly of slate with minor interbedded quartzite. The slate is composed of clay- and silt-sized particles, and commonly contains thin interbeds of siltstone to produce a laminated texture. The siltstone layers are generally characterized by parallel layering or ripple

Figure 10. Example of interbedded quartzite (pale and blotchy) and slate (darker beds) in the Goldenville Formation (location 2, Fig. 7). The tabular nature of this layered bedrock presents opportunities for dimension stone products (see Fig. 11).

cross-lamination. The colour varies from black to blue-grey to pale green-grey. Contact metamorphism near granites has resulted in metamorphism in these fine-grained rocks varying from greenschist to amphibolite facies. Foliation cleavage and schistosity are pervasive in the slates. The sulphides pyrite and pyrrhotite are common. Arsenopyrite is less common, but may occur in significant amounts on a local scale.

Halifax Formation slate (commonly called shale by industry) has a long history of use as aggregate in the western half of the province. This is largely a reflection of the characteristics of the deposits and the absence of more suitable materials in the area. In general, the production sites (Fig. 14) consist overwhelmingly of slate; however, interbeds of siltstone are common and minor quartzite may be present at the transition zone. The materials have been very popular because they are easily ripped, requiring minimal equipment and cost to extract. The aggregate clasts are platy in nature, so they 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 most of these sites have been abandoned because of problems with acid drainage and inferior quality.

The Halifax Formation slates were not tested in this study because of characteristics inherent to the rock type that make them undesirable as a construction material. These slates are a deleterious stone which performs poorly in laboratory tests and product applications where high quality aggregate is required. Physical properties that negatively affect quality are softness, fissility, cleavage and platy shape. These characteristics result in low durability in the stone, causing it to break down when subjected to a variety of stresses. In applications such as highways, soft, fissile aggregate such as slate tends to cause early mechanical failure. Cleavage makes the rock more susceptible to water absorption, freeze-thaw cycles and weathering. The aggregate particles tend to rapidly break down where exposed to the

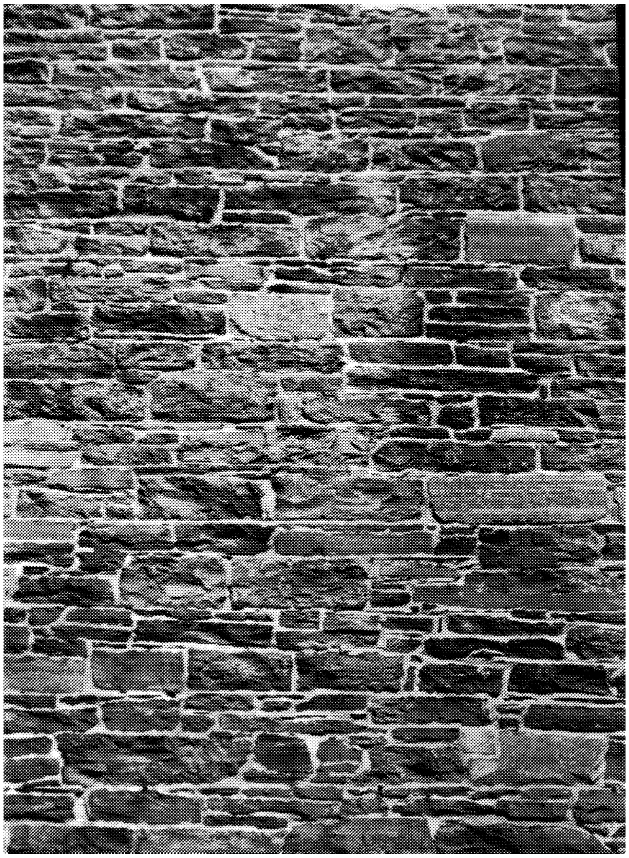


Figure 11. Wall at Historic Properties in Halifax (location 3, Fig. 7) constructed from blocks of Meguma Group slate and quartzite. The source of the material is probably similar to bedrock observed in Figure 10.

weather. In asphalt concrete, slate clasts tend to swell from water absorption and expand with freezing to cause popouts. The tabular, platy shape of slate clasts is undesirable in bituminous concrete because a bridging effect tends to cause large voids requiring additional asphalt or creating areas of structural weakness (Fig. 15). In concrete, the 'flakiness' or tabular shape of the coarse aggregate can reduce flexural strength and adversely affect the workability of the mix (Smith and Collins, 1993). The result is that the Halifax Formation not been included on the aggregate potential maps (pocket).

Acid Drainage

A major problem in using Halifax Formation rocks for aggregate purposes is acid drainage associated with pyritic slates (e.g. King, 1985; Environment Canada, 1987; King and Hart, 1987; Lund *et al.*, 1987). Research indicates that when pyritic slates are exposed to air and water through excavation, the sulphides react with water to produce weak sulphuric acid. This occurs mainly through quarrying or the preparation of industrial sites (e.g. airports or industrial parks) when the protective overburden is removed and fresh rock is exposed. The problem is further exacerbated when the materials are extracted and crushed for aggregate, dramatically increasing the surface area of the slates and exposure of the sulphides. Acid generation occurs not only at the aggregate production sites, but at all locations where the materials have been exposed (e.g. roads). The acidic runoff can then leach potentially harmful metals (e.g. aluminum, arsenic or mercury) out of bedrock or soils, causing them to be mobilized into the water system. When acidic waters enter a river or stream the natural pH of the waterway is lowered. Collectively, the acidity and metal contamination alter the water chemistry and stress the stream ecology. The result is a water system that can stress the aquatic life and cause toxic metals to enter the food chain. Fish kills related to acid drainage have been well documented (Scott, 1961; Environmental Protection Service, 1976).

Recent research has been conducted to identify and evaluate potential areas of concern in the Halifax Formation (e.g. Manchester, 1986). Efforts have also been made to remediate problem areas, with treatment facilities now operating at the Halifax International Airport and along Route 107 at Petpeswick Lake (Fig. 16). Environmental guidelines are now in place regarding the development of quarries in slate (Nova Scotia Department of the Environment and Environment Canada, 1990). As a result, the exposure or use of slates with greater than 0.4% sulphides (12.51 kg/t H_2SO_4) is now prohibited. Examination of the Halifax Formation slates as part of this study indicates that sulphide levels exceeding this value are common in the study area.

Sulphide-bearing Rock as Building Stone

Quartzite and slate have had a long history of use in the Metro area as dimension stone in the construction of buildings and retaining walls because of local availability, natural shape and architectural appeal (Fig. 17a&b; Fig. 17c). Many older buildings in the Metro area are made entirely with these materials. There have also been several recent projects involving restoration and replication of historical structures. Collectively, these dimension stone applications represent a small portion of total annual stone production in the area; however, they are of significant value to the aesthetic appeal of the area. Although generally viewed as distinct from bedrock aggregate production, they are included in this report because much of the Meguma Group stone for these purposes comes from aggregate quarries.

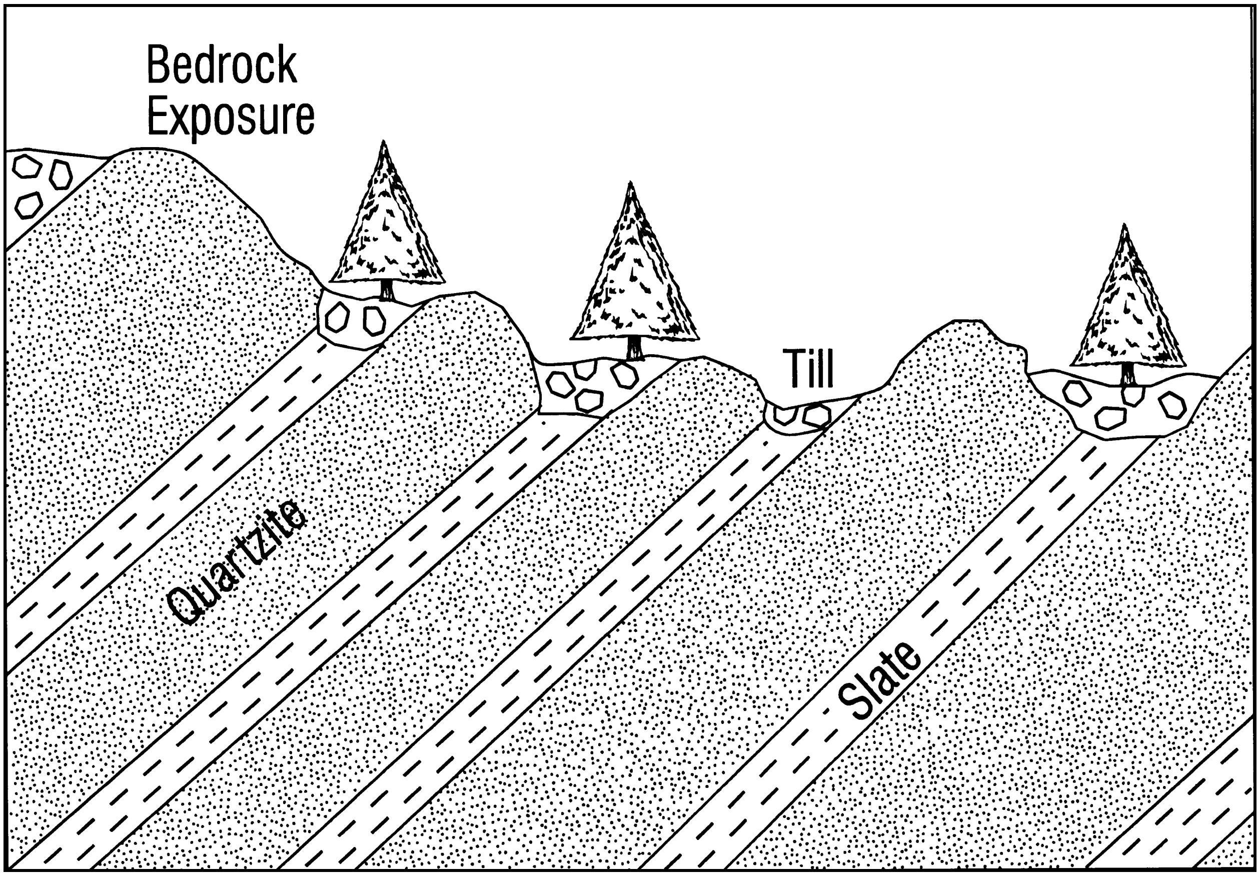


Figure 12. Field mapping of bedrock exposure in sedimentary rocks such as the Goldenville Formation can be deceptive in terms of aggregate potential. This schematic illustration shows that the more competent quartzite beds were less susceptible to glacial erosion than the softer slates. Till subsequently infilled the low areas, hiding slate units beneath the till cover. What appears to be a good area to quarry quartzite actually has unacceptable amounts of slate. Trenching, diamond-drilling or geophysical surveys are needed to reveal the subsurface stratigraphy.

The presence of sulphide-bearing rock in architectural applications where the stone will be exposed to the weather should be avoided. When pyrite or pyrrhotite in the stone reacts with water to produce small amounts of dilute sulphuric acid and iron precipitate, over time the iron migrates or 'bleeds' down the wall to produce a rust-coloured stain. The result is visually unappealing and can be costly to correct. There are several structures in the Metro area where minor sulphide, in exposed aggregate concrete panels or building stone, has caused serious staining problems (Fig. 18). It takes very little pyrite to create stains and they occur a very short time after exposure. There are several retaining walls in the Metro area (gabion walls and exposed aggregate concrete walls) where one or two pieces of pyritic stone have ruined the entire face of the structure. This should serve as a warning to stone masons and architects to be aware that the slates and quartzite of the region commonly contain sulphides, which can detract from the visual appeal of exposed structures. Appropriate action should be taken to ensure that the prospective stone source is as free as possible of these deleterious materials.

Intrusive Rocks

Intrusive rocks underlie almost half of the study area (Fig. 7). Although technically called felsic igneous intrusive rocks, for the purpose of this paper they will be referred to as granite. Granite in the study area consists of parts of two batholiths, the South Mountain Batholith and the Musquodoboit Batholith, and a small pluton at Fall River, the Kinsac Pluton. Collectively, granite constitutes approximately 40% of the study area. The South Mountain Batholith is one of the largest batholiths in the Appalachian Orogen, outcropping over approximately 7300 km^2 in western Nova Scotia (MacDonald *et al.*, 1992). It was emplaced in several stages and is composed of monzogranite, leucomonzogranite, granodiorite, mafic porphyry and leucogranite (MacDonald *et al.*, 1992). The Musquodoboit Batholith, which is smaller and shows less lithological variation, is

Figure 13. Example of a concrete structure in the advanced stages of alkali-aggregate reactivity. Once the reaction has begun, deterioration of the structure is accelerated by freeze-thaw cycles.

composed of leucomonzogranite and monzogranite (Ham, 1994). The Kinsac Pluton, which was originally mapped by Faribault (1909a), has more recently been identified by Coolen (1974) as a porphyritic monzogranite. It is similar in composition and texture to the coarse-grained leucomonzogranite of the South Mountain Batholith (Horne *et al.*, 1996). It has been suggested that the South Mountain Batholith, the Musquodoboit Batholith and the Kinsac Pluton are all connected at depth (Douma, 1978; Creaser, 1996).

Granitic rocks were investigated according to their lithological groupings as identified on the published geological maps (Fig. 5) by MacDonald and Horne (1987) and Corey (1987). This was based on the premise that a mineralogically distinct granitic rock type might exhibit a range of aggregate test values which would make it distinguishable from other rock types. Table 5 provides a summary description of granitic rock types found in the study area. These were examined and described as part of this study. The granitic rocks were sampled, with the exception of the mafic intrusives. The decision not to sample the mafic rocks was based on their restricted occurrence along the coast in a location where quarrying would not be allowed.

Four rock types from 46 locations were sampled and tested in the study (Appendix 4; Table 2, Table 6). They consisted of leucogranite, monzogranite, leucomonzogranite and granodiorite. Los Angeles abrasion loss results varied from 28.0% to 61.5% (n=46) with a mean weight loss of 40.1% (s=7.0%). Magnesium sulphate soundness loss results varied from 1.1% to 37.4% (n=46) with a mean weight loss of 7.6% (s=6.3%). Collectively, the test results indicate that resistance to impaction, abrasion and weathering varied substantially among samples.

Although the granites of this study were not tested for Micro-Deval abrasion loss, Table 3 shows analyses of several samples taken from comparable South Mountain Batholith rocks adjacent to the study area. This included fine- to coarse-grained megacrystic stone. Results indicate that the Micro-Deval abrasion loss of

Figure 14. Slate quarries such as this one near Wyses Corner, Halifax County (location 4, Fig. 7), have been a primary source of aggregate in some parts of the province.

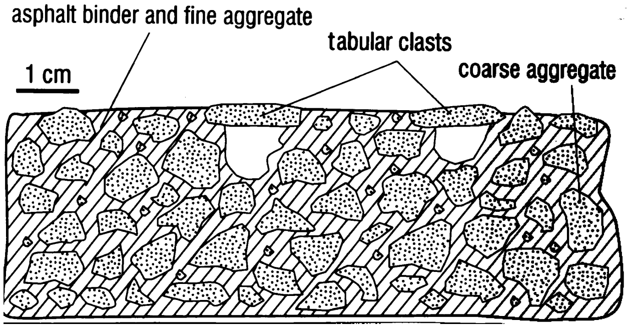


Figure 15. Consequences of tabular or platy aggregate clasts in bituminous concrete (asphalt). These clasts can create voids (white space), resulting in poor bonding and areas of structural weakness.

the samples (n=13) varied from 3.6% to 10.7% with a mean value of 7.9%. This falls well within acceptable limits for highways materials as outlined in Appendix 3.

Examination of the analytical results for granite could not establish a link between their lithology and aggregate quality. This may reflect a sample population (n) in the study which was insufficiently large to make this determination. However, the author suspects that the mineralogy of the granite sample plays a minor role in determining aggregate quality. Alternatively, it is suggested here that characteristics that most affect aggregate performance are the physical or textural traits, grain size and microfracturing. Below is a discussion of the findings.

Grain Size

Grain size in granite refers to the average size of the mineral crystals which make up the rock. The term 'average' is used because the rocks in the study area vary from a uniform grain size, to a range of grain sizes, to a bimodal distribution of sizes. The grain size descriptions used in this study are based on the classification scheme of MacDonald *et al.* (1992). The rocks were divided into fine grained (<0.1 cm), medium

Figure 16. Attempts to seal acid-generating slates exposed during construction of Route 107 near Petpeswick Lake (location 5, Fig. 7) have not eliminated the problem. Rusty, iron stains (they look like shadows in the photo above) on the shotcrete and in the drainage ditch are a telltale sign of acid-generating slate. A containment pond at the base of this hill is used to buffer the low pH runoff before it enters the local lake system.

grained (0.1-0.5 cm), coarse grained (>0.5 cm) and megacrystic (containing at least a few per cent of feldspar crystals >2 cm long). Some of the textures fell between these categories, resulting in fine-medium and medium-coarse categories. Porphyritic rocks consist of medium- to coarse-grained phenocrysts within a fine-grained matrix or groundmass. Examples of these textures are shown in Figure 19.

