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ALKALI-AGGREGATE REACTIVITY IN NEWFOUNDLAND

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ABSTRACT

Alkali-aggregate reactivity is a chemical reaction that occurs in concrete structures. It may not be the main cause of premature deterioration in some concrete structures, but it is often the catalyst for other forms of degradation or deterioration.

Since 1989, field work and laboratory testing for alkali-reactivity has been undertaken on selected aggregate, rock and concrete samples. The tests consist of an assessment of the bedrock and aggregate sites to determine their quality and quantity for use as construction aggregates, as well as an examination of the existing concrete structures to assess their durability with regard to alkali-reactivity. Site investigation of concrete structures consists of noting their date of construction, rock types used, types of cracking, and the degree and type of deterioration of each structure.

Results from laboratory testing, petrographic examination and visual analysis show that certain sedimentary, igneous and metamorphic rock types may be potentially alkali-reactive, but the reaction may not always be deleterious to the concrete structure.

INTRODUCTION

Alkali-aggregate reactivity (AAR) is a chemical reaction that may weaken the internal strength and integrity of a concrete structure and thus cause premature deterioration of the structure. It occurs in some concrete structures as a result of various factors such as the alkali content of cement, moisture content of the concrete, and reactivity of the aggregate particles used in the concrete mix. Although it may not be the main cause of deterioration in some structures, it may be the catalyst for other forms of deterioration such as freeze–thaw cracking. Signs of alkali-aggregate reactivity were first noted in concrete structures in 1983 by the author while conducting an aggregate investigation of the province. Alkali-aggregate reactivity was first systematically investigated on a limited basis by White and Soles (1990) and was followed with work by Bragg (1991, 1993), Bragg and Foster (1992), Bragg and Katayama (1993) and Katayama and Bragg (1995).

This paper is intended to document occurrences of alkali-aggregate reactions that occur in concrete structures throughout Newfoundland and to discuss the significance of these reactions.

A combination of qualitative tests (site assessments and petrographic examination) and quantitative tests (accelerated mortar bar, mortar bar and concrete prism) were performed on samples to evaluate their potential reactivity and to try and determine the geological source of the reactive aggregates found in the concrete.

FIELD INVESTIGATION

Three hundred and seventy-five (375) concrete structures were investigated, and examined for signs or indications of AAR, such as map-cracking, gel exudation and reaction rims (Dolar-Mantunia, 1983). The concrete structures investigated were bridges, retaining walls, overpasses, wharfs, dams and breakwaters (Table 1); some of the structures are up to 88 years old (Table 2).

Field investigations consisted of a detailed examination of each concrete structure and completion of a site-evaluation

Table 1. List of concrete structures investigated

Number	Structure
319	Bridges
17	Retaining Walls
15	Overpasses
13	Wharfs
9	Dams
2	Breakwaters

Table 2. Degree of deterioration due to alkali-aggregate reactivity based on age of the concrete structure in Newfoundland

Age of structure	Degree of deterioration
1 - 10 years	None
10 - 20 years	Slight
20 - 30 years	Moderate
30 - 88 years	Severe

form (Table 3). Visual assessment of the concrete structures consisted of noting the construction date (found on the end blocks of the bridge); where the construction date was not known, an approximate date was established by contacting local residents for information. The aggregate types used in the construction of the concrete structures consisted of fluvial–glaciofluvial gravel, beach gravel, crushed gravel and crushed stone. Aggregate rock types used in the concrete structure were identified according to their geological name and where possible the source area was identified. The degree of deterioration at each site was rated from none to severe. Figure 1 shows the sites where one or more AAR indicators were noted, and Figure 2 shows the sites where moderate to severe deterioration caused by AAR occurs.