Aggregate test results (Table 2) indicate that, in general, the durability of the intrusive samples can be correlated to grain size. This is graphically represented in Figure 20 and numerically determined by calculating mean values for the different test results (Table 6). The graphs show two general trends. (1) The fine- to medium-grained rocks (sample size n=11) consistently have the lowest Petrographic Numbers (Fig. 20a, b), ranging from 100.0 to 106.0, with a mean value of 104.2. (The one exception is sample HC 14 with PN=134.0.) The coarse-grained samples (n=23) have highly variable Petrographic Numbers, ranging from PN=102 to PN=347. The mean value for coarse-grained stone is 133.7. Elimination of sample HC 24 (PN=347), which is inexplicably high, from the sample population reduces the coarse-grained mean value (n=22) to 124.2. However, the Petrographic Number for the coarse-grained rock is still substantially higher than that of the fine-grained rock. Because the Petrographic Number test depends primarily on a scratch test to determine hardness, mineralogy is an important factor in its outcome. The presence of soft minerals such as mica or some alteration minerals (e.g. kaolin) will strongly influence the test results. The high PN value for sample HC 14 can probably be attributed to a high percentage of biotite which could affect the stone's performance in the scratch test. (2) The Los Angeles abrasion loss (Fig. 20 a, c; Table 6) is generally lower in the fine- to medium-grained samples (n=12) with a mean abrasion loss of 33.4 %. Conversely, the coarse-grained stone (n=33) has a mean abrasion loss of 42.8 % and appears to break down much more easily.

Magnesium sulphate soundness loss results are less clearly defined in Figure 20b and c. In general, the fine-grained rocks have lower loss values than the coarse-grained rocks; however, most of the coarse-grained samples still have loss values falling within acceptable industry standards for the test. For fine- to medium-grained samples (n=13) the mean soundness loss is 4.3%, and for coarse-grained samples (n=33) the mean soundness loss is 9.0 %. Collectively, these results reflect the greater durability of the finer grained stone for aggregate purposes.

The correlation between grain size and quality in granites is well known in the aggregate industry (e.g. National Stone Association, 1991; Irfan, 1994). Recent research on granitic rocks in Hong Kong had findings similar to this study with fine-grained intrusives demonstrating better quality than coarse intrusives (Irfan, 1994). Presumably, the amount of surface area bonding between grains per unit volume of rock is an important factor in determining the mechanical strength of the rock.

Microfracturing

Microfracturing is defined here as hairline cracks (less than 1 mm wide) present in granitic rocks. It is a common feature in the intrusive rocks of the study area and appears to be characteristic of the Devono-Carboniferous granites of western Nova Scotia. The exact cause of the fracturing has not been documented; however, it is speculated here that the primary cause was tectonic stresses following emplacement of the plutons. Presumably, mineralogical alteration (e.g. kaolinite) and recent weathering (e.g. freeze-thaw cycles) have also contributed to the intensity of near-surface microfracturing at some locations (e.g. grus and saprolite).

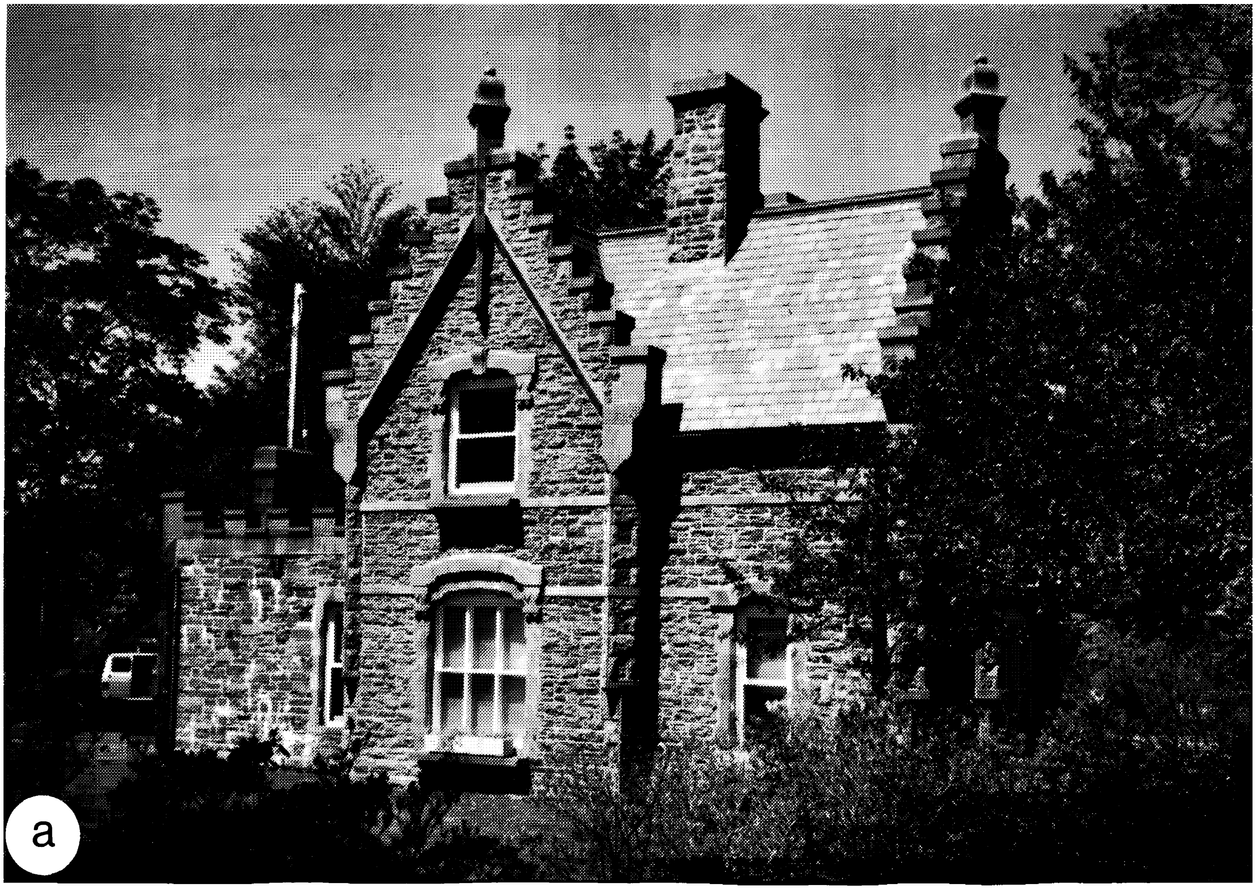
The presence of microfractures (also called microcracks) was initially discovered in laboratory samples following the field phase of the project. When cut and polished, several samples from the study area revealed microfractures (Fig. 21a). The remaining samples were cut and wet on their surfaces. More samples were then polished to further document the occurrence and magnitude of this characteristic. Thin sections were made of several samples for petrographic examination (Fig. 21b). Finally, some of the samples were impregnated with blue epoxy to demonstrate the extent and configuration of the fracture systems (Fig. 22). Based on visual examination, samples were assigned a relative descriptive value of the intensity of microfracturing (Table 2; low, medium, high). Below is a discussion of microfracturing as it was documented in this study.

Microfractures were observed in all of the granite samples that were cut, polished and examined in reflected light. The fractures were also observed in the cut, unpolished samples; however, they are much less obvious. Fracturing in uncut, freshly broken rock was poorly visible to undetectable, except in some of the coarse-grained rock.

The fractures vary from cracks in individual grains to complexly branched networks that cut across several grains or several centimetres of the rock face. Fractures filled with blue epoxy show that cracks through grains commonly stop sharply at grain boundaries. The fractures can display a preferred orientation or occur randomly, commonly within the same samples, suggesting there may be different generations of fractures. The severity of fracturing in the samples varies from minor to moderate to pervasive. The cracks vary from being open with no apparent infilling to being infilled with sericite, calcite and hematite (Charles Jessome, personal communication). The degree of microfracturing is usually a reflection of grain size of the rock, with coarse-grained rock being highly fractured and fine-grained granite containing minimal fractures. However, it should be emphasized that not all of the coarse-grained rocks are intensely microfractured.

Analytical results indicate that microfractures in the intrusive rocks significantly reduce the mechanical strength of the stone. Furthermore, the strength of the rock appears to be inversely related to the intensity of microfracturing (bearing in mind the subjective nature of assigning microfracturing descriptive values and the small sample size of some categories). In the Los Angeles abrasion loss test, the six samples identified as being highly fractured (HC-6, HC-9, HC-24, HC-25, HC-39, HC-55) had a mean abrasion loss of 50.5%, compared to the total intrusive sample population (n=46) with a mean abrasion loss of 40.1% (Table 6). In the Magnesium sulphate soundness test, the six samples identified as highly fractured had a mean soundness loss of 17.8%, compared to the total intrusive sample population (n=46) with a mean soundness loss of 7.6%.

The test results are significant because they indicate that microfractures can be detrimental in stone being used as an aggregate material for structural purposes. First, the fractures produce planes of weakness in the aggregate clasts, reducing their compressional strength and making them more susceptible to early mechanical failure. This is particularly problematic in applications such as 100 series highways where heavy traffic causes severe load stresses (e.g. compression and grinding) to the aggregate in the road bed. Second, the microfractures become pathways for water infiltration when the aggregate is exposed to the weather. Freeze-


a


b

Figure 17. Examples of quartzite and slate dimension stone in the Metro area. (a) This stone building in Point Pleasant Park (location 6, Fig. 7) is a testimony to the lasting architectural appeal of quartzite as a building stone. (b) Retaining walls constructed of quartzite are a common site in Metro. The mortared wall shown here is in Rockingham (location 7, Fig. 7). (c) Fence rows of slate are a focal point in the south end of Halifax (location 8, Fig. 7).

thaw cycles then cause the fracture system to become progressively more extensive, resulting in the premature breakdown of the stone. This is especially significant in exposed concrete where expansion and progressive cracking can lead to more widespread structural deterioration.

Suggesting a causal relationship between microfracturing and the analytical results is a tenuous conclusion to draw because of: (1) the effect that grain size appears to have on mechanical strength, and (2) the role that grain size appears to play in the intensity of microfracturing. All of the highly microfractured samples were coarse grained; therefore, a comparison could not be made between the two features. However, a comparison between all of the coarse-grained samples and the coarse-grained samples with strong microfracturing (Table 6) indicates mean abrasion losses of 40.1% and 50.5%, respectively. Although the sample size for the highly microfractured, coarse-grained intrusives is very small (n=6), the results suggest that microfracturing may further reduce the strength of coarse-grained stone. This probably reflects the fact that microfractures in the coarse-grained rock, either alone or interconnected, create lines of weakness several centimetres in length. In fine-grained rock the cracks are commonly confined to individual grains and measured in millimetres. Because the specifications for aggregate products usually require materials with a clast size upper limit of a few centimetres, microcracks in coarse-grained granite aggregate can easily cut across entire clasts. If the microfracture does not become a break in the rock during crushing to produce smaller particles, it then remains as a zone of weakness in the clast and vulnerable to a variety of mechanical stresses such as compression and freeze-thaw cycles. Furthermore, the acts of blasting and crushing the coarse-grained, microfractured granitic rock for aggregate probably enhances fracturing in the resulting aggregate clasts, increasing the probability of early failure of the product (Fookes *et al.,* 1988).

In conclusion, microfracturing negatively influences the mechanical performance of granite. Several characteristically different types of microfractures were observed in the granite samples; presumably, each type influences the host rock differently. For example, open fractures cause planes of weakness and conduits for

Figure 18. Iron stained (dark blebs and stains in white) mortar resulting from exposed pyrite in a slate wall, downtown Halifax (location 3, Fig. 7). Just one or two pyrite crystals in the rock can ruin the visual appeal of a structure.

water entry into the aggregate clasts. Fractures infilled by secondary minerals, on the other hand, may only marginally reduce the strength of the stone. The significance of microfracturing depends on the product application and degree of exposure to weathering processes and mechanical stresses.

The findings of this study are preliminary. Although microfracturing clearly can affect aggregate performance, there are many other parameters that must be evaluated in order to determine the overall potential of a deposit. Many coarse-grained (and presumably microfractured) granite deposits in the province have been successfully quarried for high quality aggregate. Discussions with Nova Scotia Department of Transportation and Public Works have confirmed that most quarried granite passes specifications for road materials in Nova Scotia.

Alkali-Aggregate Reactivity in Granite

Granitic rocks in Nova Scotia have been tested for alkali-aggregate reactivity (AAR) and are generally considered to be nonreactive (Langley *et al.*, 1993). However, research indicates that granitic rocks in general are potentially susceptible to AAR (Dolar-Mantuani, 1983). The author strongly recommends that any site being considered for concrete aggregate should be tested for alkali-aggregate reactivity.

Carboniferous Sedimentary Rocks

Carboniferous sedimentary rocks occur in the study area at Meaghers Grant and French Village (Fig. 7). They consist of carbonates (limestone and dolomite), sandstone, shale and conglomerate unconformably overlying metasediments of the Meguma Group. A brief examination of these rocks during field investigations and testing of one carbonate sample (HC-34) resulted in rejection of the Carboniferous rocks as a potential source of high quality aggregate for the Metro area. These rocks are generally soft, lack durability and commonly have high water absorption values. They can be used for low grade applications such as fill, woods access roads, and other products where durability is not a critical factor. However, it would not make economic sense to haul inferior materials such as these tens of kilometres to the Metro market. Furthermore, the common presence of good bedrock potential in proximity to the Carboniferous rocks (e.g. quartzite or granites) makes it unlikely that they would be considered as an aggregate source, even locally. Carboniferous rocks have not been classified as having aggregate potential on the resource maps (pocket).

Grain Size Analysis

The primary focus of an aggregate quarry is the production of coarse stone for products such as concrete, road base and back fill. Although minus ¼ inch sand fractions are used in a variety of applications, they represent a relatively minor component of the marketable materials. The silt and clay fractions are generally treated as deleterious materials which must be removed to ensure product quality. These waste fines not only have little marketable value, they incur operational costs related to handling and stockpiling. Consequently, the optimal aggregate deposit should generate a maximum amount of coarse stone and a minimum of fines.

Table 5. Summary description of the granite rocks found in the study area.

Rock Type	Map Units Found in the Study Area	General Description	Other Comments
Leucogranite	Walsh Brook	buff to orange pink; fine- to medium-grained; moderately equigranular; biotite (1-2%), muscovite (2-4%).	-
Monzogranite	Sandy Lake/Harrietsfield/ Unnamed units in the Musquodoboit Batholith and Kinsac Pluton	light grey to buff to orange brown; very fine- to coarse-grained; moderately equigranular, megacrystic (5-25%); biotite (2-12%), muscovite (0-4%), quartz and K-feldspar phenocrysts.	subdivided by MacDonald *et al.* (1992) into muscovite-biotite monzogranite and biotite monzo-granite
Leucomonzogranite	Halifax Peninsula/Sandy Lake/Tantallon/Panuke Lake/Unnamed unit in the Musquodoboit Batholith	light grey to buff-brown, to buff-orange, pink, dark red; fine- to coarse-grained, megacrystic (5-50%); equigranular, aplitic to porphyritic; biotite (1-7%), muscovite (1-5%), large alkali feldspar phenocrysts and megacrysts	subdivided by MacDonald *et al.* (1992) into fine grained and coarse grained
Granodiorite	No formal name	medium to dark grey; bluish quartz; medium- to coarse-grained, equigranular to slightly megacrystic (2-10%); biotite (12-15%), trace muscovite and abundant xenoliths	-

Sieve analysis was conducted on the crushed samples of this study to determine how the rock types react to processing. The author also wanted to test the hypothesis that grain size distribution may be linked to sample durability. In other words will a sample that performs poorly in other aggregate tests generate more sand and fines? Although the grain size distribution produced in a small jaw crusher in a laboratory setting may vary significantly from processing in a modern aggregate operation, the method should provide a useful comparison of the rock types. A discussion of the methodology is provided in Appendix 2.

Figure 23 is a graph comparing the percentage of plus 4 mesh stone (gravel size) to the LA abrasion loss for each sample. The abrasion test was chosen for comparison because it is a fairly good measure of stone durability. General trends in the graph support the other findings of this study. The quartzite samples, which are the hardest stone in the study area, produced the greatest percentage of coarse materials. The fine- to medium-grained granitic rocks generated slightly less coarse stone. The coarse-grained granitic rock produced the largest amount of minus 4 mesh materials (sand/silt/clay).

To summarize, the grain size distribution of the prepared bedrock samples shows a positive correlation with stone durability. Harder rock types should generate less fines during the quarrying process. Rocks that perform well on the LA abrasion loss test theoretically should produce the maximum amount of marketable stone and a minimum of waste fines. Performance in the granitic rocks is inversely related to rock grain size. However, micro fracturing in the granites probably also plays a significant role in these results.

Weathering

Weathering is defined for this study as changes in minerals and rock as a result of physical, chemical and biological processes which occur at or near the earth's surface. This can include processes such as wetting and drying, freeze-thaw cycles, temperature changes, mechanical breakage, water-related chemical reactions, the rooting of vegetation, and other plant-related influences. It usually is first recognized as a discoloration of the rock and, depending on its severity, can cause a friable or rotted appearance. It can vary from a superficial effect where a thin rind occurs at the

Table 6. A statistical comparison of grain size and microfracturing in granites based on aggregate test performance.

Rock Type	Sample Size	L. A. Abrasion Loss		MgSO4 Soundness Loss		Petrographic Number	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
all granites	46	40.10	7.00	7.64	6.34	124.15 (n=33)	45.04
fine- to medium-grained intrusives	13	33.40	4.81	4.32	2.63	104.18 (n=11)	9.60
coarse-grained, megacrystic intrusives	33	42.75	5.88	8.95	6.87	133.70 (n=23)	51.69
highly microfractured intrusives	6	50.47	6.54	17.80	10.10	NA	NA
moderate to low microfractured intrusives	40	38.56	5.61	6.12	3.62	114.78 (n=30)	19.30
low microfractured intrusives	13	34.28	4.82	3.50	1.72	105.29	9.12
coarse grained, highly microfractured intrusives	6	50.47	6.54	17.80	10.10	NA	NA

surface of the rock or along joint faces, to a deep, pervasive effect that can penetrate several metres into the bedrock. Although generally a process that takes place over millennia, weathering can also be a recent effect and can result from modern human activities (e.g. the deterioration of slates when they are exposed in pits and road cuts).

Severe weathering of bedrock was rarely observed during the field phase of this study; however, aggregate producers should consider weathering as a significant parameter in choosing a quarry site. It is detrimental to stone quality, and negatively impacts the economics of quarrying a deposit. The following discussion and Table 7 summarize weathering as it applies to the general categories of stone in the study area.

Quartzite of the Goldenville Formation showed virtually no weathering (Table 7). Exposed quartzite bedrock was consistently observed to be sound and ‘fresh’ within millimetres of its surface. Therefore, weathering is not considered to be a concern when quarrying quartzite for aggregate.

Slates of the Halifax Formation, on the other hand, are commonly weathered where they are exposed in quarries or other excavation sites (Fig. 24). This reflects the ease with which water can be absorbed into the clay minerals and along cleavage planes to cause breakdown of the rock through swelling and freeze-thaw cycles. The severity of weathering appears to depend on grain size and mineralogy of the slate, with the pure clay slates showing the greatest propensity for problems.

The granitic rocks (Table 7) varied widely in degree of weathering, which cannot be predicted in terms of location and extent. The weathering can be categorized as: (1) a leached, discolored zone or layer at the surface of solid bedrock or along fracture planes, (2) friable stone associated with shear zones, and (3) a disaggregation of surface bedrock to produce grus and saprolite.

The most commonly observed type of weathering in the intrusive rocks is the leached zone or rind at the bedrock surface or along fracture planes. It is observed as discoloration associated with alteration minerals such as kaolin or iron minerals such as limonite. The primary cause of this weathering is prolonged exposure to water or other surface-related physical and chemical conditions. Its severity depends on variables such as lithology and grain size. There is mechanical weakening of the stone in weathered zones. Depending on the number of fractures and the depth of the weathering (from the surface of the outcrop or away from the fracture plane), the result can be a serious downgrading of the quality of an otherwise sound rock. A sample of crushed stone with an abundance of weathered clasts may not pass a Petrographic Number test because of its softness.

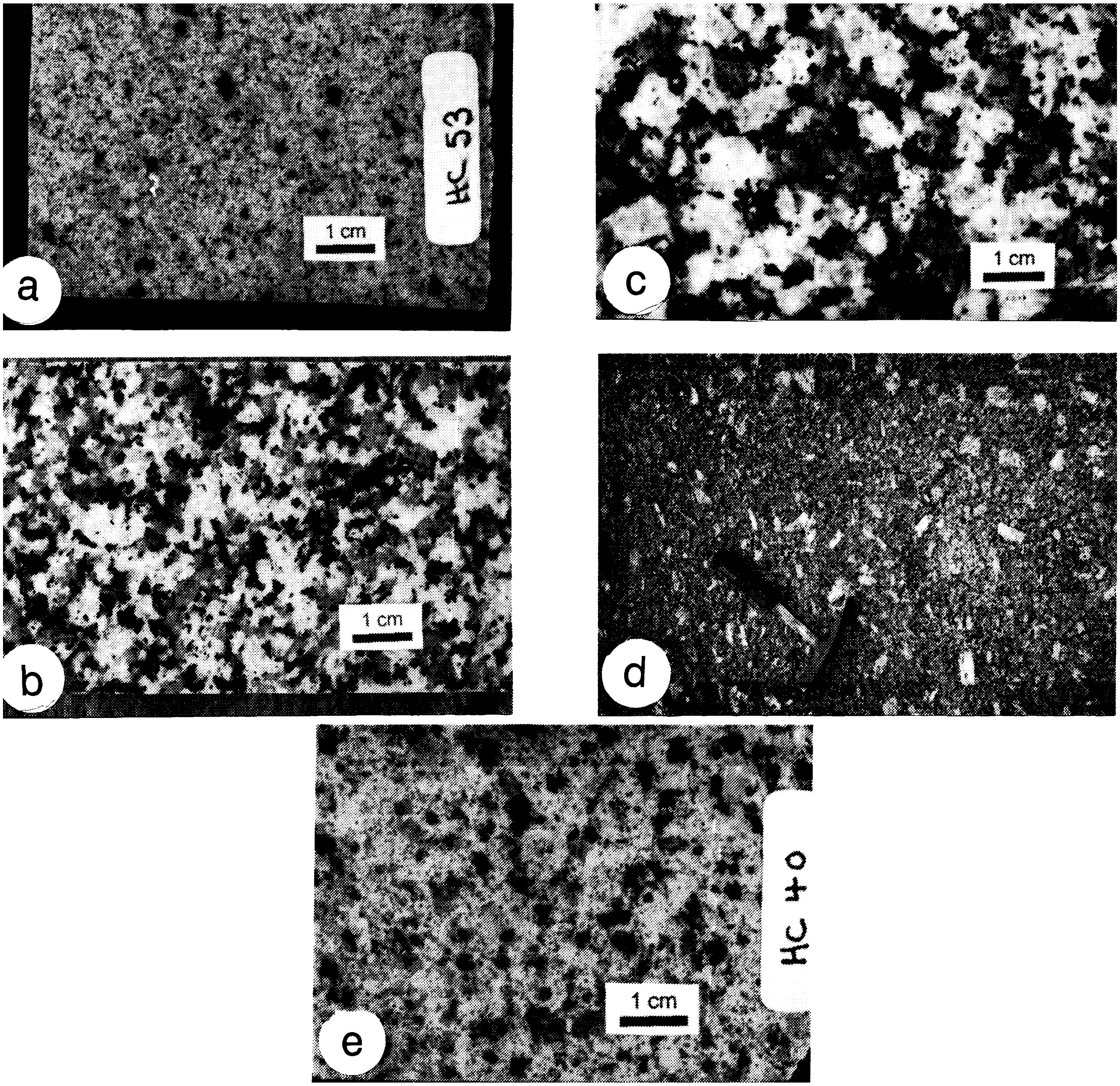


Figure 19. Common grain sizes and textures in granite: (a) fine grained, (b) medium grained, (c) coarse grained, (d) megacrystic and (e) porphyritic.

Shearing in bedrock is the result of movement along multiple, parallel fractures. Shear zones are susceptible to mechanical weakness and become conduits for water and chemical/physical breakdown of the stone. Exposure of these zones to the surface initiates the weathering process and accelerates the breakdown of the stone. Figure 25 shows shearing in course-grained intrusives. In Figure 25a much of the rock in proximity to the shear planes has disaggregated from exposure to water and freeze-thaw cycles. This road cut was opened only a few years ago, demonstrating how quickly weathering can occur. Shear zones do not appear to be common in the study area; however, their presence could significantly downgrade the quality of a deposit.

Grus is a surficial deposit of rock materials produced from the *in situ* alteration and fragmentation of granitic bedrock. The intrusive rocks are susceptible to disaggregation because they contain mica and feldspar, which react with water. Groundwater infusion into the bedrock fracture system causes the expansion of mica and breakdown of feldspar into minerals such as kaolin.

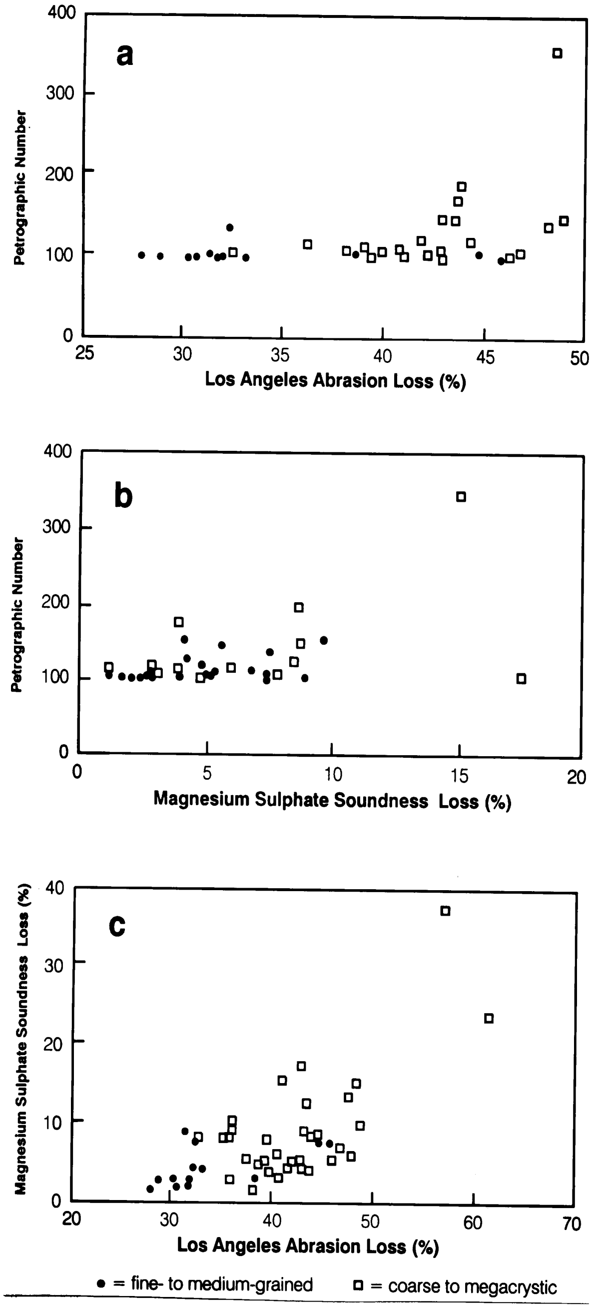


Figure 20. Graphs of aggregate test results in granites based on grain size differences

Initially this produces exfoliation shells around the jointed rock, followed by the later formation of corestone and grus, a sand-like granular material (Fig. 26 and Fig. 27). The weathering is usually deeper in humid climates with grus up to 100 m in depth (Rahn, 1986). In other surficial studies done by the Nova Scotia Department of Natural Resources (Stea *et al.*, 1986; Prime, 1992) grus was usually observed to be a maximum depth of 5-6 m; however, locally the weathering can go much deeper. The intensity of weathering in bedrock decreases with depth so that a few metres below the surface the rock is generally solid. However, the characteristics of the stone that make it susceptible to weathering (shearing or microfracturing) probably are present at depth in what appears to be solid stone. As a result it is unlikely that high quality stone can be found at depth. In other words, removing the disaggregated materials at the surface with the hope of finding high quality bedrock at depth could be a costly mistake. Grus was rarely observed during this field study. Furthermore, it could not always be determined if the weathering recorded was due to shearing or surface conditions.

Virtually all of the weathering in the study area occurs in association with coarse-grained rock. Fine-grained intrusives consistently showed a low level to absence of weathering. The relationship between grain size and weathering is also widely recognized by the aggregate industry (Barksdale, 1991). However, grain size alone does not appear to account for this phenomenon. Locations where weathering is observed in coarse-grained rock commonly occur adjacent to similar coarse-grained stone where weathering is virtually absent. Although preferential glacial erosion may cause this to occur, it is speculated here that pervasive microfracturing may be the agent in the coarse-grained stone that initiates and accelerates weathering. The reasoning is that an extensive, continuous network of cracks, such as is commonly observed in the coarse-grained rock, permits the easy access of water into the stone to promote its physical and chemical deterioration.

The timing and rate of weathering in the intrusives is generally unknown. Work by Stea *et al.* (1986) suggested that weathering in granites found in the Cobequid Highlands may predate glaciation. This may be the case of the grus found in the study area. At the lower end of the time scale, a few naturally exposed outcrops in the study area have a loose layer of quartz grains (5-10 mm thick) with a minor component of kaolinized feldspar crystals at the surface of generally unweathered bedrock (Fig. 28). This has obviously taken place following deglaciation, with the majority of the feldspar grains decaying to the point of disappearing. Thus, the timing of this weathering can at most be a few thousand years.

In summary, pervasive weathering does not appear to be a primary concern in the study area (Table 8). It is mentioned here as a cautionary note when considering coarse-grained granite for quarry potential. Significant weathering zones along joint planes and in near-surface

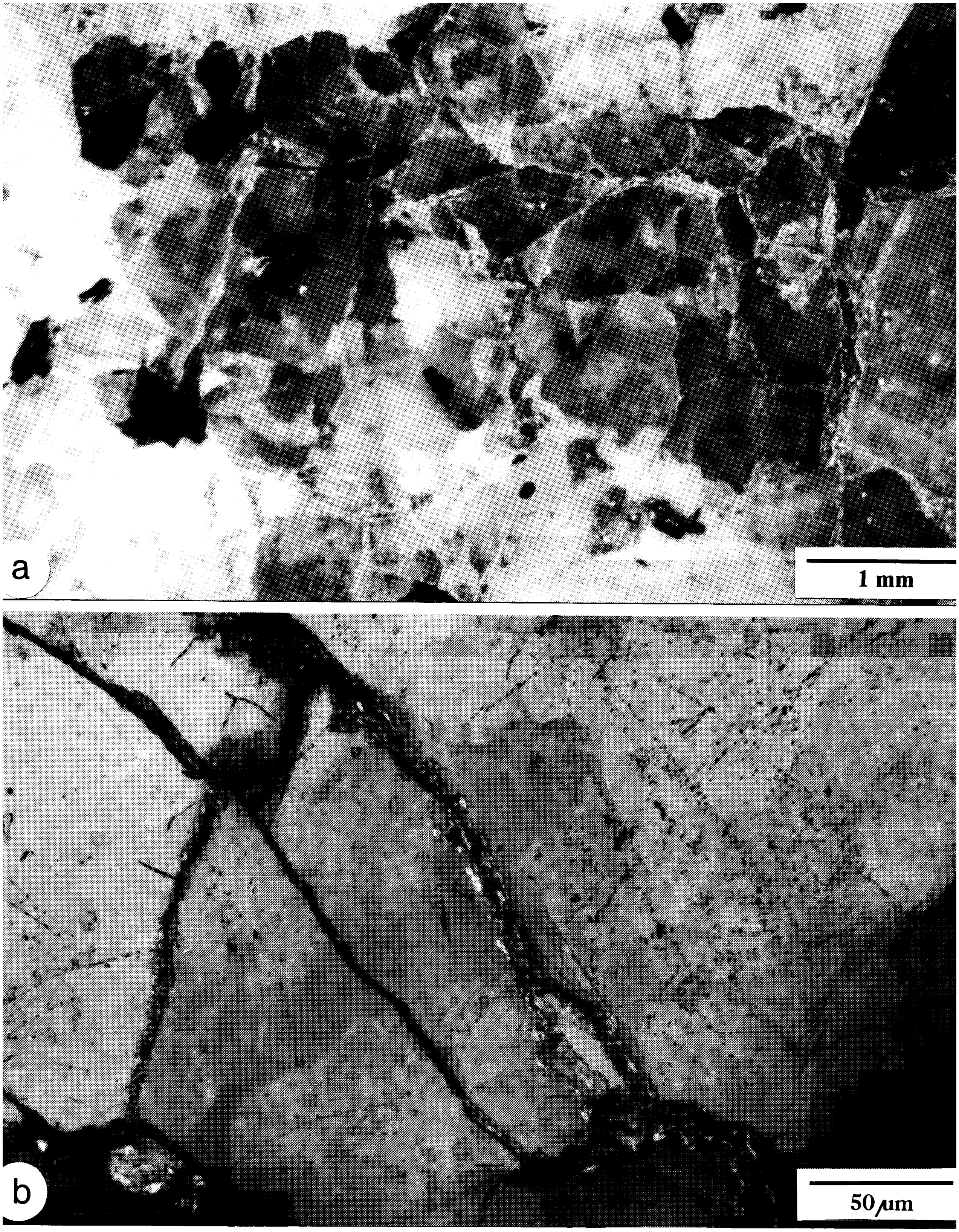


Figure 21. Microfracturing in coarse-grained granite. (a) Microfractures in a magnified, cut and polished hand specimen. Fractures are most easily seen in quartz crystals. (b) Petrographic thin section showing microfractures in a quartz grain.