Concrete Structures

The oldest concrete structure investigated was the lighthouse at Cape Race; it was constructed in 1907 and is still in excellent condition. The youngest structure, a bridge in central Newfoundland, was constructed in 1994. Most structures were built after 1930; 5 percent were built before 1930, 15 percent were built in the1930s and 1940s, 5 percent were built in the 1950s, 60 percent were built in the 1960s and 1970s, and the remaining 15 percent were built in the 1980s and 1990s. Most of the concrete structures that generally show signs of premature deterioration caused by alkali-aggregate reactivty were built in the late 1960s and early 1970s. The main cause of deterioration of the concrete structures was either freeze–thawing or alkali-aggregate reactivity; however, in many cases a combination of these two factors and others were present in structures that were severely deteriorated.

Cracking was a common feature noted in most of the concrete structures. Several different types were noted, including dry shrinkage, which is caused by the hydration of the cement. Tensional or longitudinal cracking caused by stress or a load being applied to the concrete or rebar, and alkali-reactivity or map-cracking caused by the reaction of the alkali in the cement with certain types of silica in the aggregate, was also common.

Of the 375 concrete structures investigated (Table 4), 255 were rated in good condition with no signs of AAR, and 120 showed signs of premature deterioration caused by alkali-aggregate reactivity that ranged from slight to severe. Of these, 78 concrete structures had only slight deterioration or minor map-cracking, 29 showed moderate signs of deterioration caused by AAR, and 13 showed signs of severe deterioration caused by AAR.

Where concrete bridges were affected by AAR, the reaction mainly occurred on the end blocks of the structures; however, not all end blocks were affected on a single structure even though the same aggregate was used in the construction of the whole bridge. Very rarely were the concrete railings and abutments affected by AAR. Only 10 bridges had signs of AAR throughout their structure (end blocks, abutments, decks, railing decks and railing) and all these structures were more than 50 years old.

Construction Aggregates

Newfoundland, due to its complex geology produces a wide range of rock types that are used as construction aggregates. Figure 3 (Hayes, 1987) shows a generalized geology map of Newfoundland.

Fluvial and glaciofluvial deposits are the main sources for gravel used for construction aggregates in eastern, central and western Newfoundland, whereas crushed stone from bedrock quarries is mainly used on the Avalon Peninsula. The main rock types used for construction aggregates in Newfoundland are siliceous sediments (sandstone, siltstone, argillite), tuffaceous sediments (siltstone and sandstone), arkose, greywacke, and sandstone. Siltstone and argillite are the main rock types that are commonly used as construction aggregates on the Avalon Peninsula. Other less common rock types used on the Avalon Peninsula include, rhyolite, felsic tuff, basalt, basaltic tuff, dacite, dacitic tuff and granite. Greywacke, sandstone, siltstone, rhyolite, felsic tuff, mafic tuff, psammite, phyllite, schist, gneiss, granite, gabbro, diorite, pelite, andesite, and andesitic tuff are the most common rock types used as construction aggregates for the rest of the province. Laboratory testing was performed on most of the rock types to evaluate their potential reactivity.

ANALYTICAL METHODS

The laboratory investigation consisted of petrographic analysis and chemical testing.

PETROGRAPHIC ANALYSIS

Petrographic analyses (ASTM, 1985) were performed on all aggregate and bedrock samples collected, and on aggregate samples taken from concrete structures. This consisted of examining samples using a hand lens and by

Table 3. An example of the Concrete Structure Evaluation form

Investigator: Dan Bragg

Date: June 20, 1995

Location: Clarke's Beach, Conception Bay, Newfoundland

Type of Structure: Bridge

Construction Date: 1966

Aggregate Used: Crushed stone/gravel

Aggregate Rock Type: Greenish-grey and red siliceous siltstone–argillite

Aggregate Source: Local

Degree of Deterioration: Moderate

Type of Deterioration: Map-cracking, gel exudation, reaction rims, spalling–scaling

Possible Causes: Alkali-aggregate reactivity, freeze–thawing

Comments:

Map-cracking, gel exudation and reaction rims, which are usually signs of AAR, were noted on three of the four end blocks. Spalling and scaling were dominant on the end abutments. Reactions rims were present around the greenish-grey aggregate fragments in the concrete end blocks. There were no signs of deterioration caused by AAR on any of the bridge railing or railing deck although the same aggregate was used in its construction.

thin-section examination using a petrographic microscope. After each analysis, a petrographic rating number (Bragg and Foster, 1992) was assigned to each sample. This number gives the initial evaluation of the potential for alkali-aggregate reactivity of a rock or aggregate sample. The criteria used for establishing a petrographic rating number is shown in Table 5.

CHEMICAL TESTING

Alkali-reactivity testing such as concrete prism (CSA, 1977) and mortar bar (ASTM, 1987) were performed on selected samples. The accelerated mortar bar test (Oberholster and Davies, 1986) was performed on all of the collected samples. Table 6 shows the comparison of test results from the petrographic rating, accelerated mortar bar, mortar and concrete prism tests with the field performance of the aggregate involved.

DISCUSSION

Table 7 shows the main types of potentially reactive

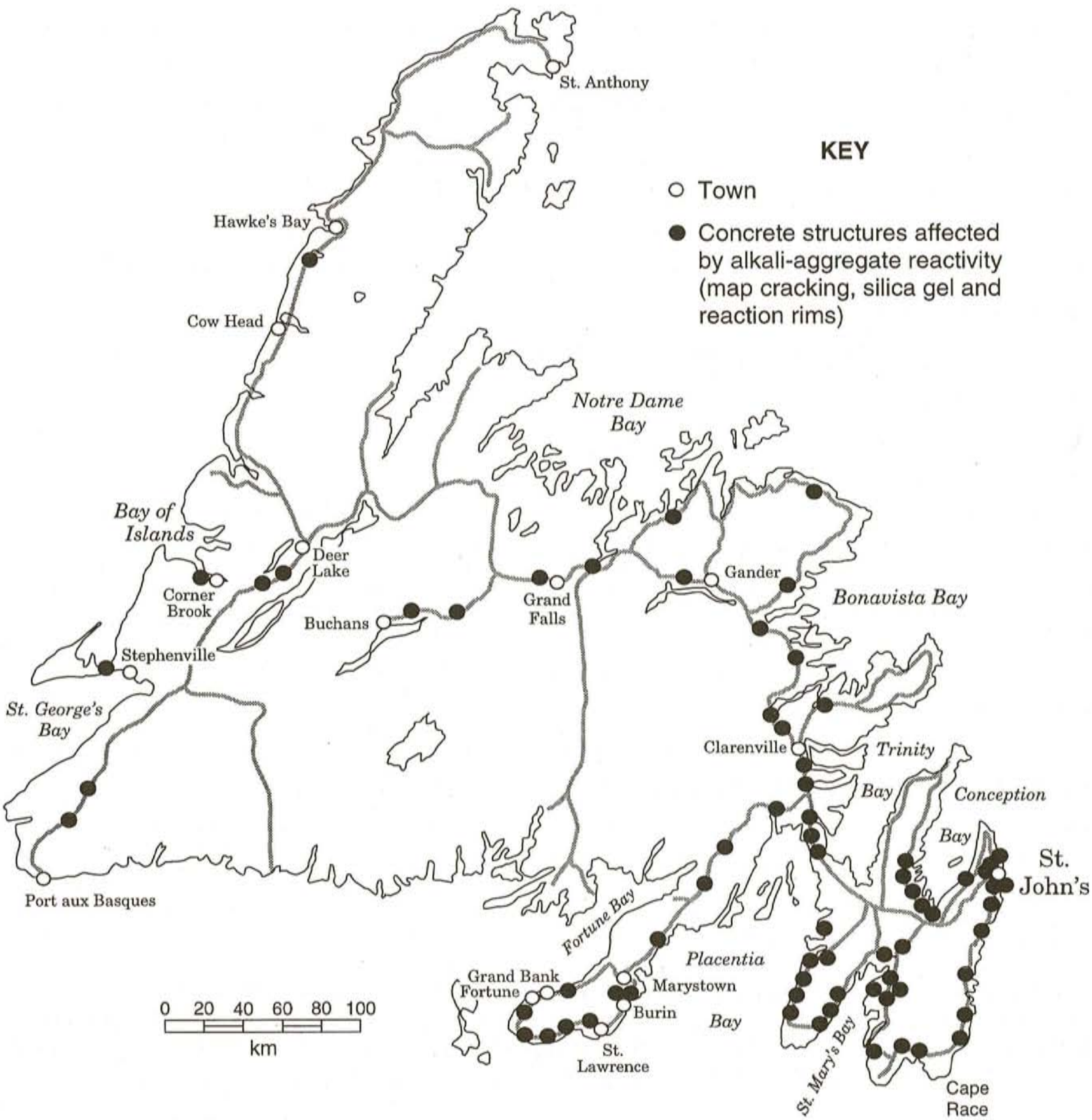

Figure 1. *Site location map of concrete structures that show one or more AAR indicators.*