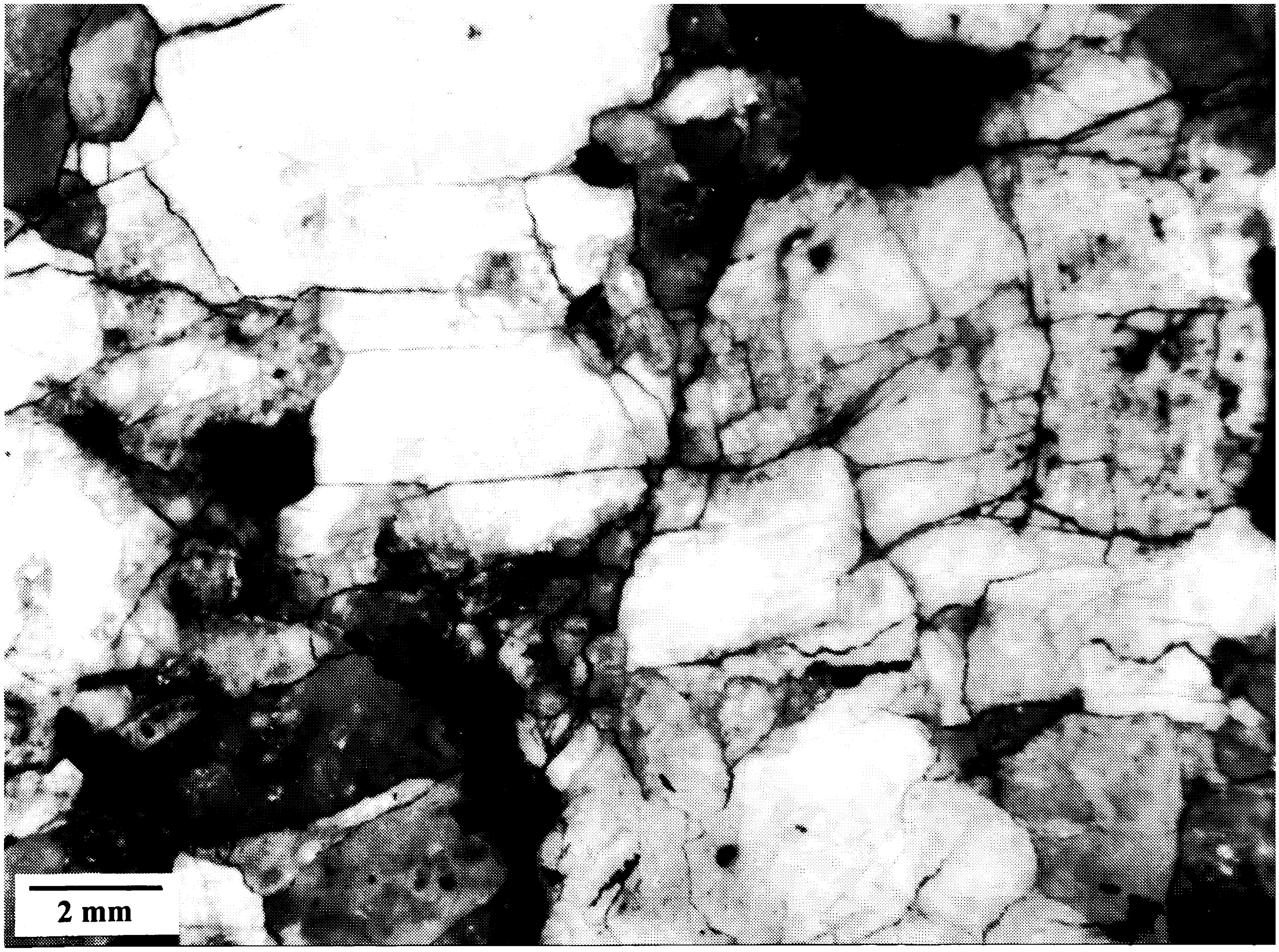


Figure 22. Specimen of coarse-grained granite impregnated with dyed epoxy to highlight microfractures, especially in feldspar grains. Such fractures are accessible to fluids, one of the primary reasons for breakdown of the rock.

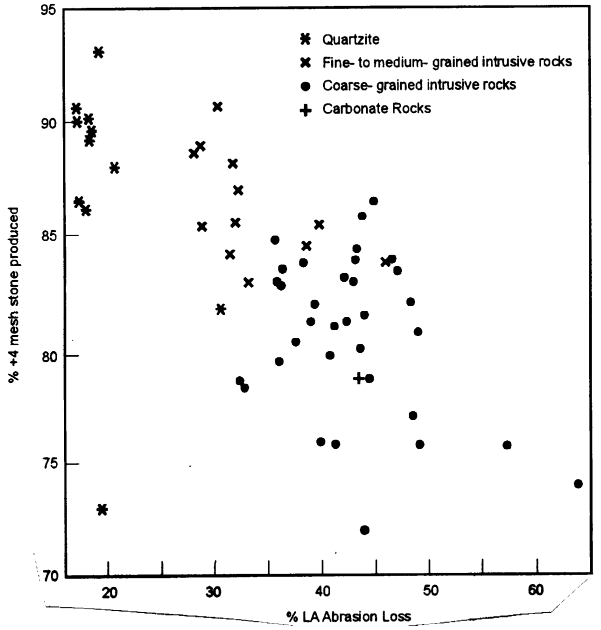


Figure 23. Graph of coarse stone production (+4 mesh) vs. L. A. Abrasion Loss.

bedrock may reduce the overall quality of an aggregate deposit. Locations where there is a higher concentration of joints in the rock and areas where shearing has been identified should be considered as susceptible to weathering.

Discussion: Necessity of a Local Resource

Finally, as a conclusion to this report, the author would like to discuss whether or not a local aggregate resource is necessary. Although there are no simple answers to this question, the author would like to suggest that preservation of the local resource is important and that aggregate should be viewed as a strategic material. Consider the possibility that, based on current trends, local aggregate reserves will become exhausted at some point in the future. Furthermore, based on current municipal planning policies, the resource land will not have been protected through zoning. The direct and obvious result of this would be the need for Metro

Table 7. Susceptibility of bedrook and aggregate products to weathering.

Rock Type	Susceptibility To Weathering	Comments
Goldenville Formation (Quartzites)	Negligible	Low permeability, hard stone which is impervious to water penetration; surface weathering is minimal; weathering along joint and other fracture planes is negligible; aggregate products do not break down from weathering.
Halifax Formation (Slates)	High	Exposed slate bedrock has a tendency toward early weathering due to water penetration of cleavage planes; rock readily weathers in exposed aggregate products.
Fine-grained Intrusives Rocks	Low	Generally low permeability; surface weathering not observed; weathering along joint planes and other fractures is minimal; exposed aggregate products should be resistant to weathering.
Coarse-grained Intrusive Rocks	Variable (low to high)	Tendency to weather along shear planes or areas of pervasive microfracturing; some rocks exhibit extensive weathering along joint planes where leaching and alteration may be present up to tens of centimetres away from the fracture face; the weathered areas in the rock tend to produce aggregate particles which are soft, less durable or susceptible to water penetration; depending on the proportion of affected particles, the quality of the stone may be significantly reduced for aggregate purposes.
Carboniferous Sedimentary Rocks	Moderate to High	Most Carboniferious sedimentary rocks are quite susceptible to water penetration; shales are rapidly broken down due to water penetration of parting planes and clay minerals; the high porosity and permeability commonly found in sandstone and conglomerate make these rocks susceptible to water and freeze-thaw cycles in aggregate products; weathering in carbonate lithologies is variable.

Figure 24. This recently exposed slate road cut at Waldeck, Annapolis County (location 9, Fig. 7b), demonstrates how quickly weathering can take place. Rubble at the base of this outcrop is the result of weathering.

producers to look farther afield for their materials, in areas where quarries are considered more acceptable (or less obtrusive) by the community. This, in turn, would result in increased haulage distances to the markets. Less obvious are the economic, social and environmental impacts which this situation creates.

First consider the economic consequences. Transportation is a major factor in the delivered price of aggregate. A recent examination of aggregate in Ontario (Planning Initiatives Ltd., 1992) determined that, based upon the average haulage distances within that province, the delivered price of the aggregate is double that of the f.o.b. (see Appendix 1, Glossary of Terms) value at the quarry gate. Thus the average haulage cost for aggregate to an urban centre is 50% of the landed price of the product. Similar estimates for the U.S. market suggest a doubling of the cost of materials at a 32 km haulage distance (Banino, 1994). Using an average value of $5.00 per tonne for crushed stone in Nova Scotia (Ian MacLellan, Nova Scotia Department of Natural Resources, personal communication) and an annual consumption of 3 million tonnes of materials in the Metro area, the quarry gate value of the stone is $15 million. Correspondingly, the cost of transportation (based on average urban haulage distances) would also be $15 million dollars. Thus, delivery distance can have an enormous impact on the price of the product.

This introduces the second implication to long haulage distances, social costs. Based upon the financial constraint under which governments currently operate, there are fixed annual budgetary expenditures allowed for items such as infrastructure development and maintenance. Thus, there is a maximum dollar value that can be spent each year on projects such as road construction and repairs, erosion control, or breakwaters. Because aggregate represents a major component in the cost of these projects, it soon becomes apparent that transportation of these materials from distant sources can have a dramatic effect on the amount of infrastructure work that gets done in a given year. Millions of dollars earmarked for construction sites would be needlessly consumed in truck haulage. The

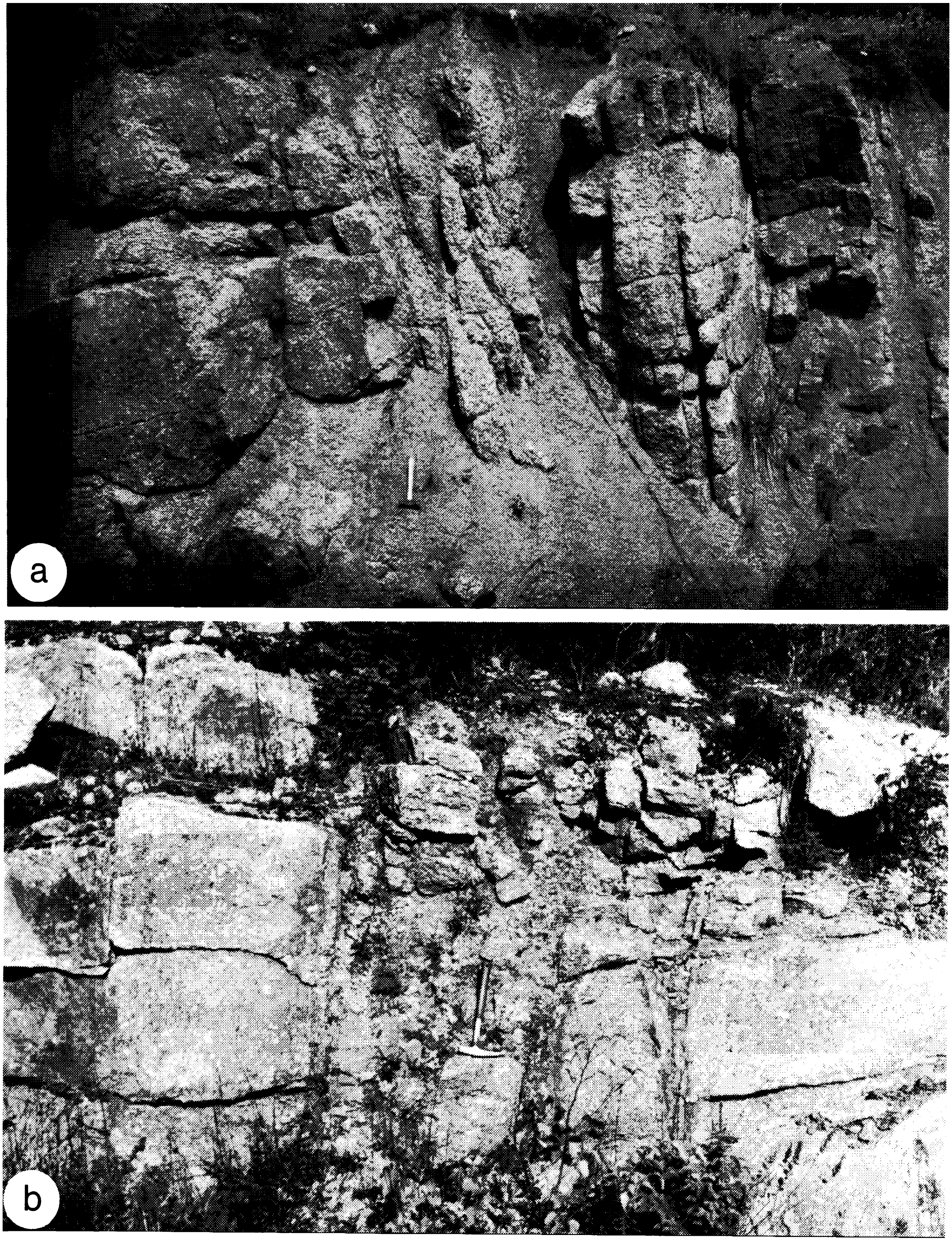
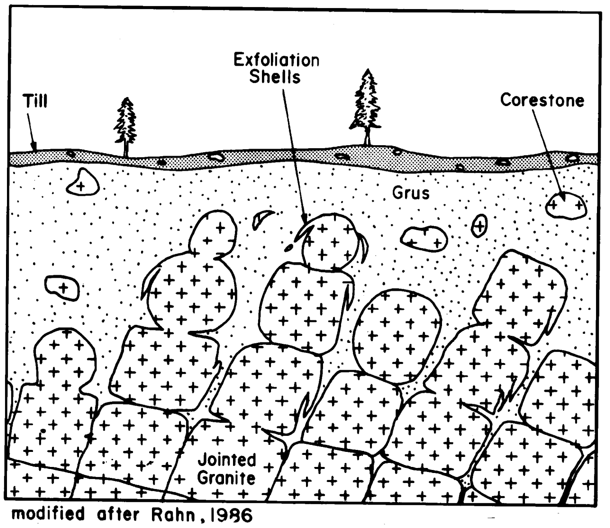


Figure 25. Subvertical shearing in granite road cuts. (a) Pervasive weathering can be seen at this outcrop (location 10, Fig. 7b), as opposed to very moderate weathering in photo b (location 11, Fig. 7b). Note that the location shown in photo 25a has been more recently exposed. The difference in the two sites probably reflects variation in the intensity of shearing.

result would be at least some decline in the delivery of infrastructure development and repair. This, in turn, ultimately has an effect on the day-to-day functioning of the community, which is so commonly taken for granted.

Finally, there are environmental costs associated with distant aggregate sources. The farther a bulk commodity such as aggregate has to be hauled, the more fossil fuels are consumed, there are greater air emissions and there is accelerated wear of haulage equipment and highways (per tonne of stone delivered).



modified after Rahn, 1986

Figure 26. Schematic illustration of grus formation.