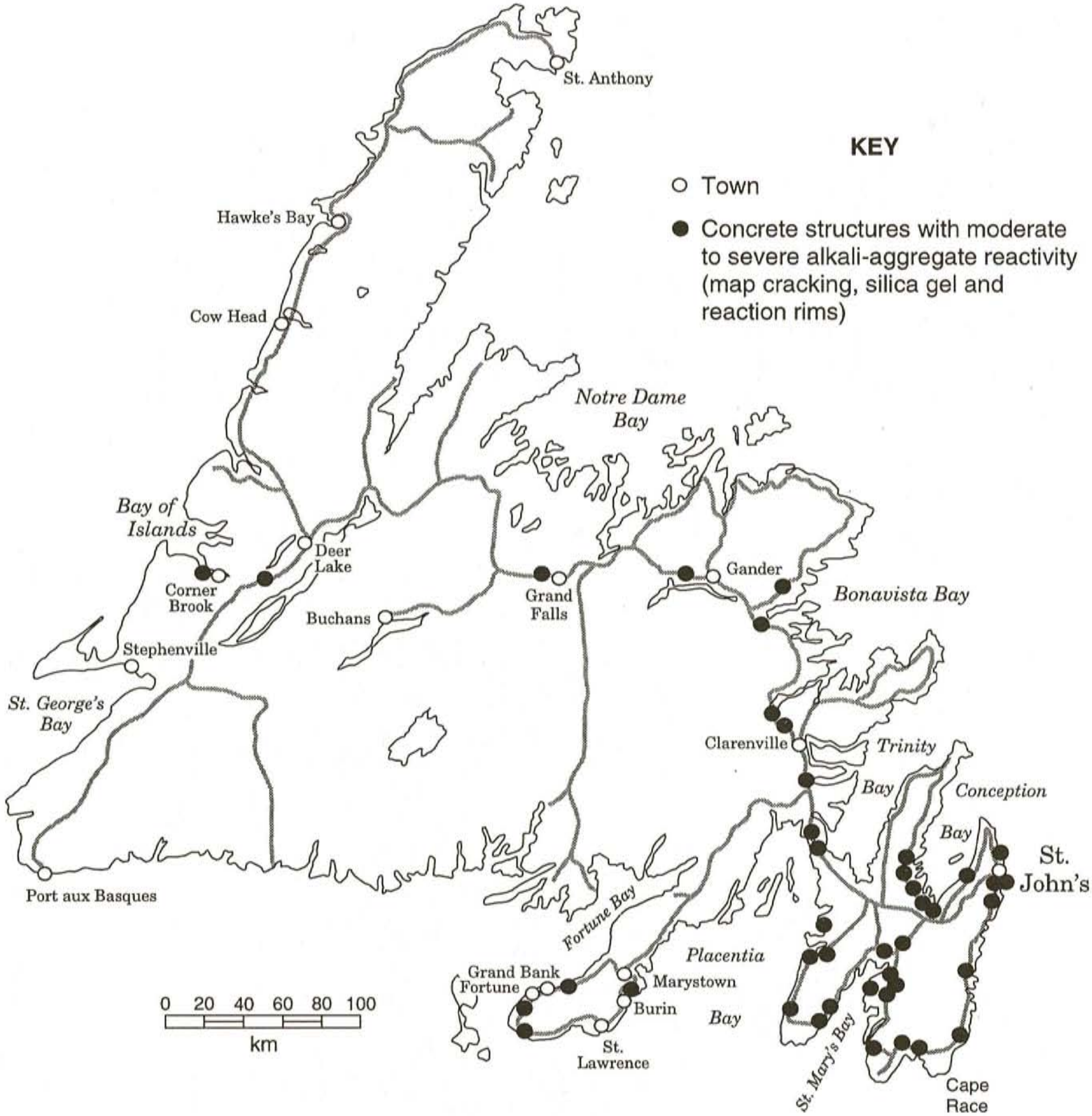

Figure 2. *Site location map of concrete structures that show moderate to severe deterioration caused by AAR.*

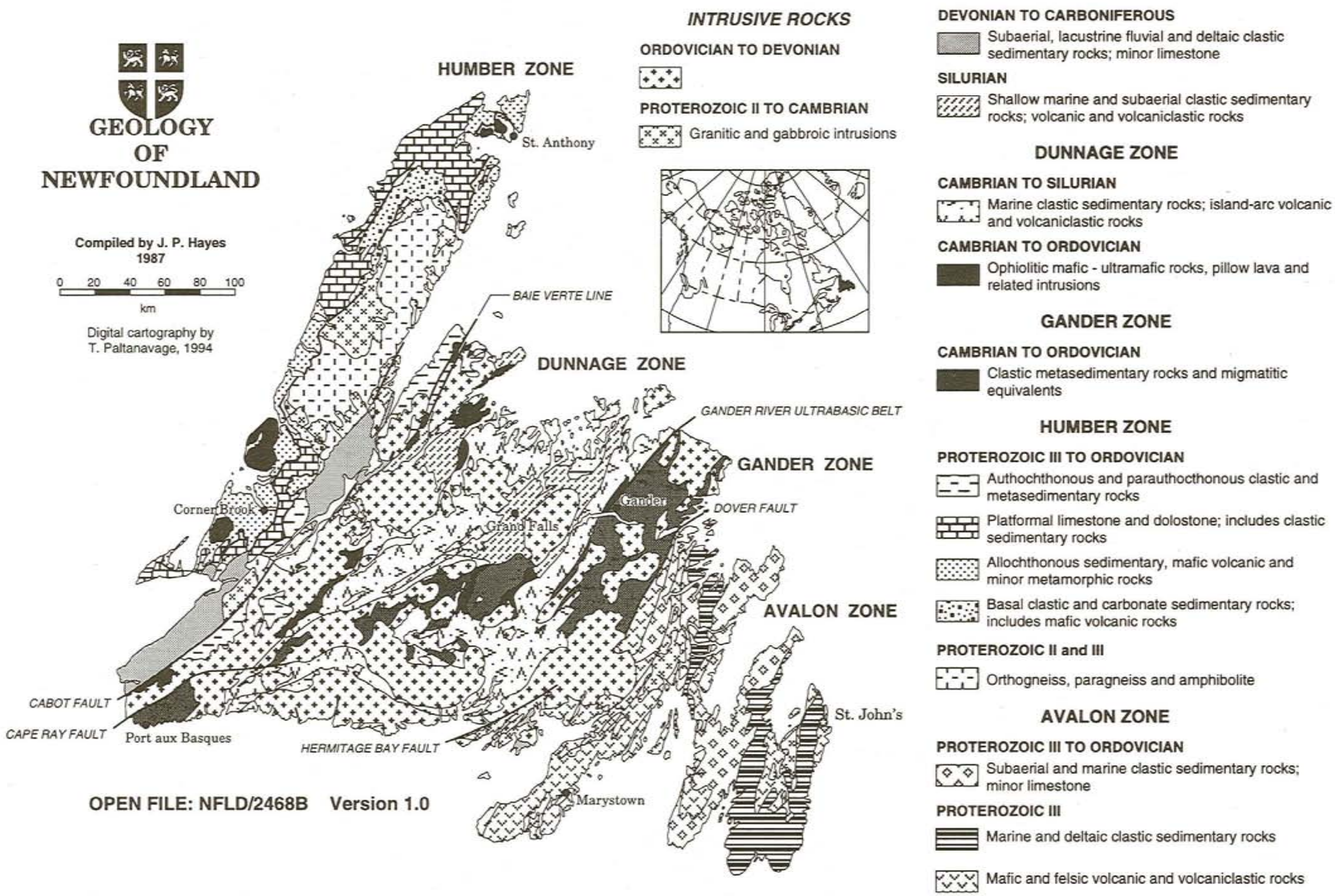

Figure 3. *Generalized geology map of Newfoundland (Hayes, 1987).*

Table 4. Evaluation of concrete structures for signs of AAR

Number	Evaluation
255	Good (no signs of AAR)
78	Fair (minor signs of AAR, no structural damage)
29	Moderate (significant signs of AAR, surface damage)
13	Severe (serious map cracking, large cracks, some structural damage)

rocks used for construction aggregates in Newfoundland based on testing and field performance. Siliceous sediments (sandstone, siltstone and argillite), rhyolite, felsic tuffs, tuffaceous sandstone and siltstone, greywacke and arkosic sandstone are the main potentially reactive rock types on the Avalon Peninsula. Gneiss, schist, greywacke, psammite and pelite are the main potentially reactive rock types of central Newfoundland. Gneiss, schist and rhyolite are the main potentially reactive rock types of western Newfoundland. Further investigation is necessary to determine or identify the geological units from which the above rock types originate. Also worth noting are the test results and field performance, which show the following rock types (in Newfoundland) to be potentially non-reactive: sandstones, siltstones, argillites, granite, diorite, basalt and basaltic tuffs of the Avalon Peninsula; sandstone, siltstone, basalt and granite, diorite and gabbro of eastern Newfoundland; granite, gabbro, diorite, basalt, and sandstone of central Newfoundland; limestone, dolomite, granite, diorite, gabbro, basalt, granitic gneiss, and phyllite of western Newfoundland; granite, diorite, gabbro, gneiss, sandstone and siltstone of the south coast of Newfoundland.