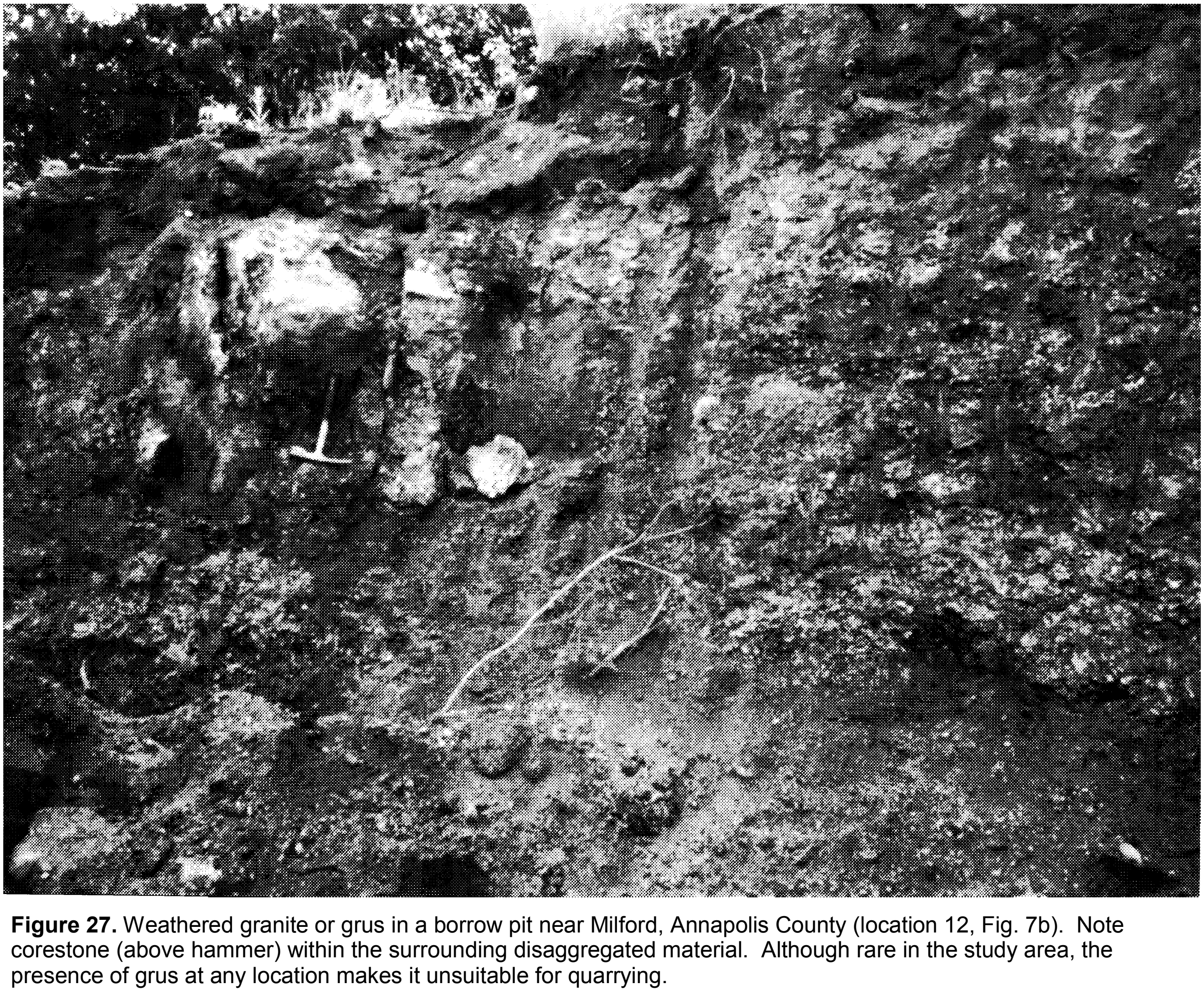


Figure 27. Weathered granite or grus in a borrow pit near Milford, Annapolis County (location 12, Fig. 7b). Note corestone (above hammer) within the surrounding disaggregated material. Although rare in the study area, the presence of grus at any location makes it unsuitable for quarrying.

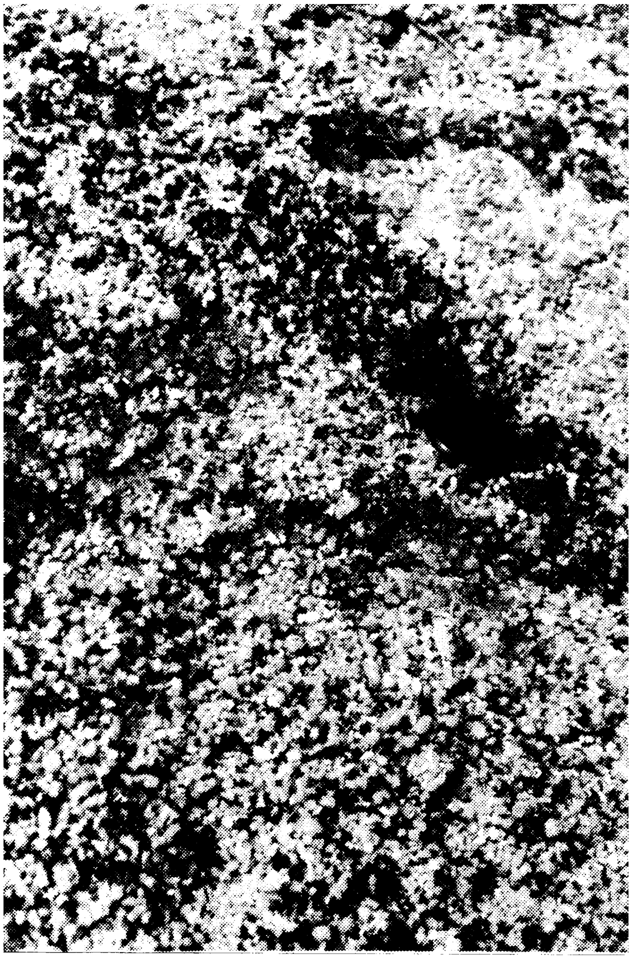


Figure 28. Thin surface layer (1-2 cm) of disaggregated granite near Devon, Halifax County (location 13, Fig. 7b). It consists primarily of quartz crystals (grey) with minor feldspar (white). This natural exposure is an example of surface weathering that post-dates glaciation. The dark areas are moss covered. Note the lens cap (right centre) for scale.

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Table 8. Summary of bedrock aggregate potential in the Metro Area

Rock Type	Aggregate Potential	Other Comments
Quartzite (metagreywacke)	Very hard, durable rock with low porosity and permeability; produces a very high quality aggregate for most applications.	Historically the preferred aggregate by industry in the Metro area; low susceptibility to weathering; may cause alkali-aggregate reactivity in exposed concrete; the common presence of interbedded slate and siltstone in excessive amounts can significantly reduce the quality of a deposit; the presence of sulphides can cause iron staining in weather-exposed applications such as dimension stone or concrete panels; layering and fracture patterns in the bedrock are reportedly excellent for blasting.
Slate (shale)	Very soft, platy materials which readily absorb water; low durability; unsuitable for high quality aggregate; can be excellent for low traffic access roads and driveways.	Commonly used in the past as aggregate; may contain excessive amounts of acid generating sulphide mineralization; excavation of sulphide-rich slates is prohibited by NSDOE (Guidelines For Development On The Status of Nova Scotia); aggregate products lack durability and are very susceptible to weathering.
Granite (fine- to medium-grained or porphyritic)	Hard, durable rock with low porosity and permeability; based on aggregate test results this group of rocks appear to make excellent aggregate potential for most aggregate products materials. Very limited past use in the metro area.	Sulphides rare or present in very minor amounts; no record of alkali aggregate reactivity in concrete (not tested in this study); minor microfracturing; weathering not observed; usually closely spaced joints (fractures) in bedrock which should be beneficial for blasting and crushing.
Granite (coarse grained to megacrystic)	Moderate to low durability; aggregate potential dependent on several variables; the marginal quality of some of the coarse grained stone suggests that quarrying these deposits should be approached with caution.	Minor aggregate production in Metro area at present; no history of alkali aggregate reactivity (not tested in this study); microfracturing, varies from moderate to pervasive; weathering infrequently observed as grus and in shear zones; weathering along fractures appears to be common; the presence of weathering and pervasive fracturing may cause the premature deterioration of the aggregate; joint spacing is variable, but can be quite wide; closely spaced drillholes are commonly required for blasting; the widely spaced joints can be useful for the production of armour stone.
Carboniferous sedimentary rocks	Rock types such as sandstone, shale and carbonate are generally soft and porous, with low durability; low aggregate potential; commonly used in other areas for haulage roads and fill.	This group of rocks is rare in the Metro area; weathering can be a problem in exposed aggregate applications; generally poor mechanical strength; aggregate products can be susceptible to deterioration and early failure.

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Appendix 1 - Glossary of Terms

Aggregate: Any of several hard, inert mineral materials used for construction purposes. They include sand, gravel, crushed stone from bedrock and recyclable materials such as slag. The materials can be used alone in products such as road base or with a cementing medium to form asphalt or Portland cement concrete.

Alkali-Aggregate Reactivity: The tendency for specific types of mineral aggregates to react with the alkali content of Portland cement in concrete. Continuous exposure of the concrete to moisture causes reaction rims to form around the reactive aggregate particles, creating pressure and cracking the concrete. This eventually leads to the premature deterioration of the concrete structure. Specific silicate and carbonate minerals are prone to this problem.

Alteration: Mineralogical changes in rock which occur as a result of physical and chemical agents. Common causes for these changes are increased heat or pressure.

Amphibolite: A metamorphic rock which consists primarily of amphibole minerals and plagioclase. It forms under conditions of medium to high pressure and temperatures in the range of 450°-700°C.

Batholith: A very large body of igneous rock which formed at depth in the earth's crust following the cooling of magma-filled chambers. They generally form as part of mountain building processes and are exposed today due to erosion.

Carbonate: A general group of sedimentary rocks which formed from the organic or inorganic precipitation in water of calcium and magnesium carbonate, e.g. limestone and dolomite.

Conglomerate: Coarse-grained sedimentary rock which consists of lithified gravel. These ancient sediments formed primarily in high energy river channel systems.

Core-stone: A solid, boulder-shaped piece of bedrock resulting from the *in situ* weathering of near-surface bedrock. The stone, which is surrounded by disaggregated bedrock materials (grus), is generally a product of weathering which penetrates the bedrock along joint planes.

Dolomite: A carbonate sedimentary rock which is magnesium-rich and consists primarily of the mineral dolomite.

Evaporites: Chemically precipitated sedimentary rocks produced during the evaporation of saline brines in a restricted marine or lake environment. They include rock types such as gypsum, salt and anhydrite.

Exfoliation: Scaling or fracturing of the bedrock surface in concentric-shaped pieces or shells. Stripping of the successive layers in this fashion is related to differential stresses in the rock. One cause is the load and release pressure associated with glaciers and deglaciation.

FOB (Free On Board): A pricing term indicating that a commodity will be delivered to a point of shipment and loaded aboard (e.g. ship or railway car) without further charge to the buyer for the loading.

Glacial-fluvial (Glaciofluvial): Sediment transport in meltwater streams associated with the wasting or melting of a glacier. These fluvial systems occur on, in, under or adjacent to the glacial ice.

Granite (granitic rock): A common term for light-coloured igneous intrusive rocks which consist primarily of quartz, feldspar and mica.

Greenschist: A low-grade metamorphic rock with a schistose fabric, green colour and an abundance of minerals such chlorite and epidote.

Grus: Fragmented granitic rock which is the product of *in situ* weathering due to physical and chemical agents. Excavation at these sites produces a gravel-like material composed of angular particles.

Intraclast: A fragment of cohesive, soft sediment (e.g. clay) which gets ripped from the sides of a stream through erosion and redeposited in a channel downstream. The clasts are generally well-rounded and appear oversized for the sediment (commonly sand) in which they are deposited.

Intrusive: An igneous rock which forms from the emplacement of magma deep in the earth's crust. The component crystals are almost always large enough to be seen with the unaided eye and can be several centimetres long.

Kaolin: A group of clay minerals formed by the alteration of alkali feldspar and micas.

Limestone: A sedimentary rock formed by the organic or inorganic precipitation of calcium carbonate.

Lithify: To consolidate an unconsolidated sediment (e.g. sand) into stone (e.g. sandstone) through processes such as compaction and cementation.

Metagreywacke: A metamorphosed coarse-grained sandstone which is poorly sorted and sedimentologically immature. Although the composition of the rock can be quite variable, it typically contains dark rock fragments, quartz and feldspar embedded in a clay/silt matrix.

Metamorphism: Mineralogical, chemical or structural changes in rock associated with physical and chemical processes which occur at depth. Factors which typically cause these changes are shear stress and increases in pressure or temperature.

Pluton: A moderately large igneous intrusive body (smaller than a batholith) derived from magma deep in the earth's crust.

Popouts: Depressions in the surface of asphalt or Portland cement concrete which are created when unstable aggregate particles expand and are forced out of the structure. Conditions such as freeze-thaw cycles or alkali-aggregate reactivity are major causes for this problem and can lead to the premature deterioration of the structure.

Quartzite: A metamorphosed sandstone composed predominantly of quartz grains. The presence of at least some recrystallization and silica cementing causes the rock to break across, rather than around, individual grains.

Recrystallization: The formation of new mineral crystals in a rock as a result of chemical and/physical processes. The composition of the new crystals may or may not be the same as the original rock.

Sandstone: A sedimentary rock which formed from the lithification of sand deposits. Common sources of these sediments are ancient river channel and marine shoreline deposits.

Saprolite: A soft, earthy surficial layer resulting from the *in situ* weathering and decomposition of bedrock. The materials typically contain many of the preserved structures of the original bedrock.

Schist: A metamorphic crystalline rock consisting of platy or elongated minerals and containing a foliated layering. The rock typically splits into thin flakes. Common minerals include mica and amphiboles.

Shale: A sedimentary rock which forms from the lithification of a clay deposit. Common sources of these sediments are bodies of standing water such as deep lake and offshore marine environments.

Shear Zone: A tabular zone of tectonic deformation in the bedrock where there has been displacement along multiple, parallel fractures. The zones typically contain a foliation fabric and are metres to tens of metres or more in width.

Siltstone: A sedimentary rock which forms by the lithification of a silt layer or deposit. In terms of grain size, this sedimentary rock falls between a shale and a sandstone.

Slate: Metamorphosed shale which is characterized by a flaky texture known as slaty cleavage. The rock is generally quite friable and can be split into thin layers.

Sterilization: A land-use term referring to the permanent exclusion of land for a specified resource use.

Tectonic: Pertaining to the large scale forces associated with the earth's plate movements. This dynamic process determines and shapes the earth's crust throughout time.

Terrane: A fault-bound tectonic region which has a geological history distinctly different from that of adjoining regions.

Turbidite: A sedimentary rock sequence resulting from deposition in an ancient turbidity current environment. This type of deposit typically occurred in large, deep lakes or along marine continental slopes. Unstable sediments along the top of a slope were set in motion by events such as earthquakes. The materials rapidly moved down the slope as a sediment-laden slurry and were deposited in deeper water as fan-shaped bodies of sand. This was followed by the deep water deposition of muds. Repeated layering of the two sediments, followed by deep burial, produced thick, distinct sandstone/shale sequences.

Appendix 2 - Aggregate Test Descriptions

Grain Size Analysis

Sieve analysis for this study may be defined as the determination of grain size distribution of the rock particles in a naturally occurring state (e.g. gravel) or as a manufactured product (e.g. quarried and processed bedrock). It is used as an approximate measure of properties such as permeability, ability to compact, stability and structural integrity. (As an example, if road base has too many fines it retains water causing frost heave and rutting.) In the bedrock samples of this study it was determined by crushing and sieving.

The procedure was conducted at the Technical University of Nova Scotia. The first step consisted of crushing the bedrock samples to NSDOTPW Class A aggregate using a small jaw crusher. Subsequently the samples were oven dried at 100 degrees Celsius and sized from 4” to No. 4 materials using Gilson Sieves. The minus No. 4 materials were split using a Riffle Splitter and approximately 1000 g were wet sieved with a No. 200 screen. The remainder of the sample was dried and sized from No. 8 to No. 200 screens using a Ro-Tap sieve shaker. Combined sieve fractions were then calculated (Table 1) to determine the percentage of stone (plus No. 4 mesh), sand (minus No. 4 mesh to plus No. 200 mesh), and fines (minus No. 200 mesh).

Los Angeles Abrasion Loss

The Los Angeles Abrasion Loss Test (ASTM Standard 131-81) is a method for determining the relative competence and durability of the materials in an aggregate source as compared to other sources. It is a test that helps determine the potential for early failure in a structure. It presents a measure of the degradation of the particles in a dry aggregate sample which has been subjected to a combination of actions including abrasion, grinding and impaction.