Results from the field assessments show that alkali-reactivity is generally always present in a large number of concrete structures (32 percent). Of these, 20.8 percent show only minor or slight deterioration, 7.7 percent show signs of moderate deterioration and 3.5 percent show signs of severe deterioration. Of those seriously affected, 84 percent are between 31 and 65 years old whereas the remaining 16 percent are between 25 and 30 years old.

Field assessments also show that when siliceous sediments (sandstone, siltstone, and argillite), tuffaceous sediments (sandstone and siltstones) and felsic tuffs were used as aggregate for concrete construction, signs of AAR usually occurs after 10 years of service. However when sandstone, siltstone, argillite, greywacke, gneiss, schist, psammite, pelite and rhyolite are used as aggregate in concrete, the reactivity of the aggregate varied, from non-reactive to reactive.

Table 5. Petrographic rating system of aggregates for their potential alkali-aggregate reactivity

Rating	Criteria	Comments
Low (1)	No known alkali-reactive rocks or minerals	Non-reactive
Fair (2)	* 1 to 10 percent of known alkali-reactive rocks or minerals	Marginal (tending toward non-reactive)
Moderate (3)	>10 percent, but less than 20 percent of known alkali-reactive rocks or minerals	Marginal (tending toward reactive)
High (4)	**>20 percent of known alkali-reactive rocks or minerals	Reactive

Note: * Very low amounts (> 1 percent) of microcrystalline quartz (chert, opal, cristobalite) may cause alkali-reactivity due to the pessimum effect.

** Some reactive rocks and minerals cause a pessimum effect (amount of material that causes maximum expansion). Therefore, these rocks or minerals would not react deleteriously with the cement paste if the pessimum amount is not reached (5-50 percent) for some rock types and < 1 percent for some minerals.

Table 6. Comparison of results from different tests with field performance of the aggregate

Sample #	Deposit Type	Petro. Rating	Accelerated Mortar Bar (0.15%)	Mortar Bar (0.1%)	Concrete Prism (0.04%)	Field Perf.
90-101	Aggregate	Low (1)	0.066	0.000	0.029	N.R.
90-102	Aggregate	Fair (2)	0.000	0.000	0.069	*N.R.
90-103	Bedrock	Low (1)	0.129	0.000	0.000	N.R.
90-104	Bedrock	High (4)	-	-	0.111	R.
90-105	Aggregate	Low (1)	0.060	0.000	0.043	N.R.
90-106	Bedrock	High (4)	0.359	0.392	0.112	R.
90-107	Bedrock	Low (1)	0.213	0.000	0.047	*N.R.
90-108	Aggregate	Low (1)	0.144	0.296	0.046	*N.R.
90-109	Aggregate	Moderate (3)	0.162	0.111	0.084	*R.
90-110	Bedrock	Moderate (3)	0.339	0.358	0.028	R.
90-111	Aggregate	Fair (2)	0.090	0.102	0.042	-
90-112	Bedrock	High (4)	0.232	0.267	0.041	*R.
90-113	Bedrock	Low (1)	0.171	0.209	0.021	*R.
90-114	Aggregate	High (4)	0.198	0.116	0.028	N.R.
90-115	Aggregate	Fair (2)	0.000	0.000	0.042	N.R.
90-116	Aggregate	Low (1)	0.090	0.000	0.024	N.R.
90-117	Bedrock	Low (1)	0.046	0.062	0.034	N.R.
90-118	Aggregate	Moderate (3)	0.283	-	0.033	*R.
90-119	Aggregate	High (4)	0.149	0.119	0.031	R.
90-120	Aggregate	Moderate (3)	0.305	-	0.074	R.
90-121	Bedrock	Low (1)	0.000	0.000	0.024	N.R.
90-122	Aggregate	High (4)	0.257	0.000	0.019	*N.R.
90-123	Bedrock	High (4)	-	-	0.191	R.
90-124	Bedrock	High (4)	0.380	-	-	R.
90-125	Aggregate	Fair (2)	0.151	0.039	-	*R.
90-126	Aggregate	Fair (2)	0.092	0.000	0.000	N.R.
90-127	Bedrock	Low (1)	0.000	0.024	0.000	N.R.
90-128	Aggregate	Fair (2)	0.180	0.000	0.000	-
89-408	Bedrock	Low (1)	0.025	0.000	0.000	-
89-416	Bedrock	Fair (2)	0.092	0.000	0.000	-
89-419	Bedrock	Low (1)	0.038	0.000	0.000	-
89-430	Bedrock	Low (1)	0.053	0.000	0.000	-
89-435	Bedrock	Low (1)	0.073	0.000	0.000	-
89-436	Bedrock	Low (1)	0.085	0.000	0.000	-
89-438	Bedrock	Fair (2)	0.052	0.000	0.000	-
89-442	Bedrock	Low (1)	0.023	0.000	0.000	-
89-451	Bedrock	Moderate (3)	0.064	0.000	0.000	-
90-001	Bedrock	High (4)	0.365	0.000	0.000	R.
90-008	Bedrock	Low (1)	0.020	0.000	0.000	N.R.
90-010	Bedrock	Low (1)	0.029	0.000	0.000	N.R.
90-013	Bedrock	Moderate (3)	0.404	0.000	0.000	*R.
90-025	Bedrock	High (4)	0.078	0.000	0.000	*R.
91-001	Bedrock	Low (1)	0.053	0.000	0.000	N.R.
91-002	Bedrock	Low (1)	0.037	0.000	0.000	N.R.
91-003	Bedrock	High (4)	0.254	0.000	0.000	R.
91-004	Bedrock	Low (1)	0.015	0.000	0.000	N.R.
91-005	Bedrock	High (4)	0.286	0.000	0.000	R.
91-006	Bedrock	Low (1)	0.018	0.000	0.000	N.R.