The test was conducted by Geocon Atlantic Ltd. using a steel drum containing a specific number and size of steel balls. The aggregate sample (crushed to NSDOTPW specifications for Type A aggregate) is weighed, put into a steel drum and rotated 500 times. The aggregate is then removed from the drum and reweighed to determine the weight loss, which is expressed as a per cent. This number can be compared to allowable maximum limits determined for the different grades of aggregate. The test is important where the aggregate product is subjected to static and dynamic stresses, impact and wear action. It is significant in Nova Scotia for determining the resistance to wear of aggregate used in highway applications. Appendix 3 provides the tables indicating acceptable maximum abrasion loss for different products. For a complete explanation of the test procedure, refer to ASTM Standard 131-81 (American Society for Testing and Materials, 1988a).

Magnesium Sulphate Soundness Test

Nova Scotia's maritime climate produces severe weathering conditions which can have a serious effect on exposed aggregate. Depending on where the aggregate is being used, the weathering can result from a variety of conditions, including temperature-related freeze-thaw cycles, combined temperature and road salt freeze-thaw cycles, or marine tidal freeze-thaw exposure. These conditions produce significant volume changes in some types of aggregate at or near the surface of products such as bituminous concrete or Portland cement concrete. The resulting stress causes breakage, spalling or disintegration of the aggregate particles. This can result in unsightly surfaces, structural weaknesses or reduction in wear life of the product.

The magnesium sulphate soundness test (ASTM Standard C88), conducted by Geocon Atlantic Ltd., is a measure of the effect that severe weathering has on aggregate. First a carefully graded and weighed aggregate sample (NSDOTPW Type A) is immersed in a solution of magnesium sulphate and oven dried. The procedure is repeated on the sample for a total of five cycles. Oven drying causes dehydration of the salt which is retained in the pores and fractures of the aggregate particle. With subsequent immersions, the salts are rehydrated, causing expansion and simulating the action of freezing water. Like freeze-thaw conditions, salt expansion causes the breakdown of aggregate particles. After the final drying, the sample is washed of salts and dried. The weight loss of each sieve fraction is determined and expressed as a percentage of the initial weight of the test fraction. A weighted percentage loss is then determined by multiplying the percentage of weight loss by the weight percentage for that sieve size in the original sample (before test fractions were extracted). The total weighted percentage loss is then calculated. This number can then be compared to maximum limits or standards required for different aggregate products. Appendix 3 indicates acceptable maximum soundness loss for different products. For a complete explanation of the test procedure, refer to ASTM Standard C88 (American Society for Testing and Materials, 1988b).

Petrographic Number

The quality of an aggregate sample can be determined by a petrographic analysis of the coarse particles. In other words, a geotechnical examination of the component rock particles in an aggregate sample can permit a quantitative evaluation of the materials. The test used in this study is the Petrographic Number method, the standard test used by the aggregate industry in Nova Scotia when a petrographic analysis is required. It was developed by the Ontario Ministry of Transportation and Communications (OMTC) for asphalt aggregates and is a modified version of Canadian Standards Association Test Method A23.2, Appendix B (Canadian Standards Association, 1977) for concrete.

The procedure, conducted by Geocon Atlantic Limited, begins with crushing, sizing and drying of a sample to produce NSDOTPW Type B aggregate. Approximately 1800 g of the sample falling within four size ranges are examined to determine particle rock type and characteristics which would prove deleterious in an aggregate (e.g. coatings and high porosity). This includes index tests such as strength, scratch hardness and acid reactivity. The particles are then grouped into rock types described in CSA Test Method A23.2, Appendix B (Canadian Standards Association, 1977) with each group being weighed and expressed as a percentage of the total weight. The percentage is then multiplied by a factor assigned according to the following qualitative descriptions: good = 1, fair = 3, poor = 6, and deleterious = 10. The Petrographic Number (PN) is determined as a sum of the above products for each rock type. An example is provided in Table 2-1. Theoretically, the Petrographic Number can vary between 100 and 1000 with the lowest numbers indicating the best quality. In Nova Scotia the Petrographic Number is used exclusively for evaluating highway materials. Maximum acceptable limits for this test vary according to asphalt concrete type (Appendix 3) For a complete explanation of the test procedure, refer to the OMTC Laboratory Testing Manual.

Absorption Analysis

Absorption is defined by the National Stone Association (1991) as "the penetration of liquid into aggregate particles with a resulting increase in particle weight". It is conducted to determine how readily dry stone particles take up water or other liquids within a specified time period. This can be important in applications where water in the stone can cause the stone to deteriorate in freeze-thaw conditions.

The test used for this study, ASTM Standard C127, was conducted by Geocon Atlantic Limited. A brief summary of the procedure is described as follows. First, a predetermined amount of sized material is sieved and washed as specified in the procedure. The sample is then oven dried at 110°C until a constant weight is achieved and recorded (oven dried weight or ODW). This is followed by air cooling for 1-3 hours and subsequent immersion in room temperature water for 24 hours. The particles are then surface dried with a cloth and weighed again (saturated-surface-dried weight or SSDW). The absorption is then recorded using the following calculation:

$$\% \text{ Absorption} = [(\text{SSDW}-\text{ODW})/\text{ODW}] \times 100)$$

For a complete explanation of the test procedure, refer to ASTM Standard C127 (American Society for Testing and Materials, 1988c).

Micro-Deval Abrasion Test

One concern with laboratory testing of aggregate is that the tests do not accurately mimic the field conditions which can produce early structural failure. The Los Angeles Abrasion Loss test, for example, has been criticized for using oven dried materials in the test procedure. However, the aggregate in road base is always under wet conditions, which can substantially weaken certain rock types (Rogers, 1978). This has led to the development of another test, the Micro-Deval test, which more accurately reflects field conditions.

The Micro-Deval abrasion test is a wet abrasion/impact test which was developed more than a century ago. Approximately 35 years ago it was modified in France to test aggregate for construction purposes. The procedure has been adopted by Quebec and Ontario to select highways materials. Most recently the test has been added to the specifications for highway materials in Nova Scotia. A description of the test is provided below.

Laboratory analysis for the Micro-Deval abrasion test was conducted by Jacques Whitford Ltd. The test begins with a predetermined size class and weight of coarse dried stone which is soaked in water for 24 hours. The sample is then placed in a 5 l jar mill with 5000 g of 9.5 mm steel balls and 2.5 l of water. The mill is rotated at 100 rpm for two hours and the sample then washed and dried. The weight of material passing the 1.18 mm sieve is determined and expressed as a per cent weight loss of the weight of the original sample. Maximum allowable losses for highways applications in Nova Scotia are shown in Appendix 3. For a complete explanation of the test procedure, refer to Ontario Ministry of Transportation and Communications test method LS 618.

Table 2-1. Examples of determination of Petrographic Number, Warnock Hersey Professional Services Ltd.

PETROGRAPHIC ANALYSIS		
File Number 50544-0264	Lab No. 968	Date January 31, 1989
Description of Sample Laboratory crushed to 3/4		Mix Type
Source Marked: C124		
Client NS Department of Mines & Energy		Date Submitted November 21, 1988

Rock Types	Quality (Per Cent)			
	Excellent (1)	Good (3)	Fair (6)	Poor (10)
Sandstone	26.8	16.6	0.9	0.9
Volcanic	29.0			
Gneiss	1.8			
Granite	18.5			
Schist			0.8	
Slate		0.5	0.4	
Quartzite	3.4			
Quartz	0.4			
TOTALS	79.9	17.1	2.1	0.9
Petrographic Number	152.8			

Appendix 3 - Aggregate Specifications Tables

Canadian Standards Association's specifications for coarse and fine aggregate in concrete*

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A. General Requirements for Coarse Aggregate

		Total Passing Each Sieve[+], Percent by Mass										
	Nominal Size of Aggregate, mm	112 mm	80 mm	56 mm	40 mm	28 mm	20 mm	14 mm	10 mm	5 mm	2.5 mm	1.25 mm
Group I	[++]40-5	--	--	100	95-100	--	35-70	--	36828	36742	--	--
	[++]28-5	--	--	--	100	95-100	--	30-65	--	36747	36742	--
	20-5	--	--	--	--	100	90-100	--	25-60	36747	36742	--
	14-5	--	--	--	--	--	100	90-100	45-75	36752	36742	--
	10-2.5	--	--	--	--	--	--	100	85-100	36828	36747	36742
Group II	80-40	100	90-100	25-60	36752	--	36742	--	--	--	--	--
	56-28	--	100	90-100	30-65	36752	--	36742	--	--	--	--
	40-20	--	--	100	90-100	25-60	36752	--	36742	--	--	--
	28-14	--	--	--	100	90-100	30-65	36752	--	36742	--	--
	20-10	--	--	--	--	100	85-100	--	36757	36742	--	--
	14-10	--	--	--	--	--	100	85-100	0-45	36747	--	--
	36803	--	--	--	--	--	--	100	85-100	36757	36742	--

[+] Sieves shall meet the requirements for woven wire cloth testing sieves given in CGSB Standard 8.2.
[++] To prevent segregation, aggregates that make up either of these gradings shall be stockpiled and batched in two or more separate sizes selected from Groups I and II.
Note: Group I comprises combined aggregate gradings most commonly used in concrete production. Group II provides for special requirements, i.e., gap grading, pumping, etc., or for blending two or more sizes to produce Group I gradings.

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*Canadian Standards Association, 1990.

B. Grading Limits for Fine Aggregate

Sieve Size	Total Passing Sieve Percentage by Mass
10 mm	100
5 mm	95-100
2.5 mm	80-100
1.25 mm	50-90
630 µm	25-65
315 µm	10-35
160 µm	2-10

Notes:
(1) The minimum percentages for material passing the 315 µm and 160 µm sieves may be reduced to 5 and 0, respectively, if the aggregate is to be used in air-entrained concrete containing more than 250 kg/m^3 of cementing material or in non air-entrained concrete containing more than 300 kg/m^3 of cementing material.
(2) For high-strength concrete it is desirable to limit the amount of material passing the 160 µm sieve to a maximum of 2%.

Nova Scotia Department of Transportation and Public Works specifications for road granular materials (Nova Scotia Department of Transportation and Public Works, 1996).

Gravel Borrow

Description and Construction Method

When gravel or rock is specified for use in subbase, shoulders or for any other purpose, for which the ordinary borrow is not permitted, such gravel or rock will be classified as Gravel Borrow, provided it is obtained outside of the slopes of the roadway. No Gravel Borrow shall be obtained from within the right-of-way without the approval of the Engineer.

Gravel Borrow shall be composed of approved hard, durable stones and sand, shall show wear of not over 45% when tested according to the latest edition of ASTM Standard C 131-76, Grading A (Los Angeles Abrasion Test), shall be well graded from coarse to fine and shall contain the required amount of suitable binding material, practically free from silt or clay, and when tested by means of laboratory sieves not more than 50% shall pass a 14 000 sieve; stones which have a dimension larger than 112 mm shall be removed from the Gravel Borrow before it is placed on the road. Gravel Borrow will not necessarily be placed in uniform amounts throughout the section under contract. The amount of Gravel Borrow placed on any one area will be dependent on the nature of the material in the subgrade. Gravel Borrow shall be compacted to 100% of Standard Proctor Density (corrected for oversized material), and the shaping and compaction of each layer shall be to the satisfaction of the Engineer before a successive layer is placed, and the final cross-section shall be as authorized.

Gravel Type 1, 1S & 2

Description

Gravel Type 1, Type 1S and Type 2 shall be composed of crushed and screened rock or gravel. The material shall be transported and placed upon the subgrade, subbase or shoulder and compacted as directed and in accordance with these specifications.

C. Limits for Deleterious Substances[+] and Physical Properties

Maximum Percentage by Mass of Total Sample

		Coarse Aggregate	
Property	**Fine Aggregate**	**Exposure Classifications[++] F-1, C-1, C-2**	**Other Exposure Conditions**
Clay lumps (see Note 1)	1	0.25	0.5
Low-density granular materials (see Note 2)	0.5	0.5	1
Material finer than 80 µm	3.0 K[++++]	1.0[+++]	1.0[+++]
$MgSO_4$ soundness loss	16	12	18
Abrasion loss[+++++]	N/A	50	50

[+] Limits for deleterious substances not listed in the Table, such as shalestone, siltstone, sandstone, or argillaceous limestone, shall be specified by the Owner to encompass deleterious materials known to be present in a particular region. In the absence of such information aggregate shall be accepted or rejected in accordance with Clause 5.9.

[++] See Table 7 and Table 8.

[+++] In the case of crushed aggregate, if material finer than the 80 µm sieve consists of the dust of fracture, essentially free from clay or shale, the maximum shall be 1.5%.

[++++] This limit shall be 5.0% if the clay size material (finer than 5 µm) does not exceed 1% of the total fine aggregate sample. The amount of material of clay size shall be determined by performing a hydrometer analysis as per CSA Test Method A23.2-18A on a sample washed through an 80 µm sieve.

[+++++] The abrasion loss shall not be greater than 35% when the aggregate is used in concrete paving or for other concrete surfaces subjected to significant wear. This does not refer to air-cooled iron blast-furnace slag coarse aggregate.

Notes:

(1) Clay lumps are defined as fine-grained, consolidated, sedimentary materials of a hydrous aluminosilicate nature.

(2) A liquid with a relative density of 2.0 is used generally to separate particles classified as coal or lignite. Liquids with relative densities higher or lower than 2.0 may be required to identify other deleterious low-density materials.

(3) See Clause 5.9.1 for D-Cracking.

Materials

The materials for Gravel Type 1, Type 1S and Type 2, shall consist of hard and durable stone particles in conformance with this specification.

Gradation Requirements

The gravels shall be free from flat, elongated or other objectionable pieces and shall be well graded from coarse to fine, and must be approved by the Engineer. The gravels shall be tested by washed sieve analysis according to the latest ASTM edition of the C117 and C136 and shall fulfil the gradation requirements listed in Table 3.1.

Table 3.1 - Gradation

	Percent Passing		
Sieve Size, µm	**Type 1**	**Type 1S**	**Type 2**
80000			100
56000			70-100
28000			50-80
20000	100	100	
14000	50-85	50-85	35-65
5000	20-50	30-55	20-50
160	36657	36726	36657
80	3-5(1)	5-12(2)	3-5(1)

(1)Where percentages passing the 5000 µm sieve are between 20 and 35%, the allowable percentage passing the 80 µm sieve shall be 3 to 8%.
(2)Where percentages passing the 5000 µm sieve are between 30 and 45%, the allowable percentage passing the 80 µm sieve shall be 3 to 12%.

Table 3.2 - Fractured Particles

Gravel	Fractured Particles (one face), % min	Test Method
Type 1(1)	80	NSDOT&C
Type (2)	50	NSDOT&C
Type 2 and 1S	50	NSDOT&C

(1)For highways with truck (FHWA Class 4 or above) traffic equal to or greater than 200 per day.
(2)For highways with less than 200 trucks (FHWA Class 4 or above) per day.

Fractured Particles Content

The gravel shall have a fractured particle content conforming to values listed in Table 3.2. The fractured particle shall have at least one well defined fresh face resulting from fracture, with the face comprising no less than 20 percent of the particle surface area. Particles with smooth faces and rounded edges, or with only small chips removed, are not considered fractured.

Physical Properties

Gravel materials shall conform to the physical properties listed in Table 3.3.

Table 3.3 - Physical Properties

Property	Test Method[1]	Type 1	Type 1S	Type 2
Absorption, % maximum	ASTM C127	1.75	1.75	1.75
Plasticity Index	ASTM D4318	0	0	0
Micro-Deval, % maximum	NSDOT&C	25	35	25

[1] Latest edition

Clear Stone

Description

Clear Stone Cl, C2 and C3 shall be composed of screened rock. Clear Stone is typically specified for use as drainage enhancement, flow checks or slope protection.

Materials

Materials for Clear Stone shall consist of hard, durable stone particles, in conformance with this specification.

Gradation Requirements

The stone shall be free from flat, elongated or other objectionable pieces and must be approved by the Engineer. The gravels shall be tested by wash sieve analysis according to the latest ASTM edition of C117 and C136 and shall fulfil the gradation requirements listed in Table 3.4.

Physical Properties

To ensure the clear stone aggregates are durable they shall conform to the following properties listed in Table 3.5.

Armour Rock

Description and Construction Method

When rock is specified for use as a protective barrier from erosion in an aquatic environment, such rock will be classified as Armour Rock. The Armour Rock shall be placed to the lines and grades shown on the drawings or as directed by the Engineer. Placement shall be by machine in order to avoid waste and to ensure that the stone is in a stable position.