Table 6. Continued

Sample #	Deposit Type	Petro. Rating	Accelerated Mortar Bar (0.15%)	Mortar Bar (0.1%)	Concrete Prism (0.04%)	Field Perf.
94-001	Aggregate	High (4)	0.344	0.000	0.000	*N.R.
94-002	Bedrock	Moderate (3)	0.149	0.000	0.000	N.R.
94-003	Aggregate	Moderate (3)	0.158	0.000	0.000	*R.
94-004	Aggregate	High (4)	0.374	0.000	0.000	*N.R.
94-005	Aggregate	High (4)	0.409	0.000	0.000	*R.
94-006	Aggregate	Moderate (3)	0.161	0.000	0.000	-
94-007	Aggregate	Moderate (3)	0.484	0.000	0.000	*R.
94-008	Aggregate	High (4)	0.241	0.000	0.000	*R.
94-009	Aggregate	Low (1)	0.225	0.000	0.000	N.R.
94-010	Aggregate	Moderate (3)	0.468	0.000	0.000	*R.
94-011	Aggregate	High (4)	0.318	0.000	0.000	R.
94-012	Bedrock	Low (1)	0.038	0.000	0.000	N.R.
94-013	Aggregate	Moderate (3)	0.270	0.000	0.000	*R.
94-014	Aggregate	Moderate (3)	0.327	0.000	0.000	*N.R.
94-015	Bedrock	Low (1)	0.043	0.000	0.000	N.R.
94-016	Aggregate	Fair (2)	0.131	0.000	0.000	N.R.
94-017	Aggregate	Fair (2)	0.141	0.000	0.000	N.R.
94-018	Aggregate	Moderate (3)	0.127	0.000	0.000	-

N.R. = Non-reactive in field performance
R. = Reactive in field performance
* = Aggregate varies in field performance

Table 7. Reactivity of rock types that are "potentially" alkali-aggregate reactive in Newfoundland; based on laboratory and petrographic results and field performance

Rock Type	Laboratory Rating	Petrographic Rating	Field Rating
Siliceous Siltstone	Reactive	Reactive	Reactive
Siliceous Argillite	Reactive	Reactive	Reactive
Siliceous Sandstone	Reactive	Reactive	Reactive
Arkose	Reactive	Reactive	Reactive
Tuffaceous Sandstone	Reactive	Reactive	Reactive
Tuffaceous Siltstone	Reactive	Reactive	Reactive
Felsic Tuff	Reactive	Reactive	Reactive
Dacitic Tuff	Reactive	Reactive	Reactive
Rhyolite	Reactive	Reactive	Reactive
Rhyolitic Tuff	Reactive	Reactive	Reactive
Andesitic Tuff	Reactive	Reactive	Reactive
Pelite	Reactive	Reactive	Reactive
Greywacke	Reactive	Reactive	Reactive
Psammite	Reactive	Reactive	Reactive
Phyllite	Reactive	Reactive	Reactive
Schist	Reactive	Reactive	Reactive
Gneiss	Reactive	Reactive	Reactive

CONCLUSIONS

Field assessments show that signs of alkali-aggregate reactivity in various degrees of deterioration is present in a significant number (32 percent) of the concrete structures investigated. The degree of deterioration is usually related to age of the structure. Of the 32 percent, 11.2 percent range from moderate to severe in degree of deterioration.

Based on laboratory and petrographic results and field performance, most of the potentially reactive rock types found in eastern Newfoundland are: siliceous sandstone, siltstone, argillite and tuffaceous sandstone and siltstone and felsic tuff, all of which contain micro-crystalline quartz. Only sporadic occurrences of potentially reactive greywacke, sandstone, gneiss, schist, phyllite, psammite and tuff are found throughout the rest of the province.

Field performance of concrete aggregates shows that the reactivity of certain aggregates or rock types may change without any apparent or obvious reason. More research and investigation into the geochemistry and mineralogy of the aggregate has to be carried out to determine why a certain rock type, when used in concrete construction, is reactive in one case and non-reactive in another or even varied in reactivity in the same structure.

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