The thickness of the Armour Rock layer will normally vary from 1.0 to 1.5 times the maximum rock size in the gradation and shall be specified in the Special Provisions.

Armour Rock shall be hard, durable, field or quarry stone, free from splits, seams or defects likely to impair its soundness during handling or by the actions of water and ice. Shale, slate or rocks with thin foliations shall not be acceptable. The greatest dimension of each rock shall not exceed two times the least dimension. The minimum density of the rock shall be 2 650 kg/m^3. Durability properties shall be as defined in Table 3.6. Sizes of Armour rock shall be as defined in Table 3.7.

Table 3.4 - Gradation			
Sieve Size, mm	Percent Passing		
	C1	C2	C3
250	100		
200		100	
150	20-35	90-100	
112		20-35	
80		0-20	
56	0-10		
40			
28			100
20		0-10	90-100
14			
10			0-40
5			0-10

Table 3.5 - Physical Properties		
Property	Test Method(1)	Class C1 to C3
Absorption, % maximum	ASTM C127	1.75
Plasticity Index	ASTM D4318	0
Micro-Deval, % maximum	NSDOTC	25
(1)Latest edition		

Table 3.6 - Durability		
Property	Test Method	Specification
Absorption, % maximum	ASTM C127	2.0
Los Angeles Abrasion, % maximum	ASTM C131	35

Table 3.7 - Armour Rock Sizes		
	Percent Smaller Than	
Approximate Size, mm	R1	R2
1050	100	
850		100
650	0-50	
550		0-50
300	0-15	
230		0-15

Fill Against Structures

Description

Fill Against Structures shall consist of the placing and compaction of material, as hereinafter specified, in the immediate area of structures.

Materials

The material for Fill Against Structures shall be crushed and screened gravel or rock. It shall be well graded from coarse to fine and shall be approved by the Engineer.

Fill Against Structures shall be tested by washed sieve analysis according to the latest edition of ASTM C117 and C136 and shall fulfill the following requirements:

Passing a 112 000 sieve	100%
Passing a 40 000 sieve	60 to 85%
Passing a 5 000 sieve	25 to 50%
Passing a 315 sieve	5 to 15%
Passing a 80 sieve	2 to 7%

The sand portion shall have a liquid limit not greater than 25 and a plasticity index not greater than 6 when tested according to the latest edition of ASTM D423 and D424.

The coarse aggregate, when tested according to the latest edition of ASTM C131, Grading A, shall show a percentage of wear less than 45.

Nova Scotia Department of Transportation and Public Works specifications for asphalt concrete (hot mixed - hot placed) aggregate.

The aggregates shall be crushed natural or manufactured stone or slag and sand conforming to the quality requirements as stated herein and shall be free from coatings of clay, silt or other deleterious material.

Nova Scotia Department of Transportation and Public Works specifications for asphalt concrete aggregate (from Department of Transportation and Public Works, 1996).

Table 3.8 - Physical Requirements of Aggregate (1)

Test Name	Standard (2)	Coarse Aggregate Requirement
Los Angeles Abrasion, % (Maximum Loss)	ASTM C 131	35
Soundness, % (Maximum Loss) (3)	ASTM C 88 (6)	15
Petrographic Number (4)	NSDOTC (7)	See Table 3.9
Fractured Particles - (4) 2 Fractured Faces, % (Minimum) by Mass (8)	NSDOTC (7)	See Table 3.9
Flakiness Index, %	British Standard 812	MAX 45
Stripping Test, %	AASHTO T-283	MIN 0.73
Absorption, % (5)	ASTM C 127	MAX 1.75

(1) Applies to all aggregates including those used for blending.
(2) Latest edition
(3) The soundness loss permitted -will be 15% on fine aggregate other than for A, B-HF, C and C-HF. Soundness loss on fines for A, B-HF, C and C-HF, will be 10%.
(4) In the event of a disagreement regarding the Petograpliic Number or Fractured Particles percentage, the Contractor will note his objections in writing to the Engineer. An analysis will then be done, as follows:

The Director of Technical Services will arrange to have the stockpile sampled. If a Technical Services Specialist is not available to sample, the Engineer will sample the stockpile. The Contractor will observe the sampling procedure.

The sample will be taken to the Technical Services Division. All Consultants that are retained by the Department for asphalt concrete quality control or a minimum of two consultants, will be asked to send a representative to the Technical Services Division to test a representative portion of the sample.

The sample will be split and each Technician will perform the Petrographic test or Fractured Particles Test. The results will be given to Executive Director Highway Programs, who will make the final decision with respect to the use of the aggregate, using the average of the test results as a guide.

(5) Fine aggregate shall have maximum absorption of 1.75% when tested by ASTM C 128 latest edition.
(6) Test to be performed using sodium sulphate.
(7) Standard test procedures are available from Technical Services Division, if requested.
(8) A fractured particle consists of two (2) fractured faces which each consist of a minimum of 20% of the surface area of the particle.

Table 3.9 - Quality of Coarse Aggregate vs AADT			
Type	**AADT[1]**	**PN[2]**	**Fractured Particles, %**
A	N/A	135	95[3]
B-HF	N/A	135	95[3]
C-HF	N/A	135	95[3]
C	2500-4000	150	70
C	1000-2499	165	40
B	1000-2499	185	40
C	Below 1000	185	40
B	Below 1000	200	40
D	N/A	N/A	N/A
E	N/A	20	40

[1] Average Annual Daily Traffic
[2] Modified Petrographic Analysis
[3] The coarse aggregate shall be made from a quarried source or contain 95% fractured particles.

The number in brackets within this note pertain to C-HF.

Table 3.10 - Gradation of Combined Aggregates							
Cumulative Percent Passing							
Sieve Designation	Type A	Type B	Type B-HF	Type c	Type C-HF	Type D	Type E
40 000	100						
28 000	95-100	100	100				
20 000	-	95-100	95-100	100	100		100
14 000	60-80	-	70-90	95-100	195-100	100	85-100
10 000	-	60-80	60-75	-	-	95-100	-
5 000	25-60	35-65	40-55	45-70	45-60	60-80	65-80
2 500	15-45	20-50	25-45	25-55	25-55	35-65	50-65
315	3-18	3-20	3-20	5-20	5-20	6-25	18-30
80	1-7	2-8	3-6.5	2-9	3-6.5	2-10	5-15
Normal Usage	Base	Base/ Surface	Base/ Surface	Surface	Surface	Surface	Curbs/ Gutters Medians

The coarse aggregate shall be produced from bedrock, or in the case of a natural deposit from the aggregate held on the 28,000 (20,000) sieve. A tolerance of 10% passing 28,000 (20,000) sieve, based on a washed sieve analysis, will be permitted.

The fine aggregate shall be produced from bedrock, or in the case of a natural deposit, from the aggregate held on the 10,000 sieve. A tolerance of 10% passing the 10,000 sieve, based on a washed sieve analysis, will be permitted. The final combined aggregate gradation shall conform to Table 4.4 of these specifications.

All material from the natural deposit shall be screened using a 28,000 (20,000) sieve and then a 10,000 sieve.

The material from the natural deposit shall be screened using a 28,000 (20,000) sieve and the 10,000 sieve shall be held in stockpiles for possible future use.

The material from the natural deposit which is retained on 28,000 (20,000) sieve shall be crushed to a 20,000 (14,000) sieve to produce the coarse aggregate. Any material produced from this crushing operation which passes through a 5000 sieve shall be used as fine aggregate.

The material from the natural deposit which passes through the 28,000 (20,000) sieve but is retained on the 10,000 sieve shall be crushed to 5000 sieve or as fine as possible and then re-screened to 5000 to produce the fine aggregate.

If the additional fine aggregate is required, over and above that produced from the two crushing operations noted above, to meet the required gradation of aggregates then the contractor may use the stockpiled material which passed the 10,000 sieve in the original screening operation. This material will be rescreened on the 5000 sieve. A portion of the material, as per below, that passes the 5000 sieve may be used.

In the event that there is still an insufficient supply of fine aggregate to meet the gradation requirement, the Contractor may bring in fine aggregate at his expense from an outside source as outlined in these specifications.

The maximum amount of natural uncrushed fine aggregate produced from the original screening operation combined with any imported blending sand shall be limited to 10% of the total aggregate.

The gradation of the combined processed aggregate for the asphalt concrete shall conform to the values shown in Table 3.10 when tested by washed sieve analysis according to the latest edition of ASTM C 117, C 136 and D 546.

Appendix 4 - Sample Locations

Description of sample locations.

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-1	Campbell Hill	11D/13 (428440E, 4959520N)	Granite Sandy Lake Monzogranite (Corey, 1987)	Road Cut: pale grey, coarse grained, megacrystic, moderately spaced joints, microfractures moderate.	
HC-2	Big Indian Lake	11D/13 (425040E, 4958820N)	Granite Sandy Lake Monzogranite (Corey, 1987)	Road Cut: pale grey, coarse grained, megacrystic, moderately spaced joints, microfactures moderate.	
HC-3	Big Indian Lake	11D/13 (425920E, 4960650N)	Granite Walsh Brook Leucogranite (Corey, 1987)	Small Abandoned Quarry: buff coloured, fine grained, equigranular, 1-2% biotite, 1% muscovite, closely spaced joints, iron mineralization on joint faces, very minor microfracturing.	
HC-4	Kehoe Hill	11D/13 (424000E, 4961250N)	Granite Granodiorite (Corey, 1987)	Road Cut: medium grey, medium- to coarse-grained, equigranular, moderate microfracturing.	
HC-5	Five Mile Lake	11D/13 (423800E, 4967300N)	Granite Monzogranite (Big Indian Polyphase Intrusive Suite) (Corey, 1987)	Road Cut: pale orange-brown to buff, fine-medium grained, 1-2% biotite, 2% muscovite, scattered red garnet, some weathering of outcrop as surface veneer, closely spaced joints, moderate microfracturing.	
HC-6	Brunswick Lake	11D/13 (426500E, 4967770N)	Granite Granodiorite (Corey, 1987)	Road Cut: pale pinkish grey, coarse grained, megacrystic, 5-10% biotite, pervasive koalinization, stone is quite soft, pervasive microfracturing, low durability.	Outcrop occurs in shear zone, sample taken from more solid rock between shear planes.
HC-7	Ingram River	11D/12 (422950E, 4951370N)	Granite Tantallon Leucomonzogranite (MacDonald and Horne, 1987)	Road Cut: pale pink-red, medium grained, equigranular, moderately spaced joints, minor microfracturing.	Colour is a localized feature due to hematite.

Description of sample locations (continued).

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-8	Sandy Lake	11D/12 (429820E, 4952960N)	Granite Sandy Lake Monzogranite (MacDonald and Horne, 1987)	Natural Outcrop: medium grey with pale green tinge, medium- to coarse-grained, 8-10% biotite, minor disseminated pyrite, moderate microfracturing.	
HC-9	Five Mile Lake	11D/13 (425930E, 4971030N)	Granite Granodiorite (Corey, 1987)	Natural Outcrop: medium grey, coarse grained, megacrystic, 8-10% biotite, pervasive microfracturing, outcrop surface is strongly weathered to a depth of several centimetres.	Sample taken from fresh exposure below the surface weathering.
HC-10	Island Lake	11D/12 (426260E, 4950700N)	Granite Tantallon Leucomonzogranite (MacDonald and Horne, 1987)	Natural Outcrop: pale buff brown, medium grained equigranular, 4% biotite, 2-4% muscovite, common koalinization, moderate microfracturing.	
HC-11	Brushy Hill	11D/13 (439320E, 4979730N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908a)	Small Quarry: pervasively fractured bedrock, medium green grey, fine-medium grained, stone breaks easily along fracture planes, no visible sulphide mineralization.	
HC-12	Brushy Hill	11D/13 (441330E, 4982730N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908a)	Natural Outcrop: medium green grey, fine-medium grained, easily broken along abundant fracture planes, no visible sulphides.	
HC-13	McGrath Lake	11D/13 (441660E, 4976350N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908a)	Natural Outcrop: medium green grey, fine- medium grained, no apparent sulphide mineralization, appears to be very durable.	Exposure occurs on shooting range property.
HC-14	Mount Uniacke	11D/13 (433450E, 4969030N)	Granite Granodiorite (Corey, 1987)	Road Cut: white grey with blue tinge, medium grained, equigranular, locally common sulphides associated with abundant zenoliths, 15% biotite, minor microfracturing.	

Description of sample locations (continued).

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-15	Stillwater	11D/13 (426920E, 4972890N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908b)	Road Cut: medium grey, fine grained quartzite (80%) and slate (20%), quartzite strongly fractured, minor pyrite, slate becomes more abundant at both ends of the outcrop, sampled the quartzite only.	
HC-16	Waverly	11D/13 (455130E, 4957050N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908a)	Small Abandoned Quarry: medium green-grey, medium grained, quartzite with minor slate, minor bands and pods of pyrite, abundant iron stains on fracture faces in some parts of the quarry, low incidence of fractures, sampled quartzite only.	Subdivision is in proximity to this site.
HC-17	Oldham	11D/14 (460230E, 4972550N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908a)	Road Cut: medium green grey, medium grained quartzite with minor slate (5-10%), no visible sulphide mineralization, sampled quartzite only.	
HC-18	Dutch Settlement	11D/14 (465750E, 4979600N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908a)	Natural Outcrop: blue grey, fine grained quartzite, probably quite silty, rock is foliated, nearby outcrops have slate and siltstone.	
HC-19	Enfield	11D/13 (460530E, 4976300N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908a)	Road Cut: medium grey quartzite and slate, some of the quartzite is fine grained and foliated, some of the siltstone in the rock is finely laminated, no visible sulphides, some shearing evident, outcrop is strongly fractured, sampled quartzite.	
HC-20	Enfield	11D/13 (460530E, 4976300N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908a)	Road Cut: sampled interbedded slate and fine grained, foliated quartzite (siltstone).	Sample taken from same outcrop as HC-19.

Description of sample locations. (continued).

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-21	Beaverbank	11D/13 (445620E, 4969450N)	Quartzite Goldenville Formation Metagreywacke (Faribault, 1908a)	Natural Outcrop: medium green-grey, medium grained, very solid outcrop with no evidence of slate on a local scale, moderately spaced joints producing nice 90° block shaped pieces, no visible sulphides.	
HC-22	Pockwock Lake	11D/13 (434955E, 4960830N)	Granite Granodiorite (Corey, 1987)	Natural Outcrop: has weathered surface, blue grey, fine-medium grained, small zenoliths common, 12-15%, biotite, iron staining along joint faces and within the solid stone (appears to be near surface related), approximately 50% of the sample is iron stained, pervasive microfracturing.	Water supply area; difficult to sample due to deep leaching and weathered zone at outcrop surface, uncertain if sample was taken beneath weathered zone.
HC-23	Pockwock Lake	11D/13 (435920E, 4961650N)	Quartzite Goldenville Formation Metagreywacke and schist (Faribault, 1909)	Natural Outcrop: medium grey, medium grained quartzite with interbedded green-grey schist (50:50 proportion), no visible sulphide mineralization, schist and quartzite were included in the sample, schist is platy, quartzite is solid.	Water supply area; rock has been affected by contact metamorphism from nearby intrusives.
HC-24	Pockwock Lake	11D/13 (433100E, 4965000N)	Granite Granodiorite (Corey, 1987)	Loose Stone From Nearby Outcrop: ripped during road construction, white grey, coarse grained, 10% biotite, megacrysts 4-5 cm long, small zenoliths common, pervasive microfracturing, rock appears quite friable.	Water supply area.
HC-25	Pockwock Lake	11D/13 (432350E, 4962000N)	Granite Granodiorite (Corey, 1987)	Natural Outcrop: white grey, coarse grained, 8-10% biotite, megacrystic, pervasive microfracturing.	Water supply area.
HC-26	Pockwock Lake	11D/13 (430600E, 4958020N)	Granite Walsh Brook Leucogranite (Corey, 1987)	Loose Stone In Borrow Pit:: appears to have come from outcrop in pit, pale red-buff colour, fine grained, 2-3% biotite, very minor microfracturing, very competent rock.	Water supply area.

Description of sample locations (continued).

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-27	Beechville	11D/12 (446200E, 4944700N)	Granite Granodiorite (MacDonald and Horne, 1987)	Loose Stone: ripped from adjacent road cut, white grey, medium-coarse grained, 15% biotite, common small zenoliths, moderate microfracturing.	Outcrop is near contact with Meguma Group slates, sample taken in industrial park development.
HC-28	Beechville	11D/12 (446700E, 4942500N)	Granite Sandy Lake Leucomonzogranite (MacDonald and Horne, 1987)	Loose Stone: ripped from adjacent road cut, white grey, coarse grained, megacrystic, 3-4% biotite, moderate microfracturing	Sample taken in industrial park development.
HC-29	Lewis Lake	11D/12 (433000E, 4947500N)	Granite Tantallon Leucomonzogranite (MacDonald and Horne, 1987)	Natural Outcrop: white grey with pale orange feldspars, coarse grained with small megacrysts, 2-3% biotite, some large muscovite crystals, moderate microfracturing.	Exposure near subdivision.
HC-30	Stillwater Lake	11D/12 (431050E, 4950000N)	Granite Halifax Peninsula Leucomonzogranite (MacDonald and Horne, 1987)	Road Cut: pale grey with pink tinge locally, coarse grained, megacrystic, closely spaced vertical jointing, some shearing with slickenslides, fluorite along fracture planes, modern microfracturing.	Exposure near subdivision.
HC-31	Ingram Lake	11D/12 (425300E, 4949250N)	Granite Tantallon Leucomonzogranite (MacDonald and Horne, 1987)	Loose Stone: fallen from road cut outcrop, pale orange, medium grained, equigranular, 2-3% biotite, closely spaced joints, iron mineralization on joint faces, moderate microfracturing.	
HC-32	McGrath Lake	11D/12 (431350E, 4929000N)	Granite Halifax Peninsula Leucomonzogranite (MacDonald and Horne, 1987)	Road Cut: white grey with green tinge, coarse grained, 3-4% biotite, megacrystic (<5 cm long), minor shearing, moderate alteration of feldspars, moderate microfracturing.	

Description of sample locations (continued).

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-33	Middle Village	11D/12 (429500E, 4929820N)	Granite Halifax Peninsula Leucomonzogranite (MacDonald and Horne, 1987)	Outcrop In Small Borrow Pit: buff-brown, medium-coarse grained, megacrystic, iron mineralization on fracture planes, 4-5% biotite, alteration of the feldspars, common microfracturing.	
HC-34	Meaghers Grant	11D/14 (477340E, 4976500N)	Limestone Gays River Formation Fossiliferous Dolostone (Giles and Boehner, 1982)	Road Cut: dark brown, fossiliferous, vuggy, brecciated, slickensides, appears quite soft and poor durability.	
HC-35	Devon	11D/14 (471220E, 4963130N)	Granite Leucomonzogranite (Ham, 1999a)	Natural Outcrop: buff to orange, coarse grained, megacrystic (<5 cm length), 5-10% biotite, 3-5% muscovite, some alteration of biotite, closely spaced joints, scattered small voids (<1%) with small amounts of pyrite and hematite, moderate microfracturing.	Remote location.
HC-36	Devon	11D/14 (472120E, 4964000N)	Granite Leucomonzogranite (Ham, 1999a)	Natural Outcrop: white grey, medium-coarse grained, megacrystic (<5 cm long), 10% biotite, some of the biotite has been altered, joints with moderate spacing, moderate microfracturing.	Remote location.
HC-37	Devon	11D/14 (475200E, 4960700N)	Granite Leucomonzogranite (Ham, 1999a)	Natural Outcrop: white-grey, medium-coarse grained, megacrystic (<5 cm), appears to be strongly weathered and has pervasive rust colour, 10-15% biotite, moderate microfracturing common.	Remote location.

Description of sample locations (continued).

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-38	Devon	11D/14 (473870E, 4964670N)	Granite Leucomonzogranite (Ham, 1999a)	Loose Stone: ripped from outcrop during construction of road, buff coloured, medium grained, scattered megacrysts (<4 cm), 4-5% biotite, closely spaced joints, bedrock shows layering (due to grain size differences), shatters when struck with hammer, moderate microfracturing.	Remote location.
HC-39	Devon	11D/14 (475680E, 4964770N)	Granite Leucomonzogranite (Ham, 1999a)	Natural Outcrop: white-grey with pink-brown tinge, coarse grained, megacrystic (<3 cm), 4-5% biotite, surface of outcrop weathered and iron stained, pervasive microfracturing.	Remote location, the sample may be influenced by surface leaching.
HC-40	Devon	11D/14 (475100E, 4965900N)	Granite Leucomonzogranite (Ham, 1999a)	Natural Outcrop: orange brown, fine- to medium-grained, porphyritic, 7-8% biotite, scattered pods of pale green alteration minerals, scattered small vugs, outcrop is highly fractured with iron mineralization along fractures, stone appears very durable, very minor microfracturing.	Remote location.
HC-41	Porters Lake	11D/14 (469560E, 4961190N)	Granite Leucomonzogranite (Ham, 1999a)	Road Cut: white grey, medium-coarse grained, minor megacrysts (<7 cm), 10-20% biotite, some areas of exposure enriched with biotite, scattered small zenoliths, moderate microfracturing.	Exposure is in immediate area of residential dwellings.
HC-42	Musquodoboit Harbour	11D/14 (488120E, 4960300N)	Granite Leucomonzogranite (Ham, 1999a)	Bedrock In Borrow Pit: pink to white-grey, medium-coarse grained, megacrysts in exposure vary from scattered to abundant and have a preferred alignment, 10% biotite, kaolin and iron mineralization abundant on joint surfaces, grain size differentiated layering, stone seems fairly weathered, moderate microfracturing.	Exposure is in immediate area of residential dwellings.

Description of sample locations (continued).

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-43	Gibraltar Rock	11D/14 (482060E, 4965060N)	Granite Leucomonzogranite (Ham, 1999a)	Bedrock In Borrow Pit: pink to white grey, medium-coarse grained, megacrysts, extensive fracturing with iron mineralization on fracture faces, patchy biotite (10-20%), seems fairly weathered, moderate microfracturing.	Remote location.
HC-44	Gibraltar Rock	11D/14 (482940E, 4964970N)	Granite Leucomonzogranite (Ham, 1999a)	Road Cut: buff to pale pink-grey, coarse grained, megacrystic (<5 cm), preferred alignment of megacrysts, scattered small zenoliths, moderate microfracturing.	Remote location.
HC-45	Gibraltar Rock	11D/14 (483450E, 4964600N)	Granite Leucomonzogranite (Ham, 1999a)	Road Cut: buff to pale orange, medium grained, equigranular except for minor megacrysts (<5 cm in length), strongly fractured, 8-10% biotite, minor chlorite, rock is locally quite pitted at the surface due to weathering, minor microfracturing	Remote location.
HC-46	Gibraltar Rock	11D/14 (482420E, 4968950N)	Granite Leucomonzogranite (Ham, 1999a)	Railway Cut: white grey to pale blue-grey, medium- to coarse-grained, megacrysts (<5 cm in length), 10% biotite, minor tourmaline, highly fractured, scattered small zenoliths, moderate microfracturing.	Sample location is within a few hundred metres of the Meguma contact, sample is very similar to HC-47.
HC-47	Gibraltar Rock	11D/14 (481150E, 4969580N)	Granite Leucomonzogranite (Ham, 1999a)	Railway Cut: white grey, medium- to coarse-grained, megacrystic (<5 cm), 10% biotite, microfracturing moderate.	Sample location is within a few hundred metres of the Meguma contact, sample is very similar to HC-46.
HC-48	Paces Lake	11D/14 (483900E, 4963170N)	Granite Leucomonzogranite (Ham, 1999a)	Natural Outcrop: buff to pink-red, fine grained, equigranular, 5% biotite, scattered pods of alteration minerals, closely spaced joints, stone is very hard, very minor microfracturing.	

Description of sample locations (continued).

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-49	Paces Lake	11D/14 (483850E, 4962700N)	Granite Leucomonzogranite (Ham, 1999a)	Blocks From Talus Slope At Base Of Large Cliff: buff coloured, fine-medium grained, some layering by grain size, very hard stone, very minor microfracturing.	The blocks are typically 1-3 m long, this site is a popular location for recreational activity (repelling).
HC-50	Cowie Hill	11D/12 (449800E, 4941850N)	Granite Granodiorite (MacDonald and Horne, 1987)	Road Cut: white-grey, medium-coarse grained, 10-15% biotite, small zenoliths throughout, moderate microfracturing.	Sample location is within a few hundred metres of Meguma contact, site is within City limits near water supply and residential dwellings.
HC-51	Harrietsfield	11D/12 (449120E, 4933470N)	Granite Harrietsfield Monzogranite (MacDonald and Horne, 1987)	Road Cut: white-grey, medium-coarse grained, megacrystic (20%) (5-7 cm long), 10% biotite, minor tourmaline, sheared in places with extensive weathering in shear planes, moderate microfracturing.	
HC-52	Hubley Station	11D/12 (435700E, 4943550N)	Granite Tantallon Leucomonzogranite (MacDonald and Horne, 1987)	Road Cut: white-grey, medium-coarse grained, megacrystic (2-5 cm long), 10-12% biotite, rock is quite sheared with iron mineralization in the fracture planes, minor microfracturing.	Exposure occurs in new subdivision.
HC-53	Lewis Lake	11D/12 (433280E, 4946750N)	Granite Halifax Peninsula Leucomonzogranite (MacDonald and Horne, 1987)	Outcrop In Borrow Pit: possibly a large erratic (uncertain), pale orange, fine-medium grained, 2-3% biotite, tight joint pattern with iron mineralization on joint facies, stone appears very hard, very minor microfracturing.	

Description of sample locations (continued).

Sample	Location Name	NTS Map Sheet (Approximate Coordinates)	Rock Type Specific Name (Reference Map)	Sample Description	Other Comments
HC-54	Sambro	11D/05 (451500E, 4925320N)	Granite Harrietsfield Monzogranite (MacDonald and Horne, 1987)	Road Cut: white-grey with local green tinge, coarse grained, minor megacrysts (<5 cm long) 10% biotite, some areas of concen-trated biotite, zenoliths abundant, locally very large, bedrock exhibits layering (grain sized based), small aplite dyke, quartz stringers common, minor microfracturing, only sampled coarse grained stone.	Exposure occurs in new subdivison.
HC-55	Fall River	11D/13 (451000E, 4964920N)	Granite Monzogranite (Coolen, 1974)	Road Cut: white-grey to pink buff, coarse grained, abundant megacrysts (1-2 cm), 7-8% biotite, jointing results in some large blocks, local shearing which is strongly weathered along shear planes, pervasive microfracturing.	Exposure occurs in new subdivision.
HC-56	Lakeside	11D/12 (443300E, 4942220N)	Granite Halifax Peninsula Leucomonzogranite (MacDonald and Horne, 1987)	Road Cut: white-grey, coarse grained, mega-crystic (<5 cm), some exposures consist predominantly of megacrysts, 5-10% biotite (some exposures contain up to 50%), minor zenoliths, some shearing and associated weathering, alteration of the feldspars, some outcrop intensely weathered, sample taken from solid rock, minor microfracturing	Exposure is adjacent to subdivision.
HC-57	Bear Cove	11D/12 (456410E, 4931780N)	Granite Halifax Peninsula Leucomonzogranite (MacDonald and Horne,1987)	Road Cut: white grey to pinkish grey, medium- to coarse-grained, 5% biotite, locally looks pegmatitic, minor microfracturing.	Sample taken near residential dwellings.
HC-58	Herring Cove	11D/12 (454450E, 4934920N)	Granite Harrietsfield Monzogranite (MacDonald and Horne, 1987)	Bedrock Exposure In Old Pit: white-grey, medium-coarse grained, 10-50% mega-crystic (<10 cm), 5-10% biotite, scattered large zenoliths and locally abundant small zenoliths, small pockets of alteration minerals, moderate microfracturing.	Exposure occurs in the residential area.

Appendix 5 - Geological History of the Metro Area

As a preface to the discussion of the geological history of the study area it should be noted that much of the stratigraphic record present in the Meguma Zone has not been observed in the study area. This may be the result of (1) nondeposition in the area, (2) deposition and subsequent removal of the strata by erosion, or (3) the possibility that some of these strata are present, but remain hidden from view due to limited exposure of bedrock. In all likelihood the incomplete rock record is a combination of all three reasons. The result is that the following discussion of the geological history of the area has substantial gaps in time compared to the known history for all of the Meguma Zone (Fig. 6).

The oldest rocks in the study area (and the rest of the Meguma Zone) are the Cambro-Ordovician Meguma Group metasedimentary rocks which consist of a thick sequence of slate and metagreywacke. These rocks have been interpreted as turbidites deposited in a deep ocean/continental slope environment (Phinney, 1961; Schenk, 1970; Harris, 1971 and 1975). The depositional area, which lies to the east of what now makes up Nova Scotia, was part of a large ocean similar to and predating the Atlantic Ocean. Turbidites formed when coarse sandy sediments, accumulating at the edge of an ancient continental shelf, became unstable through an event such as an earthquake. The resulting underwater avalanche or land slide formed a submarine ‘river’ of sediment-laden slurry rushing down canyons incised in the continental slope, much as is occurring today off the Scotian Shelf. At the base of the canyons these sandy sediments splayed in a fan shape onto the continental rise and deep ocean floor where deep ocean mud is slowly and continuously deposited. Following deposition of the sand, clay particles continued to settle out of the water column onto the ocean floor. The cyclical process of slow, continuous clay sedimentation punctuated by brief episodes of catastrophic sand deposition was repeated many times over millions of years to form interlayering of the two sediment types. Depending on location in this depositional system the deposits became either sand- or clay-dominated. In the main channel areas, sand deposition would have been accompanied by substantial erosion of the underlying materials, causing stacked sequences of sand deposits with very little interbedded clay. On the fringes of this depositional system, mud accumulated continually. With prolonged burial under kilometres of sediment load the sand and mud were lithified to form sandstone and shale, respectively. Subsequent heat and pressure associated with deep burial caused metamorphism of the sandstone to form metagreywacke and the shale to produce slate. The maximum measured composite thickness of these strata is 10 km (Harris, 1975) and because the base of the Meguma has not been observed anywhere in the province, the combined thickness is probably much greater than this. Due to the type and thickness of these deposits, the depositional environment that produced the strata probably continued for tens of millions of years.

Schenk (1971) proposed that the Meguma Group rocks were deposited on a continental slope off Morocco, northwestern Africa, in a proto-Atlantic Ocean. It was suggested that subsequent closing of this ocean resulted in a collision between Africa and North America, causing the Meguma block to be welded to the northern half of Nova Scotia, the Avalon Zone (Fig. 6). The plate collision during the Early Devonian initiated the Acadian Orogeny, a period of intense mountain building throughout the region. Rocks of the Meguma Group became strongly folded and subsequently intruded by several granitic plutons during the Middle Devonian. The study area contains portions of two batholiths, the South Mountain Batholith and Musquodoboit Batholith, and a small pluton at Waverley. By the Late Devonian, orogenic activities had stopped.

During the Late Devonian to Early Carboniferous, movement along a major fault system in Atlantic Canada resulted in the formation of numerous interconnected sedimentary basins collectively called the Fundy Basin System. Today they are observed in the region as structurally deformed and eroded remnants of clastic deposition. The northeastern corner of the study area contains the western edge of the Musquodoboit Basin (Fig. 7) (Giles and Boehner, 1982). This location shows some of the early deposition in the basin during the Early Carboniferous. Clastic alluvial (river) sediments of the Horton Group were deposited unconformably on the Meguma Group strata. Subsequent marine incursion into the basin resulted in the deposition of dolostone, evaporites, shale and fine-grained sandstone of the Windsor Group. These sedimentary rocks are the uppermost bedrock units in the study area. Windsor Group shale and sandstone also occur in a small outlier of Carboniferous rocks at French Village on St. Margarets Bay (Fig. 7). These strata are believed to be indicative of marine incursion at this location as well.

The geological history of the study area between Carboniferous deposition and Pleistocene glaciation is unknown. Deposition may have occurred during this period, but there is no record of it. This time gap may reflect nondeposition, erosion or simply that rock units dating from this period have yet to be discovered. Presumably deposition did occur during this time (Triassic, Jurassic and Cretaceous strata are found elsewhere in the province, and on the continental shelf).

Bedrock is unconformably overlain by unconsolidated Quaternary sediments, mainly Pleistocene deposits resulting from the movement of several ice sheets across the province over the last 100 000 years. During this time, glacial erosion extensively reworked and reshaped the bedrock surface and overlying soil cover. Approximately 10 000 years ago the last vestiges of ice disappeared from the region, leaving a thick blanket of till over most of the region. Other reminders of glaciation include drumlins, minor amounts of glacial meltwater gravel, and scoured, exposed bedrock. Modern stream processes and transgressive changes in sea level have reworked and modified much of the glacial geology over the last 10 000 years to produce the topography that exists today.